

Article

The Impact of Sargassum Inundations on the Turks and Caicos Islands

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Abstract: Since 2011, holopelagic *Sargassum fluitans* and *natans* have been arriving en masse to the wider Caribbean region and West Africa, impacting near-shore habitats and coastal communities. We examined the impacts of the Sargassum influx on tourism-related businesses through face-to-face interviews and focus groups and on near-shore seagrass beds through in-water surveys in the Turks and Caicos Islands (TCI). Substantial accumulations of sargassum were found on the beaches of South Caicos and Middle Creek Cay in 2018 and 2019, including a Sargassum brown tide in 2018. A variety of different approaches to removing sargassum from the beaches were mentioned and a desire from local businesses as well as local authorities to find a sustainable, cost-effective solution to what is viewed by many as a serious problem. The brown tide and sargassum accumulating as a layer on the benthos inside the seagrass beds caused significant loss of *Thalassia testudinum*. *Halodule wrightii*, macroalgae and sand plains were found in the areas lost by *T. testudinum*. This finding suggests that, if a cost-effective end use for sargassum could be identified, harvesting material in inshore waters rather than when it has arrived on the beach would have dual benefits.

Keywords: seagrass; *Thalassia testudinum*; brown tide; tourism; fisheries; tour operators; management; sargassum brown tide; beach



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1. Introduction

Note: the term sargassum is used in this report as the common name for the *Sargassum* species found in the beach drift on the Turks and Caicos Islands, predominantly *S. fluitans* III and *S. natans* I and VIII.

In recent years, the Caribbean has experienced sudden inundations of seaweed masses on coastlines and beaches, predominantly of the holopelagic *Sargassum fluitans* III, *Sargassum natans* I and *Sargassum natans* VIII [1,2]. Thought to originate from the Sargasso Sea, this is now acknowledged to be from the North Equatorial Recirculation Region (NERR), located off the coast of Brazil and Northwest Africa, drifting into the eastern Caribbean on currents [3–8].

The floating sargassum rafts provide a rich habitat for many species such as sea turtle hatchlings (*Chelonioidea* spp.), seahorses (*Hippocampus* spp.), flying fish (*Exocoetidae* spp.), more than 145 invertebrate species and at least 100 other species of fish reported to use them for forage, refuge, and breeding [9–11]. There is little peer-reviewed evidence on what species remained when the rafts washed on to coastal shores, although there are anecdotal reports of dead fish producing an odor, and of birds feeding amongst the rotting seaweed. Researchers working in the Mexican Caribbean took samples at 2, 5 and 500 m from the shore and found high diversity and number of individuals in rafts at sea but lower abundance near the shore. This led to the suggestion that harvesting sargassum from within the reef lagoon might be less damaging than taking it from the sea, although this was caveated by the recommendation for more research to inform management decisions [12].

There are more than 350 species of seaweed in the genus *Sargassum*, and these regularly wash onto beaches in small quantities. It is only since 2011 than massive inundations have occurred, damaging local economies and the environment across the Caribbean, Gulf of Mexico, and West Africa [1]. This led to the United Nations producing ‘The Sargassum White Paper’, referring to ‘golden tides’ and advising monitoring to enable understanding of the abundance and distribution of sargassum landings [13]. This phenomenon has attracted considerable attention as a biomass resource, with commercial potential for products ranging from biochemicals, livestock feed, food, fertilizer, and fuel. However, as pointed out by Milledge and Harvey [14], lack of knowledge of the composition and level of pollutants, combined with the unpredictability of the resource, presents considerable challenges. The warning of potential toxicity has been reiterated in the recent Sargassum Uses Guide [15].

This research, part of a larger project which aimed to address these knowledge gaps, was conducted in the Turks and Caicos Islands, a British Overseas Territory comprising approximately 40 inhabited and uninhabited low limestone islands and golden sandy beaches, in the Atlantic Ocean, southeast of the Bahamas (Figure 1).



Figure 1. Location of the Turks and Caicos Islands.

The objective was to determine firstly what impact the sargassum was having on tourism-related businesses and secondly whether it was affecting the seagrass meadows known to be important for the economically important fisheries.

The business basis of TCI trade changed with the collapse of solar salt production and the rise of tourism in the mid-1960s, with Caribbean Islands seen as exclusive, upmarket, destinations [16]. Providenciales rose in importance, with tourism described as the engine for economic growth [17] and as ‘an economic revolution’ [18]. This trend has continued, with a reported 17.5% increase in tourist arrivals in 2016, estimated at over 455,000 visitors to the archipelago, with a consequent dramatic increase in development, particularly of luxury villas and coastline beach resorts. There is a seasonal pattern, with higher numbers of visitors in winter and early spring. Brief visits, typically measured in hours rather than days, are made by cruise ships calling in to Grand Turk, the only terminal in the islands. The number of ships has increased along with their passenger capacity. Providenciales is the main island, with most resorts, and includes the most famous beach, Grace Bay. It is the gateway for tourists arriving by air, although South Caicos and Grand Turk also have small airports providing inter-island flights, with Grand Turk, to the east, having a cruise ship terminal. The key attraction is the natural environment, particularly the pale sandy beaches and turquoise blue, crystal-clear, water, and this has given rise to the phrase ‘beautiful by nature’ used in much promotional material. It is abundantly clear that the tourism industry, based on a combination of the pristine beaches and marine wildlife, is vital to the economy of the Turks and Caicos Islands.

Tourism, prior to the COVID-19 pandemic, made the greatest contribution to the Gross Domestic Product, [19], followed by the offshore banking sector and fisheries, notably Queen conch (*Strombus gigas*) and spiny lobster (*Panulirus argus*), which are consumed locally and exported, mostly to the United States [20], with fishing the main economic activity on South Caicos [21]. The same fisher fleet targets both species [22,23]. Historically, Queen conch (*Strombus gigas*) was the principal food source, with the indigenous Lucayans and Arawak Indians using the TCI as temporary fishing platforms. The conch fishery increased after the collapse of the salt industry [24]. The lobster fishery developed after the introduction of snorkeling and freezing technology in the 1950s and 1960s with export markets in Florida and the US driving demand, with TCI-sourced conch attracting a premium [22].

The Caicos Bank, on the leeward side of the Turks and Caicos Islands, is shallow and sandy with vast seagrass beds consisting of *Syringodium filiforme*, *Halodule wrightii* and *Thalassia testudinum*, the latter being dominant [22]. These sustain the conch, lobster, and fish stocks of the TCI, providing habitat for 56 fish species, representing 22 families, at various points of their life cycle, including 8 of the 10 most abundant species landed by commercial finfish fishers [25]. A study conducted on South Caicos found that the habitat most populated by juvenile lobsters was in East Bay and dominated by the seagrass *Thalassia testudinum* with approximately 10–20% cover of the red algae *Neogoniolithon* [26]. The seagrass beds are also foraging ground for the protected hawksbill (*Eretmochelys imbricata*) and green sea turtles (*Chelonia mydas*), which have been harvested in TCI since at least AD 700 [27] although this is now permitted only for domestic consumption [28].

The tourism sector benefits from seagrass beds as they contribute to the crystal-clear turquoise waters that lure visitors to the islands. Restaurants often serve seagrass-associated species, such as conch, lobster, Nassau grouper or yellowtail snapper and snorkel and kayak tours visit seagrass meadows so tourists can encounter green sea turtles [29]. However, the tourism industry adversely affects seagrass beds through dredging for ports, marinas and shipping channels, chemical run-off from hotels, use of motorboats and clearance of inshore seagrass to provide guests with a sandy substrate [25].

