Assessment and Monitoring of Marine Debris in Gray's Reef National Marine Sanctuary

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EXECUTIVE SUMMARY

Gray's Reef National Marine Sanctuary (GRNMS) is located 32.4 km offshore of Sapelo Island, Georgia. The ecological importance of this area is related to the transition between tropical and temperate waters, and the existence of a topographically complex system of ledges. Due to its central location, GRNMS can be used as a focal site to study the accumulation and impacts of marine debris on the Atlantic continental shelf offshore of the Southeast United States. Previously, researchers characterized marine debris in GRNMS and reported that incidence of the debris at the limited densely colonized ledge sites was significantly greater than at sand or sparsely colonized live bottom, and is further influenced by the level of boating activity and physiographic characteristics (e.g., ledge height). Information gleaned from the initial marine debris characterization was used to devise a strategy for prioritizing cleanup and monitoring efforts. However, a significant gap in knowledge was the rate of debris accumulation.

Image. Fishing line entangled in the coral *Oculina* at a monitoring site in GRNMS.

The primary objective of this study was to select, mark, and perform initial marine debris surveys at permanent monitoring sites within GRNMS to quantify long-term trends in types, abundance, impacts, and accumulation rates of debris. Ledge sites were selected to compare types, abundance, and accumulation rates of marine debris between a) areas of high and low use and b) short and tall ledges. Nine permanent monitoring sites were marked and initially surveyed in 2007/2008. Surveys were conducted within a 50 x 4 m transect for a total survey area of 200 m^2. All debris was removed and detailed information was taken on the types of debris, quantity, and associations with benthic fauna. Information on associations with benthic fauna included degree of entanglement, type of organism with which it is entangled or resting on, degree of fouling, and visible impacts such as tissue abrasions. Sites were re-surveyed approximately one year later to quantify new accumulation.

During the initial survey, a total of ten debris items, totaling 16.3 kg in weight, were removed from two monitoring stations, both "tall" sites within the area of high boat use. Year-one accumulation totaled five items and approximately 7 kg in weight. Similar to the initial survey, all debris was found at sites in the area of high boat use. However, in contrast to the initial survey, two of these items were found on medium-height ledges. Removed items included fishing line, leaders, rope, plastic, and fabric. Although items were often encrusted in benthic biota or entangled on the ledge, impacts such as abrasions or other injuries were not observed.

During the 2009 monitoring efforts, volunteer divers were trained to conduct the survey. Monitoring protocols were documented for GRNMS staff and included as an appendix of this report to enable long-term monitoring of sites.

Additionally, national reconnaissance data (e.g. satellite, radar, aerial surveys) and other information on known fishing locations were examined for patterns of resource use and correlations with debris occurrence patterns. A previous model predicting the density of marine debris based on ledge features and boat use was refined and the results were used to generate a map of predicted debris density for all ledges.

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INTRODUCTION

Marine debris has been documented as an increasing problem affecting many coastal regions of the United States. Despite the growing body of research focused in regions such as Hawaii, the West Coast, Chesapeake Bay, and Gulf of Mexico (e.g. http://marinedebris.noaa.gov/), large sections of the US shelf have remained largely unstudied. One such region, the Atlantic Coast of the Southeast USA, has received virtually no scrutiny despite bottom types and human activities that indicate the propensity for a marine debris problem. This region is comprised of a broad, sandy continental shelf interspersed with patchy hard bottom or limestone ledges that harbor a diversity of sessile invertebrates and reef fish (SEAMAP-SA 2001; Dunn and Halpin 2009). The shelf area in this region is comprised of 21.1% flat hardbottom and 1.7% high relief patches (Parker et al. 1983). The sessile invertebrate community of these small but structurally complex ledge patches includes large sponges, gorgonians, and branching hard corals that can snag, trap, and entangle debris. The reef fish associated with these bottom types includes many that are routinely targeted by recreational fishermen.

Gray's Reef National Marine Sanctuary (GRNMS) is located centrally in the region on the continental shelf, 32.4 km offshore of Sapelo Island, Georgia (Figure 1) and because it encompasses bottom types and human use representative of the region, can be used as a focal site to study the accumulation and impacts of marine debris. Gray's Reef was selected as a sanctuary in part due to the complex mosaic of habitats (e.g., sand plains, caves, and rocky ledges) that support a diverse assemblage of benthic invertebrates and fish. The sanctuary is approximately 58 square km, about 75% of which is characterized as flat or rippled sand (Kendall et al. 2005). Sparsely colonized live bottom accounts for about 25% of the bottom. Densely colonized ledges account for less than 1% of the total area (Kendall et al. 2005). Primary human activities at GRNMS include recreational fishing and SCUBA diving. Gray's Reef is a popular site for anglers after pelagic species such as king mackerel and bottom fish such as red snapper, grouper, and especially black sea bass. Rod and reel is the dominant gear type to target these species, although spearfishing with non-power spearheads was also conducted in the sanctuary until a recent ban (GRNMS 2006). Several sport fishing tournaments take place off of the Georgia coast each year, with Gray's Reef and other hard bottom sites being premier locations.

Recently, there has been increased concern about the potential accumulation of marine debris in GRNMS (GRNMS 2006). Since the designation of GRNMS in 1981, the population of neighboring coastal counties has increased substantially (~40% from 1980-2000), and has been forecast to increase an additional 32% by 2015 (CGRDC 2006). Coincident with this population increase, boat surveys indicate that recreational use of the sanctuary has also increased (GRNMS 2006). The most recent management plan calls for specific measures to assess, monitor, and remove debris from targeted areas within the sanctuary (GRNMS 2006). Specifically, activities were proposed to a) develop and implement a marine debris education and outreach program; and b) develop and implement a debris monitoring and assessment study. An understanding of the types and spatial distribution of marine debris

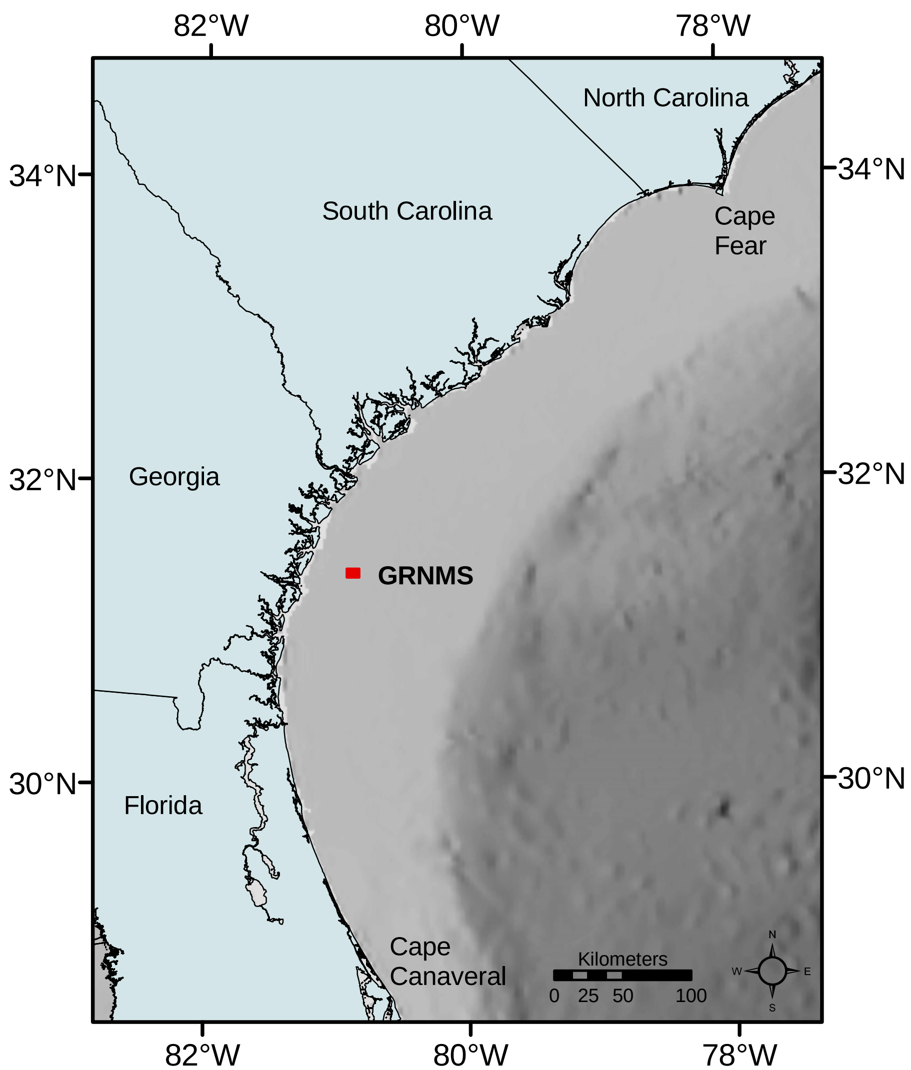


Figure 1. Location of Gray's Reef National Marine Sanctuary (GRNMS).

in the sanctuary are necessary prerequisites to conduct clean-up and education activities efficiently. Knowledge of the spatial distribution of debris enables the sanctuary to focus clean-up efforts on the most affected areas given limited resources. Knowledge of the types of debris and potential mechanisms of transport and deposition allow education and outreach activities to focus their efforts on primary sources of debris. Knowledge of accumulation rates allows the frequency of clean-up activities to be optimized and temporal scope of the impacts to be understood.

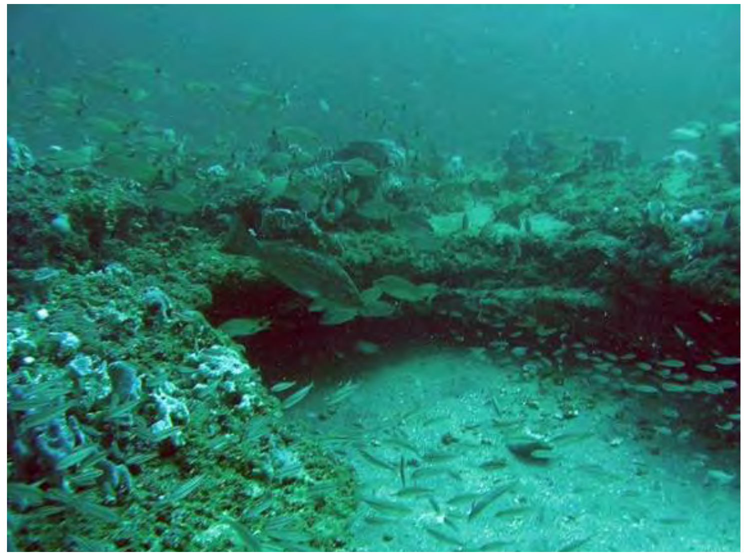


Image 1. Densely colonized, undercut ledge and the associated fish community in GRNMS.

