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Impacts of cruise ship anchoring during COVID-19: Management failures and lessons learnt

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ABSTRACT

The Government of Barbados welcomed cruise ships during the early COVID-19 period of 2020, allowing them to seek safe harbour at a time when many countries were turning them away. A total of 28 cruise ships were given unprecedented permission to anchor along the west and south coasts of the island during this period (1 March – 1 September 2020). This study examines the 132 anchoring events of these cruise ships, using automatic identification system (AIS) data to determine anchored locations and track vessel swing at anchor in relation to sensitive coral-rich habitat. These data, together with SCUBA surveys on several anchoring sites were used to describe the nature of the habitat damage and to assess the potential area of impacts on coastal marine habitats. The huge anchors and hundreds of metres of chain required to secure these mega-vessels, together with their typical wide swinging motion dragging the anchor chain over the bottom are estimated to have caused thousands of square metres of structural damage to the island’s valuable coral reefs. This study revealed weaknesses in coral conservation policy and practise to which the Government of Barbados has responded. A stated new Government policy prohibits cruise ships from anchoring on the coral-rich west coast and restricts anchoring to the designated anchorage on the south coast. Additional cruise ships that cannot be accommodated in the anchorage are now being asked to use their dynamic positioning system or to drift offshore.

1. Introduction

1.1. Importance of coral reefs

Coral reefs are diverse marine ecosystems comprising a myriad of species and providing humans with valuable ecosystem services (Mumby et al., 2014). Approximately 10 percent of the world’s coral reefs are found in the Western Central Atlantic, with most occurring in the Caribbean Sea (Burke et al., 2011).

Barbados and the wider Caribbean, receive significant benefits from the ecosystem services of healthy coral reefs that underpin both the vital fisheries and tourism sectors (Burke et al., 2011; Patil et al., 2016; Oxenford and Mahon, 2021). Reef-associated fisheries in the Caribbean are key to coastal livelihoods and food security (Oxenford and McConney, 2021) and the Caribbean is recognised as being the most tourism-dependent region in the world (WTTC 2021b). As is typical of many of the Small Island Developing States (SIDS) in the Caribbean, tourism is the leading economic sector in Barbados, and for over four decades it has been the major foreign exchange earner contributing in excess of 15 percent to GDP annually, with few exceptions (Environmental Planning Group Inc. and HLA Consultants, 2014). This contribution continues to rise; in 2019, tourism contributed 30 percent in total to the GDP, and approximately 37 percent of total employment in Barbados was in the travel and tourism sector (WTTC 2021a). Like many Caribbean destinations, cruise ship tourism plays a major role in the tourism sector of Barbados, with the number of cruise ship passengers continuing to increase on an annual basis. In the 1980s around 0.5 million tourists were visiting the island annually with approximately 30 percent being cruise ship passengers. By the first decade of 2000s this had risen to 1.2 million tourists with 55 percent being cruise ship passengers. Over the last decade this has now risen to 1.3 million tourists with 56 percent from cruise ships (Daly and Fernandez-Stark 2017; Barbados Port Inc, 2020; Barbados Statistical Service 2021). Cruise ship numbers have increased more slowly over the last two decades and typically range between 400 and 500 calls a year, but the ships have become increasingly large. Although the ongoing COVID-19 pandemic has temporarily disrupted this trend, the industry is already bouncing back with a total of 178 cruise ship calls to Barbados in the first three

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months of 2022 (Tourism Analytics, 2022).

1.2. Anchor damage

Even though coral reefs provide human populations with a plethora of benefits and are fundamental for the marine-based tourism industry in the Caribbean, human activities (including tourism) continue to negatively affect the health of reefs across the region. Particularly relevant to this study, Caribbean coral reefs are impacted by physical damage caused by intentional anchoring of ships and recreational vessels (Allen 1992; Burke and Maidens 2004; Burke et al., 2011; Forrester et al., 2015). Anchor damage has been recognised as an important stressor on Caribbean reefs for many decades (e.g. Davis, 1977; Halas, 1985; Smith, 1988; Rogers et al., 1991). In Barbados, a public consultation to canvass recommendations for coral reef management action noted that one of the most crucial non-pollutant stressors to corals in the island was anchor damage. A subsequent study of 11 popular SCUBA diving sites indicated anchor damage at 10 of them (Edwards 1994). When vessels anchor, it results in anchor scour as the anchor is dragged to set it and the chain drags back and forth over the substratum as the vessel moves with the wind and changing tides (Davis et al., 2016; Broad et al., 2020). Cruise ships in particular, can cause significant damage to coral reefs because of the size of the vessels and weight of the chain and anchors needed to hold them. Burke and Maidens (2004) noted that reckless anchoring can cause up to 200 m² of damage to the ocean bottom, even when the sea is calm. Other reports record even greater damage (e.g. Smith, 1988; Rogers et al., 1991). Research in the British Virgin Islands found that areas with high anchoring frequency had a reduction in hard corals by a factor of approximately 1.7 and the coral colonies were 40 percent smaller in surface area when compared with areas of low anchoring frequency (Flynn and Forrester 2019). Additionally, they reported that only 60 percent of the species richness of low anchoring frequency sites was found on the high anchoring frequency sites. Anchor and chain scour damage to reefs was reported by Broad et al. (2020) to result in slow coral recovery and increased algal cover, whereas Forrester et al. (2015) reported an absence of recovery.