This study investigated the effects of sargassum on tourism-related businesses and seagrass beds, which are known to support the principal economic sectors of the Turks and Caicos Islands. The first aim was to determine how strongly tourism-related businesses were affected by sargassum inundations and if the impacts varied between islands and between different business types. The second aim was to measure the sargassum accumulations on beaches on South Caicos and Middle Creek Cay and monitor the adjacent seagrass beds to determine if seagrass cover was lost and what type of substrate replaced the lost seagrass. This paper describes the results of the first stage of a larger investigation to address some of the gaps in information necessary to identify and evaluate potential sustainable solutions to the Sargassum inundation, supported by DEFRA Darwin Plus grant number DPR7P\100059.

2. Method

This section will first describe the method used to determine the views of local stakeholders and tourism-related businesses regarding the impact of sargassum and secondly the investigation into the inshore sea grass meadows.

2.1. Stakeholder/Tourist Business Interviews

Research into the views of local stakeholders, particularly businesses associated with tourism, was carried out during a visit to TCI in June 2019. It comprised face-to-face interviews and focus groups and was conducted on Providenciales, South Caicos and Grand Turk, the three islands with most tourist activity. This combined approach was selected as personal interaction is generally a more effective method of engagement than paper survey [30] and, as time was limited, bringing people together in focus groups effectively increased the number of businesses and stakeholders reached with the additional advantage

of providing deeper and richer content through interactions and group dynamics which can be particularly informative when there are differing perspectives [31,32]. A framework, serving as the schedule for both the focus groups and semi-structured interviews, was devised in consultation with local partners from both the Department for the Environment and Coastal Resources (DECR) and the School for Field Studies (SFS), based on South Caicos, to ensure questions were relevant and locally appropriate. The questions, with the rationale for each one, are given in Table 1.

Table 1. The interview schedule and rationale for the questions.

Questions	Rationale
Q1. Has sargassum had an impact on your business?	The fundamental rationale for this research.
Q2. If yes has this been Low, Moderate or High?	To estimate the scale of impact on business
Q3. Comments on this, e.g., when this happened, amounts of sargassum, customer comments	Supplemental evidence on nature of impact.
Q4. When did you first notice sargassum?	To identify when sargassum began arriving in TCI and to try to determine if there have been seasonal patterns
Q5. Are you taking any action such as removing sargassum?	To establish if businesses affected are removing sargassum from beaches.
Q6. If you are removing sargassum how is this done?	To identify methods and management techniques currently utilized in TCI.
Q7. How often?	To quantify regularity of clean-up and contribute to understanding level of impact and seasonality.
Q8. Do you keep a record?	Any records could contribute to quantifying impact and quantity arriving and when this is happening.
Q9. Request for any further information on sightings of sargassum on beaches	To collect data, build records of frequency and size of inundations and continue engagement on this issue.

The focus groups were advertised by DECR on their website and on posters displayed in places frequented by tourism-related business operatives. The meetings were hosted by DECR in their offices on Providenciales and South Caicos, by the National Museum on Grand Turk, and the Sustainable Tourism Association, again on Providenciales.

All meetings began with the two MSc students from the University of Greenwich, who were acting as research assistants, presenting desk study research they had done into sargassum prior to visiting TCI. This included an overview of the sargassum issue across the Caribbean region and information on the ecology and species associated with the floating rafts to provide a context for this research.

The semi-structured interviews were conducted face to face with individual businesses identified from advertisements and publicity material aimed at tourists. These were visited and the interviewer recorded responses on a pre-prepared form, based on the questions in Table 1, with any additional information and the business type noted. Where possible, potential respondents were phoned in advance and an appointment made; those operating from shops or beach-side locations were approached directly but given the option for the interviewer to return at a more convenient time.

2.2. Data Analysis

Focus group discussions were transcribed, and the content analyzed thematically. Differences in the views of participants on different Islands were identified, as well as themes emerging for TCI as a whole.

Interview responses were input into an excel spreadsheet and countif(s) functions used to enable extraction of specific criteria and used if there was more than one condition being analyzed. Some analysis was split by island and/or business type to enable interpretation using tables and graphs.

2.3. Sargassum and Seagrass Surveys

Ten beach sites were surveyed for seagrass and sargassum coverage, East Bay Beach, Coast Guard, Shark Bay Beach, East of Shark Bay, Long Bay Beach North, Long Bay Beach South, and Highland House, all on the windward side of South Caicos Island, and the beaches at the End, Middle, and Tip of Middle Creek Cay, just north of the South Caicos peninsula (Figure 2). All these sites consisted of sandy beaches, with sand plain, algal plain, patch reefs, rock, or seagrass beds in the shallow water, typically less than 3 m deep.

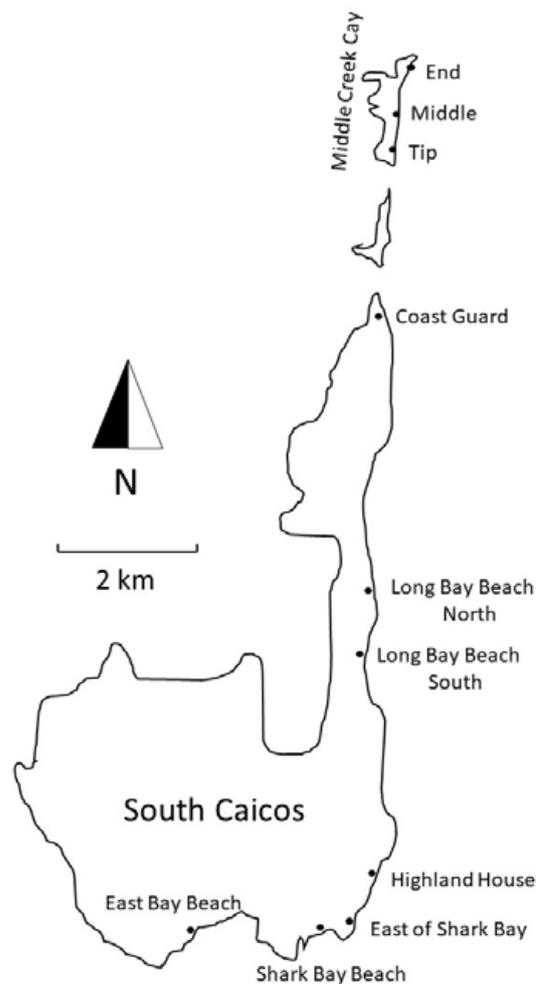


Figure 2. Map showing the 10 beaches and adjacent seagrass beds surveyed on South Caicos and Middle Creek Cay.

In November and December 2018, Middle Creek Cay End and Middle as well as the two Long Bay Beach sites were monitored and large areas covered in dense stumps of the seagrass species *T. testudinum* were found, indicating recent loss of seagrass beds. These sites as well as Middle Creek Cay Tip were monitored again in February and March of 2019. In April 2019, a large effort was put in place to monitor all accessible eastward facing beaches on South Caicos and Middle Creek Cay (Table 2). This effort was replicated in November and December; however, the two beaches that are regularly cleaned were not included in the surveys at that time.

Table 2. List of survey sites for beach and in-water surveys listed from north to south including the dates they were surveyed.