Recent work by NOAA's Center for Coastal Monitoring and Assessment (Bauer et al. 2008; Kendall et al. 2007) partially addressed the activities outlined in the management plan strategy. The assessment characterized the type and quantity of marine debris at GRNMS, the type of bottom features it is routinely associated with, and proposed a strategy for continued assessment and monitoring. In that study, three field surveys were conducted in 2004 and 2005 for a total of 179 sites in GRNMS. Approximately two-thirds of all observed debris items found during the field surveys were fishing gear, and about half of the fishing related debris was fishing line. Other fishing related debris included leaders and spear gun parts, and non-gear debris included cans, bottles, and rope. The spatial distribution of debris was concentrated in the center of the sanctuary and was most frequently associated with ledges rather than at other bottom types. In fact, although densely colonized ledges account for less than 1% of the total area within the sanctuary, over 95% of debris items were found on ledge bottom type. Several factors may contribute to this observation. Ledge features are targeted by fishermen due to the high abundance and diversity of target fishes that reside there. In addition, ledges are structurally complex and are often densely colonized by biota, providing numerous places for debris to become stuck or entangled. Thus, despite their limited area, ledges appear to be most vulnerable to debris accumulation.

Analysis of observed boat locations indicated that higher boat activity, which is an indication of fishing, occurs in the center of the sanctuary. On ledges, the presence and abundance of debris was significantly related to observed boat density and physiographic features including ledge height, ledge area, and percent cover. Information gleaned from the initial marine debris characterization was used to devise a strategy for prioritizing cleanup and monitoring efforts. However, a significant gap in knowledge is the rate of debris accumulation. Debris found in the initial assessment had been in place for an unknown period of time. Knowledge of rate of debris accumulation will aid managers in determining how often debris should be removed from target locations.

The objectives of this study were to:

1) Select, mark, and perform initial marine debris surveys at permanent monitoring sites within GRNMS to quantify long-term trends in types, abundance, impacts, and accumulation rates of debris.

2) Compare types, abundance, and accumulation rates of marine debris between a) areas of high and low use and b) short and tall ledges.

3) Examine national reconnaissance data (e.g. satellite, radar, aerial surveys) and other information on known fishing locations for patterns of resource use and correlations with debris occurrence patterns.

4) Refine models predicting the density of marine debris based on bottom type, benthic features, and boater density.

5) Document monitoring protocols for GRNMS staff based on year-one results to enable long-term monitoring of sites.

METHODS

Site selection

The basic approach was to monitor debris accumulation along a 50 x 4 m transect conducted along a ledge. Ledge sites were selected to compare debris metrics between regions with differing relative use and among ledge height classes. From a previous GIS analysis, there are 436 mapped ledges within GRNMS with known spatial position, height (m) and area (m^2) (Kendall and Eschelbach 2006). Area calculations were used to categorize ledges as small, medium, or large, by rank ordering their area and assigning 1/3 of the ledges to each category. The same method was applied to height to categorize ledges as short, medium, or tall.

Previously, we used boat count data to partition the sanctuary into areas of relatively "high" vs. "low" boat density as a proxy for human use and fishing levels (Kendall et al. 2007; Bauer et al. 2008). There are 156 and 280 ledges located within the regions of high and low boat density, respectively.

Sites were selected in order to test the following hypotheses:

a) Among ledges of similar height and area (tall and large), debris accumulation is significantly different between ledges within regions of high and low boat density.

b) Among ledges of similar area (large) within the region of high boat density, debris accumulation is significantly different on ledges of different height categories.

To test the hypotheses, three ledges were randomly selected from each of the following strata:

1) Tall/large (height/area) ledges within the region of low boat density.

2) Tall/large (height/area) ledges within the region of high boat density.

3) Medium/large (height/area) ledges within the region of high boat density.

Short ledges were eliminated from consideration due to the low number of short/large ledges within the region of high boat density.

Sites were randomly selected provided that the selected ledge was suitable to conduct the survey after examining the bathymetry and backscatter. The starting point on each ledge was predetermined using the using the random point generator in HawthsTools v3.23, and the direction of the survey along the ledge (e.g., left or right) was randomly selected. Exceptions were made on smaller ledges where only one direction was long enough to accommodate a 50 m transect.

Field methods

Initial surveys were conducted in September 2007 and May 2008 (Figure 2). Four sites were initially surveyed and marked in September 2007. The remaining sites could not be completed at that time due to sea conditions but were established during the May 2008 GRNMS research cruise on the R/V Nancy Foster. The four sites that were marked in September 2007 were also re-surveyed during the May 2008 cruise. All sites were re-surveyed after one year in June 2009.

Two divers performed the survey at each site. For initial site establishment, there were two main components to the survey methodology, which was conducted within a 50 x 4 m transect for a total survey area of 200 m^2 at each site. First, the divers marked a 50 m transect along a ledge using ground anchors. One diver strung along the 50 m transect tape while the other diver inserted the anchors in the sand immediately

Image 2. NOAA divers inserted sand anchors at both ends of the 50 m transect to mark the permanent monitoring sites.

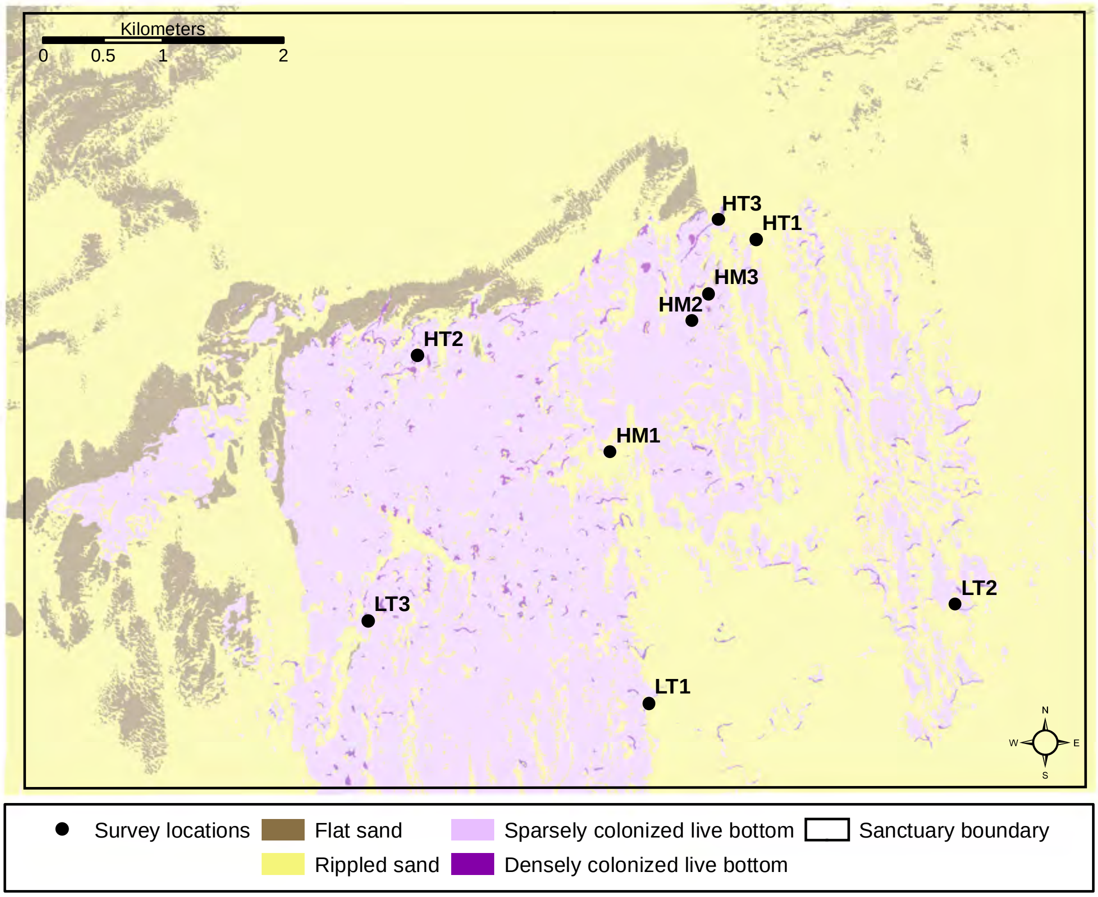


Figure 2. Location of permanent marine debris monitoring sites.

next to the ledge at the beginning and the end of the transect only. The tape was laid out to follow any curves in the ledge edge (Figure 3).

Divers then quantified and removed debris from 2 m on either side of the ledge lip, using the tape measure as a guide. All debris was removed and detailed information was taken on the types of debris, quantity, and associations with benthic fauna. Information on associations with benthic fauna included degree of entanglement, type of organism with which it is entangled or resting on, degree of fouling, and visible impacts such as tissue abrasions. In addition, the height, undercut width, and undercut height of the ledge were measured at five randomly selected points along the transect to further quantify ledge characteristics. The debris removed from each site were kept in separate buckets/bags with the site name and then sorted and weighed upon return to shore/ship.

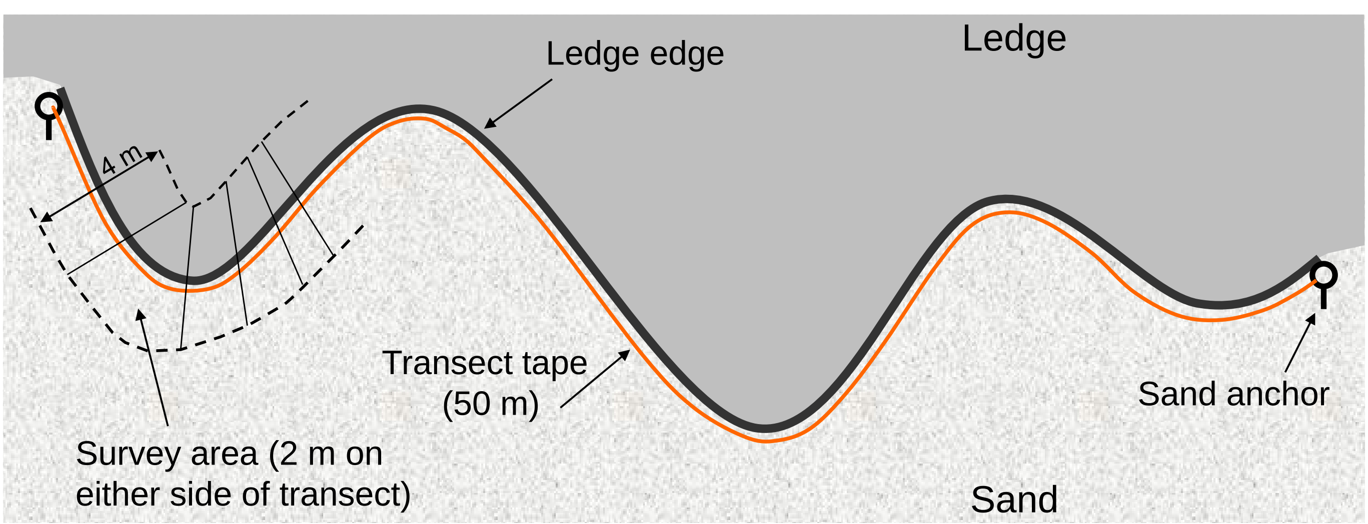


Figure 3. Schematic of how survey transect was placed along the edge of a ledge.