1.3. Existing marine policy in Barbados

Barbados has long recognised the importance of its marine resources and ecosystems in supporting fisheries and tourism amongst other sectors, along with the stressors that coral reefs face such as overfishing, pollution, and physical damage (Irvine et al., 2020). This has led to the island implementing various laws and mechanisms to help manage these resources, and being recognised as a leader in the region for integrated coastal zone management (Scruggs and Bassett 2013). From as far back as 1982, Barbados designated a government unit to manage the coastal zone. Established originally as the Coastal Conservation Project Unit, the unit later transformed into the now Coastal Zone Management Unit (CZMU) in 1996. The CZMU is supported by the Coastal Zone Management Act (1998) and the Integrated Coastal Management (ICM) Policy and Plan (CZMU 1998). The CZMU comprises three technical sections with one of them being the Marine Research section “responsible for monitoring the health of marine ecosystems around Barbados” (CZMU Sections, accessed June 23, 2020. http://www.coastal.gov.bb/content/czmu-sections). The Marine Research section has programmes in place for coral reef and water quality monitoring, marine education and permanent mooring buoys, and works in tandem with other Government agencies such as the Fisheries Division (supported by the 1993 Fisheries Act and the 1998 Fisheries (Management) Regulations), the National Conservation Commission (supported by the 1982 National Conservation Commission Act), and the Environmental Protection Department (supported by the 1998 Marine Pollution Control Act), as well as the University of the West Indies, to execute its mission. The ICM policy specifically mentions anchor damage to reefs as an area of concern, highlighting that the island depends heavily on shipping, and has high levels of recreational boating, particularly along the west coast, and nearshore fishing, which all use anchors (CZMU 1998). To alleviate this, designated anchoring zones have been established in less sensitive areas for ships and visiting yachts, and the CZMU, along with the Fisheries Division and the Professional Association of Dive Operators, have established permanent mooring buoys at popular dive sites and within the Folkestone Marine Park to avoid damaging the reefs repeatedly from anchoring. More recently, in 2018, the Government of Barbados created a Ministry of Maritime Affairs and Blue Economy (MMABE), which has ignited a new focus on developing marine-based industries and using marine resources to generate further revenue. This has resulted in a renewed interest in better protection and even restoration of damaged marine habitats, since they are recognised as being a vital part of the blue economy. This new ministry is working towards introducing improved legislation, addressing sea-use conflicts and challenges faced by the fisheries sector, amongst other things and is currently in the early stages of developing a marine spatial plan (MSP) for the country’s entire ocean space (Humphrey 2018; Rawlins-Bentham 2021). Furthermore, the Government of Barbados has now embarked on a ‘Roofs to Reefs’ programme to further integrate the management of land-based and marine activities (Ministry of the Environment and National Beautification, 2019).

1.4. Cruise ships anchoring in Barbados

Despite these policies and institutions in place, an unprecedented marine management issue arose as a consequence of the COVID-19 pandemic leading to many cruise ships being stranded at sea. Barbados took the opportunity to assist by allowing these cruise ships to enter Barbados’ territorial waters and to dock and disembark passengers at the Bridgetown Port. This policy attracted many cruise ships to the island’s shores; more than the port could accommodate. The overflow was, for the first time ever, allowed to anchor in the designated ships anchorage in Carlisle Bay and at alternative sites on the south and west coasts where coral reefs are located. This resulted in significant consternation on social media from dive shops and other stakeholders.

The focus of this study is to investigate the extent of damage caused by the anchored cruise ships in Barbados, to highlight weaknesses in coral conservation policy and to guide new policy for the management of ships anchoring. It is hoped that this will help in the long-term management of coral reefs not only in Barbados but across all cruise ship destinations in the Caribbean and other coral-rich areas.

2. Methods

2.1. Cruise ship descriptive data

Descriptive data on all cruise ships visiting Barbados between 1 March and September 1, 2020 were downloaded from MarineTraffic (sup>2</sup>, a leading provider of ship tracking and maritime intelligence. Additional data were obtained from the Scheepvaartwest<sup>3</sup> website where necessary. Descriptive data included vessel size (length and width), gross tonnage, draught, and number of passenger decks. Cruise ships were grouped into three size categories based on their gross tonnage (small: < 45,000; medium: 45,001–105,000; large: >105,001). To protect the identity of these ships, they were numbered arbitrarily.

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1. CZMU, “CZMU Sections”, accessed June 23, 2020. http://www.coastal.gov.bb/content/czmu-sections.
2. MarineTraffic: Global Ship Tracking Intelligence | AIS Marine Traffic. https://www.marinetraffic.com.
3. Scheepvaartwest, “Passengers & cruise”, accessed August 14, 2020. https://www.scheepvaartwest.be/CMS/index.php/passengers-cruise.
2.2. Mapping anchored cruise ship locations

The location and navigational status of cruise ships (passenger vessels) were monitored using processed AIS (automatic identification system) data from MarineTraffic as archived data or freely accessible real-time data. Since 2008, all passenger vessels, regardless of size, are required to carry an AIS device (Robards et al., 2016). Cruise ships’ AIS transponders are most likely located in or near the bridge close to the bow (front) of the ship; therefore, the AIS location transmitted represents the bow section of the ship. The navigational status field is manually set by the crew.

