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A baited remote underwater video system (BRUVS) assessment of elasmobranch diversity and abundance on the eastern Caicos Bank (Turks and Caicos Islands); an environment in transition

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Abstract The present study was undertaken to assess the diversity and abundance of elasmobranch fishes in coral reef and sand flat environments on the eastern Caicos Bank, with a view to informing marine spatial planning as the island of South Caicos and its environs transition to a tourism-based economy. Using baited remote underwater video systems (BRUVS), the nurse shark *Ginglymostoma cirratum*, Caribbean reef shark *Carcharhinus perezi*, spotted eagle ray *Aetobatus narinari*, southern stingray *Hypanus americanus*, lemon shark *Negaprion brevirostris*, tiger shark *Galeocerdo cuvier*, blacknose shark *Carcharhinus acronotus*, and great hammerhead shark *Sphyrna mokarran* were observed to use these waters, with *G. cirratum* and *C. perezi* being particularly abundant. Species diversity and overall abundance was greater in the reef environment than on the sand flats, but *G. cirratum* was equally abundant in both environments. Furthermore, even reef-associated species such as *C. perezi* were occasionally encountered on the flats a considerable distance from the reef. This indicates that although marine conservation efforts in the Turks and Caicos Islands should continue to focus on coral reef areas, less dramatic environments such as sand flats should not be ignored.

Keywords Caribbean region · Chondrichthyes · Biodiversity · BRUVS · Coral reef

Introduction

Populations of elasmobranch fishes (sharks, skates, rays) have undergone dramatic declines on a global scale in recent decades (Dulvy et al. 2014). While industrial longline fleets are responsible for the largest component of elasmobranch landings worldwide (Worm et al. 2013), landings from artisanal fishers can also be considerable, especially in developing countries (Walker 1998). However, although the impacts of fishing on elasmobranch stocks, both targeted and non-targeted, remain a major concern, habitat loss/degradation and climate change also pose notable

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threats. This is particularly true of species that use shallow, coastal environments (Knip et al. 2010).

Historically, information on the biology and ecology of elasmobranch species has typically been gleaned from a combination of fishery-dependent and fishery-independent sources. Their potentially negative impacts notwithstanding, commercial fisheries have provided researchers with access to the large numbers of specimens required for fundamental life-history assessments (age and growth characteristics, size at maturity, annual reproductive cycle etc.) (e.g. Henderson et al. 2002), as well as providing important information on species' occurrences and distributions (e.g. Henderson et al. 2005). Fishery-independent approaches can, and have been, employed in regions were relevant commercial fishing activities do not exist, or when the live release of study animals is desirable - for conservation reasons, or because the research question at hand requires it (e.g. Morrissey and Gruber 1993).

Unfortunately, even when the utmost care is taken, the capture, work-up and release of live animals tends to be at least somewhat invasive (e.g. Whitney et al. 2017). In the case of sharks and other elasmobranchs, the most common capture techniques are with baited hooks or demersal trawl. Both approaches are known to induce capture stress (Dodd and Duggan 1982; Skomal 2007; Brooks et al. 2012), and hooks necessarily puncture the skin causing additional localised tissue trauma. Therefore, it is unsurprising that post-release mortality has been highlighted as a matter of considerable concern (Heberer et al. 2010). Nevertheless, the physical capture of study animals is currently unavoidable when the collection of certain tissue samples is required (e.g. blood), or when particular types of tags or other equipment must be attached to the study animal (see Hammerschlag et al. 2011).

Baited Remote Underwater Video Systems (BRUVS) offer an alternative, non-invasive and non-destructive, approach to data collection in cases where specimen capture is not absolutely necessary (Cappo et al. 2003; Cappo et al. 2004; Santana-Garcon et al. 2014; Whitmarsh et al. 2017), e.g. when the research is primarily concerned with species occurrence and relative abundance (Espinoza et al. 2014). These systems use bait to attract nearby animals to a video camera, the footage from which is analysed post-deployment. This design is well suited to elasmobranch studies given the mobile, predatory nature of this taxon, and their highly-developed sense of smell. Indeed, BRUVS have been successfully utilised in a number of elasmobranch studies, particularly in shallow, tropical environments (e.g. Brooks et al. 2011; Bond et al. 2012; Goetze and Fullwood 2013; Espinoza et al. 2014).

The present study was undertaken to assess the elasmobranch fauna of the eastern Caicos Bank (Turks and Caicos Islands) in the Tropical Northwestern Atlantic (Fig. 1), using a BRUVS approach. Although this region of the Caicos Bank supports the bulk of the country's commercial fishing activity, most fishing effort is concerned with spiny lobster *Panulirus argus* and queen conch *Lobatus gigas*, with finfish forming a relatively minor component of the landings (Vaughan 2004). While sharks are opportunistically captured by fishers on occasion (A. Henderson, pers. obs.), there is currently no directed fishery for any elasmobranch species. However, South Caicos, the island at the epicentre of the fishing industry is currently undergoing a transition toward a tourism economy (Zuidema et al. 2011), with the recent completion of the island's first major hotel and the transfer of most coastal public land to a private, overseas developer. This will likely lead to a dramatic shift in the island's demographics, coastal development, and increased pressure on marine resources (Davenport and Davenport 2006).