All sites were re-surveyed approximately one year later during the 2009 GRNMS cruise on the R/V Nancy Foster. Once at each site, divers located the first ground anchor, which marked the beginning of the survey. The transect tape was tied to the first anchor and strung along the ledge as a guide until they reached the second pin. The same survey procedures were used as in the year prior: any debris was documented, measured, photographed, and removed. Ledge characteristics were measured at the location where debris was found.

Additionally, during the 2009 cruise, a pair of volunteer divers from Team Ocean accompanied the NOAA divers on the monitoring survey. The Team Ocean divers were trained in the survey protocol so that they may conduct the annual monitoring in the future. Survey instructions and copies of the data sheets for each site are located in Appendices B and C, respectively.

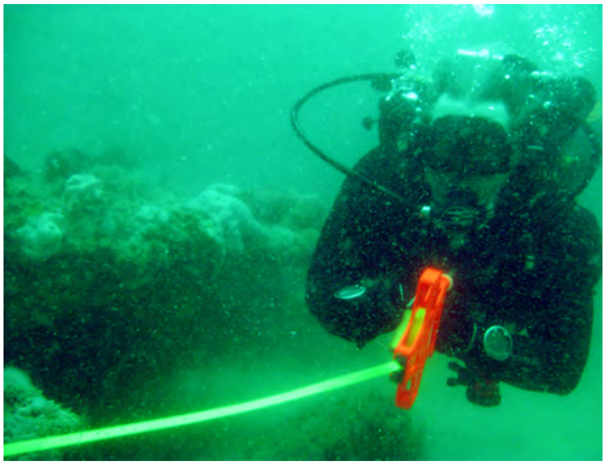


Image 3. Team Ocean diver Mike Mullinex rolls out the transect tape.

Data analysis

Summary statistics and analyses were conducted in JMP (v.7.0). Statistics for the quantity, weight, and types of debris were calculated for the entire survey domain and by strata type for Year 0 and Year 1. The amount of new debris collected in Year 1 was used to calculate the one-year accumulation rate.

The hypothesis that number of items and weights of debris were significantly different between a) ledges located in areas of high versus low boat density and b) ledges of medium versus large height were using non-parametric ANOVA for both Year 0 and Year 1.

Assessment of User Data

Previously, we used boat data to partition the sanctuary into areas of relatively low and high boat use using the density of boats in a 0.25 km^2 grid (Kendall et al. 2007; Bauer et al. 2008). Additional recent boat positional data was obtained from multiple sources, including national reconnaissance systems and the Georgia Department of Natural Resources (GA DNR), and entered into a Geographic Information System (GIS). The mean center was calculated by year (1999-2007) to examine potential changes in user patterns over time.

The additional boat positions were used to refine the areas of relative “high” vs. “low” use using the Directional Distribution (Standard Deviational Ellipse) function in ArcGIS. This tool measures the dispersion of features around the mean center in both x and y directions to show the distributional trend of the data. The ellipse was calculated for one standard deviation of the x and y coordinates of the boat positions for all years (1999-2007), meaning that 68% of the boat positions were included in the output ellipse feature. The area and extent of the ellipse was defined as the “high” use area, while the remaining area was defined as the “low” use area. This is an improvement upon our previous grid method in that it can be more easily updated over time as more data becomes available. In addition, this method is less subjective in that it eliminates the need for the user to define a new cutoff between low and high density each time data is added.

Additional information on user patterns was obtained directly from local fishermen, who were asked to identify popular fishing locations. The GPS coordinates were entered into a GIS and examined in concert with the boat data.

Models of debris distribution

Previously, we modeled debris presence and abundance as a function of boat use and ledge characteristics (Bauer et al. 2008). Data from 2004/2005 field surveys were used to create a two-part conditional model (Cunningham and Lindenmayer 2005). Results indicated that boat use, ledge area, and percent cover were significant predictors of debris presence, and that boat use and ledge height were significant predictors of abundance, given presence. While informative, the model itself could not be used to extrapolate predictions sanctuary-wide because information on the percent benthic cover is not available for all ledges. In this effort, we reconstructed the model using only parameters that are available for every ledge: 1) boat use (high/low), 2) ledge area (m^2) and 3) maximum ledge height (cm, measured *in situ*). Because we previously found that ledge height is correlated with total benthic cover (Kendall et al. 2007) we do not believe this leads to a significant loss of information. Only 2004/2005 survey data (n=92) were included as the new monitoring stations were selected using a different sampling scheme.

Analyses were conducted in SAS v9.1. Briefly, the two-part conditional modeling approach separates variables that determine whether or not debris is present form variables that determine the amount of debris, given presence. In the first step, debris was treated as present or absent and modeled using logistic regression. In the second step, only sites in which debris was present were considered. At sites with debris, the number of debris items was modeled with a generalized linear model (GLM) with a negative binomial distribution and a log link. The negative binomial distribution was chosen because it requires fewer assumptions than the normal or Poisson distribution and is appropriate for modeling skewed count distributions (White and Bennets 1996). A Pearson's Chi-Square test was used to assess the goodness of fit of the negative binomial model to the data. At both stages, only main effects were considered, and conservative models were selected by using backward elimination of non-significant variables (α=0.05).

The resulting model parameters were used to make predictions of debris density (#/100 m^2) for all mapped ledges within the sanctuary. Two calculations were made for each ledge: results from the logistic model were used to calculate the probability of occurrence (p),

$$p = 1/\{1+\exp[-(\beta_0 + \beta_1 x.....)]\} \qquad (1)$$

while results from the negative binomial GLM were used to predict mean abundance, given occurrence (λ),

$$\lambda = \exp(\beta_0 + \beta_1 x.....) \qquad (2)$$

The product of equations 1 and 2 yields the overall predicted debris abundance for a given ledge. Predictions were mapped in ArcGIS. The new prediction map improves upon the previous version (Kendall et al. 2007) in which predicted debris density was generated by simple interpolation of survey data rather than in relation to predictor variables.

RESULTS AND DISCUSSION

Summary statistics of year-0 and year-1 mean debris density and weight by strata are shown in Figure 4. During the initial survey, a total of ten debris items, totaling 16.3 kg in weight, were removed from the monitoring stations (Table 1). Debris was present at two sites, both "tall" sites within the area of high boat density (Figure 5). Five items were removed from each of these sites, respectively. HT2 accounted for the majority of the weight due to the presence of heavily encrusted rope, lead weights, and a window sash weight. Other debris items included fishing line, wire, and leaders. At one site, two pieces of plastic were found that appear to have been part of the NOAA data buoy. All of the items were fouled with algae, and many others were colonized by sponges, tunicates, barnacles and the coral *Oculina*. Although items were often entangled on the ledge, impacts such as abrasions or other injuries were not observed. In one instance a piece of fabric was lying on top of a dead colony of *Oculina* but it is unknown whether the debris contributed to the coral's death or became entangled afterword.

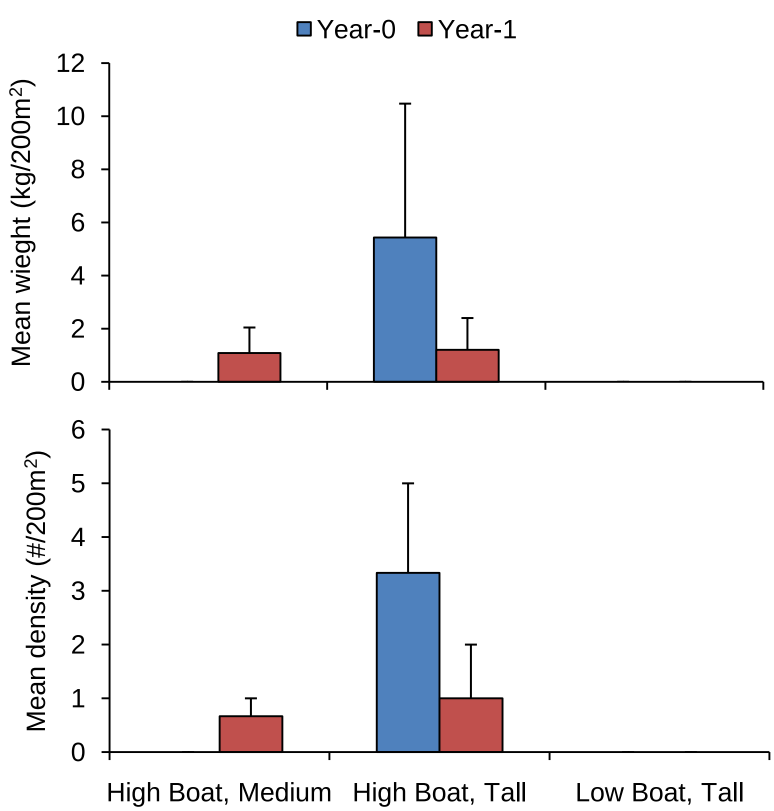


Figure 4. Mean (±SE) weight and density by strata in initial and Year-1 surveys.