Location as latitude and longitude coordinates (WGS84) and navigational status (anchored, underway, moored, underway using engine, restricted manoeuvrability, stopped, and not under command) data were obtained from MarineTraffic for all cruise ships in close proximity to Barbados for the period 1 March to September 1, 2020. This involved purchasing archived data from 1–31 March, as well as accessing open-source, real-time data from the MarineTraffic website and through their dedicated mobile phone application between 1 April and 1 September.

All the cruise ship data (descriptive and anchored locations) were entered into a MS Excel database where data were manipulated and summarised using the ‘Pivot Table’ and ‘Filter’ tools, and various formulae. Since purchased archived data were hourly, but real-time data for anchored ship positions were only collected every 4 h, the resolution of all the data was reduced to 4-hourly for calculation of mean anchored position. Four-hourly and mean anchored locations were exported to ESRI ArcMap for visualisation and area analysis.

Several additional spatial datasets were used to produce maps displaying the location of cruise ships while anchored and their proximity to various benthic marine habitats and other features using ESRI ArcGIS software to produce overlays. The geographic coordinate system used to create these maps was WGS_1984_UTM_21_N.Zone. Cruise ships’ mean positions whilst at anchor were mapped onto the 2015 geospatial marine habitat map for Barbados (Baldwin et al., 2019) where ‘hard coral patch reef’ and ‘hard coral framework reef’ were selected as the main coral-rich habitats. Additional datasets such as dive sites, reef monitoring sites, anchorages, and designated bathymetry were added as layers to create the maps. Extra details and Excel datasheets created as well as metadata for additional spatial data used in mapping are provided in Small and Oxenford (2021).

2.3. Validating anchor location

Since AIS position data gives the location of the ship’s hull (bow section), it was necessary to obtain further information to map the location of the anchor and length of chain deployed. For this we used both direct observation by SCUBA and detailed past track plots available from MarineTraffic as described here.

2.3.1. Direct observation

A SCUBA dive was conducted on the ‘live’ anchor of one of the cruise ships to observe the length and movement of the anchor chain, as well as the size and placement of the anchor, and thus better understand the damage caused at other sites. A video was recorded of the entire length of deployed anchor chain so the number of links could be counted, and the length of chain estimated. The GPS location of the dive boat at the start of dive (directly below the anchor hawsehole) and at the end of the dive (directly over the anchor) were also used to validate the length of the anchor chain deployed.

2.3.2. Detailed past track plots

The actual position of the anchor drop was also obtained for a select number of cruise ships by using the MarineTraffic application to check the cruise ship’s past track immediately prior to changing their status to ‘At anchor’ (Fig. 1a). This provided further evidence of the approximate length of chain typically deployed.

2.4. Assessment of reef damage by anchored cruise ships

2.4.1. Visual reconnaissance

Qualitative coral reef damage assessments were carried out in person using SCUBA gear. Approximate area of damage was estimated by swimming over the entire area and counting fin kicks to estimate distance, and damage was recorded using an underwater camera (as still photographs and video footage). The damage was qualitatively characterised by describing the status of coral, sponge and gorgonian colonies as: scarred, toppled, completely overturned, or reduced to rubble. Sensitive areas (i.e. on coral-rich habitat) where cruise ships were known to have anchored were selected for this qualitative assessment. As such, SCUBA dives were carried out at several bank reef locations (Bright Ledge Reef, The Farm Reef and Horseshoe Reef on the west coast and Quarantine Reef on the south coast) to examine and characterise the damage.

![Fig. 1. Maps showing the movement of cruise ship No. 21 while at anchor in Carlisle Bay between 11 and July 23, 2020: (a) Screenshot from MarineTraffic showing the past track (recorded every few minutes) clearly showing the incoming track and location of the anchor deployment (blue circle), as well as the subsequent swinging movement of cruise ship at anchor. (b) Map showing the hourly positions (blue dots) as received from MarineTraffic, and the estimated location of the anchor when first deployed (black circle). (c) Map showing the polygon representing the estimated maximum area of potential habitat damage for this anchoring event.](image-url)
2.4.2. Mapping

Using the ship’s position data from MarineTraffic together with the presumed position of the anchor, the maximum area of potential benthic habitat damage caused by each cruise ship at anchor was calculated in ArcMap. This was done using the Measure tool to draw a polygon around the swinging ship and its anchor chain (Fig. 1c). Overlap of cruise ship anchoring locations (polygon overlap) was accounted for in the final total calculated for all anchoring events.