Relatively little is known about the elasmobranch fauna of the Caicos Bank or the roles these species play in the country's coastal ecosystems. Previous elasmobranch studies have investigated nearshore habitat utilisation by juvenile lemon sharks *Negaprion brevirostris* (Henderson et al. 2010; Henderson et al. 2016), but information on the presence of other species beyond the nearshore environment is lacking. Given the potential disturbance to local elasmobranch populations through increased fishing activity, water-based recreation, and coastal development associated with the transition to a tourism economy (Juhel et al. 2018), the present study was established to assess elasmobranch diversity and abundance in areas that are likely to see dramatic increases in human activity in the coming years. The utilisation of BRUVS to address this goal has the added advantages of (a) providing a baseline visual record of the study sites that could be utilised in future research, and (b) allowing species' behaviours to be observed.

Materials and methods

This study was undertaken adjacent to South Caicos in the Turks and Caicos Islands. The waters surrounding

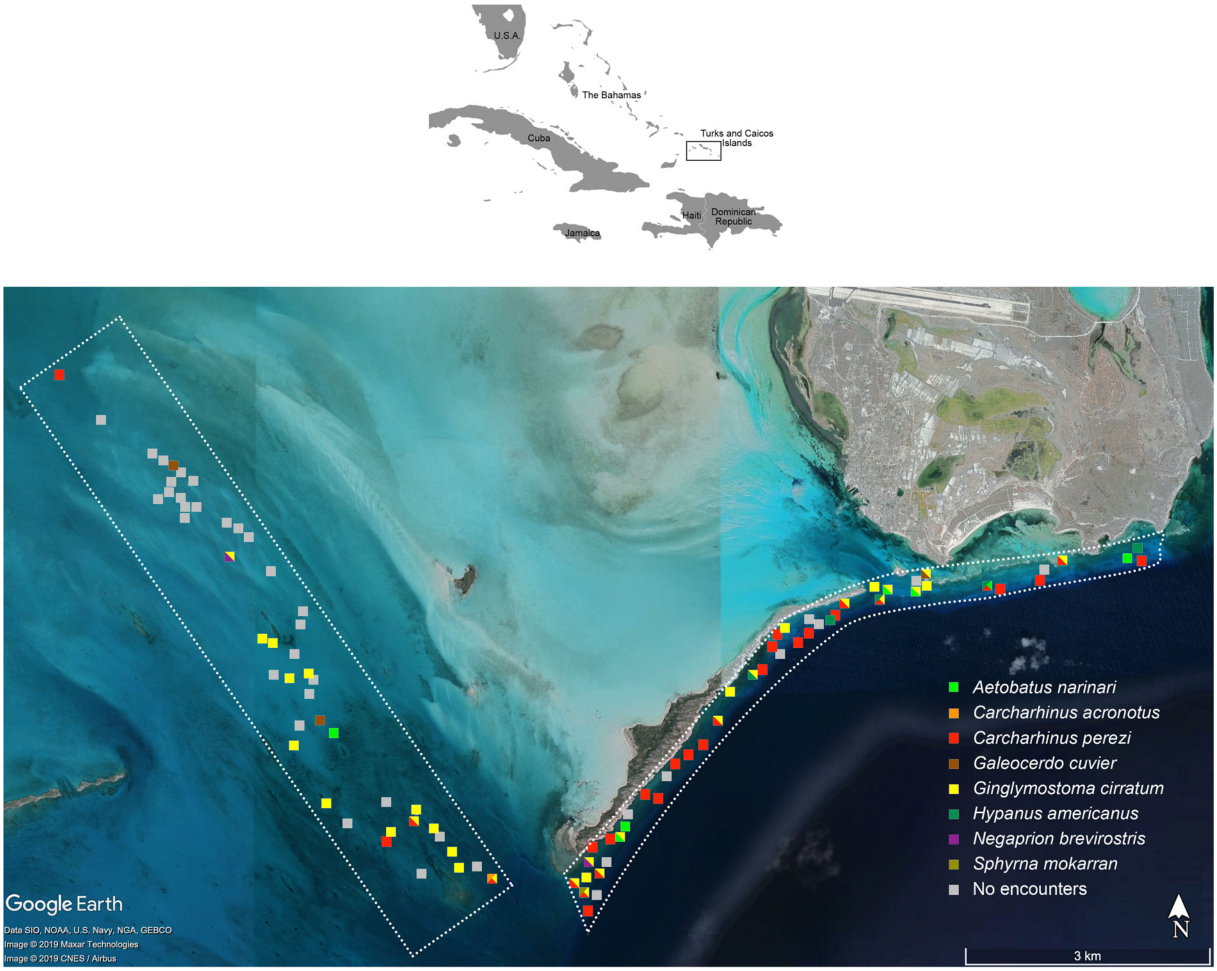

Fig. 1 Elasmobranch species encounters on BRUVS deployed off South Caicos. The sampling site outlined on the left is referred to herein as 'the Flats' while the sampling site outlined on the right is 'the Reef'

this island encompass a variety of environments including coral reef, mangrove and seagrass ecosystems, as well sand flats and open ocean. The nearshore environment (mangrove forests, seagrass meadows, shallow sand flats) has been surveyed for elasmobranchs previously (Henderson et al. 2010; Henderson et al. 2016), so the present study focused on coral reef and deeper sand flat environments. The study area was divided into two sampling sites, namely a section of continuous fringing reef ('the Reef') to the south of the island, and a sand flat site ('the Flats') to the southwest (Fig. 1).