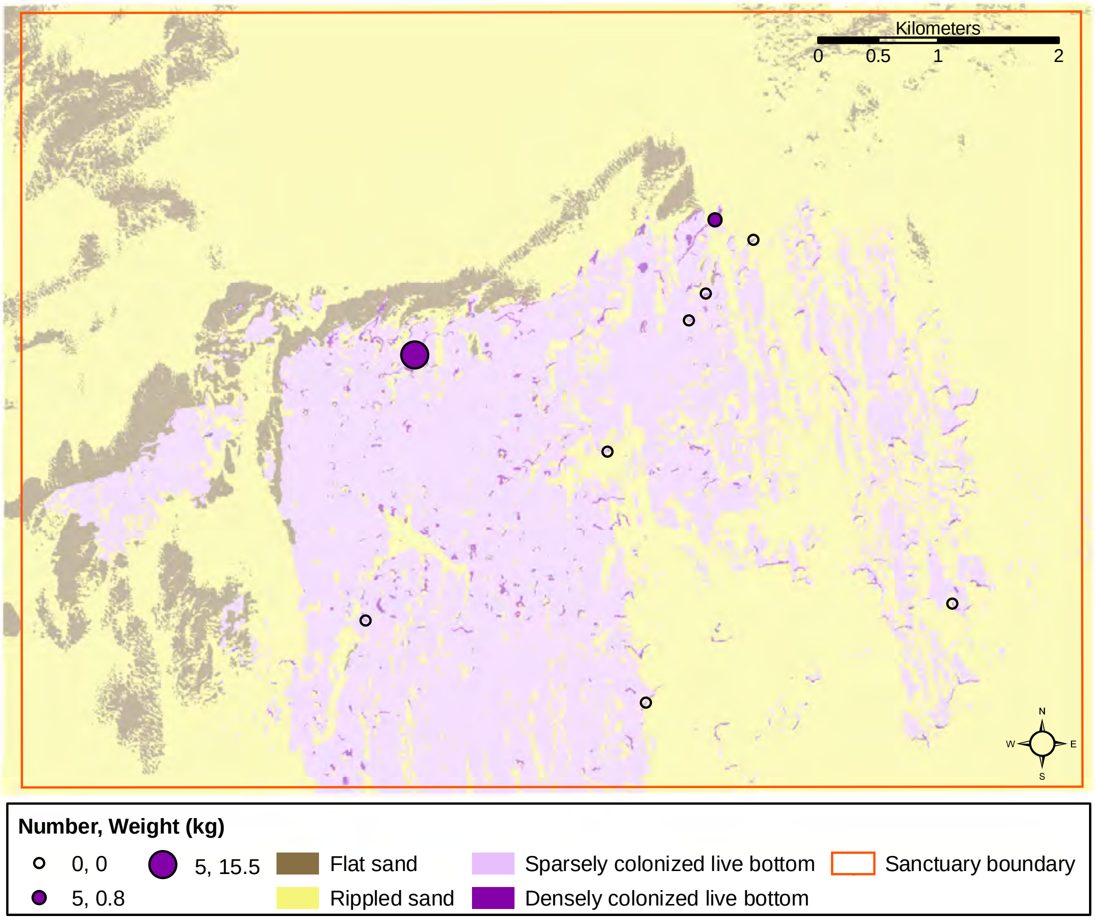


Figure 5. Density (#/200 m^2) and weight (kg/200 m^2) of marine debris at permanent sites in the initial (Year-0) survey.

Table 1. Summary of debris types found in initial (Year-0) survey.

Site	Debris type	Area (cm^2)	Entanglee	Fouling	Impacts/Notes
HT2	Rope	112000	*Oculina*, substrate	*Oculina*, sponges, barnacles, tunicates, algae	None observed; item was heavily colonized
	Wire w/ window sash weight	700	Substrate	Sponges, tunicates, algae	None observed
	Rope w/ lead weights	300	Substrate	Barnacles, tunicates, algae	None observed
	Wire leader	2500	Substrate	Tunicates, algae	None observed
	Wire leader	2500	Substrate	Tunicates, algae	None observed
HT3	Hook and wire	30	Substrate	Algae	None observed
	Wire	60	None	Algae	None observed
	Fabric	150	*Oculina*	Tunicates	Entangled on dead *Oculina*
	Plastic	120	None	Algae	None observed
	Plastic	180	None	Barnacles, tunicates, mollusks, gorgonians, tube worms, algae	None observed

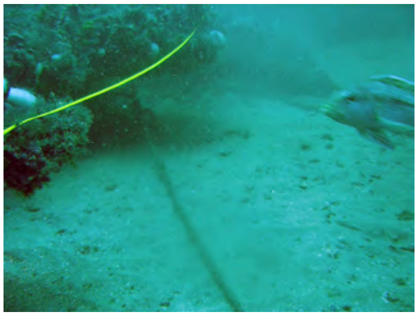


Image 4a-c. Examples of debris items found in initial survey

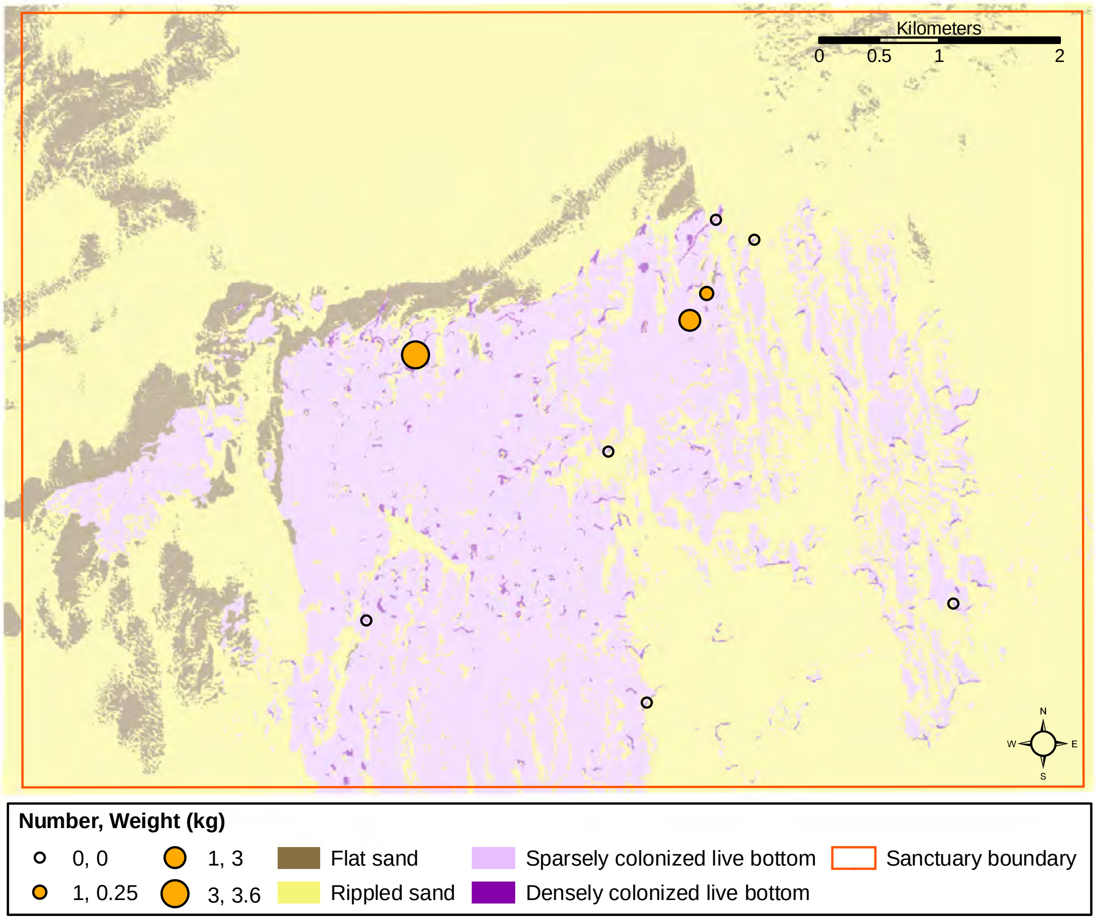


Figure 6. Density (#/200 m^2) and weight (kg/200 m^2) of marine debris at permanent sites in the Year-1 survey.

Table 2. Summary of debris types found in Year-1 survey.

Site	Debris type	Area (cm^2)	Entanglee	Fouling	Impacts/Notes
HMALT1	Lead ball	120	None	Tunicates, algae	None observed; Item was not removed
HMALT2	Wire	70	Substrate	Algae	None observed
HT2	Wire leader	100	Oculina	Barnacles, sponges, tunicates, algae	None observed, but entangled in coral
	Rope w/ lead weights	30000	None	Barnacles, sponges, tunicates, mollusks, tube worms, algae	None observed
	Rope w/ lead weights	5000	Substrate	Oculina, barnacles, sponges, tunicates, calcareous algae, turf algae	None observed

Image 5a-c. Examples of debris items found in Year-1 survey. A one meter long PVC pole (left panel; black tape denotes 10 cm increments) and clipboard (middle and right panels) are shown for scale.

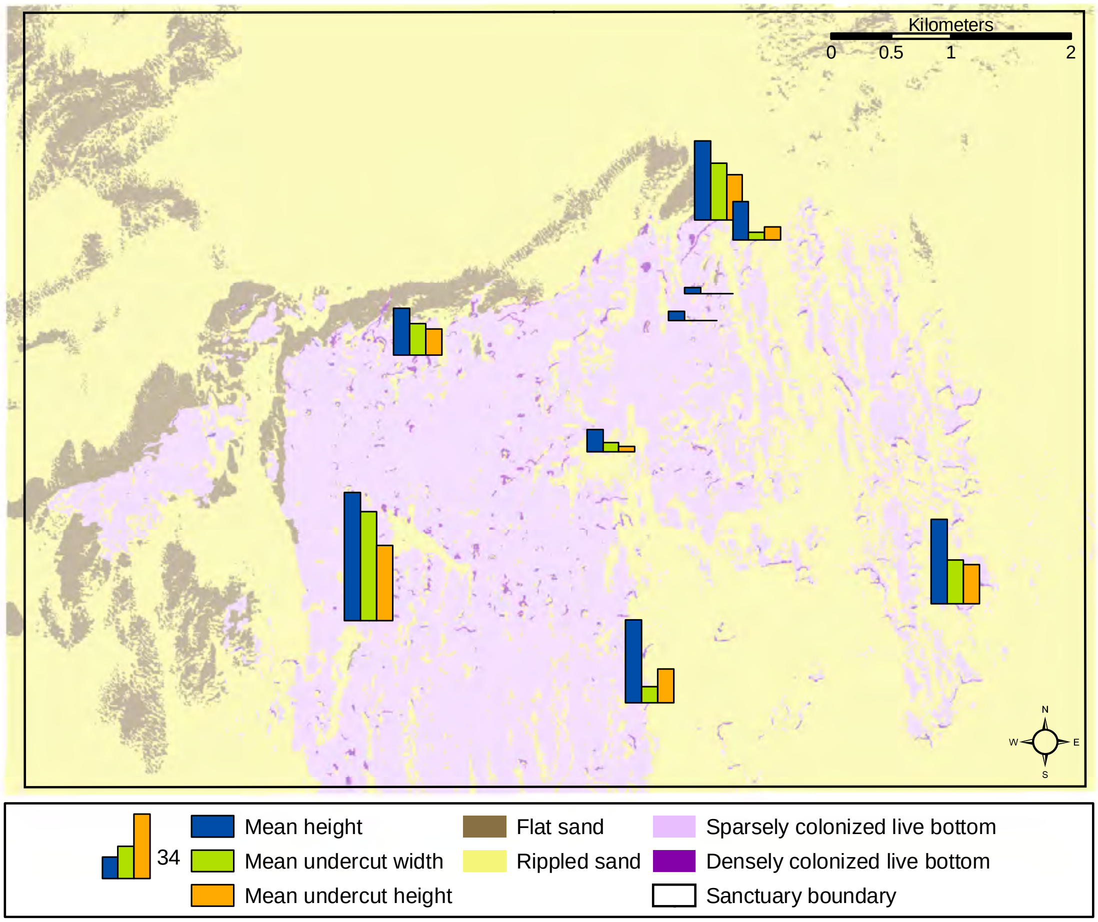


Figure 7. Mean ledge dimensions (total height, undercut width, undercut height) at permanent monitoring sites. The tallest bar in the legend is 34 cm.

