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Identifying Habitat Associations of Sea Turtles Within an Area of Offshore Sub-Tropical Reefs (NW Atlantic)

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Abstract - We observed sea turtles with time-lapse video cameras (deployed for studies of fish behavior during June 2017) at "live-bottom" reefs in depths of 18–20 m within Gray's Reef National Marine Sanctuary off the coast of Georgia, USA (NW Atlantic). These reefs, sandstone ledges emerging from surrounding sand seafloor, were deeply undercut and apparently served as resting habitat for turtles to wedge themselves between sand seafloor and hard rock overhead. We observed 22 distinct individuals over 27 occurrences including 10 *Caretta caretta* (L.) (Loggerhead), 3 *Chelonia mydas* (L.) (Green Sea Turtle), and 9 unidentified to species based on individual markings. We documented resting periods up to 144 minutes (mean = 37.2 min, SD = 39.1). Notable was that most observations (67%) occurred during twilight and night periods. To put these video observations in perspective, we analyzed diver observations of 34 turtles encountered at the surface prior to and during visual fish census surveys (2010–2017) at 18 ledges. Those ledges had significantly taller and deeper undercuts than 18 other ledges with no turtles (ANOSIM $P = 0.043$ and SIMPER comparisons). These limited observations indicate time-lapse video of seafloor habitats along with diver surveys may yield new insights into sea turtles' habitat requirements, patterns of site fidelity, and ecological role as ecosystem engineers, as well as effects on sea turtles of coincident human uses such as fishing, vessel use, and recreational diving.

Introduction

Multiple approaches have been used to better understand patterns of habitat use by different species of sea turtle in diverse ecological settings. Various types of tags (e.g., visual, radio, acoustic, and satellite) along with depth-time recorders have been used on sea turtles to help understand their broad- and fine-scale movement and dive patterns in relation to their habitats (Griffin et al. 2013, Hays et al. 2000, Lamont and Iverson 2018). Aerial and shipboard visual surveys, snorkel and diver-held video surveys, and baited remote underwater video in mid-water have been implemented in shallow coastal regions and around nearshore reefs to parse patterns of habitat use and migratory routes (Letessier et al. 2014, Schofield et al. 2006, Stadler et al. 2014, Thomson et al. 2013). Animal-borne imaging systems (Dodge et al. 2018, Narazaki et al. 2013, Seminoff et al. 2006) have addressed

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behavior patterns of individual animals within subtidal landscapes. While a significant focus of research has been in shallow, nearshore coastal waters, little is known about offshore sites. Understanding fine-scale patterns of interactions with particular seafloor habitats, especially those offshore, could yield additional insight into ecological relationships and potential management needs related to habitat conservation. Indeed, Letessier et al. (2014) notes the challenges for addressing research to develop turtle conservation strategies for offshore systems and the potential for novel applications of video technology to address questions about movements and patterns of habitat use.

Here we report on patterns of habitat use by sea turtles at sub-tropical sandstone "live-bottom" reefs at Gray's Reef National Marine Sanctuary (GRNMS) off the coast of Georgia, USA (NW Atlantic, depths of ~18–20 m). Data were collected by time-lapse video camera deployments, by visual observations at the surface from small boats, and with direct underwater observations by SCUBA divers. The primary purpose of the camera deployments was to conduct a preliminary study of interactions between piscivorous fishes and their prey over diel periods. However, coincident to this goal, we recorded behaviors and attributes of habitat use of *Caretta caretta* (L.) (Loggerhead) and *Chelonia mydas* (L.) (Green Sea Turtle) at reefs. Subsequent examination of records over 8 years from underwater and surface sightings of turtles during broad-scale reef fish surveys within GRNMS revealed characteristics of reefs that clarify habitat use inferred from video. While this report is limited in time and space in terms of the ecology and life-history of sea turtles, our goal here is to demonstrate the utility of site-specific, time-lapse video cameras deployed within sea turtle habitats, coupled with broad-scale surveys by divers, to address variation in patterns of habitat use in an area of offshore reefs.

Methods

Time-lapse digital video cameras were deployed in pairs by divers at select sites in Gray's Reef National Marine Sanctuary (GRNMS; Fig. 1), pointed to avoid overlap in field-of-view, and positioned 1.5–2 m distance normal to the undercut side of reefs at depths of ~18–20 m. Cameras were programmed to record 80 seconds of video every 9 minutes, with LED lights on for the final 40 seconds of each recording period. Video recording interval and use of lights were based on optimal use of available battery and digital storage media, assuming 48-hour deployments. Vessel logistics for deployment and recovery, as well as complications with battery power, reduced durations of some deployments. Recordings were made at 4 stations from 11–21 June 2017. Three stations were inside a designated research area (stations 05, 07 alt, and 09 alt; closed to all forms of fishing; "alt" indicating this site was an alternative to the original station coordinates) while the other station (station 19 alt) was outside the research area but within GRNMS (area prohibits anchoring, but drift and troll fisheries are allowed). We analyzed videos to assess reefs as habitat for sea turtles based on patterns of: individual occurrences and behavior, species occurrences, time of day, duration per occurrence (based on total elapsed time between successive occurrences in video records), and distribution of occurrences by station.