3. Results

3.1. Description of cruise ships and anchoring behaviour

A total of 132 anchor drops were made by the 28 cruise ships along the west and south coasts of Barbados between 1 March and September 1, 2020. The 28 anchored cruise ships ranged in size from 53 to 339 m long, 12–42 m wide, and 674 to 156, 271 gross tonnage making them among the largest ships in the world. Typical of cruise ship design they also had multiple decks and shallow drafts (4–9 m) allowing them to carry thousands of passengers and access shallow water locations, but also presenting enormous windage and making them highly susceptible to movement at anchor.

Most ships anchored multiple times and based on their observed tracks, either entered the Bridgetown Port (for refuelling, picking up supplies, dropping off passengers, changing crew, or disposing of solid waste) or travelled 12 or more nautical miles out to sea (to dispose of treated liquid waste outside of Barbados’ territorial waters as required by law) in between anchor drops. Eight of the 28 cruise ships anchored only once, whilst four of them anchored 10 or more times. Not only did the majority of cruise ships anchor more than once, but they also anchored for different lengths of time ranging from just 33 min to 17 days, 22 h and 18 min for a single anchoring event and as much as 103 days of accumulated anchor time per ship (Table 1).

Cruise ships anchoring in Barbados were monitored over a period of 27 weeks from 1 March to September 1, 2020 (Fig. 1). The highest number of anchor drops (9–16 per week) happened in weeks three to seven (15 March – 18 April), remained fairly stable through May–June and then declined through July–August with the last anchor being hauled on 16 August (Fig. 2).

3.2. Location of anchoring

The mean position of each anchored cruise ship over each anchoring event is shown in Fig. 3, and indicates that cruise ships anchored along the sheltered (leeward) west coast and within Carlisle Bay on the south coast between 13.0504° and 13.3000° N and 59.6778° and 59.5772° W. The anchoring locations were also clustered, with five ships making 20 anchor drops at the northern end of the west coast, approximately 1 km from the shore, and the remainder of the anchor drops being recorded at the southern end of the west coast, off the Bridgetown Port and the western end of the south coast in Carlisle Bay (Fig. 3b). Most ships anchored repeatedly in approximately the same location, but a few moved between the clusters.

As seen in Fig. 3c and d many cruise ship anchors were likely dropped on or near coral reef such that the anchor itself and/or the anchor chain would have come into contact with the benthic coral reef community. Almost half of the cruise ships (11) anchored on hard coral framework reef. Additionally, many of the anchored cruise ship positions are close to popular SCUBA diving sites used by the island’s dive shops given that dive sites are mainly found on hard coral framework reefs (Fig. 3c and d). All five cruise ships that anchored on the west coast (Cruise ship Nos. 11, 23, 24, 25 and 28) anchored in close proximity to the hard coral framework (i.e. the bank reef). Three ships on the west coast anchored close to or directly on three popular SCUBA diving sites. On the south coast, the cruise ships mainly anchored on hard coral

### Table 1

| Vessel Name      | Vessel size class | Time spent at anchor | No. Times anchored |
|------------------|-------------------|----------------------|--------------------|
|                  |                   | Total Days hr min    | Average Days hr min|
| Cruise ship No. 20 | S                  | 3 4 30               | 3 4 30             |
| Cruise ship No. 14 | S                  | 0 0 34               | 0 0 34             |
| Cruise ship No. 13 | S                  | 15 20 10             | 7 22 5             |
| Cruise ship No. 22 | S                  | 1 0 32               | 0 12 16            |
| Cruise ship No. 23 | S                  | 10 12 51             | 2 15 12            |
| Cruise ship No. 11 | S                  | 12 2 11              | 3 0 32             |
| Cruise ship No. 28 | S                  | 21 8 31              | 4 6 30             |
| Cruise ship No. 25 | S                  | 13 19 11             | 2 17 30            |
| Cruise ship No. 24 | M                  | 63 7 56              | 4 12 34            |
| Cruise ship No. 17 | M                  | 4 21 26              | 4 21 26            |
| Cruise ship No. 15 | M                  | 0 21 39              | 0 21 39            |
| Cruise ship No. 26 | M                  | 0 11 55              | 0 11 55            |
| Cruise ship No. 19 | M                  | 6 9 24               | 3 4 42             |
| Cruise ship No. 21 | M                  | 44 6 30              | 11 1 37            |
| Cruise ship No. 10 | M                  | 10 1 40              | 2 12 54            |
| Cruise ship No. 1  | M                  | 103 8 40             | 8 14 43            |
| Cruise ship No. 27 | M                  | 72 18 19             | 4 1 1 18           |
| Cruise ship No. 5  | L                  | 8 22 28              | 8 22 28            |
| Cruise ship No. 3  | L                  | 1 22 28              | 1 22 28            |
| Cruise ship No. 8  | L                  | 0 0 33               | 0 0 33             |
| Cruise ship No. 16 | L                  | 7 20 48              | 3 22 24            |
| Cruise ship No. 12 | L                  | 1 20 42              | 0 22 21            |
| Cruise ship No. 4  | L                  | 9 10 14              | 3 3 24             |

(continued on next page)
framework reefs and hard coral patch reefs. Fortunately, even though nine bank reef monitoring sites are established along the south and west coast, none of the anchoring activity took place on these reef monitoring sites.