Year-one accumulation totaled five items and approximately 7 kg in weight (Table 2; Figure 6). The lag between the two dates in which initial surveys were conducted could have potentially caused computational difficulty in the one-year accumulation rates. However, of the four sites that were established in September 2007, no new accumulation was present when they were re-visited in May 2008 or June 2009, so no adjustments in accumulation rates were necessary.

Similar to the initial survey, all debris was found at sites in the area of high boat density. However, in contrast to the initial survey, two of these items were found on medium-height ledges. Site HT2 again accounted for the majority of the debris weight (3.6 kg). Two of these items were rope with weights attached to the bottom of a fishing net (i.e., "lead line") that were heavily encrusted with benthic organisms (see Image 5). The degree of fouling suggests that the debris had been underwater longer than a year, yet due to the large size and conspicuous nature of both items, it was unlikely that these would have been missed in the first survey. It is possible that they were outside the transect during the initial survey and were pushed closer to the ledge in the time since. The lead ball found at HMALT1 was not removed due to miscommunication between divers, and should be picked up during the next survey.

Overall, the types of debris found were consistent with the previous survey, with fishing-related items making up a large component of the debris. Various components of hook and line gear, for instance, accounted for 6 of the 15 items. Other items such as the rope may also have been used for fishing related purposes. For instance, the rope segments with the lead weights attached to the bottom is of the type that is attached to the bottom of a fishing net/seine, although the actual net was not found.

Physical ledge dimensions shared similar patterns with the previous characterization (Kendall et al. 2007). Ledges within the medium height category were shorter with little or no undercut, while tall ledges showed varying degrees of undercut (Figure 7). Some of the ledges, particularly within the medium height class, appear to have been filled in with sand and were often discontinuous. Regular measurements of the height of the sand anchors/pins at each site will shed light on the dynamics of sand movement at those locations.

Statistically, the initial amount and one-year accumulation rates of debris were not significantly different between medium vs. tall ledges or low vs. high boat density areas (Table 3). This may be due to the high degree of variance within strata, small sample size and low amounts of debris found. Statistical estimates should improve as the time series of data collection is extended. However, the results were in agreement with the previous findings that presence and abundance of debris tend to be higher in the area of high use and correlated with larger ledges. As expected, no debris was recovered during either time period on ledges within the low boat use area.

Table 3. Chi-square statistics for non-parametric Kruskal-Wallis tests comparing Year-0 and Year-1 debris density and weight by strata.

Category	df	Chi-Square	Prob>ChSq
Year-0 density	2	4.50	0.11
Year-0 weight	2	4.57	0.10
Year-1 density	2	2.13	0.35
Year-1 weight	2	2.10	0.35

While no impacts to benthic biota were directly observed, many of the items, particularly the rope, wire, and hooks/leaders, were snagged on the ledge or in two instances, resting on or entangled in coral. Other work has indicated that progressive algal growth on entangled fishing line can eventually lead to coral death (Schleyer and Tomalin 2000; Asoh et al. 2004; Yoshikawa and Asoh 2004). The potential for injuries, therefore, was evident even though they weren't directly observed in either of these sampling periods. The degree of encrusting varied among objects but was often quite high and appears to accrete quickly. After one year, several of the pins marking the survey transect were completely encrusted with algae, sponge, and tunicates (Image 7).

Image 7. Example of a pin marker encrusted in benthic organisms at the time of the Year-1 survey.

Newly acquired boat location data for 2004-2007 was similar in distribution to the previous collections. The mean center of distribution, calculated by year from 1999-2007, was similar among all years and located in the center of the sanctuary along the northern line of ledges. It should be noted that collections of boat positions were largely opportunistic or collected during pelagic fishing tournaments. However, tournaments are a key activity within the sanctuary and potential source of debris. In addition, the spatial distribution of locations and center of distribution are similar even when points were separated by season: May-October, when the majority of fishing tournaments and pelagic fishing takes place, and November-April, when bottom fishing is the primary activity (Figure 8).

Known targeted fishing locations share a common distribution with observed boat positions (Figure 9). Three of the four identified locations, the "East ledge," "SW Ledge," and "West Ledge," are situated in the central portion of the sanctuary along the northern line of ledges. Approximately 25% of the boat positions were located within a 500 m buffer of these three fishing locations. An additional 25% of the boat positions were located within a 500 m buffer of the NOAA data buoy, which is frequented by fishermen to catch bait. In contrast, few boats were observed around the fourth identified site in the Northeast corner of the sanctuary, the "Rock Ledge."

The Standard Deviational Ellipse tool was used modify the area of relatively "high" vs. "low" boat use using the available boat positional data from 1999-2007 (Figure 10a). The ellipsoid contains one standard deviation, or 68%, of the data points. The area is similar to the previous gridded version in orientation, as it is situated on a SW-NE axis in the center of the sanctuary (Figure 10b). It differs slightly in extent, as it excludes a few grid cells on the western extent of the gridded version. However, there are few ledges in this area. The ellipsoid encompasses the same core group of ledges and overall approximately the same number of ledges as the grid version (146 vs. 145). This method is advantageous in that it represents a more continuous feature than the grid cells, and will allow managers to more easily update the high use area feature as more boat position data becomes available. In addition, ellipsoids may be created by year/season to monitor usage patterns over time, which will be useful for prioritizing areas for marine debris cleanup.

Results from the two-part conditional model on the 2004/2005 marine debris data were consistent with previous findings, with some small differences. Both ledge height and boat density were significant predictors at both stages of the model (Table 4). Although ledge area was a significant predictor in the previous version (Bauer et al. 2008) this variable was no longer significant following the removal of percent cover. Predicted debris abundance ranged from 0.2 to 8.9 items/100 m^2 (Figure 11). Highest debris abundance was predicted on tall ledges in the area of high boat density. An examination of predicted vs. observed values indicates that the

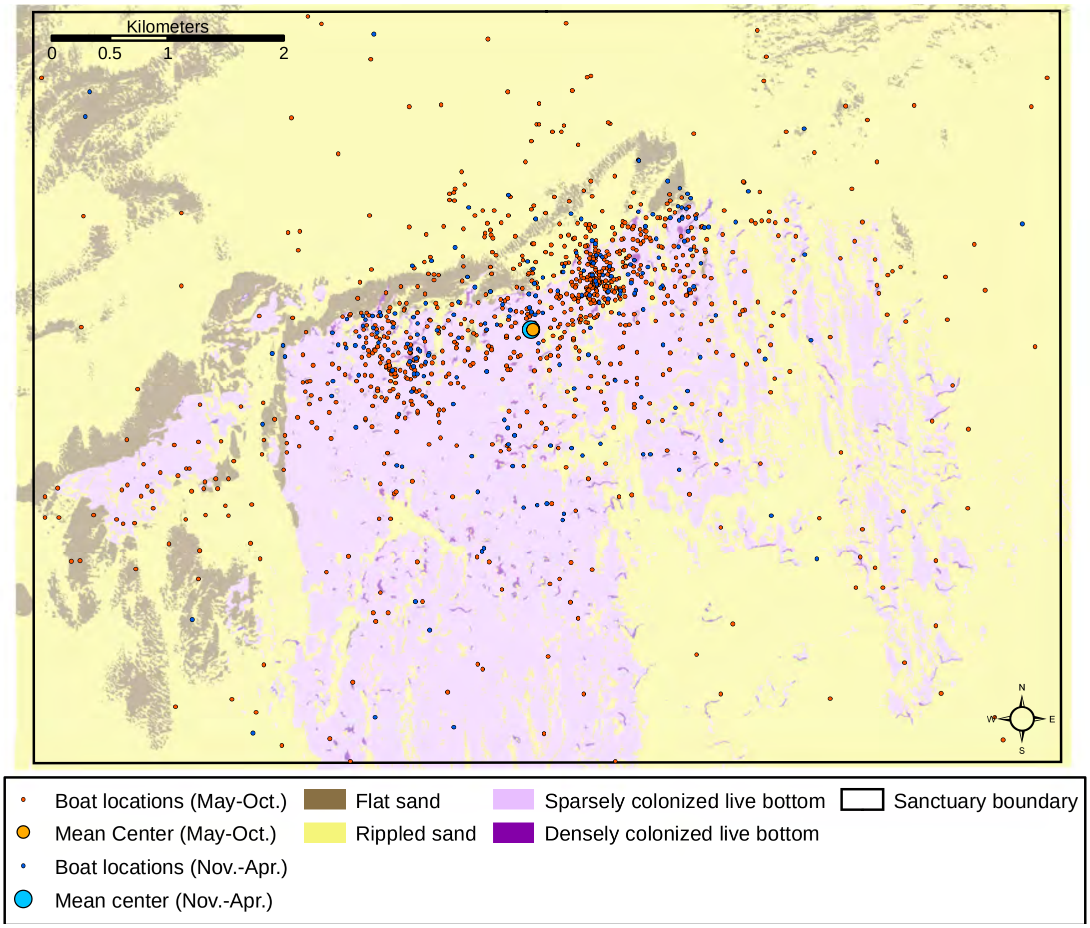


Figure 8. Geographic mean center of observed boat sightings for all years (1999-2007) by season (May-October, April-November).