Site	Nov/Dec 2018	Feb/March 2019	April 2019	Sept/Nov/Dec 2019
Middle Creek Cay End	29 November 2018	13 February 2019	8 April 2019	2 December 2019
Middle Creek Cay Middle	29 November 2018	13 February 2019	8 April 2019	2 December 2019
Middle Creek Cay Tip		24 February 2019	8 April 2019	2 December 2019
Coast Guard			18 April 2019	20 November 2019
Long Bay Beach North	8 December 2018	2 March 2019	4 April 2019	
Long Bay Beach South	8 December 2018	2 March 2019	4 April 2019	19 September 2019
Highland House			11 April 2019	18 November 2019
East of Shark Bay			11 April 2019	14 November 2019
Shark Bay Beach			11 April 2019	7 November 2019
East Bay Beach			17 April 2019	

If sargassum was present on the beach, a transect was walked, placing the weighted end of the line at the start of the pile (or row) of beached material closest to the water's edge, and then pulling the line perpendicular to the water until the end of the pile. The depth of the sargassum deposit was determined by digging through it until sand was reached and the transect line placed inside it. At the 0.5 m mark and at each 1 m mark on the transect line, the depth was measured in cm. This enabled the cross-sectional area to be calculated using the following formulas:

$$\begin{aligned} \text{Cross sectional area} \\ = \frac{h_{0.5} \times 50 \text{ cm}}{2} + h_{0.5} \times 50 \text{ cm} + \frac{(h_1 - h_{0.5}) \times 50 \text{ cm}}{2} + \frac{(h_n - h_{n-1}) \times 100 \text{ cm}}{2} \\ + \sum_k^{n-1} (h_k \times 100 \text{ cm} + \frac{(h_{k+1} - h_k) \times 100 \text{ cm}}{2}) \end{aligned}$$

h_x = measured height of Sargassum at the 1 m mark x , and
 n = last 1 m mark that had Sargassum below it.

Pictures of the beaches were taken using a Galaxy S8 Active smart phone, a Sealife DC2000 underwater camera, and a GoPro.

2.4. Seagrass Cover

The distribution of seagrass habitat was mapped by snorkeling three separate 100 m long transects perpendicular to the shore and 5 m apart from each other at each of the 10 sites. The surveyor swam along these lines, noting at each 1 m the dominant substrate: sand, living and dead seagrass. Results were recorded graphically, and photographs were taken at the sites of the Sargassum on the beach.

3. Results

This will follow the same order as the method, the focus groups and interviews, followed by the beach and in-water surveys.

3.1. Focus Groups

The numbers attending and the composition of the groups was varied (see Table 3), with males predominating. It was not possible to record the occupation or particular interest of the attendees as some were keen to remain anonymous; being hosted by DECR and the presence of officers may have been an issue.

Table 3. Focus Group composition.

Location	Host	Meeting Time	Males	Females
Providenciales	DECR offices	Evening	9	1
Grand Turk	DECR/National Museum	Afternoon	11	4
South Caicos	DECR offices	Evening	3	
Providenciales	The Sustainable Tourism Association	Afternoon	3	1
totals			26	6

The discussions were recorded in note form, and the discussion points organized into themes for analysis.

Positive impacts were raised in 12 separate comments (Table 4) and negative ones in 18 (Table 5). The largest number of comments (15) and most detailed discussion occurred during the focus group on Grand Turk.

Table 4. The Positive Impact of Sargassum (PLS = Providenciales; GDT = Grand Turk; XSC = South Caicos; STA = Sustainable Tourism Association).

PLS	GDT	XSC	STA	Positive Comments
1	1		2	Sports fishers benefit from more fish (particularly Mahi-mahi) using the rafts
	1		1	Line fishing catches
	1		1	Many birds are catching fish in sargassum
	1		1	Large increase in shark numbers over the last few years
		1	1	Sargassum is good—as long as it stays out at sea
1	4	1	6	12

Table 5. Negative Impact of Sargassum (PLS = Providenciales; GDT = Grand Turk; XSC = South Caicos; STA = Sustainable Tourism Association).

PLS	GDT	XSC	STA	Negative Comments
	1			Sargassum affecting kayaking for cruise passengers in north creek
	1		1	Problem for horse rides as horses sink into it, and react badly to floating sargassum round their legs
1				Consensus sargassum has become an issue over the last 2–3 years
	2			Obstructs light that promotes algae growth on sea grass beds conch feed on; corals
	2			Effect on mangroves depends on species (red, black, white); spiny lobster needs mangroves as breeding site
	2			Effect on human health of decomposing sargassum; unpleasant smell
	1			Hydroids on sargassum irritate human skin
	1			Sargassum means sharks cannot be seen on the east side
	1			Dead fish in the sargassum causes a fly problem
		1		Fish yields have reduced significantly (from 700 to 800 lbs of conch a day to 80 to 100 lbs)—is this related to sargassum?
		1	1	Guests checking out of affected hotels, moving to others or cancelled their bookings; poor reviews on Trip Advisor
		1		Concern was raised about turtle nesting sites and damage to seagrass beds
			1	What is the real economic impact—real estate?
1	11	3	3	18

There was discussion about whether sargassum landings were a new phenomenon or if these had just been more severe recently with the issue of nomenclature being raised (Table 6).

Table 6. Occurrence and location of inundations (PLS = Providenciales; GDT = Grand Turk; XSC = South Caicos; STA = Sustainable Tourism Association).

PLS	GDT	XSC	STA	Comments
1				Sargassum is brought in by the north wind
1				Tourism is on the west of Grand Turk, Sargassum on the easterly coast
1				Caribbean wide problem
	1			Older ridge residents reported it has been as bad in the past (but when?)
	1			Big rafts form in calm weather, wind breaks up so it becomes a nuisance
	1			Enough in Pigs Ear Bay last week to fill a shipping container
	1			8 ft depth of deposited sargassum recorded on the east side of the island
		2		How recent is the problem? Was there sargassum 30 years ago in East Bay or was it seaweed? Or sea grass?
1				Grace Bay is on the side of Provo least affected, Sargassum only comes in when the SE-NW Trades move to the north
			2	First a problem in 2011, then in 2012/13/14. Worst in March/April
2				It has been an issue in the last 2–3 years; longer on GT
1				Dive instructors have seen bigger blooms in the last 2–3 years out to sea
1				Always been present, now more, and more troublesome, last four or five years
			1	In 2018 and 2019, it has come in May and lasted into the summer months
8	4	2	3	17

Questions 5, 6 and 7 focused on whether sargassum was being removed and what method was used. The results were varied, with least removal on Grand Turk (Table 7).

Table 7. Removal and disposal of sargassum (PLS = Providenciales; GDT = Grand Turk; XSC = South Caicos; STA = Sustainable Tourism Association).

PLS	GDT	XSC	STA	Comments
1				Raking it from water onto shore or at the water's edge is the most common method.
1				Raking into the sea to clean it (removes sand) but required 4–5 members of staff daily for a four-months then to be bagged up, put into a skip and taken off site to dump.
1				This was successful but labour intensive.
1				consensus visitors were pleased to see attempts made to remove sargassum.
1				There is currently no integration of management between hoteliers.
1				unsuccessfully, to use a boom to hold seaweed but this created a vortex and sucked it in to the shore side.
	1			East Bay removed sea grass under license from the DECR.
		1		East Bay have 3 men raking every day; cheaper than fuel (very expensive).
		1		have not used the Barber Surf Raker for several months.
		1		Interest in a hay lifting type of machines—lift the seaweed leaving the sand behind.
		1		Overall, the problem is manageable—at the moment.
		1		Hand raking and burying the sargassum is good for the beach as it stabilises it but if there is too much then it has to be removed and taken off site.

Table 7. Cont.