The Reef is characterised by a variety of hexacorals, octocorals and sponges, interspersed with sandy patches (Fig. 2a), ranging from a depth of approximately 2 m close to shore down to approximately 40 m at the drop-off. The boundary of this sampling site mostly follows that of the Admiral Cockburn Land and Sea National Park (ACLSNP), a circa 4 km^2 Marine Protected Area (MPA) in which all fishing activity is currently prohibited, but which is open to boating and water-based recreation. This MPA contains a number of dive sites with permanent moorings, which currently see only periodic use; however, as tourism on the island increases, it seems likely that boat traffic and diving activity will increase dramatically throughout the MPA. It is also possible that the boundary of the MPA, or its status, could be changed to facilitate economic interests, as has already happened with the nearby Bell Sound Nature Reserve.

The Flats are characterised by a predominantly sandy substrate with sparse seagrass, macroalgae and octocorals (Fig. 2b), and a depth range of approximately 2–8 m. This 11.5 km^2 area represents a cline of decreasing depth with increasing distance from the Bank edge

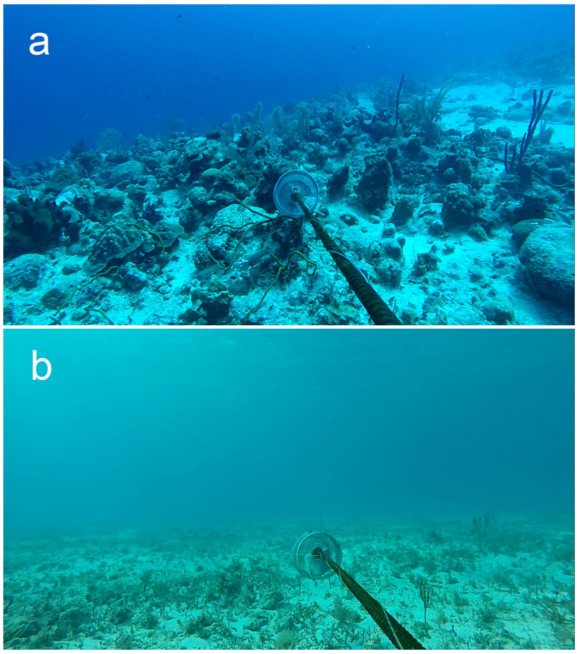

Fig. 2 Representative images of the ecosystems within the Reef (a), and Flats (b), sampling sites. Time of day and depth were 13:25 and 11.5 m (a), 14:15 and 4.7 m (b)

and, consequently, live cover gradually gives way to bare sand. Given the substrate, it seems unlikely that this area will attract dive operators; however, pleasure craft activity and recreational fishing activity are likely to increase in the general area.

The BRUVS followed a standard trapezoidal design (e.g. Brooks et al. 2011) constructed from welded metal rebar, fitted with a GoPro Hero 3 camera (settings: wide, 1080p, 60 fps). For each deployment, 1 kg of thawed barracuda *Barracuda sphyraena*, sourced from local fishers, was placed in a bait canister 180 cm in front of the camera. Sampling was conducted opportunistically and weather permitting between October 2015 and March 2017. Fifty sampling points per sampling site were generated randomly in ArcGIS, giving a total of 100 sampling stations, and deployment duration was standardised at 90 min per station (Brooks et al. 2011; Bond et al. 2012). A maximum of three deployments were made at any one time, with a minimum distance of 500 m between them.

Captured video footage was viewed in VLC Player (VideoLAN). A conservative measure of abundance (MaxN) was used, recorded as the maximum number of individuals of the same species appearing in the field of view at the same time (Priede et al. 1994; Ellis and DeMartini 1995). Therefore, MaxN excludes double-counting of the same individual re-entering the field of view at different times during the deployment. However, when distinct body markings clearly indicated that an animal entering the field of view was different to one that had left it, this animal was treated as a new record (Sherman et al. 2018). Where possible, all elasmobranchs entering the field of view were identified to species; their time of arrival (T_A) as well as the duration of the encounter (T_D) was noted. The time of first encounter (T_{FE}) is defined as the time that the first elasmobranch appeared on camera, i.e. the earliest T_A in each deployment. Lastly, the attitude of the animal toward the bait box was categorised as 'incidental' (i.e. it did not appear to be attracted to the bait and was filmed by the camera incidentally), 'cautious' (i.e. it was clearly attracted to the bait but maintained a cautious distance from the bait box), 'exploratory' (i.e. it approached the bait box and displayed a keen interest, but did not physically engage with it), or 'aggressive' (i.e. it forcefully engaged with the bait box and attempted to retrieve the bait) (Fig. 3).

Relative abundance was standardised as observations per unit effort (OPUE), i.e. number of sharks or rays (MaxN) per hour. The Simpson index (D) (Simpson 1949) was used to evaluate α diversity, as recommended by Magurran (2004). This index provides the probability that two specimens selected at random from a sample will be the same species, and therefore its value (which ranges from 0 to 1) increases with decreasing diversity. Evenness was assessed with Simpson's measure of evenness (E), which increases in value as species evenness increases (Smith and Wilson 1996). The elasmobranch diversity of the two sampling sites was compared with the Bray-Curtis dissimilarity index (Bray and Curtis 1957). Species accumulation curves were generated in Species Diversity & Richness 1.0 (Pisces Software) using 48 and 46 randomisations for the Reef and Flats respectively. The Chao 1 estimator was used to predict true species richness (Chao 1987), and this was also generated in the Species Diversity & Richness package.