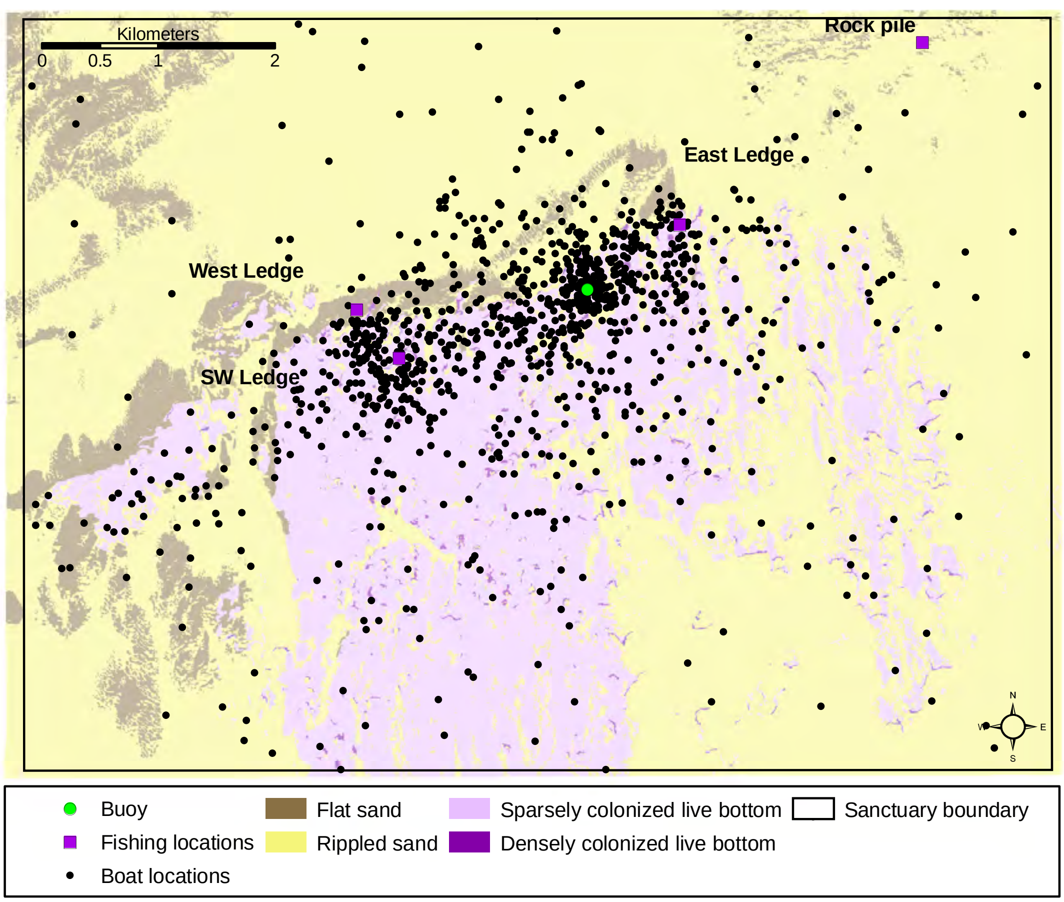
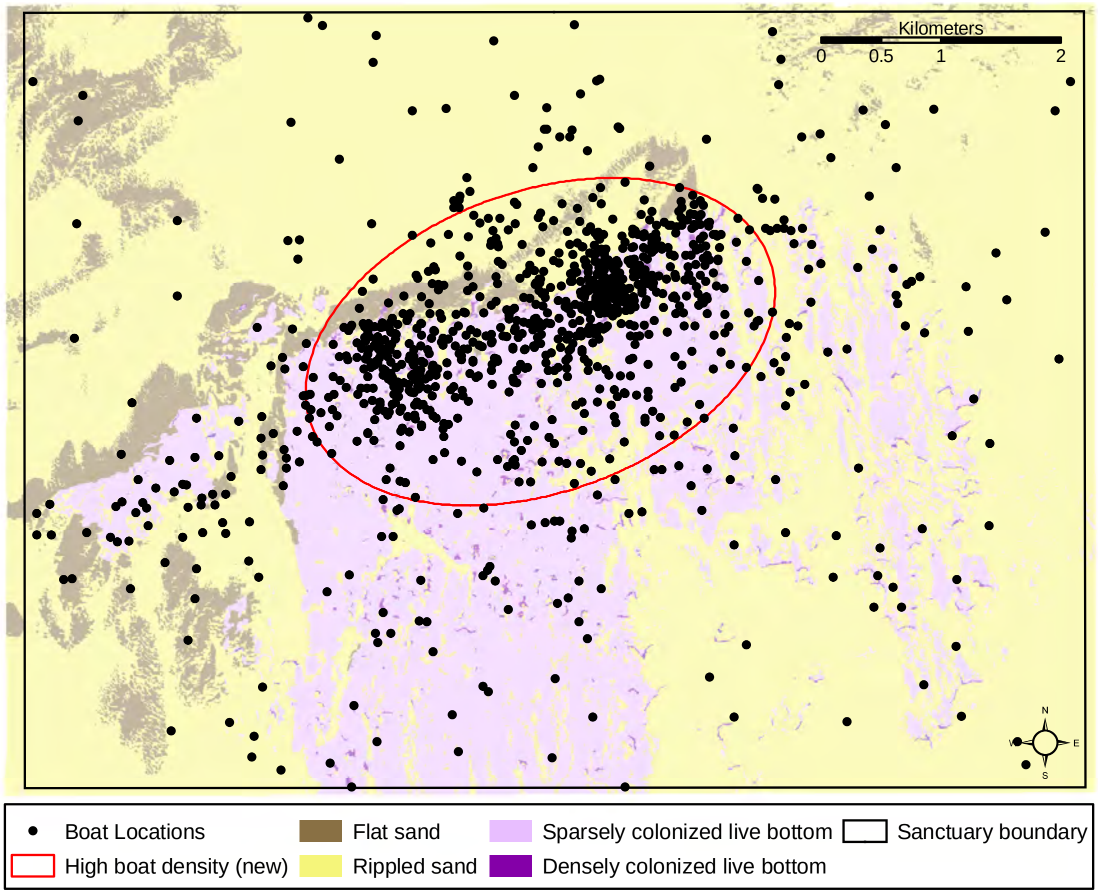


Figure 9. Spatial distribution of observed boat sightings (1999-2007) and known fishing locations.

a)



b)

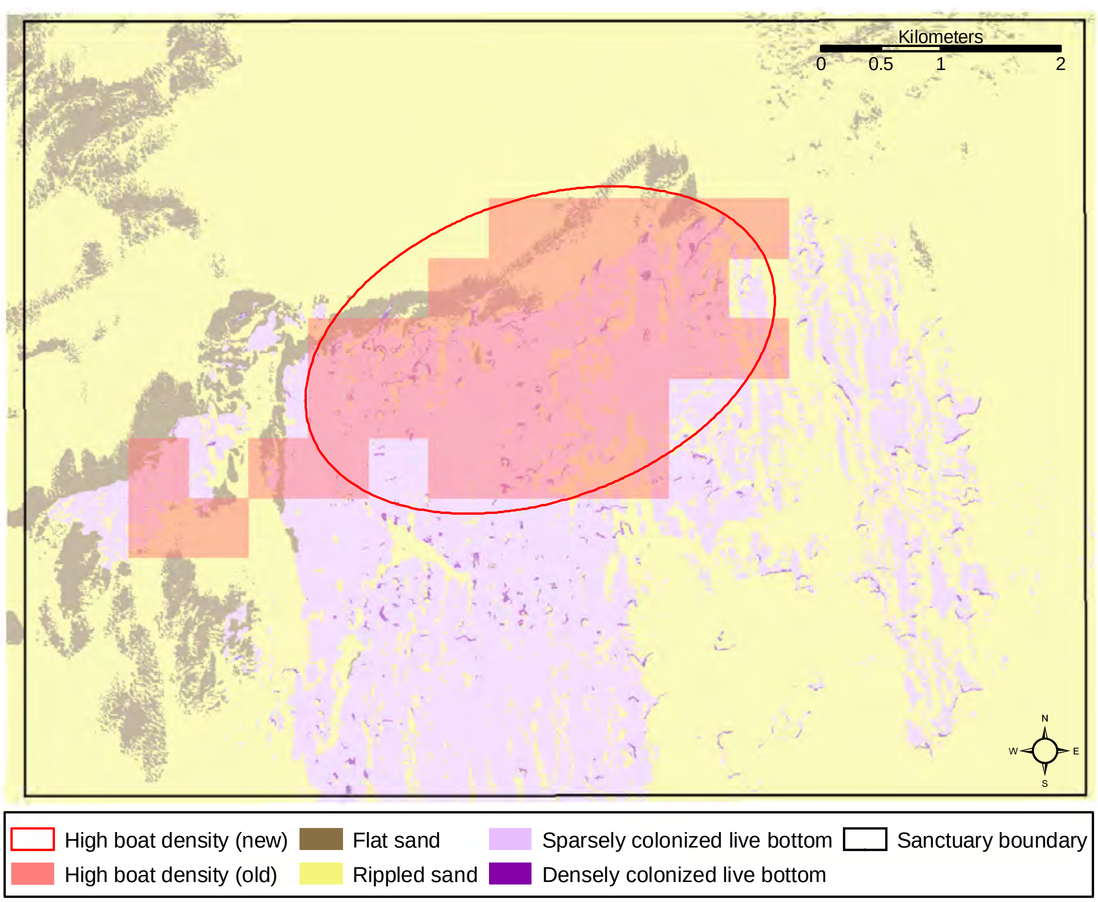


Figure 10. a) Area of high relative boat density, based on the standard deviational ellipse of the boat position data (SD=1). b) Comparison of the new revised area vs. the original gridded version (Bauer et al. 2008; Kendall et al. 2007).

Table 4. Two-part conditional model to test the effects of boat density (low, high), ledge height (cm) and ledge area (m^2) on presence and abundance, given presence, of marine debris in GRNMS. Survey data from 2004/2005 was used to construct the model (n=92). The first stage models presence-absence using logistic regression, while the second stage predicts density, given presence, with a generalized linear model with a negative binomial distribution. P-values less than 0.05 were considered to show a significant effect, and models were reduced by backward elimination to remove non-significant variables.