An ongoing study of fish communities and benthic habitat has taken place across GRNMS since 2010, and we examined records of sea turtle observations from this study to provide estimates of habitat utilization and site fidelity over a longer temporal scale. For this work, SCUBA divers utilized underwater visual census (UVC) sampling within 50-m band transects, with an estimated width of 5 m on each side that targeted mobile conspicuous fishes (>10 cm total length [TL]), resulting in a total area surveyed of 500 m^2. Surveys were not attempted if underwater visibility was <5 m.

We recorded the presence of turtles observed on the surface at each study site prior to entering the water and on the UVC surveys. Information recorded for turtles at the surface included species identification, and when possible, approximate carapace length based on visual estimates assigned to 3 different size categories (50–70 cm, 70–90 cm, >90 cm), general condition (approximate percent cover of barnacle growth on the carapace, presence of injuries), behavior (resting, swimming, feeding), and presence of a tail extending significantly beyond the edge of the carapace (presumably indicating a male). We also recorded these data for any

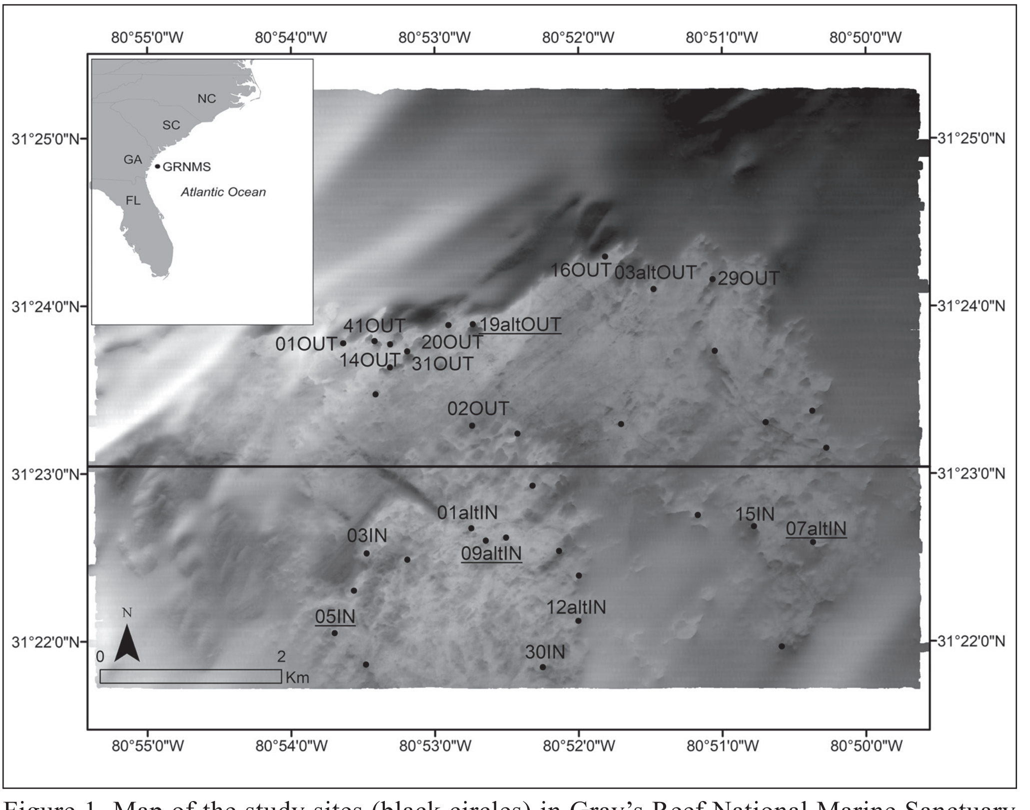

Figure 1. Map of the study sites (black circles) in Gray's Reef National Marine Sanctuary (GRNMS). Labeled sites indicate locations of turtle observations, and underlined sites indicate locations of time-lapse video recordings. Multibeam sonar image visualizes seafloor bathymetry, varying from shallow (light, ~14.5 m) to deep (dark, ~21.8 m). A designated Research Area is located below the horizontal line, where all fishing is prohibited. Inset shows location of GRNMS off the coast of Georgia, USA.

turtles encountered underwater during UVC surveys whether the turtle was directly on the transect or visible in the vicinity of the sampling station.