The variance/mean ratio of elasmobranch encounters was employed as an index of dispersion (Krebs 1999), and this was further assessed by using the χ^2 goodness of fit test to fit common models of dispersion to the data (Fowler et al. 1998) in JMP 9.0 (SAS Software). All other statistical analyses were also performed in JMP 9.0. Data sets were tested for normality with the Shapiro-Wilk test, and if the null hypothesis was not rejected ($p > 0.05$), mean values and their associated standard deviations are reported. Where the null hypothesis was rejected ($p < 0.05$), median

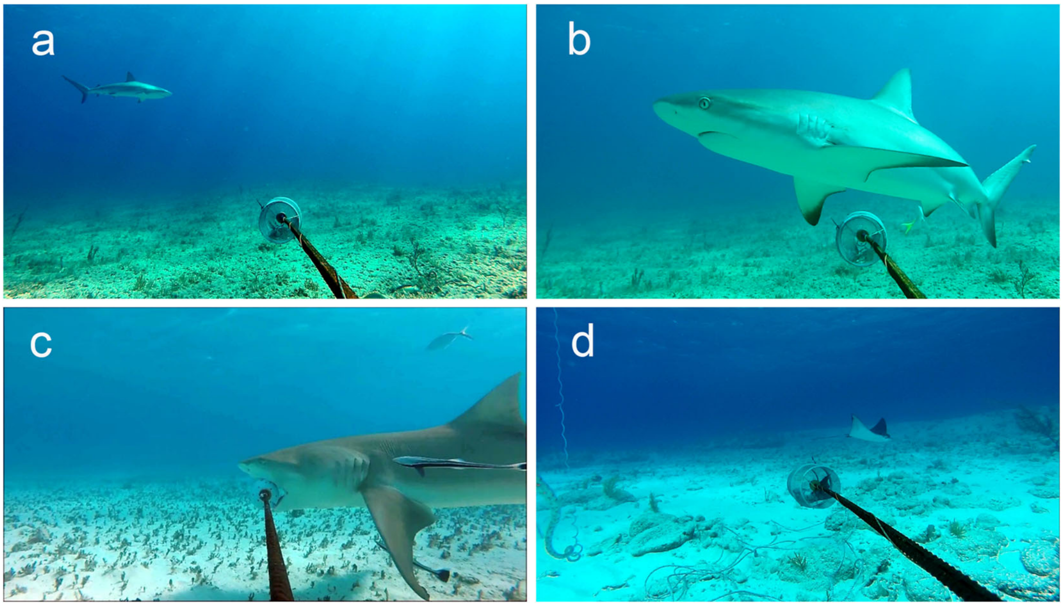

Fig. 3 Examples of the four behavioural attitudes noted during the present study; i.e. cautious (a), exploratory (b), aggressive (c), and incidental (d)

values and interquartile range (IQR) are reported. Subsequent analyses employed parametric or nonparametric tests respectively.

Results

Because of camera malfunctions and other logistical issues, 96 of the planned 100 BRUVS were successfully deployed (49 on the Reef, 47 on the Flats). During some deployments, the camera battery died before 90 min of filming was achieved, so the final footage amounted to 138 h and 46 min rather than 144 h (71 h and 08 min on the Reef, 67 h and 38 min on the Flats). Mean deployment time on the Reef was 87.1 ± 7.2 min while on the Flats it was 86.3 ± 9.4 min, a difference that was not found to be significant (t-test, $n = 96$, $p > 0.05$).

Overall, elasmobranch encounters were recorded on 61.5% of the deployments. The number of individuals encountered per deployment was generally low, with only a single deployment encountering more than four individuals, and consequently, the encounter frequency distribution displayed a strong positive skew (Fig. 4). Nurse sharks *Ginglymostoma cirratum* and Caribbean reef sharks *Carcharhinus perezi* together accounted for the majority of encounters (79.1%), with the spotted eagle ray *Aetobatus narinari*, southern stingray *Hypanus americanus*, lemon shark *Negaprion brevirostris*, tiger shark *Galeocerdo cuvier*, blacknose shark *Carcharhinus acronotus*, and great hammerhead shark *Sphyrna mokarran* accounting for the remainder (Fig. 5). This predominance of *G. cirratum* and *C. perezi* resulted in a moderately low species diversity (D = 0.33) and species evenness (E = 0.39) overall. One *Carcharhinus* sp. could not be definitely identified to species due to its distance from the camera, but appeared to be either a juvenile *C. perezi* or a *C. acronotus*. Given the ambiguity, this encounter was omitted from all analyses.

When viewed by sampling site, there were considerably more encounters on the Reef (81.6% of deployments) than on the Flats (40.4% of deployments), and there were significantly more encounters per deployment on the Reef (Mann Whitney U-test, $n = 95$, $p < 0.001$) (Fig. 4). The index of dispersion (0.76) suggested that encounters on the Reef were regularly distributed, and this was further supported by the fact that the binomial model provided a better fit to the data ($p = 0.80$) than the Poisson ($p = 0.60$) or negative binomial distribution ($p < 0.05$). On the other hand, the index of dispersion for the Flats (2.50) suggested that encounters there were aggregated, and this was supported by the fact that only the negative binomial could be successfully fitted to these data ($p = 0.40$).