	Variable	Parameter Estimate	SE	Wald Chi-Square	Pr>ChiSq
Stage 1	Boat density (high vs. low)	0.834	0.27	9.56	0.002
	Ledge height	0.0259	0.0092	7.86	0.005
Stage 2	Boat density (high vs. low)	0.822	0.361	5.18	0.023
	Ledge height	0.0045	0.0022	3.96	0.047

model over-predicted abundance at some locations. This may be partly due to the differences in the way height was used in parameterization and prediction. Maximum height values measured *in situ* during the field survey, which were used to construct the model, were often lower than the maximum height of the ledge determined from sonar data, which was used to make predictions. Other factors not captured by the model, including current patterns, preferred fishing locations, and small-scale ledge morphology can also contribute to localized debris abundance. However, overall the model captured the influence of key structuring factors that are known for all ledges. The prediction map provides managers with a tool to differentially select ledges for clean-up or study where predicted debris amounts are above a certain level.

CONCLUSIONS

Despite the low year-one accumulation, new debris was found at one-third of the monitoring sites. We recommend that the permanent sites continue to be surveyed on a yearly basis to evaluate accumulation rates. Summary profiles, including a time-series of debris accumulation, were started for each ledge monitoring site and

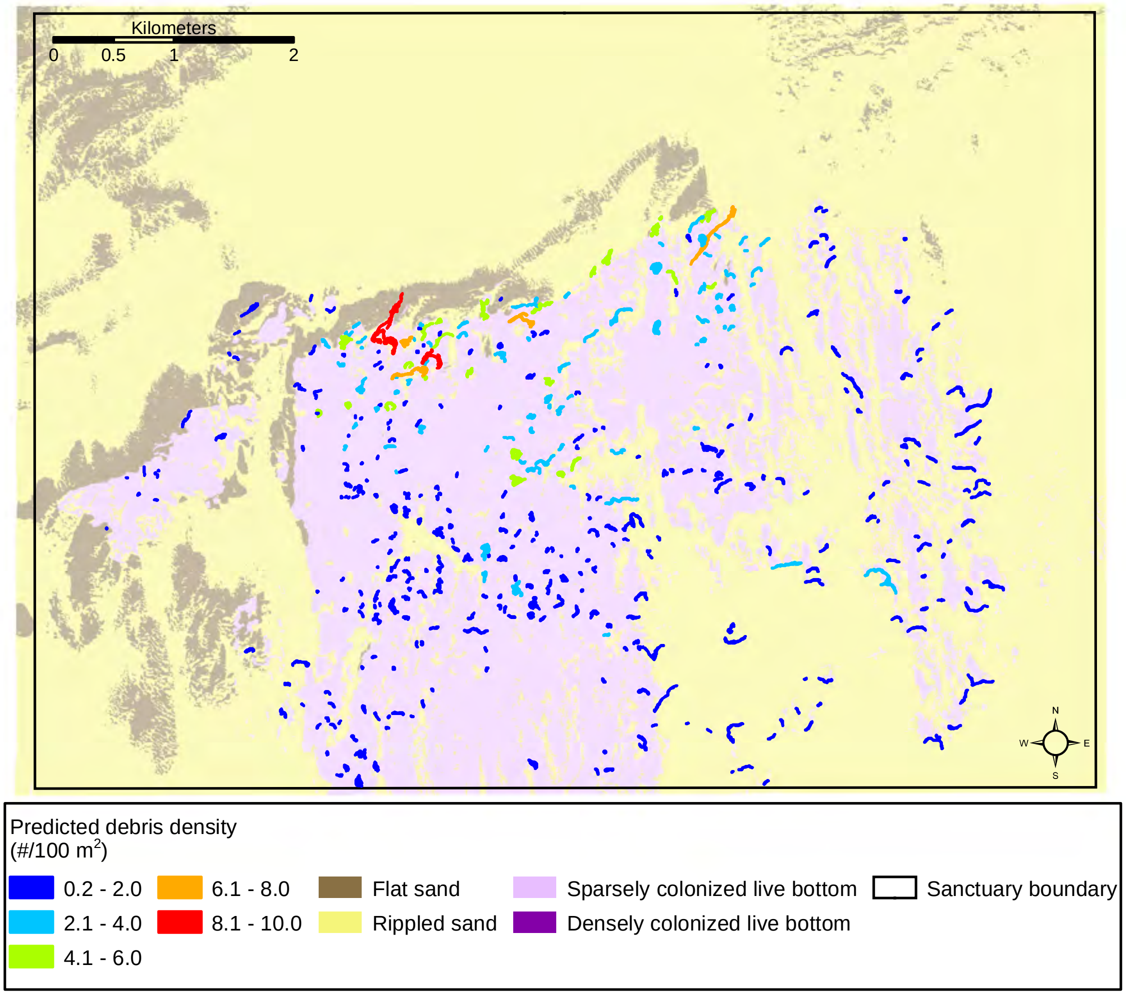


Figure 11. Predicted debris densities (#/100 m^2) for all ledges in GRNMS using the two-part conditional model.

can be filled in over time (Appendix A). Should time and resources be available, additional sites within each strata could be established to improve statistical power. Alternatively, effort could be dedicated to other high-priority removal areas. In Kendall et al. (2007), we outlined a stepwise strategy for selecting ledges where the probability of finding debris was greatest: tall, large ledges within the area of high boat use. This recommendation was reinforced by the results of the current study, as the two ledges with the highest amounts of debris fell into this category, and all debris was found on ledges within the high use area. Alternatively, the map of predicted debris density (Figure 11) can also be used to select high priority sites. We recommend that a transect still be conducted at any additional removal sites in order to quantify the area being surveyed. The 50x4 m (200 m^2) transect was generally an appropriate area that could successfully be surveyed within dive time limits when debris items need to be removed. However, for ledges that are discontinuous and difficult to follow for 50 m, a shorter transect (e.g., 25x4 m) may be more appropriate.

Image 7. Loggerhead sea turtle observed regularly at one of the monitoring sites.

A few challenges arose during the project that should be taken into consideration for future monitoring efforts. In general, ledge dimensions were similar to the estimated heights from the acoustic mapping (Kendall et al. 2005). However, there were some targeted ledges that were shorter than expected, or a continuous ledge could no longer be found, particularly those within the medium height class. When this occurred, alternate sites were chosen instead. Due to erosion, deposition and the dynamic nature of currents in the sanctuary, it is possible that shifting sands have resulted in the filling in or exposure of some ledges since the acoustic imagery was collected in 2001. Starting on the second mission, we began recording the height of the pins, which will remain part of the survey protocol in order to monitor changes in sand movement over time. In addition, periodic re-mapping of the sanctuary seafloor is recommended to revise mapped habitat areas and ledge dimensions.

Once sites were established, the biggest difficulty was re-locating the ledge and/or the pins marking the transect beginning and end. This was often compounded by challenging field conditions such as poor visibility and strong currents. For instance, there were a couple of instances where divers were carried from the target GPS location as they descended, and were either unable to locate the ledge or were on the wrong section of it. At one site, only one pin was found; if the marker is unable to be located during the next monitoring mission, a new pin should be inserted.

The revised map of predicted debris distribution at ledges marks an improvement over the previous version (Kendall et al. 2007) by incorporating factors that are significantly related to debris presence and density. Boat sighting data and information about where fishing is conducted should continue to be collected over time to monitor any changes in user patterns. As a representative hard bottom area in the Southeast Atlantic continental shelf, the methods and analytical tools employed at GRNMS can be applied to similar habitats in the region to assess patterns in marine debris.

An important component to marine debris mitigation is prevention. To this end, an additional goal of this project was to provide information to GRNMS staff to increase public awareness of both the sanctuary and marine debris through outreach and education. GRNMS staff distributed educational materials designed to encourage proper disposal of debris. Items distributed included mesh bags to store/collect trash, floatable key rings, bandanas and informational brochures about the impacts of marine debris. In addition to the volunteer divers that accompanied NOAA on the 2009 cruise, additional divers participated in the annual World Ocean's Day cleanup activities both at local beaches and in the sanctuary. Continuing these outreach efforts is crucial to reducing marine debris accumulation within the sanctuary.

ACKNOWLEDGEMENTS

Thanks to boat captain Todd Recicar and the captain and crew of the NOAA ship R/V Nancy Foster for safely getting us to and from our field sites. Mike Mullenix, Jeff Hart, and Scott Nokes assisted with collection of the field data at GRNMS. We are grateful to GRNMS staff, particularly Sarah Fangman and Becky Shortland, for logistical support and advice throughout the project. A portion of the boat positions was provided by Georgia Department of Natural Resources. Many thanks to fishermen Captain Judy Helmey and other local fishermen for sharing information about where they fish and how they find ledges. Funding for this study was provided by NOAA's Marine Debris Program.

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APPENDIX A: MONITORING SITE PROFILES

This section contains summary profiles for each monitoring site. Information provided include a ledge height profile, time series of debris accumulation by weight and density, and a summary of debris types removed by year. As new data is collected, the information sheets can be filled in to track site-specific accumulation patterns over time.