We conducted habitat surveys concurrently with fish surveys. To better quantify reef structure, we measured ledges and structural organisms (e.g., algae, sponges, tunicates) at each site. At fixed intervals along the fish survey transects (5, 15, 25, 35, and 45 m), we collected 3 ledge measurements following methods described in Kendall et al. (2009). Total ledge height was the distance from the substrate to the top of the ledge, excluding all sessile organisms attached to the substrate. Undercut depth quantified the amount of overhang of each ledge and was measured from the leading edge of the ledge to the inner most portion of the ledge. Undercut height, or the height under the ledge, was measured from the substrate surface to the underside of the leading edge of the ledge. We collected all measurements using a tape measure or, when measurements exceeded 40 cm, they were visually estimated using the transect tape as a guide. Also, at each transect interval location, we measured the maximum height of an individual macroalgal frond or invertebrate to the nearest cm. We surveyed a total of 36 sites over the study period. We implemented an analysis of similarity (ANOSIM) routine to compare reef characteristics between those with and without associated turtles and subsequently used a similarity percentage routine (SIMPER) to assess contributions of each reef measure to dissimilarity between ledge types (both routines in PRIMER 7 software, version 7.0.13; PRIMER-e, Aukland, New Zealand) .

Results

We collected a total of 1703 time-lapse video samples representing observations over 255.5 hrs (Fig. 2). Noteworthy is the small number of videos with

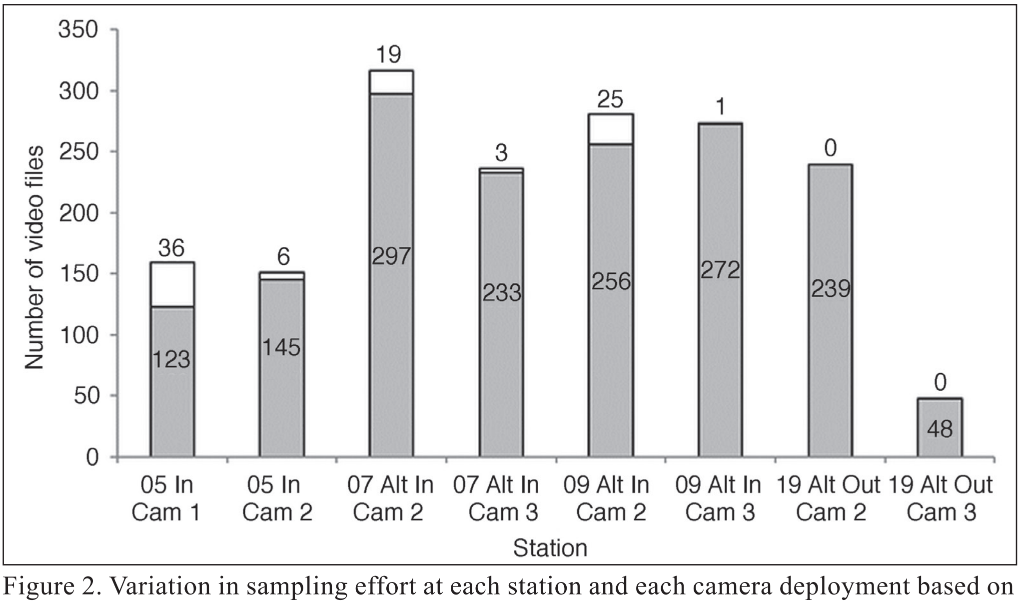

Figure 2. Variation in sampling effort at each station and each camera deployment based on number of video files recorded. Stacked bars indicate number of files with turtles in view (white bars) and those without (gray bars).