The species composition of the encounters also differed between the Reef and the Flats and could be

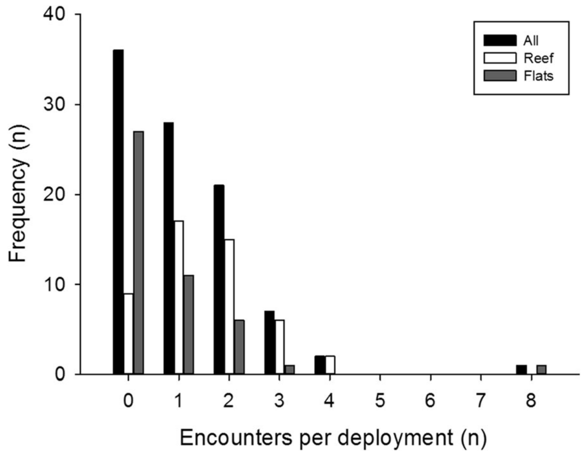

Fig. 4 Number of elasmobranch encounters per BRUVS deployment

considered only moderately similar (Bray-Curtis dissimilarity = 0.45). The most abundant species on the Reef was *C. perezi*, although *G. cirratum* was also commonly encountered in this sampling site (Fig. 5) and there was no significant difference in the abundance of these two species (Mann-Whitney U-test, $n = 56$, $p > 0.05$). *Aetobatus narinari*, *H. americanus*, *N. brevirostris*, *G. cuvier* and *S. mokarran* were also recorded here, but their abundances were extremely low and could not be statistically compared with *C. perezi* and *G. cirratum*.

On the Flats, only *G. cirratum* was routinely encountered, and it displayed a similar abundance as on the

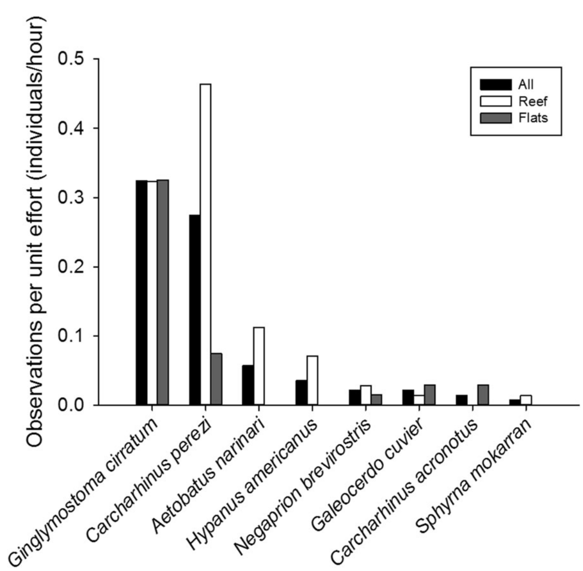

Fig. 5 Relative abundance (observations per unit effort) of elasmobranch species recorded during the present study

Reef (Mann-Whitney U-test, $n = 45$, $p > 0.05$). On the other hand, although *Carcharhinus perezi* also occurred on the Flats, its abundance was significantly lower than on the Reef (Mann-Whitney U-test, $n = 38$, $p < 0.001$). Other species occasionally encountered on the Flats were *C. acronotus*, *G. cuvier* and *N. brevirostris* (Fig. 5). Overall, this resulted in the elasmobranch diversity of the Reef being significantly greater than that of the Flats (Reef D = 0.32, Flats D = 0.51, randomisation test, $p < 0.05$). Species evenness was also significantly higher on the Reef (Reef E = 0.44, Flats E = 0.40, randomisation test, $p < 0.05$).

The species accumulation curve approached an asymptote for both sampling sites, but in neither case did it plateau (Fig. 6). Whereas seven species were recorded on the Reef, the Chao 1 index predicted that the true richness for this sampling site was 9.0 ± 3.0 species. Similarly, whereas five species were recorded on the Flats, the predicted true richness was 5.5 ± 0.61 species.

The T_{FE} varied across deployments but overall was broadly similar in both sampling sites; some encounters occurred within minutes of the BRUVS being deployed while in other cases the first encounter did not occur until the deployment was almost finished (Fig. 7). On the Reef, the bulk of first encounters happened during the first half of the deployment, resulting in a median T_{FE} of 35.0 min (IQR = 33.0 min). The median T_{FE} for the Flats was slightly later at 41.2 min, accompanied by an extended IQR (= 44.6 min), but this difference was not found to be significant (Mann-Whitney U-test, $n = 58$, $p > 0.05$).

There was no obvious trend in T_A within or between species (Fig. 8a). On both the Reef and the Flats, *G. cirratum* exhibited a slightly later median T_A relative to *C. perezi*, but the difference was not significant in either case (Reef: Mann-Whitney U-test, $n = 56$, $p > 0.05$; Flats: Mann-Whitney U-test, $n = 27$, $p > 0.05$); i.e. neither species was more likely to appear earlier than the other. Similarly, when the T_A of each of these species was compared between sampling sites, no significant differences were found (*C. perezi*: Mann-Whitney U-test, $n = 38$, $p > 0.05$; *G. cirratum*: Mann-Whitney U-test, $n = 45$, $p > 0.05$); i.e. neither of these species were likely to appear sooner in one sampling site than the other. The relatively small number of encounters with other species precluded any meaningful statistical comparison of their T_A.