The cruise ships anchored in a relatively narrow range of depths (Fig. 3e and f) with most cruise ships apparently anchoring in water between 30 and 40 m deep, although some anchored in water more than 40 m deep. The Quarantine Anchorage was the only designated anchorage that was used by the cruise ships (Fig. 3f). Seven cruise ships used this anchorage and 18 anchor drops were made here. Outside of the Bridgetown Port is a ‘No anchoring zone’; however, four anchor drops by three ships still happened within or close to this zone (Fig. 3f).

3.3. Assessment of anchor damage

3.3.1. Visual

On the July 12, 2020, while Cruise ship No. 27 was anchored in Carlisle Bay, a SCUBA dive revealed first-hand, the size and placement of the anchor and active movement of the chain grinding coral skeletons to produce broken rubble and a fine sediment plume. Also witnessed were the broad anchor (and chain) scour and large pile of coral rubble heaped up on the anchor flukes. This had occurred during the two days that the ship had been anchored in this position. The anchor and chain were deployed in hard coral patch reef habitat. As reported by Baldwin et al. (2019) hard coral patch reef in Barbados refers to areas which are of medium relief, sand substrate with a medium to dense living community cover including hard coral species, particularly Orbicella annularis, sponges, gorgonians, macroalgae, and coralline algae. In this case there was extensive damage to the coral community with a large area denuded of all erect marine organisms (corals, sponges, gorgonians) and several broken live coral heads and sponges scattered over the area cleared by the moving chain (Fig. 4).

A further three dives were carried out between 21 July and September 2, 2020 on hard coral framework reef habitat at several bank reefs sites on the west coast to analyse damage done to the reefs by the anchor and chain of cruise ships that anchored directly on or to the inshore side (windward) of the reefs. As described by Baldwin et al. (2019), a typical bank reef on the west coast comprises a highly rugose, massive hard coral framework supporting a diverse reef community. The reefs are dominated by hard corals with abundant sponges and gorgonians (Fig. 5a and b).

These dives revealed extensive damage at these sites where the anchor chain had clearly dragged along the top of the bank reef and completely removed the dense cover of benthic marine organisms such as corals and sponges (Fig. 5c and d). Large areas had also been reduced to a ‘field of boulders’ comprising broken pieces of living corals, gorgonians and sponges strewn about and whole colonies dislodged from the substratum, toppled or even turned completely upside down (Fig. 5d). This large, damaged area has essentially been reduced to a loose rocky reef with severely reduced architectural complexity and minimal live coral. Visual reconnaissance revealed that the reefs had experienced 1000 s m$^2$ of damage with complete destruction of the reef framework in places.

Another dive conducted on 16 September 2020 in Carlisle Bay on the Quarantine bank reef within the designated ships anchorage, where seven cruise ships had anchored a total of 18 times, revealed the devastating impacts of multiple anchorings to hard coral framework reefs (Fig. 6). Clearly obvious at this site was the complete destruction of the coral reef community and framework from years of anchoring by ships visiting Barbados, as well as by the recent cruise ships whose new damage could be seen by the recent white scars in the substratum (Fig. 6). The reef resembled a marl road with large rock boulders strewn about and little to no architectural complexity (Fig. 6). The site is essentially now devoid of living coral and other common reef biota such as sponges and gorgonians and demonstrates the extent of damage that can be caused by continued anchoring of large commercial vessels.

| Vessel Name | Vessel size class | Time spent at anchor Total | No. Times anchored Average |
|-------------|------------------|--------------------------|---------------------------|
|             |                  | Days hr min              | Days hr min               |
| Cruise ship No. 9 | L        | 4 10 53                  | 1 2 43                    |
| Cruise ship No. 6 | L        | 31 19 44                 | 4 13 6                    |
| Cruise ship No. 18 | L       | 22 11 38                 | 3 5 5                     |
| Cruise ship No. 2 | L       | 28 6 10                  | 3 3 21                    |
| Cruise ship No. 7 | L       | 49 11 0                  | 3 12 47                   |
| TOTAL       |                  | 550 6 15                | 132                       |

Fig. 2. The weekly total number of cruise ship anchor drops that happened between 1 March and September 1, 2020 along the west coast and south coast of Barbados.
Fig. 3. Maps showing: (a) the location of Barbados (black square) within the Caribbean; (b) the two clusters of cruise ships anchoring positions on the west and south coast of Barbados; and (c)–(f) the locations of 132 anchoring events on the west and south coasts of Barbados between 1 March and September 1, 2020. Coloured dots indicate the mean position of the ship over each anchoring event, with a different colour for each of 28 individual cruise ships. Coral-rich habitats (orange and red), recreational dive sites, and permanent reef monitoring sites are shown in panels c and d. Bathymetry and anchor zones are shown in panels e and f. Bathymetry and habitat is shown to a maximum depth of 40 m (i.e. maximum penetration by LIDAR). Turquoise polygons indicate designated anchorages and lilac polygons indicate no-anchor zones (based on 2020 edition of Nautical Chart 502).
3.3.2. Mapping