turtles present (n = 90; 5.28%). Despite this low percentage, a total of 22 individual turtles were identified in videos based on species, relative size, and unique markings (e.g., barnacle pattern, marks on carapace). Markings were assumed to be static over the short time period of the camera deployments (10 days), while we acknowledge that markings may be dynamic over longer time periods (sensu Hall and McNeill 2013). We observed 10 Loggerhead, 3 Green Sea Turtles, and 9 unidentified turtles (due to position in field of view and lighting) and documented a total of 27 separate occurrences of the 22 positively identified individuals, with variation in patterns of occurrence at cameras within and between 8 stations (Fig. 3). Notable was the absence of observations from the 2 cameras outside the closed research area. We classified 15 of the 27 total occurrences as "resting" behavior with turtles wedged under and against reefs (Fig. 4). Resting was inferred when an individual was in contact with the seafloor and no flipper movement was visible during the video sample period. Turtles were observed in 6 video samples to approach reefs, or adjust position once under reefs, and use front and rear flippers to position the body and maximize contact of both the plastron and carapace under ledges. Other behaviors observed in videos (n = 11 in only a single video file and n = 1 in 2 consecutive files) involved active swimming, including apparent search behavior along reef margins (inferred by movement along the proximate reef margin) or simple transit (moving by the camera with no directional swimming along the reef margin). Continuous observations of the same individual beyond single video records included resting periods up to 144 minutes (n = 15, mean resting period = 37.2 min, SD = 39.1). Most observations (67%) occurred during twilight and night periods (Fig. 5). Due to the logistics of camera deployments, sampling effort was uneven across stations; thus, this variation may

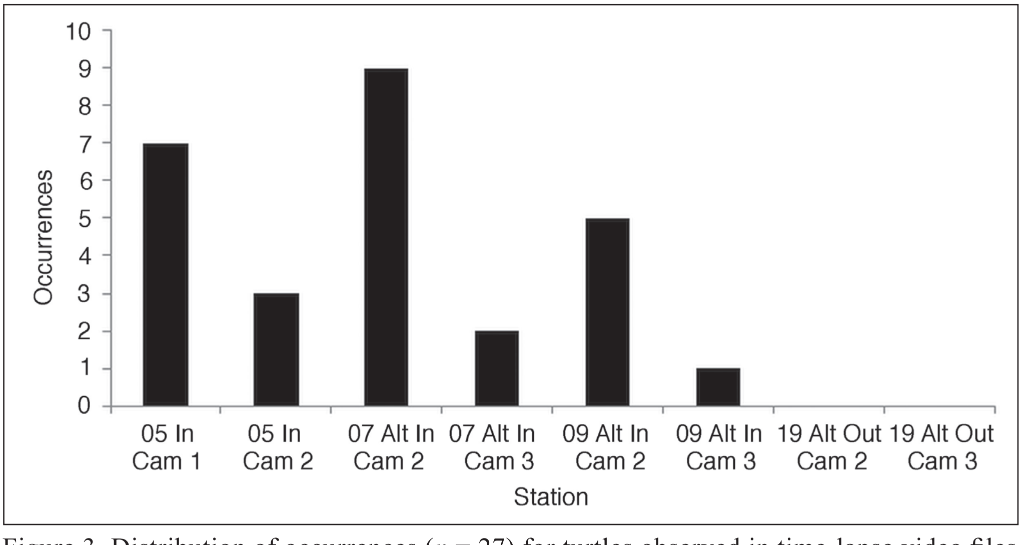

Figure 3. Distribution of occurrences (n = 27) for turtles observed in time-lapse video files by station. Occurrences are single and continuous presence of an individual turtle between successive video files. Discontinuous appearances of the same individual are separate occurrences. Note that no occurrences were observed in the video files from station 19 Alt Out.