Although T_D was also quite variable across encounters, both *C. perezi* and *G. cirratum* displayed similar overall trends in each sampling site (Fig. 8b). In the case

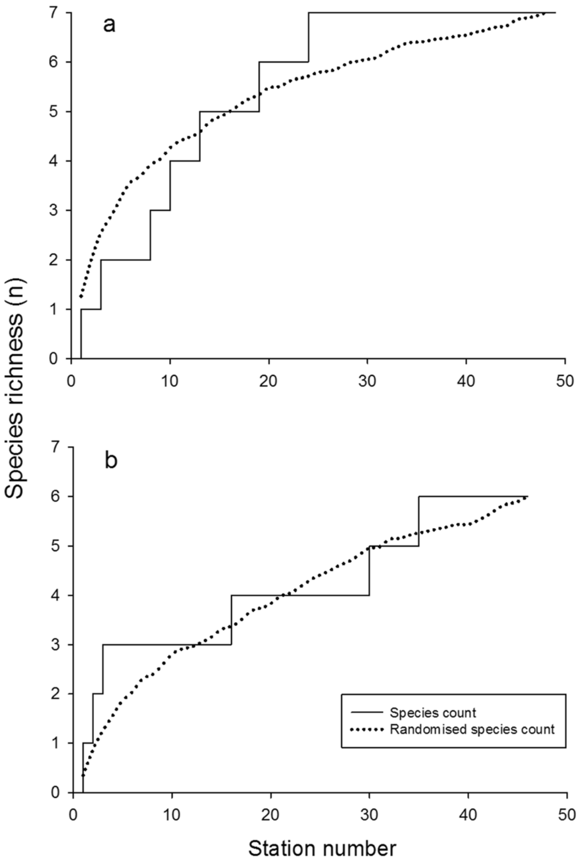

Fig. 6 Species accumulation curves for elasmobranchs observed on BRUVS deployed in the Reef (a), and Flats (b), sampling sites

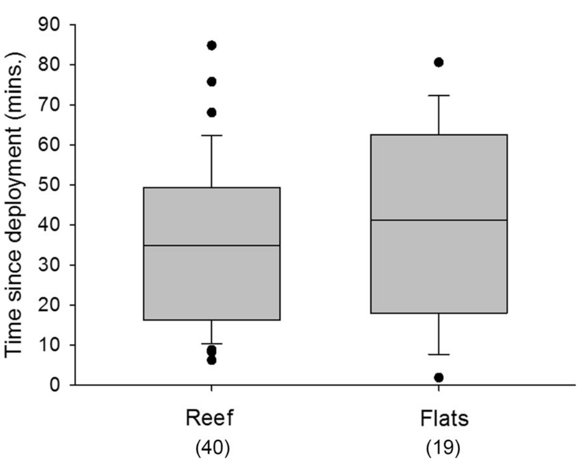

Fig. 7 Time of first elasmobranch encounter (TFE) by sampling site, expressed as minutes since deployment. Values in parentheses indicate sample size

of the former, while there was a notably greater range in T_D on the Reef compared to the Flats, median T_D differed by only 5.4 min. Similarly, although *G. cirratum* displayed a greater range in T_D on the Flats compared to the Reef, median T_D for this species differed by only 3.5 min. However, T_D was notably different between these species, with *C. perezi* spending significantly more time at the BRUVS before departing (Mann-Whitney U-test, $n = 83$, $p < 0.05$). In the case of the other species, the vast majority of encounters lasted only a few seconds. The only exceptions to this were two *H. americanus* encounters on the Reef that lasted 7.1 and 2.5 min respectively, an *N. brevirostris* encounter on the Reef that lasted 24.4 min, and a *G. cuvier* encounter on the Flats that lasted 46.8 min.

Behaviour toward the BRUVS varied within and between species. Just under half of all *C. perezi* (47.4%) displayed a cautious attitude, with 39.5%

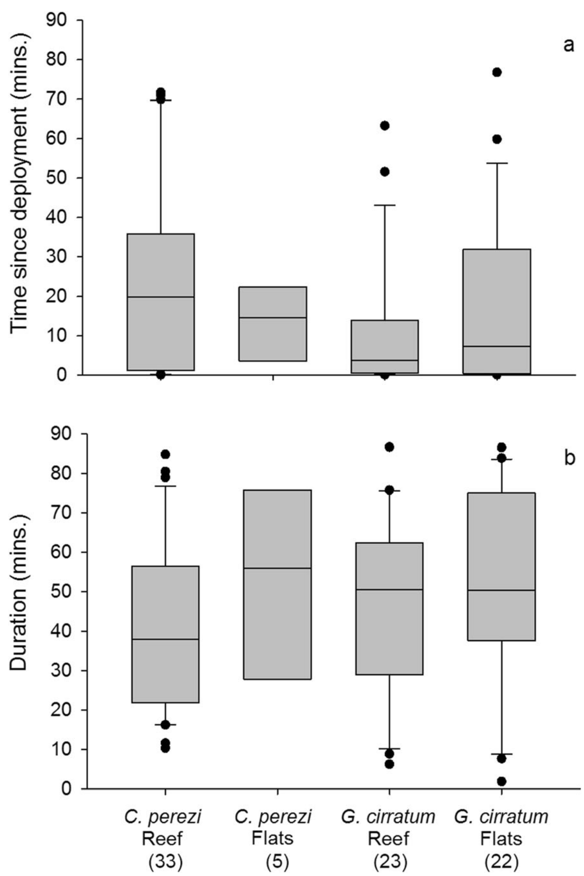

Fig. 8 Time of arrival (TA) (a), and encounter duration (TD) (b), for Caribbean reef sharks *Carcharhinus perezi* and nurse sharks *Ginglymostoma cirratum* in Reef and Flats sampling sites. Values in parentheses indicate sample size