PLS	GDT	XSC	STA	Comments
			1	Guidance discussed—inconsistent and varied between burying at the shoreline, past the shoreline or off the beach or to bag and take it to the dump.
			1	Day labourers paid minimum wage (\$6.25); 50–200 bags removed a day.
			1	Interest in ‘sweepys’ between hand raking and the Barber surf rake (used in Florida).
			1	A review of the effectiveness of all available options is needed.
6	1	5	4	16

The potential for a commercially viable end use for sargassum was a topic of great interest, with a variety of views expressed (Table 8), although the uncertainty around the composition, salinity, and potential toxicity clearly considered barriers to progress without further research.

Table 8. Potential end uses (PLS = Providenciales; GDT = Grand Turk; XSC = South Caicos; STA = Sustainable Tourism Association).

PLS	GDT	XSC	STA	Comments
1				Fertiliser potential was discussed.
	1			Very high salt levels were mentioned.
	1			Animal feed? One horse observed eating it by Lighthouse.
	1			What if it does contain heavy metals?
	1			Project to make fuel in China failed due to supply of raw material.
			1	Could it be composted? This is done in Barbados, but needs water for washing.
1	4		1	6

Other themes that emerged during the focus groups are recorded in Table 9.

Table 9. Topics raised by focus group participants (*p* = Providenciales; GT = Grand Turk; SC = South Caicos; STA = Sustainable Tourism Association).

PLS	GDT	XSC	STA	Comments
1				Surprise from some who had not realized sargassum was floating—they had thought it was attached to the seabed and stirred up by winds and storms.
1				Why are wider links not being made?
	1			Concern that many do not know what it is and think it is sewage—education/interpretation is needed.
	1			Changes in beach shape was discussed; it changes regularly with storms.
	1			after hurricanes it takes a few years for marine to settle—is sargassum just a symptom of this? Nutrients coming up from the bottom “the ocean is just cleaning itself”.
	1			Sargassum is locally referred to as ‘weed’ or ‘grass’—care is needed in interpreting comments as there is potential confusion with seagrass.
		1		Three types, floating rafts, small floating masses and washed up on the beach.
			1	of erosion—in Turtle Cove there has been 2 feet lost in the last few weeks.
			1	The whole of TCI is based on the value of real estate.
			1	visitor comments be asked for about the ‘beautiful by nature’ beaches?
			1	want to have a policy on sargassum removal. They have a ‘TCI cares’ initiative promoting wildlife, banning plastics and are keen to develop more initiatives.
2	4	1	4	12

3.2. Face-to-Face Interviews

The questionnaire-based interviews began in Providenciales, the island with greatest concentration of tourism businesses, with 60 completed forms collected, with further interviews completed on South Caicos (20) and Grand Turk (20). Seventy-one respondents were male, 29 females. In response to Question 1, which asked *Has sargassum had an impact on your business?* 58% responded in the affirmative, shown by island in Table 10; 42% that it had not.

Table 10. Number (and %) reporting impact by business category.

Business Category	Total Responses				Number Reporting Impact (Responding 'Yes' to Q1)				Percentages Impacted Per Business			
	All	PLS	GDT	XCS	All	PLS	GDT	XCS	All	PLS	GDT	XCS
Restaurant/bar	11	8	1	2	6	5	0	1	55	63	0	50
Fishing	7	1	1	5	6	1	1	4	86	100	100	80
Sports fishing	6	4	1	1	6	4	1	1	100	100	100	100
Resort	9	4	0	5	7	3	0	4	78	75	N/A	80
Accommodation	4	3	1	0	3	3	0	0	75	100	0	N/A
Real estate/developer	4	4	0	0	3	3	0	0	75	75	N/A	N/A
Wildlife charity	1	1	0	0	0	0	0	0	0	0	N/A	N/A
Snorkeling/Diving	11	7	3	1	5	2	3	0	45	29	100	0
Surface water sports	9	7	2	0	6	4	2	0	67	57	100	N/A
Shore leisure	5	2	3	0	3	1	2	0	60	50	67	N/A
Market trader	12	8	2	2	2	2	0	0	17	25	0	0
Travel/boat trips	12	6	3	3	7	2	2	3	58	33	67	100
Farmer	1	1	0	0	1	1	0	0	100	100	N/A	N/A
Independent tourism consultant	2	2	0	0	1	1	0	0	50	50	N/A	N/A
Tourist board	2	1	1	0	2	1	1	0	100	100	100	N/A
Entrepreneur	1	1	0	0	0	0	0	0	0	0	N/A	N/A
Utilities/services	1	0	0	1	0	0	0	0	0	N/A	N/A	0
Government dep.	1	0	1	0	0	0	0	0	0	N/A	0	N/A
Museum	1	0	1	0	0	0	0	0	0	N/A	0	N/A
Totals	100	60	20	20	58	33	12	13	58	55	60	65

Table 11 shows the scale of impact reported.

Table 11. Scale of impact, both negative and positive. (*p* = Providenciales; GT = Grand Turk; SC = South Caicos; STA = Sustainable Tourism Association).

Negative Impact	All	PLS	GDT	XCS
low	21	12	4	5
moderate	17	8	4	5
high	16	10	3	3
Total	54	30	11	13
Positive Impact				
low	0	0	0	0
moderate	2	2	0	0
High	0	0	0	0
Total	2	2	0	0

Table 11. Cont.

Negative Impact	All	PLS	GDT	XCS
Mixed Impact				
low	3	2	1	0
moderate	1	0	0	1
high	0	0	0	0
Total	4	2	1	1

The next question asked when sargassum was first observed, and the results are shown in Figure 3. This shows it has been more significant in recent years and in 2018 particularly.

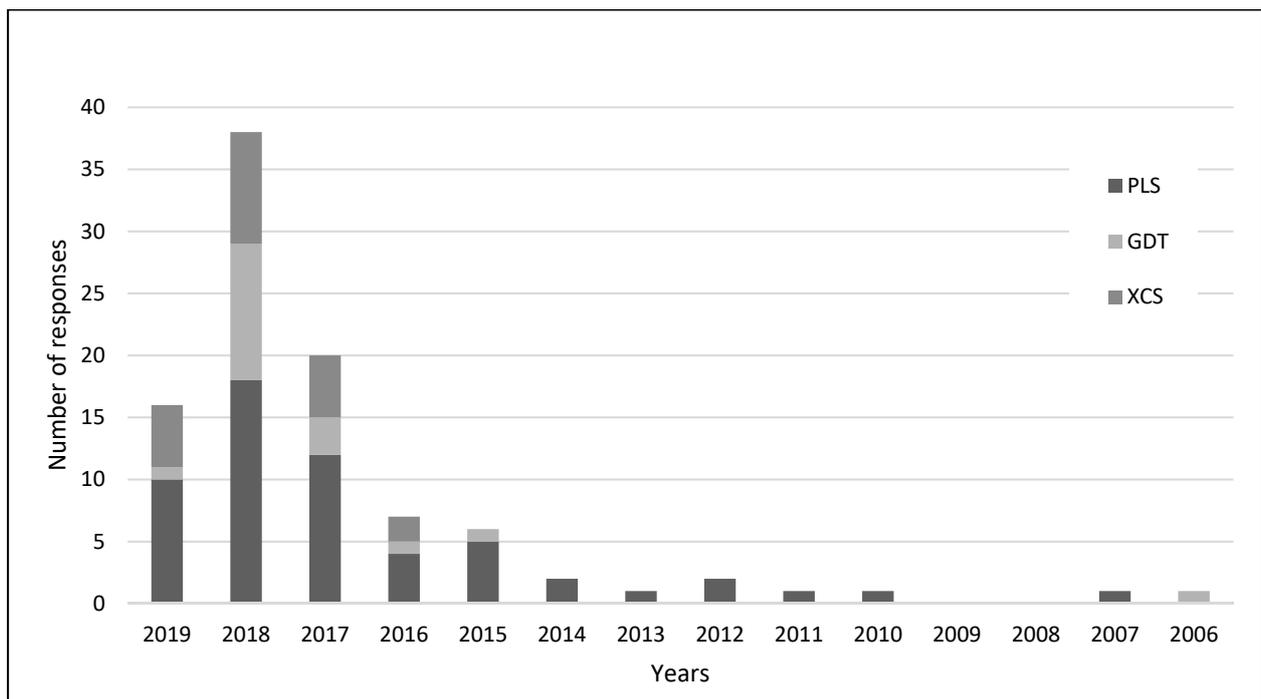


Figure 3. The years sargassum was an issue on TCI (PLS = Providenciales; GDT = Grand Turk; XCS = South Caicos).