A dive on the ‘live anchor’ provided the opportunity to estimate the length of anchor chain and the exact position of the anchor relative to the ship. Length of anchor chain measured in situ confirmed the deployment of at least 200 m of chain when anchored in just 24 m depth (estimates from: link counts was 202 m; GPS distance was 200 m). This suggests a depth to chain ratio of 1:8. Further examination of high resolution past track data on the MarineTraffic platform confirmed that the typical distance between anchor drop location and the ship’s bow as it swings at anchor is between 200 and 300 m. As such the location of the anchor for all anchorings without high resolution data was presumed to be approximately 250 m up-wind from the mean position of the anchored ship as obtained from AIS. This informed the size of polygons drawn around the four-hourly anchored positions of each cruise ship and revealed the approximate surface area covered by the anchor chain of the swinging vessel. This provided an estimate of the maximum potential area of habitat damage caused per anchoring event. This differed among the three vessel size classes of cruise ships with large vessels covering a mean surface area of 40,094 m$^2$ over a period of 3–5 days at anchor, representing almost 1.5 times more than medium vessels and more than twice the area covered by small cruise ships (Table 2). Taking the overlap of all anchoring polygons into consideration, the maximum total cumulative area of potential habitat damage was estimated to be 1.8 km$^2$ for the 132 cruise ship anchoring events.
anticipation that cruise lines may consider Barbados for home porting in the future. In fact, Barbados actively encouraged triate their passengers and crew, at a time when many countries were refusing to allow them entry. In fact, Barbados actively encouraged cruise ships to the island by offering them special reduced port rates in anticipation that cruise lines may consider Barbados for home porting in the future. When not alongside in port, cruise ships where charged US$ 250 per day to anchor, apparently to help compensate for any damages such as spills or reef damage that may occur from anchoring. Assuming that these fees were collected, this would have netted around US$ 137,500 for the 550 days of anchored time by the 28 ships in this study (Table 1). Intangible benefits included the benefit that Barbados derives from coral reefs largely depends on the health of those coral reefs. Further, the Coastal Zone Management Act puts a price of US$ 150 on every square metre of coral reef damaged.

Degraded reefs will impact the tourism sector indirectly through reduced provision of exotic food-fish, sand and shore protection services, and directly through reduced quality of dive sites, since recreational divers in Barbados are willing to pay considerably more for good coral cover, fish diversity and presence of sea turtles (Schuhmann et al., 2013). Degraded reefs will also impact reef fisheries through the loss of architectural complexity (Rogers et al. 2014; Graham 2014). The local reef fishery contributes to food security on the island and is important in supporting livelihoods particularly during the pelagic fishing off-season (Schuhmann et al., 2011; Peterson et al., 2014; Gill et al., 2019).

It is recognised that not all the maximum area of potential damage reported here would have occurred to critical coral-rich habitats because some cruise ships anchored within the designated Quarantine Anchorage in Carlisle Bay, which has been used by cargo vessels visiting Barbados since the 17th Century and is already highly degraded. Others

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**Table 2**

Crude estimate of mean potential area of benthic habitat affected by cruise ships anchoring off Barbados over the period 1 March to September 1, 2020, shown by vessel size class (L – large, M – medium, S – small) and by coast. Vessel size categories given in Table 1.

| Vessel size class | Mean maximum area affected (m²) |
|-------------------|---------------------------------|
| L                 | 40,094                          |
| M                 | 28,210                          |
| S                 | 14,349                          |

**Fig. 6.** Photographs taken on September 16, 2020 by SCUBA divers at 24 m depth at Quarantine Reef in Carlisle Bay showing a completely destroyed bank reef coral habitat from decades of ships anchoring and fresh anchor drag and anchor chain marks. Photo credits: Micaela Small.

**4. Discussion**

As the global COVID-19 pandemic took hold across the Caribbean region, the Barbados Government saw an opportunity to build and strengthen relationships with cruise lines by offering their ships safe harbour, docking facilities and access to international flights to repatriate their passengers and crew, at a time when many countries were refusing to allow them entry. In fact, Barbados actively encouraged cruise ships to the island by offering them special reduced port rates in anticipation that cruise lines may consider Barbados for home porting in the future. When not alongside in port, cruise ships where charged US$ 250 per day to anchor, apparently to help compensate for any damages such as spills or reef damage that may occur from anchoring. Assuming that these fees were collected, this would have netted around US$ 137,500 for the 550 days of anchored time by the 28 ships in this study (Table 1). Intangible benefits included the benefit that Barbados derives from coral reefs largely depends on the health of those coral reefs. Further, the Coastal Zone Management Act (1998) puts a price of US$ 150 on every square metre of coral reef damaged.

Degraded reefs will impact the tourism sector indirectly through reduced provision of exotic food-fish, sand and shore protection services, and directly through reduced quality of dive sites, since recreational divers in Barbados are willing to pay considerably more for good coral cover, fish diversity and presence of sea turtles (Schuhmann et al., 2013). Degraded reefs will also impact reef fisheries through the loss of architectural complexity (Rogers et al. 2014; Graham 2014). The local reef fishery contributes to food security on the island and is important in supporting livelihoods particularly during the pelagic fishing off-season (Schuhmann et al., 2011; Peterson et al., 2014; Gill et al., 2019).