displaying an exploratory attitude, and 13.2% displaying an aggressive attitude. *Ginglymostoma cirratum* tended to be bolder, with only 26.7% displaying a cautious attitude and the remainder almost equally exploratory (37.8%) or aggressive (35.6%). All three of the *N. brevirostris* encounters were aggressive, as was the case for one of the *G. cuvier* encounters (the other two displaying a cautious attitude). Both of the *C. acronotus* encounters were exploratory. Interestingly, the majority of ray encounters appear to have been incidental; two *H. americanus* individuals oriented themselves towards the bait and remained in its vicinity for a few minutes (see above), but none of the other three members of this species, nor any of the *A. narinari* appeared to be attracted by the bait and were seemingly transiting through the field of view when filmed.

Discussion

The eight elasmobranch species recorded during the present study have been reported from throughout the Tropical Northwestern Atlantic by previous researchers (see Compagno et al. 2005), so their occurrence on the Caicos Bank is unsurprising. Nonetheless, this study serves to confirm their presence there. What is perhaps more interesting in this regard, is that certain other shark and ray species which are known to occur throughout the rest of the Lucayan Archipelago were not encountered during the present study. The Caribbean sharpnose shark *Rhizoprionodon porosus* and the blacktip shark *Carcharhinus limbatus* have both been reported from BRUVS in the Bahamas (Brooks et al. 2011). These species together with the bull shark *Carcharhinus leucas* have also been reported from longline studies in the Bahamas (Brooks et al. 2011), so it seems reasonable to expect that they might occur on the Caicos Bank, especially given the broad global distributions of *C. limbatus* and *C. leucas*. The Chao 1 index predicted that the present study may not have sampled the full elasmobranch fauna of the study area, so it is possible that further deployments might observe these species. Indeed, there have been anecdotal reports of *C. leucas* encounters during recreational dives within the ACLSNP, but all photographs or video footage of such encounters that have been shared with the current authors have been obvious misidentifications of *C. perezi*. There have also been reports of *C. leucas* captures by recreational rod and line off Providenciales (western Caicos Bank) (D. Astwood, pers. comm.), but photographic evidence is lacking.

On the other hand, *C. limbatus* has been positively identified from a photograph taken close to South Caicos, approximately 9.5 km north of the current study area (K. Flowers pers. comm.). This is the only confirmed sighting of this species in the Turks and Caicos Islands and could represent a transient visitor. Further research is required to determine if this species is resident in the area.

Rhizoprionodon porosus occurs in inshore waters from the Bahamas down to Uruguay (Compagno et al. 2005), overlapping the distribution of the yellow round ray *Urobatis jamaicensis*, which occurs in inshore areas from South Carolina to Venezuela (Last et al. 2016). Both species have been reported from the Bahamas and Caribbean islands (e.g., Randall 1967; Kovacs and Schmidt 1980; Rasmussen and Gruber 1993; Brooks et al. 2011; Naylor et al. 2012), so their occurrence in the Turks and Caicos Islands seems entirely possible. However, there have been no specific reports of the former, anecdotal or otherwise, from this location, and reports of the latter are limited to six records from citizen science surveys (Ward-Paige et al. 2011). While citizen science can potentially contribute valuable information to research and conservation efforts, the reliability of such information is not always apparent (Brown and Williams 2019). Extensive inshore gillnetting surveys and routine scientific dives have not encountered either species on the eastern Caicos Bank, so if either or both are present in the Turks and Caicos Islands, they likely have highly localised distributions. One other elasmobranch species, the bonnethead shark *Sphyrna tiburo*, is known to occur on the eastern Caicos Bank (Henderson et al. 2010) and was not observed on BRUVS during the present study. However, all of these previous records were in nearshore mangrove and seagrass ecosystems, which seem to be its preferred habitat (Heupel et al. 2006).

Both *A. narinari* and *H. americanus* are commonly encountered during dive and snorkel activities in reef, sand flat and seagrass environments throughout the present study area. Indeed, these are the most commonly encountered elasmobranchs in these environments (A. Henderson, pers. obs.). Their relatively low abundance on BRUVS footage during the present study is almost certainly due to a lack of attraction to the BRUVS, as indicated above. The diets of these two species are dominated by invertebrates (Last et al. 2016), so it is possible that fish might not be suitable bait for them. However, Sherman et al. (2018) successfully attracted oriental bluespotted maskray *Neotrygon orientalis* and bluespotted fantail ray *Taeniura lymma* to BRUVS baited with pilchards (*Sardinella* spp.) and slimy mackerel *Scomber australiasicus* in Malaysian Borneo, and BRUVS deployed by Hanusch (2019) off Mozambique baited with Cape horse mackerel *Trachurus capensis* attracted bluespotted maskray *Neotrygon caeruleopunctata* and blotched stingray *Taeniurops meyeni*. Furthermore, a variety of demersal ray species were recorded on BRUVS baited with Indian oil sardine *Sardinella longiceps* in UAE waters (Jabado et al. 2018), while *H. americanus* was abundant on BRUVS deployed in Belize (Bond et al. 2019). Therefore, it seems clear that demersal rays which feed primarily on invertebrates will respond to BRUVS baited with fish, leading to the conclusion that it was the specific type of bait used during the present study, i.e. *S. barracuda*, that was not strongly attractive to *H. americanus*.