This was further investigated by asking about the seasonality of beach inundation and this is shown by month in Figure 4. The results suggest that beach inundation mostly occurs in mid/late summer so it must be remembered that these surveys were all carried out in June 2019, particularly when considering Figure 3.

Despite similar proportions reporting impact, 71% of accommodation- and food-related businesses (restaurants/bars, accommodation, resorts, and real estate) reported action, far more than the 44% of activity providers (travel/ boat trips, snorkeling/diving, surface water sports, sports fishing, shore leisure). Of the impacted businesses, 82% took action such as removing Sargassum (Table 12). The most reactive business sector was resorts with all impacted businesses engaged in removal. Two resorts who claimed not to be experiencing any impact also said they were removing sargassum.

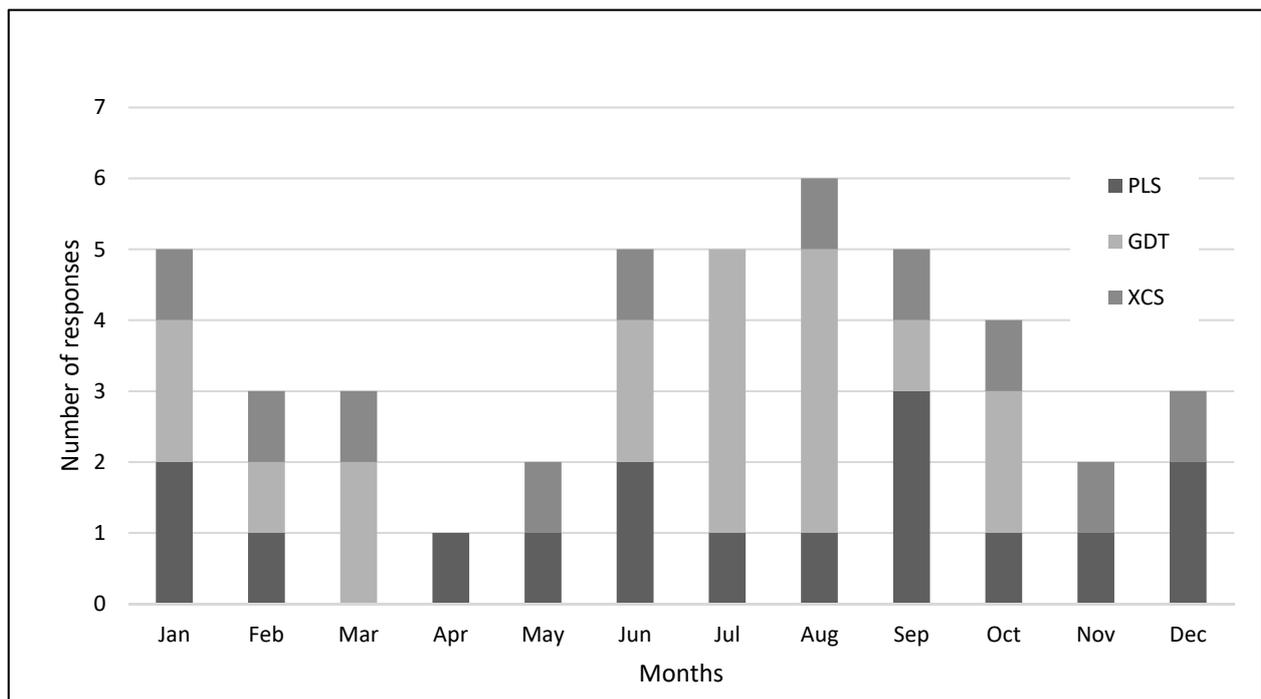


Figure 4. The seasonality of sargassum washing onto beaches; interviewees were asked to indicate all months that they observed sargassum (PLS = Providenciales; GDT = Grand Turk; XCS = South Caicos).

Table 12. Showing many of the businesses surveyed were impacted and how many of those who took action (PLS = Providenciales; GDT = Grand Turk; XCS = South Caicos).

	ALL		PLS		GDT		XCS	
	Impact	Action	Impact	Action	Impact	Action	Impact	Action
Resort	7	9	3	4	0	0	4	5
Restaurant/bar	6	5	5	5	0	0	1	0
Surface water sports	6	8	4	6	2	2	0	0
Fishing	6	1	1	1	1	0	4	0
Sports fishing	6	5	4	3	1	1	1	1
Snorkeling/Diving	5	2	2	1	3	1	0	0
Shore leisure	3	4	1	2	2	2	0	0
Accommodation	3	4	3	3	0	1	0	0
Real estate/developer	3	2	3	2	0	0	0	0
Market trader	2	1	2	1	0	0	0	0
Tourist board	2	1	1	0	1	1	0	0
Independent tourism consultant	1	1	1	1	0	0	0	0
Farmer	1	1	1	1	0	0	0	0
Totals	51	44	31	30	10	8	10	6

Raking and shovels was the most used method for sargassum removal used by 58% of the businesses, while only one business on Providenciales was using a boom (Table 13). On South Caicos the sargassum was most frequently piled on the beach for disposal, while on Providenciales it was often taken to the municipal dump or buried; Grand Turk used all three methods equally. One business on Providenciales was also composting the sargassum. All businesses in Grand Turk would remove Sargassum daily or several times a day, this was also the most common removal frequency for Providenciales and South Caicos, although some businesses removed sargassum less frequently.

Table 13. Removal Method, frequency, and disposal on the different islands (note some used more than one). (PLS = Providenciales; GDT = Grand Turk; XCS = South Caicos).

Removal Method	All	PLS	GDT	XCS
Raking and shovels	30	23	5	2
Machines	11	4	2	5
Hand cleaning of equipment	8	5	2	1
From water using hand tools	2	2	0	0
Boom	1	1	0	0
Disposal method				
Pile on beach	8	2	1	5
Skip/dump	7	4	1	2
Burying it	5	4	1	0
Composting	1	1	0	0
Frequency of removal				
Daily	23	15	4	4
Weekly	5	4	0	1
Monthly	4	4	0	0
When necessary	3	3	0	0
Other	7	4	2	1

Responses listed under the ‘other’ options ranged from twice a day, 2–3 times a day and in three cases all day. Another common response was when it is bad, so action is on an as necessary basis.

Basic content analysis of all the responses revealed the most frequently mentioned impact of sargassum impact related to its removal (22), with some also commenting that this was not permitted. The unpleasant smell was commented on by 15, with 12 referring to aesthetic appearance. 14 mentioned sargassum affecting equipment, from fishing lines, boat propellers to jet skis. A further 12 specifically referred to the negative impact sargassum had on tourism, although 14 felt it had no impact; 6 expressed the view that it was simply a natural phenomenon and not something to get worried about. A total of 12 raised health and safety issues. Similar views were expressed in the focus group discussions, with the unpleasant smell specifically an issue on Grand Turk.