It is recognised that not all the maximum area of potential damage reported here would have occurred to critical coral-rich habitats because some cruise ships anchored within the designated Quarantine Anchorage in Carlisle Bay, which has been used by cargo vessels visiting Barbados since the 17th Century and is already highly degraded. Others

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1 Senior official, Bridgetown Port, telephone call with author, August 14, 2020.

5 Coastal Zone Management Act, CAP. 394, Barbados (1998) http://extwpr.leg1.fao.org/docs/pdf/bar18058.pdf.
anchored in sand habitat far enough away from coral habitat to avoid direct physical damage, although sand-dwelling organisms are likely to be affected. Further, sediment plumes caused by the disturbance of sandy substrates could still have negatively impacted filter feeding organisms in coral communities down current (Broad et al. 2020). Also, some anchoring areas were presumed to be sand, where the depth was >40 m and thus beyond the limit of available detailed habitat maps. However, in some cases, especially seawards of the bank reef on the west coast, these ‘deep’ areas are likely to be mesophotic coral reef habitat (Lewis 1965).

4.2. Management failures and lessons learnt

It is clear from this study that significant coral reef damage occurred due to cruise ships anchoring even though Barbados has a relatively comprehensive array of management plans, legislation and institutional arrangements in place that acknowledge the value of coral reefs to the island, and provide for their management. This indicates policy failures to protect the island’s coral reefs when faced with a situation not previously encountered or anticipated and provides an opportunity to learn important lessons.

Firstly, the research demonstrates the inadequacy of the anchoring fee that was charged apparently to ‘compensate for any damage that may occur’4. The Coastal Zone Management Act is absolutely clear about the fines that could be charged for damaging coral reef and yet there is no evidence that any action was taken to pursue this. This was likely a combination of the difficulty in assigning blame to cruise ships that were given permission to anchor (Barbados Today 2021), and fear of losing favour with an industry seen as critical, especially in the post-COVID recovery of the island’s economy. Furthermore, monetary compensation is highly unlikely to adequately replace the ecosystem services lost over the long-term, especially given the difficulty in quantifying these (Woodhead et al., 2019). Coral restoration may be offered as a solution, but assisted restoration of reef framework requires costly and complex engineering that is only practical at small scales (Lirman and Schopmeyer 2016). Ecological restoration, whereby new healthy corals are transplanted onto coral reefs to replace corals that have been killed, is a slow, skilled and labour-intensive process (Bayraktarov et al., 2016) and remains highly controversial (Bosström-Einarsson et al., 2020). Despite the fact that coral restoration practitioners have made considerable advances in recent years, effective restoration projects are generally at relatively small scales 10s–100s of metres, and in shallow water (i.e. < 10 m) (Boström-Einarsson et al., 2020) and substantial research and development is still required to scale-up and improve all facets of coral reef restoration (McLeod et al., 2019). As such, coral restoration should not be considered a practical or effective solution for repairing large scale reef damage caused by cruise ship anchoring.

Secondly, although one of the most common ways to manage impacts of anchoring on marine sensitive areas by visiting vessels is through the use of designated anchorages (Steele et al., 2017), our study has shown that the only designated anchorage in Barbados that is large enough to accommodate cruise ships is the Quarantine Anchorage in Carlisle Bay. However, this anchorage is too small to accommodate more than a single cruise ship at any given time, considering its diameter of just 600 m and the fact that many cruise ships are close to 300 m in length, deploy 200–300 m of chain and swing in an arc close to 180° even when the wind is from a steady direction. To facilitate multiple cruise ships anchoring simultaneously, the Bridgetown Port allowed ships to anchor in the vicinity of this south coast anchorage (a common practice elsewhere in times of heavy marine traffic (Steele et al., 2017)) and collaborated with the CZMU to select large sandy areas on the west coast that could act as alternative anchorages. These were intended to allow the cruise ships enough space to anchor and swing without causing significant damage to benthic habitats. However, several failures were evident in applying this policy decision. Cruise ships were given GPS coordinates for the chosen locations outside the officially designated Quarantine Anchorage, but were not required to carry a pilot with them when they anchored at these locations, indicating a weakness in the prescribed protocol. On several occasions the public alerted the CZMU about cruise ships that appeared to be anchoring on reef along the west coast, and they in turn notified the Port. As a result, the ships were told to move and on more than one occasion the coastguard was deployed to assist, resulting in the ships re-anchoring in virtually the same location. A senior official from the Port stated that damage occurred to reef habitats because the ships anchored in the wrong places, dropping anchor in the vicinity of the GPS coordinates they were given and not at the exact position, indicating a failure to follow protocol. Although this may have been the case, it is also highly likely that at least some of the ‘prescribed’ anchorages were unsuitable. The 100s of metres of anchor chain required to anchor such large vessels and the swing of cruise ships whilst anchored was likely unknown or perhaps overlooked when choosing these alternative anchorages. While additional designated anchorages may be a viable solution, this research has revealed that there are few suitable alternative anchorages large enough for cruise ships in Barbados and none on the west coast because of the topography and abundance of coral rich reef habitat (Small and Oxenford 2021). As such, another solution is needed for when marine traffic is heavy. The most effective way to prevent further damage in the future would be to prohibit cruise ships from anchoring outside of the designated Quarantine Anchorage. Such a national policy and supporting legislation, could be further strengthened by the designation of the island’s coral-rich nearshore waters as a Particularly Sensitive Sea Area (PSSA) under the International Maritime Organization (IMO), which stipulates what ships must or must not do in such areas. This is relevant to many of the Caribbean SIDS which have coral-rich habitats, are highly vulnerable to environmental challenges and depend heavily on their natural marine resources for industries such as tourism and fisheries. Examples of IMO-designated PSSAs in the Caribbean include Saba Bank, Sabana-Camagüey Archipielago in Cuba and the Florida Keys. If a no-anchoring policy is implemented, cruise ships unable to enter the port or use the Quarantine Anchorage could use their Dynamic Positioning System (DPS) to maintain their position without dropping anchor.