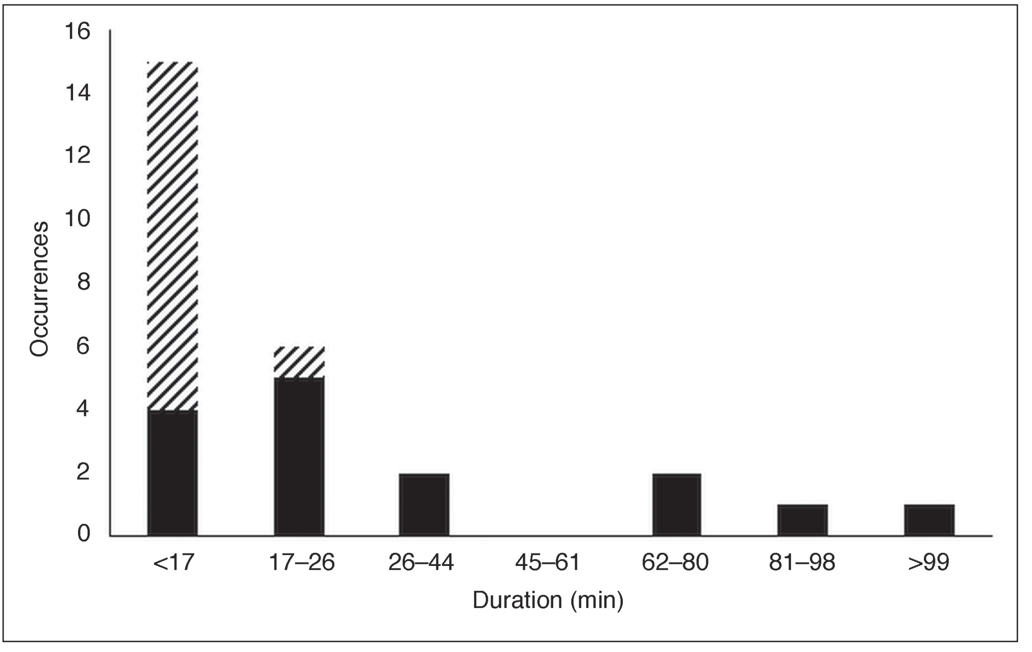

Figure 4. Time per occurrence (n = 27) for each individual turtle. Resting behavior (black) and other behaviors (hatched; i.e., search for feeding or resting sites, transit across field of view) within each time bin. Time is based on the maximum time duration of the occurrence based on elapsed time during video files and time between records. That is, the occurrence of a turtle in one 80-s video file but not appearing in the previous or next consecutive file is approximately 16 min (i.e., sequence of video recording is 80 s + 7 min 40 s + 80 s + 7 min 40 s …).

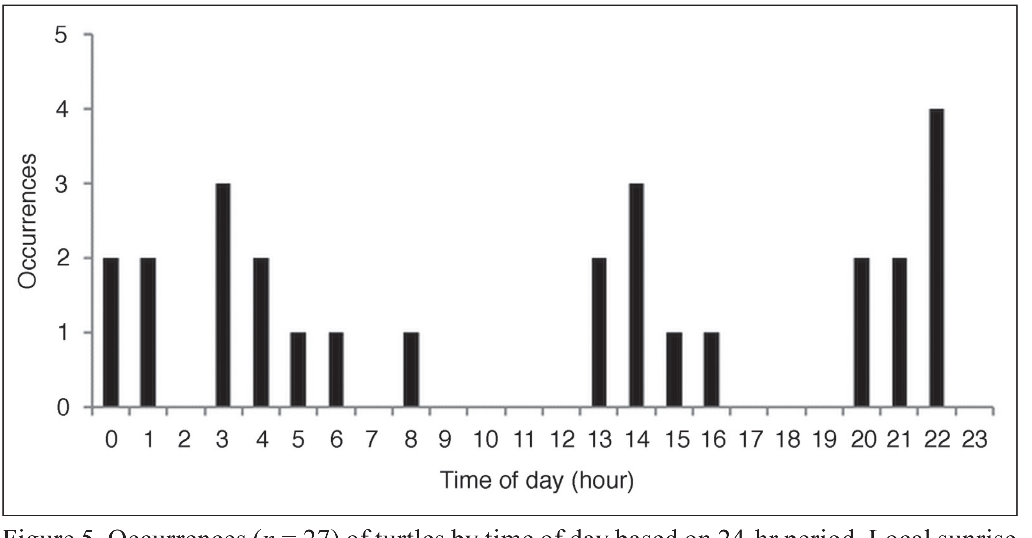

Figure 5. Occurrences (n = 27) of turtles by time of day based on 24-hr period. Local sunrise was at 0615 and sunset at 2030 hrs. Turtles resting for greater than 1 hour are counted only once during the first period of occurrence.

have created some bias in interpretation, especially due to low encounter rates from the outset. For example, as more turtles were observed inside the research area than outside, we calculated that based on rate of occurrence inside, we expected 18.2 video files with turtles outside (normalized for variation in sample size based on the proportion of video samples with turtles to total samples inside the research area). Three turtles departed and returned to the same or adjacent crevices within reefs, suggesting a degree of site fidelity for some individuals, at least over the relatively short term of our observations (36 min–8 hrs).