The situation regarding pelagic rays is less clear. Although they have been observed on BRUVS in a variety of locations, with few exceptions (i.e. Goetze et al. 2018) their abundance has generally been low (e.g. Gomelyuk 2009; De Vos et al. 2014; Bond et al. 2019; Hanusch 2019), and the extent of their attraction to the BRUVS has not been specified. However, *Aetobatus* spp. have been captured on baited longlines (Morgan et al. 2010; Dapp et al. 2013), indicating that they can be attracted by bait. As in the case of *H. americanus*, it may have been the specific type of bait used in the present study that did not attract this species.

The influence of bait type and quantity on BRUVS results has been assessed by a number of authors. Hardinge et al. (2013) determined that fish assemblages observed on BRUVS deployed off Western Australia were not influenced by bait quantity (ranging from 200 to 1000 g). However, different bait types have been shown to affect species richness (Wraith et al. 2013), relative abundance (Dorman et al. 2012) and size (Bailey et al. 2007). Therefore, given the questions raised above regarding the limited response of rays to barracuda bait in the present study, it is recommended that future studies that aim to assess the abundance and distribution of such species should use an alternative bait, e.g. pilchards (Clupeidae) (Wraith et al. 2013).

Although elasmobranch-focused BRUVS deployed in different regions of the world have recorded variable numbers of species, most studies have been dominated by one or two species, regardless of the overall species richness (Goetze and Fullwood 2013; Rizzari et al. 2014; Beer 2015; Spaet et al. 2016; Muñoz and Burton 2019; Murray et al. 2019); a situation also observed in the present study. The two most abundant species recorded here, *G. cirratum* and *C. perezi*, have generally been the most abundant species on BRUVS throughout the region. In the Bahamas, Brooks et al. (2011) reported mean abundances of 0.2148 and 0.0812 sharks/h for these two species respectively, which is 36% and 70% lower than was recorded during the present study. Similarly, *C. perezi* was over three times more abundant in the present study than has been reported from Grand Cayman and Cayman Brac, but almost identical to that reported from Little Cayman (Ormond et al. 2017). Studies conducted throughout the Dutch Caribbean also report notably lower abundances for *G. cirratum* and *C. perezi* at all study locations (St. Maarten, Bonaire, Curacao, Saba, Saba Bank, St. Eustatius, Aruba) (Winter and de Graaf 2019). Of the three other species that the studies have in common, *N. brevirostris* was also less abundant at all seven of the Dutch Caribbean locations, while both *G. cuvier* and *S. mokarran* were less abundant at five of seven (Winter and de Graaf 2019). Overall, this would seem to indicate that shark populations on the Caicos Bank are currently in a relatively healthy state, most probably due to the current invertebrate focus of the local fishery.

As the bait plume takes time to disperse from the bait canister, it can be assumed that animals visiting the BRUVS early in the deployment were attracted from a closer distance than those arriving later in the deployment. Hence, the temporal metrics employed in the present study (T_{FE}, T_A) suggest that sharks were attracted to the BRUVS over a broad range of distances, but crucially, this did not differ between the sampling sites. This indicates that the results obtained in each sampling site are similarly representative of the elasmobranch fauna in those areas. Not only were there considerably more encounters on the Reef, but these encounters were evenly spread throughout this sampling site. Whereas, the Flats were less diverse and encounters diminished with increasing distance from the Bank edge. While this highlights the importance of conserving the reef environment, it should be noted that *G. cirratum* was equally abundant in both sampling sites and even reef-associated species such as *C. perezi* were recorded a considerable distance from the reef. Therefore, future marine spatial planning in the Turks and Caicos Islands should give due consideration to non-reef environments as well.

The shark species encountered during the present study exhibited different behavioural attitudes towards the BRUVS, and this has implications for the assessment of BRUVS footage in general. Underwater visibility on the Caicos Bank is extensive, commonly in excess of 40 m (S. Bruns, pers. obs.), and this facilitated the detection of individuals that maintained a cautious distance from the BRUVS. Under conditions of poorer visibility, the abundance estimates of the present study would have been skewed towards the more exploratory/aggressive species, with a corresponding underestimate of the more cautious species. Given that *C. perezi* was the most abundant species on the reef, the second most abundant species overall, and the most cautious of the species encountered, it is strongly recommended that studies employing BRUVS in regions of low to moderate visibility should give due consideration to the behavioural traits of species that they might potentially encounter.

In conclusion, BRUVS proved to be a suitable technique for assessing elasmobranch diversity and abundance in the clear waters of the Turks and Caicos Islands. Although the elasmobranch population appears to be healthy at present, at least relative to other areas of the Tropical Northwestern Atlantic, continued monitoring is recommended to assess potential changes as the island of South Caicos and its surrounding waters transitions to a tourism-based economy. Further studies throughout the Turks and Caicos Islands are also recommended, in order to determine if *C. leucas, R. porosus*, and *U. jamaicensis* inhabit this region of the Lucayan Archipelago.

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Compliance with ethical standards

Ethical Approval This study was undertaken in accordance with Turks and Caicos Islands research permit number D2-001.

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