Thirdly, individual cruise ships have a responsibility to ensure that their anchoring is not likely to damage reef habitat. This is stated by several of the cruise lines’ various environmental management policies and reiterated by the Cruise Lines International Association (CLIA) (Sweeting and Wayne 2011). In this case, cruise ships clearly failed to take this responsibility seriously. However, if detailed habitat maps were made available to visiting vessels, they would be much better able to avoid sensitive marine habitats as stated by Davis et al. (2022). As pointed out by Kininmonth et al. (2014), it is important that habitat map resolution is compatible with management advice and should include mesophotic reef habitat. Furthermore, habitat maps should be freely accessible across all agencies charged with responsibility for protecting coral reefs and other sensitive marine habitats, in what is typically a multi-agency governance arrangement.

4.3. Policy response

The minister of Marine Affairs and the Blue Economy paid close attention to the many media reports of reef damage from the onset of cruise ship anchoring and acknowledged the original technical report from this study, as reported by Deane (2021). As a consequence, there has been dialogue among the relevant agencies in Barbados, and

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6 Senior official, Bridgetown Port, personal communication with author, August 28, 2020.
7 Dive operator on site during two such manoeuvres, personal communication with author, July 21, 2020.
between the Government and the cruise lines, resulting in a new stated policy. This indicates that cruise ships will no longer be permitted to anchor along the west coast and that any wishing to stop, or instructed to wait on the west coast, must use their DPS technology to hold position.

Compliance with the stated new policy has continued to improve over the period from the end of this study up to the end of the current cruise season (1 Sept 2020–May 1, 2022). Over this time there have been a further 57 cruise ship anchoring events (2020: 1; 2021: 26 by 5 cruise ships; 2022: 30 by 6 cruise ships). None of these have been on the coral-rich northern end of the west coast. In 2020–2021 55 percent were outside the Quarantine Anchorage, but in the vicinity of the Bridgetown Port. In 2022 all but one anchoring event has occurred within the anchorage and most of these anchoring events have been by two vessels permitted to anchor whilst acting as quarantine ships for crew and COVID-positive passengers (and only anchoring one at a time)<sup>8</sup>. Other cruise ships we have observed drifting in Barbados’ territorial waters for days or weeks at a time when not in service or using their DPS over the short-term whilst awaiting a berth in the port. Furthermore, lessons learnt in Barbados from this study have already been noted by the British Virgin Islands government in their stated policy to further protect their coral reefs from anchor damage by implementing no-anchoring zones (Haynes 2021).

5. Conclusion

This research highlights policy failures in the management of coral reefs in Barbados that allowed cruise ships to anchor in coral rich areas, and supports the recommendations of Schuhmann (2020) that the ‘hidden’ values of natural assets (such as coral reefs) and the economic losses induced by their degradation should be incorporated into national accounting. This should in turn lead to better informed policy decisions and actions that impact the marine environment. This will be critically important to avoid further unnecessary destruction of the island’s coral reefs that underpin the tourism industry, as Barbados continues to focus on further developing the cruise ship industry as a component of the emerging blue economy.

The lessons learnt from allowing cruise ships to anchor in Barbados are widely applicable to other cruise ship destinations across the Caribbean and beyond, where cruise ships and mega-yachts routinely anchor in sensitive marine habitats. This is particularly relevant globally given the importance of achieving the UN sustainable development goals, notably goal 14 ‘Life below water’, the increasing interest in developing blue economies, and the fact that cruise tourism continues to show dramatic growth in the Caribbean (Jean-Marie 2021; Clegg et al. 2021) and globally as it recovers from the financial shock of COVID-19 (Lin et al. 2022). Furthermore, as intended under the Latin American and Caribbean regional Escazú Agreement of 2018 which came into force in April 2021, this information should be shared with policy makers, managers, cruise ship companies and civil society to illustrate why cruise ships should not anchor in the coral-rich nearshore waters typical of most countries in this region. This should hold true across the globe, even where port facilities are inadequate, or cruise ships choose to visit remote locations for the benefit of their passengers.

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### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

Data will be made available on request.

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8 Senior official, Bridgetown Port, telephone call with author, 10 March 2022.
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