Additional observations conducted over a longer temporal scale (2010–2017) supported the idea of site fidelity, or at least suitability of particular reefs to turtles. Turtles were observed on 18 of 36 distinct reefs that were surveyed since 2010 (Fig 1), consisting of 32 distinct observations (Table 1). Turtles were observed on 6 of these reefs across multiple years, while others were observed from an additional reef across multiple days (Table 1). The remaining 11 reefs consisted of single-day observations (including station 19 alt OUT with no occurrences in time-lapse cameras, but where 1 Loggerhead was observed at the surface on 16 June 2014). Comparisons of structural habitat from reefs that appear to support turtles (i.e., where turtles have been observed by divers and video, including across multiple days or years) with those where turtles have not been observed reveal significant differences between reefs (one-way ANOSIM R = 0.074, $P = 0.043$; Fig. 6). The mean ± SE maximum reef height was 54.38 ± 9.46 cm on ledges with turtles ($n = 18$) vs 32.79 ± 4.77 cm on ledges without turtles ($n = 18$); similarity percentages [SIMPER] contribution to dissimilarity between ledge types was 27.59%. Undercut height (32.43 ± 9.91 cm vs 14.72 ± 2.12 cm; SIMPER: 26.47%) and undercut depth (30.01 ± 8.58 cm vs 14.87 ± 3.22 cm; SIMPER: 33.43%) of reefs supporting turtles was greater compared with those ledges where turtles were not observed. The maximum height of invertebrates (23.81 ± 2.94 cm vs 20.58 ± 2.31 cm; SIMPER: 6.54%) and algae (13.84 ± 1.61 cm vs 9.31 ± 1.27 cm; SIMPER: 5.96%) was also greater on ledges that support turtles, although these variables contributed less to differences between ledge types.

Discussion

Despite our limited sampling effort in both time and space, our results indicate undercut sub-tropical reefs appear to be regularly inhabited by Loggerhead and Green Sea Turtles and may serve as "resting" habitat for these species, among other functions. However, all ledges are not of equal value; ledges with turtles were significantly taller overall, and had significantly taller and deeper undercuts than ledges without turtles. The fidelity of turtles to specific ledges throughout all 8 years of our diver surveys suggests these results can aid in predicting where turtles may occur due to availability of seafloor habitat resources. At this point, we do not know if individual turtles are returning to specific sites (although analyses of photo and videos may allow individual identification), but we suggest that certain sites across GRNMS consist of habitat characteristics that reliably support turtles across years. Stadler et al. (2015) hypothesized that stable reefs that did not experience disturbance from storms or coverage by sand supported more juvenile Green Sea Turtles, with such sites possibly allowing preferred algal food to persist. In our study, high relief ledges with undercuts may also be more stable, resist sand coverage, have greater coverage of encrusting organisms (such as invertebrates and

Table 1. Summary of ad hoc observations from 2010–2017 of turtles (principally *Caretta caretta* [Loggerhead Sea Turtle]) at reefs during fish surveys by divers on the seafloor and on the surface made from small boats.

Site	Date	Observation type	Notes
Sites with observations over multiple years			
01altIN	7/8/2016	Surface	50–60 cm
	6/13/2017	Surface	2 turtles
01OUT	5/21/2011	Surface	
	6/16/2017	Surface	
02OUT	6/4/2013	Surface	
	6/11/2014	Diver	80 cm female turtle asleep under a ledge
	6/13/2017	Surface	
07altIN	6/10/2013	Diver	
	7/8/2016	Surface	
09altIN	6/13/2013	Diver	
	6/13/2017	Diver	Turtle resting under a ledge
41OUT	6/3/2010	Surface	
	5/28/2011	Surface	
	6/11/2013	Surface	
	5/29/2014	Surface	
	7/18/2015	Diver	Female turtle under ledge with nurse shark
	8/1/2015	Surface	
	7/8/2016	Diver	60-cm female swimming along seafloor
	6/12/2017	Surface	
Sites with observations in just a single year			
03IN	6/16/2017	Surface	Small turtle (50–70 cm)
	6/17/2017	Surface	
03altOUT	7/11/2016	Surface	
05IN	6/17/2017	Surface	
12altIN	6/10/2013	Diver	Female turtle swimming along seafloor
14OUT	6/11/2017	Surface	
15IN	6/2/2012	Diver	Large turtle (>90 cm) resting on ledge plateau
16OUT	7/14/2015	Surface	2 turtles
19altOUT	6/16/2014	Surface	
20OUT	6/14/2013	Surface	
29OUT	6/2/2012	Diver	Female turtle asleep under ledge
30IN	6/18/2017	Surface and diver	
31OUT	6/12/2013	Diver	Turtle swimming along seafloor

algae), and may support greater abundance of prey items (e.g., hard-shelled benthic invertebrates; Hawkes et al. 2006, Plotkin et al. 1993; but see Narazaki et al. 2013). Whether taller ledges are used by turtles due to their benefits for resting, foraging, or another purpose remains to be determined.

Our limited observations of repeated visits of turtles to ledges (i.e., individuals as well as multiple turtles to the same ledge) are broadly consistent with results from tagging studies of Loggerheads in the eastern Mediterranean Sea (Schofield et al. 2010). That study demonstrated that turtles in coastal habitats exhibited spatially constrained movements for foraging (mean size of core areas = 6.2 km^2) in contrast to those in open ocean regions (mean size of core areas = 108.5 km^2), linking the results to differences in distribution of prey resources. Notably, we have observed multiple turtles feeding on epibenthic fauna on ledges at GRNMS during other research dives (Fig. 7a). Future studies using time-lapse cameras could be designed to parse feeding from resting habitats in order to address how offshore reefs are used for different ecological requirements.