Q8 The final question asked if a record was kept of the quantities removed. Only 2 replied in the affirmative, with one reporting a specific beach clean that generated 52 refuse sacksful in four hours, from a 100 m of Lower Bight Beach (in April 2019).

3.3. Sargassum Loads and Interaction with Seagrass Beds

Dried loose, wet compacted and dry compacted sargassum was found on many of the beaches surveyed on South Caicos and Middle Creek Cay. Only two, East Bay Beach and Long Bay Beach North, are cleared regularly, all other beaches represent natural accumulation of sargassum that can be anywhere between several hours to several months old. The amounts varied between the sites and surveys, with no clear pattern apparent (Figure 5).

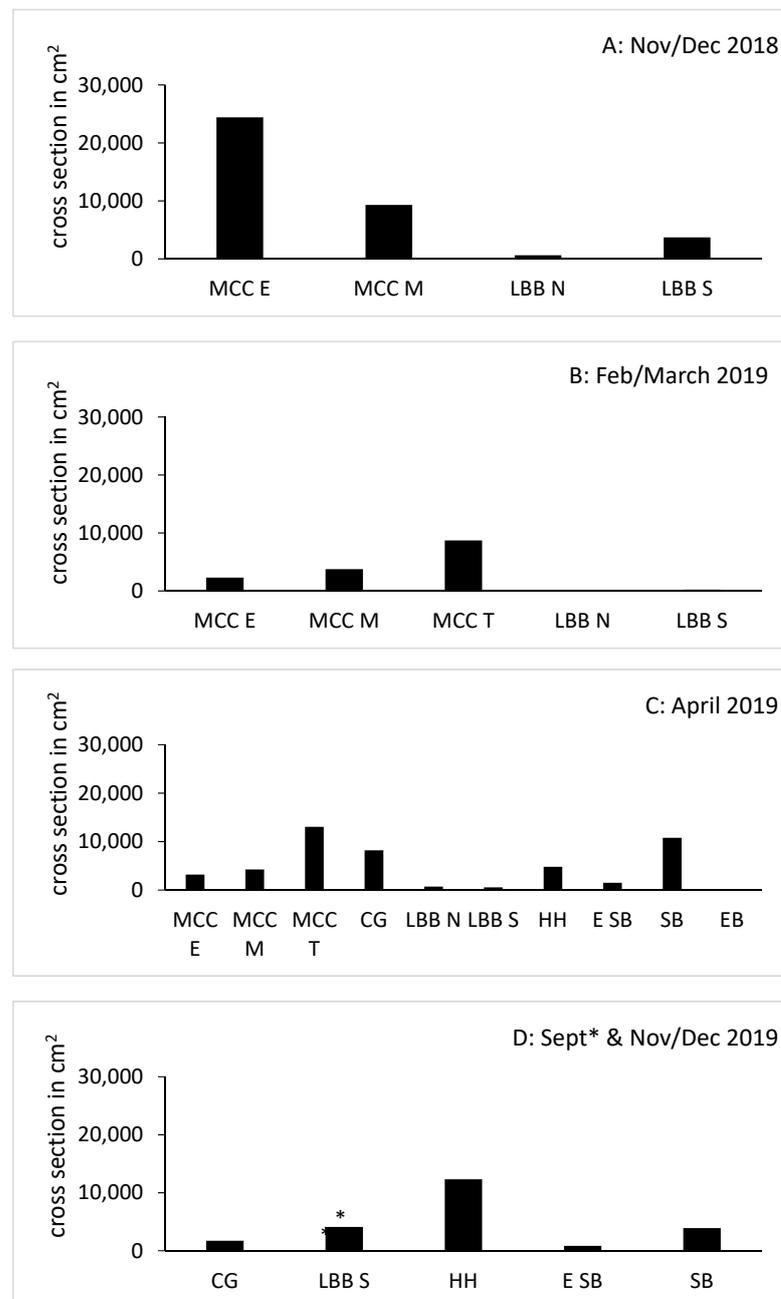


Figure 5. Amount of beached Sargassum found on beaches of South Caicos and Middle Creek Cay. Values represent cross section area perpendicular to the surf line in cm². Sites are ordered from north to south. MCC = Middle Creek Cay (T = Tip, M = Middle, E = End), CG = Coast Guard, LBB = Long Bay Beach (N = north, S = south), HH = Highland House, ES B = East of Shark Bay, SB = Shark Bay Beach, EB = East Bay Beach. One sample was taken in September 2019, indicated by an * as it is grouped with the samples from November/December 2019.

Most material was found within the first 6 m from the surf line, with small amounts of dried sargassum present further up the beach (Figure 6, Supplementary Material Figure S1A,B,C,K,L,M,R,S,V,d,l,n,o,q). At many sites, the sargassum was mixed with seagrass (Supplementary Material Figure S1S). On Middle Creek Cay End, the decomposing sargassum seagrass mix that was not in contact with the surf turned into a soil like consistency and contained worms (Supplementary Material Figure S1D) The wet compacted sargassum at Highland House and East of Shark Bay (dark mass seen in Supplementary Material Figure S1I) contained insects that were breaking down the sargassum. On East

of Shark Bay, the decomposing sargassum accumulated in dense mounds (1 m × 0.5 m × 1 m) in the surf, while at Highland House it formed a dense mat, approximately 1 m high, on top of rocks, which were also in daily contact with the surf. These mounds were first found in November 2018 and remained until at least June 2019 but were completely absent in November 2019 perhaps removed during a storm event. On some beaches, the accumulation was so high that newly arriving sargassum could not pile up on the beach but accumulated as a mat in the water adjacent to the beach (Supplementary Material Figure S1e,f). In April 2019, Highland House had 2–3 m of floating sargassum accumulate as a mat while Shark Bay had 14.6 m in April 2019 and 6 m in November 2019. In autumn 2019, the water at Long Bay Beach North was a very dark color while that on Middle Creek Cay was also slightly brown (Supplementary Material Figure S1A,R,e).

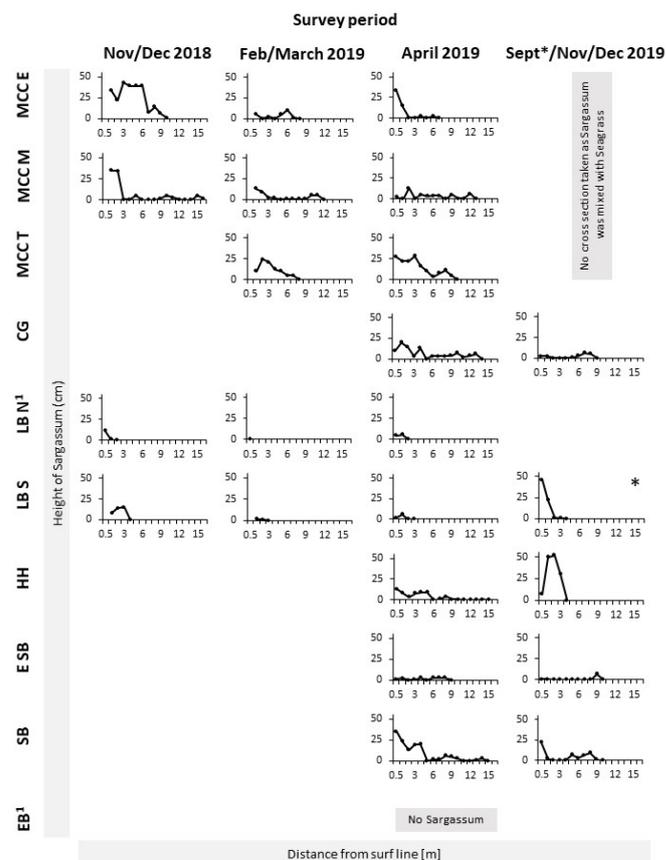


Figure 6. Cross section of the sargassum deposition on the beach. The height of the sargassum measured at the 0.5 m mark and every 1 m mark from the surf line to the end of the deposit is visualized in these graphs. Sites are ordered from north to south. MCC = Middle Creek Cay (T = Tip, M = Middle, E = End), CG = Coast Guard, LBB = Long Bay Beach (N = north, S = south), HH = Highland House, ES B = East of Shark Bay, SB = Shark Bay Beach, EB = East Bay Beach. Sargassum was removed at East Bay Beach and Long Bay Beach North. All other sites had no anthropogenic sargassum removal at any time. One sample was taken in Sept 2019, this one is indicated by an * as it is grouped with the samples from November/December 2019.