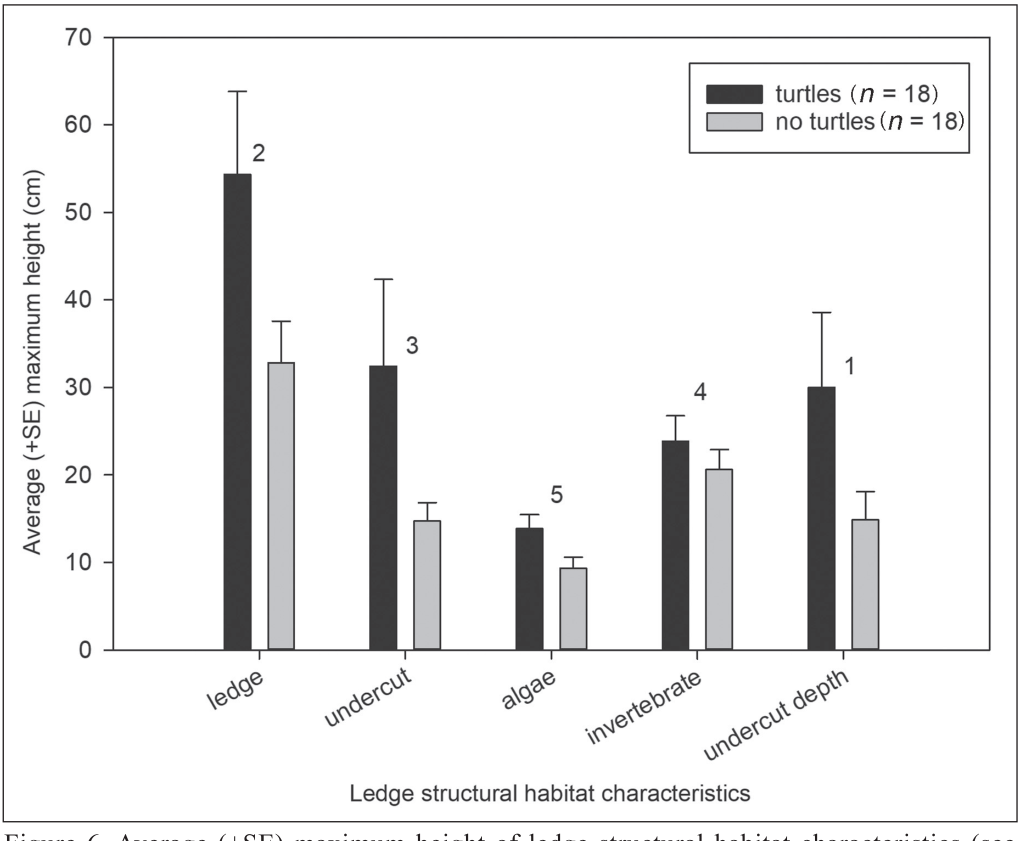

Figure 6. Average (+SE) maximum height of ledge structural habitat characteristics (see Methods for habitat characteristic descriptions). Structural attributes of ledges (total n = 36) that support turtles are significantly different from ledges that do not. Numbers above bars represent order of contribution (lower number = greater contribution, determined with SIMPER) to dissimilarity between ledges that support turtles versus ledges where turtles were not recorded.