Out of the 10 study sites, 9 contained seagrass beds within the first 100 m from the coast, the only site without any seagrass was Shark Bay Beach. Completely healthy *Thalassia testudinum* seagrass beds were found throughout the study period at Coast Guard, Highland House and East Bay Beach (Figure 7). The sites located on Middle Creek Cay, on Long Bay Beach and East of Shark Bay all showed signs of recent seagrass die off with a dense field of seagrass stumps being visible (Figure 7, Supplementary Material Figure S1E,G,H,N,O,P,Q,X,c,d). The border between seagrass stumps and healthy *T. testudinum*

seagrass was stark and often parallel to the coast (Supplementary Material Figure S1E,N,c). The timeline from Long Bay Beach North shows how the loss of seagrass progressed over time further away from the coast (Figure 7), while the pictures show the progression from stressed unhealthy seagrass (Supplementary Material Figure S1X–Z,a) to seagrass stumps and sandy substrate (Supplementary Material Figure S1b–d). The Middle Creek Cay Middle and Long Bay Beach timelines also show that sand eventually took over areas that were previously covered seagrass stumps (Figure 7). *Thalassia testudinum* was not able to recolonize the areas lost within the study period. At Long Bay Beach South, a field of *Halodule wrightii* (Supplementary Material Figure S1h) formed in early 2019 a few meters off the beach in the area that was covered in *T. testudinum* stumps in late 2018; the rest of the area stayed sandy and bare (Supplementary Material Figure S1i–k). Some of the area lost by *T. testudinum* on Middle Creek Cay was colonized by cactus tree alga (*Caulerpa cupressoides*), shaving brush alga (*Penicillus capitatus*) and *Halimeda* spp. and *T. testudinum* (Supplementary Material Figure S1H–J,Q,U). On Middle Creek Cay Middle exposed dead rhizomes were found (Supplementary Material Figure S1P). Sargassum was present on the benthos at the Long Bay Beach and Middle Creek Cay sites in November 2018 and March 2019. It was often found inside *T. testudinum* seagrass bed (Supplementary Material Figure S1F,Z,a,d) but also forming a thick layer (5–30 cm) on the sediment (Supplementary Material Figure S1g) or being present in a dense nugget-like form (Supplementary Material Figure S1b).

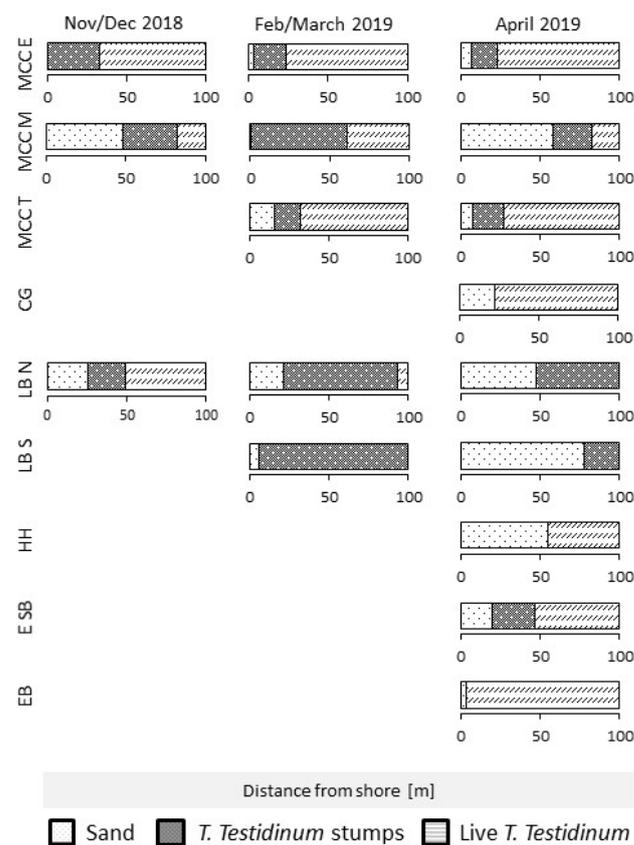


Figure 7. Benthic cover of the near-shore habitats. These graphs show the presence of sand (white with black dots), *Thalassia testudinum* stumps (black with white dots) and live *T. testudinum* (hashed) on the first 100 m from shore for the surveyed sites. The data displayed here is the average of 3 non-permanent transects that were surveyed 5 m apart. Sites are ordered from north to south. MCC = Middle Creek Cay (T = Tip, M = Middle, E = End), CG = Coast Guard, LBB = Long Bay Beach (N = North, S = South), HH = Highland House, ESB = East of Shark Bay, EB = East Bay Beach. Shark Bay Beach naturally has no seagrass cover and was not surveyed.

4. Discussion

4.1. The Impact of Sargassum on Tourism-Related Businesses

Focus group discussions and individual responses suggested greater impact was experienced by those offering activities for tourists compared to accommodation providers and food/drink businesses although this may reflect the relative proportions of the different categories sampled. For example, grouping restaurants/bars, accommodation, resorts, and real estate together would result in 68% reporting impact. Similarly combining activity businesses (travel/boat trips, snorkeling/diving, surface water sports, sports fishing, shore leisure) results in impact on 63%. A UNEP white paper (2021) summarized the impacts found across the regions affected and identified coastal livelihoods, marine transport and navigation, public health as experiencing impact [13]. In the TCI, the impact was felt most strongly by the tourism and fisheries industries, while only minor complaints regarding public health and coastal living were reported.

A similar situation has been reported from Provence, France, where the benthic algae *Rugulopteryx okamurae* has increased, forming large floating mats that inundate beaches. The main impacts there are on fisheries who have lost catch due to clogged nets, and the hydrogen sulfide (H₂S) produced by the rotting algae causing concern to local residents and water users [33]. In China, a bloom of *Ulva prolifera* occurred a few weeks before the Olympic sailing competition, leading to extensive clean-up efforts and losses for aquaculture operations [34,35]. Like the sargassum blooms, these green tides occur annually [1].

It was particularly interesting to find that 44 respondents (25 on PLS, 5 GDT and 14 on XCS) said sargassum had always been present, some adding for the whole of their lives but that it was worse some years. This suggests it is not a new phenomenon, as has been suggested but that it is the quantity arriving that has changed. This resonates with finding across the Caribbean that there was a significant increase in 2011, likely to have been caused by changes in winds and currents [7,14]. Research carried out into the impact on tourism in Mexico found that operators were encouraging inland, rather than beach, activities [36]; this is not a viable option on TCI.