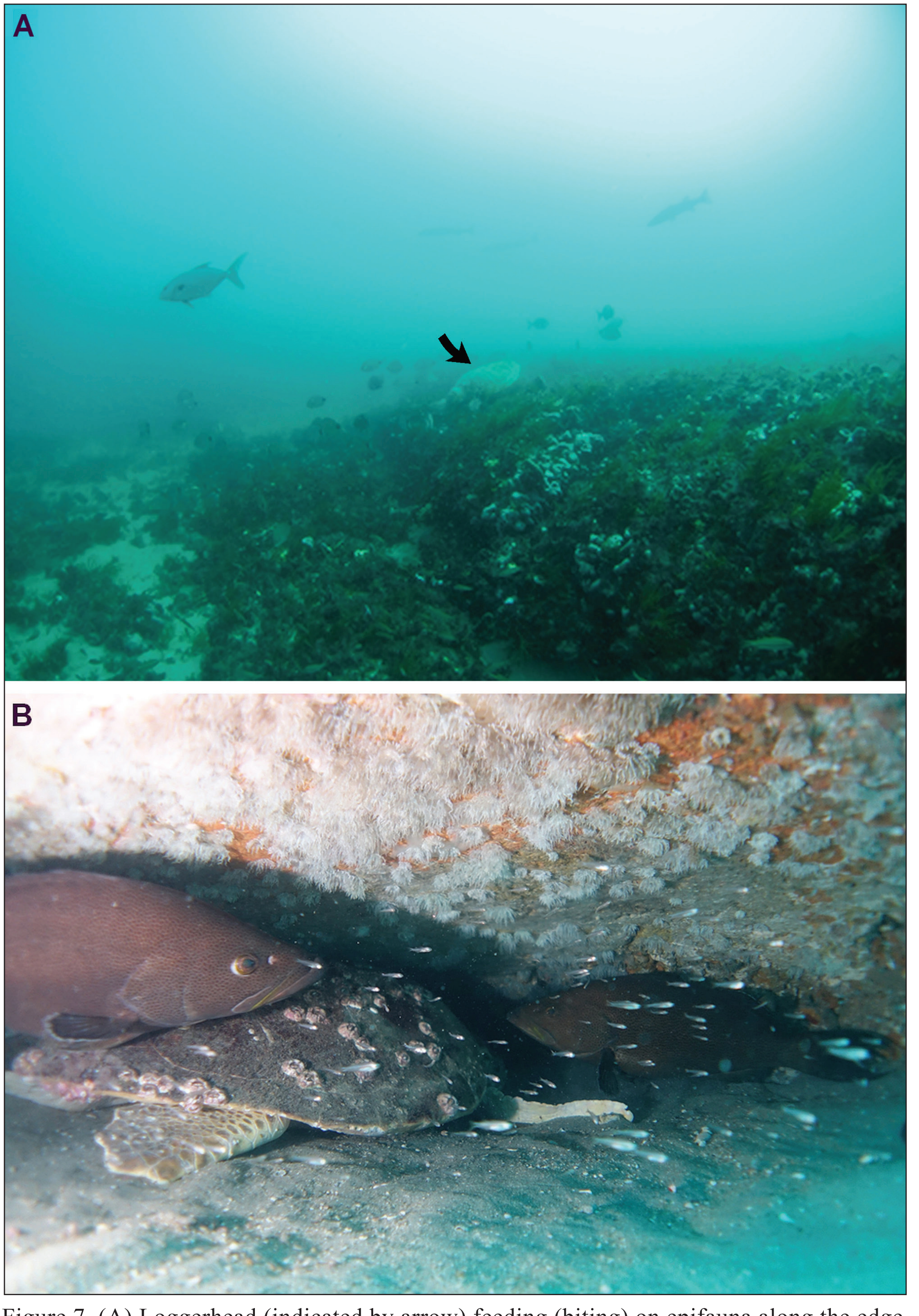

Figure 7. (A) Loggerhead (indicated by arrow) feeding (biting) on epifauna along the edge of a ledge. (B) Loggerhead under a ledge with Scamp Groupers. Such species (i.e., turtles, shelter-seeking fishes) excavate sand with movement patterns under ledges.

We suggest that time-lapse video and diver surveys of seafloor habitats in areas known for high sighting frequencies of turtles at the surface may yield new insights into habitat requirements, patterns of site fidelity, ecological roles, and the effects of coincident human uses. For example, turtles may play a role in maintaining crevices of undercut ledges by sweeping away sand while positioning themselves to rest, as observed in this study (Fig. 7b). Other megafaunal taxa that function as seafloor excavators have been observed in this same setting (P.J. Auster and R.C. Muñoz, pers. observ.), including *Ginglymostoma cirratum* (Bonnaterre) (Nurse Shark), *Mycteroperca microlepis* (Goode and Bean) (Gag Grouper), *Mycteroperca phenax* Jordan and Swain (Scamp Grouper), and *Lutjanus campechanus* (Poey) (Red Snapper). Time-lapse video and diver surveys also could aide in studies examining the impacts of human use of these sites, such as the effects of recreational diving, fishing, and other vessel-related activities on behavior and patterns of habitat use. Understanding the details of habitat requirements for multiple species of sea turtles and associated species (e.g., co-occurring fishes that excavate and sustain undercut ledges) in subtidal regions can be critical for developing effective conservation strategies. In particular, such knowledge could inform delineation of critical habitat for species listed under the United States Endangered Species Act (16 U.S.C. § 1531 et seq.), such as both Loggerhead and Green Sea Turtles, which are listed as threatened in the NW Atlantic, and for integrating the functional roles of species useful in habitat management under ecosystem approaches to fisheries.

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