4.2. Action Taken to Remove Sargassum

A total of 44 respondents reported they were removing sargassum (Table 11). Resorts and accommodation providers were removing it from the beach while water sports operators and those engaged in fishing activities were removing floating sargassum when it became entangled in lines or blocked the intakes of jet skis. Most removal was taking place on Providenciales (30) despite this island receiving least sargassum, reflecting the fact that this has the greatest importance for tourism. The most common method was by hand, using rakes and shovels (Table 13) with just three, all on Providenciales, collecting sargassum before it beached; one was using a boom to prevent landing. The CERMES Best practice guide states that it is generally agreed that in-water removal close to shore is preferable to beach collection if locally permitted [37]. This is reflected by the increasing use of containment booms across the region and new innovations in boat based collection systems [38,39]. If beach collection is necessary, then manual removal is preferable for relatively small volumes of sargassum [37].

Disposal after collection varied between simply collecting it into piles on the beach (8), taking it to landfill (7) and burying it (5), with just one example of composting. Burying has been identified as a good option for disposal on wide beaches with low volumes of sargassum, especially those with dunes as it can contribute to beach stability [37]. Frequency of collection and disposal differed widely, reflecting the irregularity of inundations being done on a 'when necessary' basis, reflecting amount of sargassum, arrival of tourists and/or available resource. Only on Martinique is there a requirement for sargassum to be removed from beaches within 3 days [38].

The results presented in this study provide a snapshot of the situation on TCI but provide little information on the amount arriving, being collected, and removed, as few

records were kept and those that were numbers of bags with no detail regarding bag size or whether the material was wet or dry. The lack of clarity on the amount and regularity of sargassum landings combined with uncertainty regarding chemical composition and potential toxicity, pose a significant barrier to development of a sustainable, commercially viable, end use [14,40].

4.3. The Interaction between Sargassum and Seagrass Beds

Two the interviewees raised concern about loss of seagrass habitat, and all fishermen answered that sargassum impacted their business. It was reported that conch yields had decreased. If this was indeed related to the Sargassum influx, it could possibly be due to loss of seagrass habitat for adult and juvenile conch and/or decreased water quality and therefore visibility, about which the freediving fishermen had expressed concern in September 2018 [41]. Dark-colored water, termed 'brown tides' by [42] were observed during the November/December 2018 surveys of Long Bay Beach North and Middle Creek Cay. This was also reported at other locations in August/September 2018, at the peak of the influx that year [41]. Only one of the ten study sites, East Bay Beach, was cleared regularly so had no decomposing sargassum on the beach; all the others had decomposing/decomposed sargassum in the surf line and dried sargassum higher on the beach in at least one survey.

Macroalgae blooms often negatively affect seagrass beds, and surface floating unattached algae have been found to cause the greatest damage [43]. Floating mats of filamentous algae have, for example, led to significantly reduced growth rate and degradation of below-ground tissue for *Zostera marina* [44]. Complete seagrass bed loss was reported as a result of brown tides on both northern and southern coasts of Quintana Roo, Mexico in 2016 [42]. Specifically, loss of turtle grass (*Talassia testudinum*) and shore grass (*Halodule wrightii*), with exposed dead *T. testudinum* rhizomes, which suggested sediment erosion followed seagrass die-off. The areas formerly occupied by seagrass were colonized by calcareous alga (*Halimeda incrassata*) and drift/epiphytic algae. These authors also found that drifting masses of sargassum resulted in extremely low dissolved oxygen (DO), reduced pH and negative REDOX values (reduction/oxidization potential) and that brown coloration of water, due to organic particles and leachates, had a similar effect but to a lesser extent on these parameters also leading to seagrass bed die off and long-term reduction in-water transparency combined with eutrophication. Other research has recorded beaching of 76 species of fauna during a sargassum brown tide event, including Caribbean spiny lobster (*Panulirus argus*), commercially important in TCI, and two Snappers (*Lutjanidae* species) [45]. It is likely these died due to hypoxia due to the deterioration in-water quality. Sargassum leachate has been found to reduce dispersal ability of elkhorn coral (*Acropora palmata*) larvae [46], an endangered coral species that is present on the coral reefs in front of East Bay Beach and Coast Guard.

The results of the surveys conducted for this research demonstrate sargassum can accumulate and persist on beaches that are not cleared, and this can cause leachate and accumulation of organic matter on the near-shore substrate. Floating masses of sargassum were found to accumulate in the water where there was lack of space for them to beach, for example at Highland House and Shark Bay Beach (April 2019), and Shark Bay Beach and Long Bay Beach South (November 2019). At Long Bay Beach sargassum derived organic matter was observed to have accumulated in the *T. testudinum* seagrass bed in December 2018, with just the tips of the seagrass blades protruding above it. These tips looked unhealthy while close by non covered seagrasses looked completely healthy. On a repeat visit in February 2019, only stumps of seagrass remained, strongly suggesting it could not survive being covered by sargassum detritus. Sandy planes were observed in areas formerly occupied by *T. testudinum* stumps, indicating that drift of sandy sediment had replaced the area of seagrass lost. Sparse benthic algae, as well as a small field of *H. wrightii*, were found in some areas from which *T. testudinum* was lost. Recovery of *T. testudinum* beds of the size lost here, up to more than 100 m off the coast, is likely to take

decades [42] with significant implication for the fisheries of South Caicos, as these are vital as nurseries and habitat for fished species [25,47,48].

Fisheries are an important component of the economy of TCI and a high proportion of South Caicos residents have fishery-based livelihoods. Sargassum brown tide leachate is likely to lower fishery yields. Fortunately, East Bay, identified as a critical habitat for juvenile lobsters [26], was not observed to be affected, as less sargassum was arriving here than in some other areas and there is daily beach clearance, either with a Barber Surf Rake or manually. The study identifying East Bay as critical habitat, only surveyed one other site surveyed in this study, Coast Guard, so there is a lack of information regarding the significance of other sites. Furthermore more recent information regarding the functional role of the East Bay seagrass beds is lacking. More up-to-date data is clearly required to determine the potential impact of sargassum on seagrass beds, the risk this poses to biodiversity in general and specifically to commercially important fishery species.

5. Conclusions

The hotel trade has a vested interest in reassuring potential holiday makers that there is no 'sargassum problem' in TCI, particularly as promotion is based on brochures showing white sand beaches and clear blue water. The results of this research suggest the impact varies from year to year and with season; this unpredictability is a real challenge for management. This research is the second to report seagrass die off during a sargassum brown tide. As these areas support conch (*Strombus* spp.) and spiny lobster (*Panulirus argus*), both exported from TCI, as well as commercially important fish, sought after by tourist restaurants, there are potentially significant economic implications. Further research should investigate the correlation between brown tides and seagrass bed loss especially to determine which components of the brown tide lead to seagrass loss. Negative effects on tourism and seagrass beds could be avoided by employing booms and near shore, in water, collection of sargassum. However, this would require a change in management practice in TCI. The enhanced quality of sargassum obtained this way, with reduced potential for sand contamination, could enable different valorization pathways and more opportunities for commercial use of sargassum [15].

While this research has attempted to determine the amount of sargassum deposited and seasonality, a more accurate assessment of the available resource for commercial exploitation is required. This paper is part of a wider study intended to inform the potential to identify a sustainable solution to the sargassum inundations on TCI but also determining the relative proportions of the different species and morphotypes of sargassum arriving and their chemical composition. Initial results have been published [49] but detailed analysis of more samples collected in TCI and particularly information on potential toxicity and methane production are awaited as these are essential for any 'sustainable' solution(s) to sargassum inundations can be identified and realized.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/phycology1020007/s1>, Text doc S1: The questionnaire, Figure S1: Photographs of Sargassum inundation and nearshore seagrass beds, Video S1: Sargassum accumulation composition and height, Video S2: Brown tide event.

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