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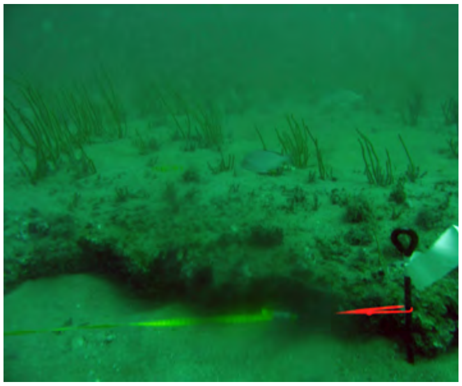
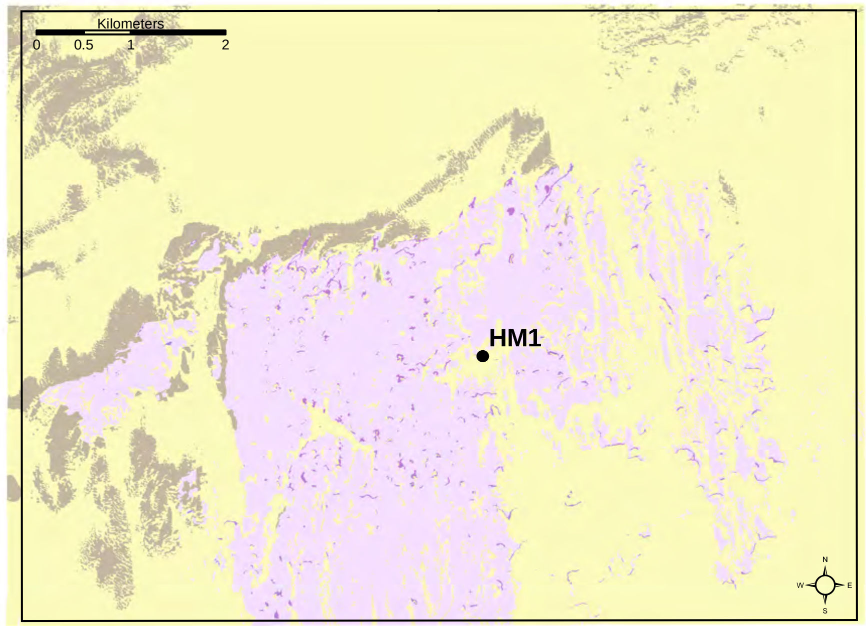
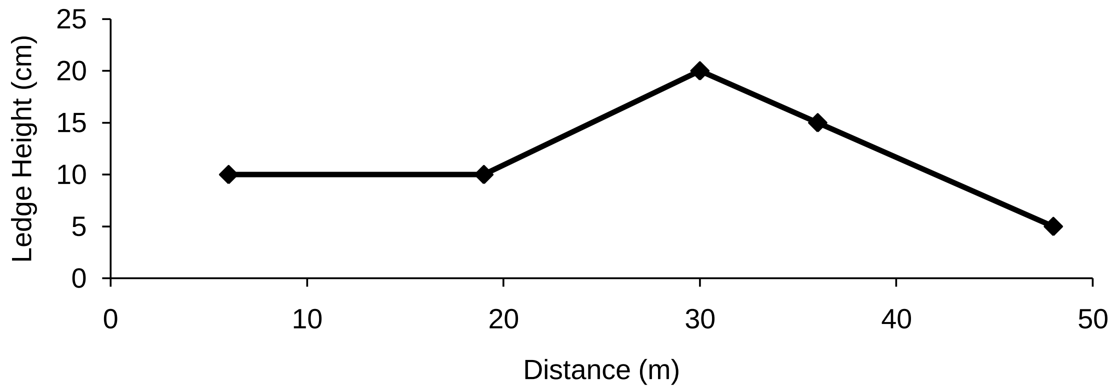
Latitude: 31.387953

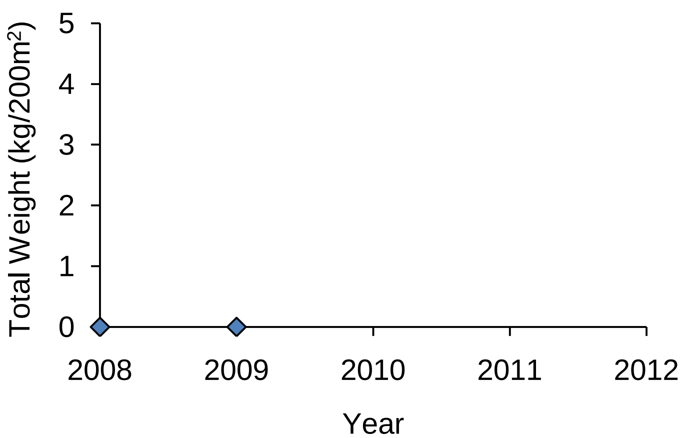


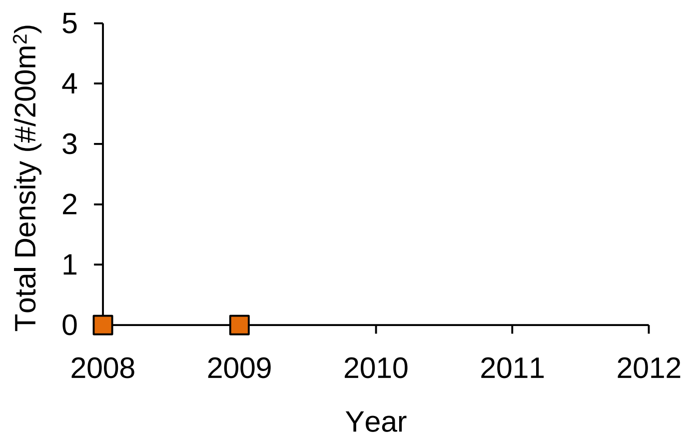


Ledge Height Profile



Time-series of debris accumulation





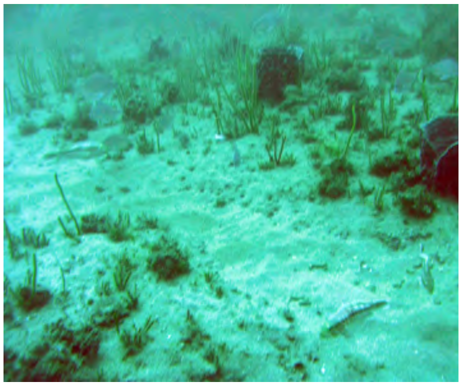
Summary of Debris Removed

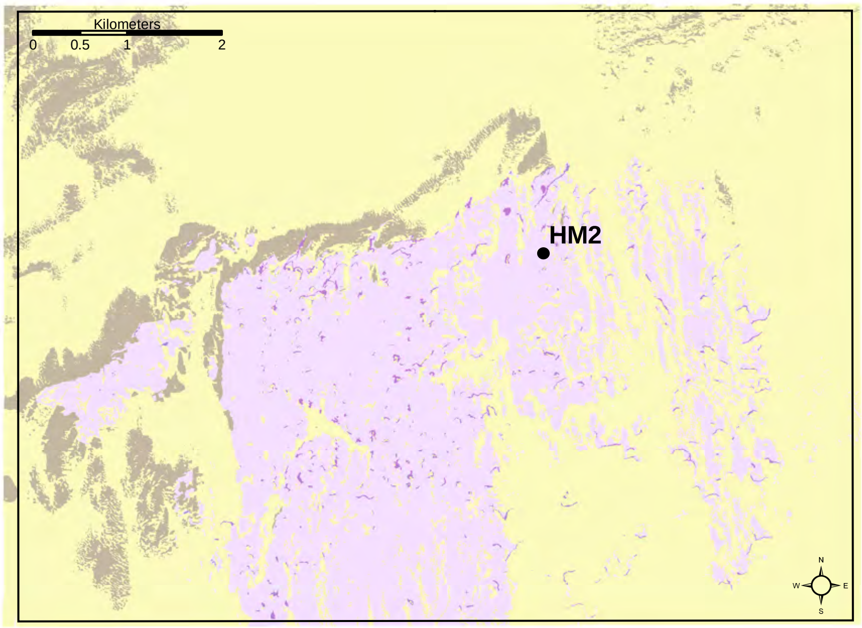
Year	Debris Type	Area (cm^2)	Entanglee	Fouling	Impacts/Notes
2008	None				
2009	None				
2010					
2011					
2012					

HM2

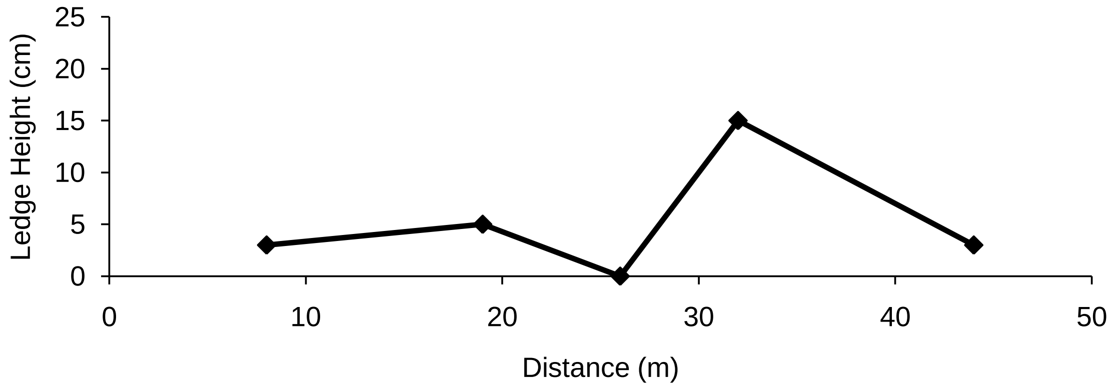
Longitude: -80.8625731

Latitude: 31.3978187

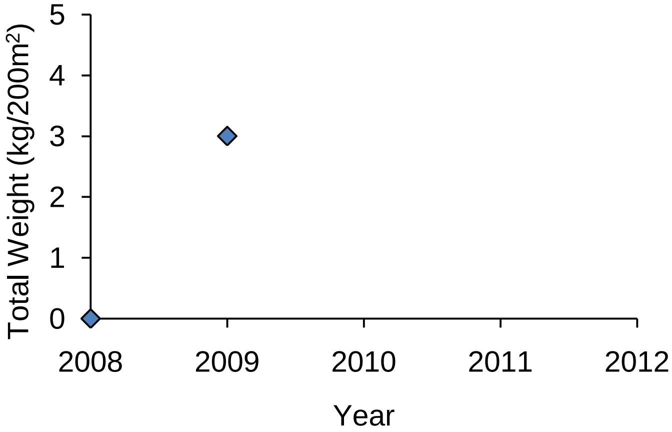


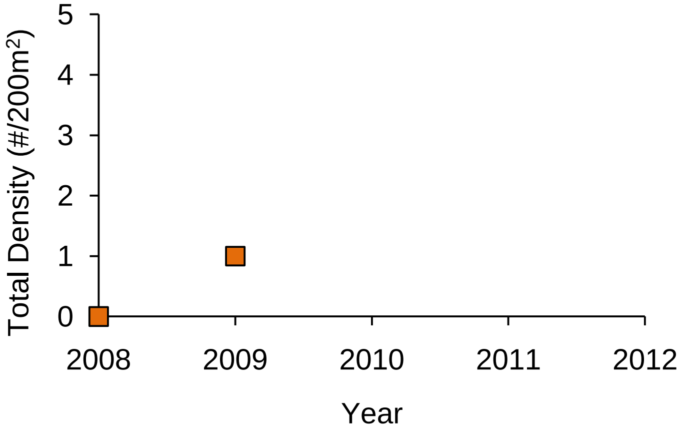


Ledge Height Profile



Time-series of debris accumulation





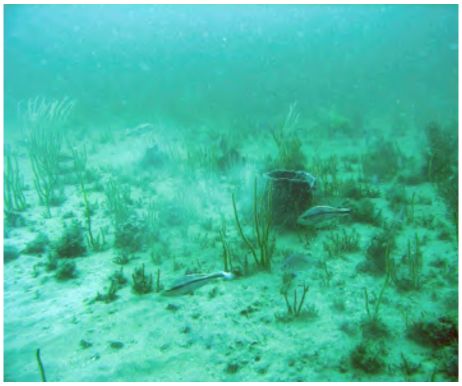
Summary of Debris Removed

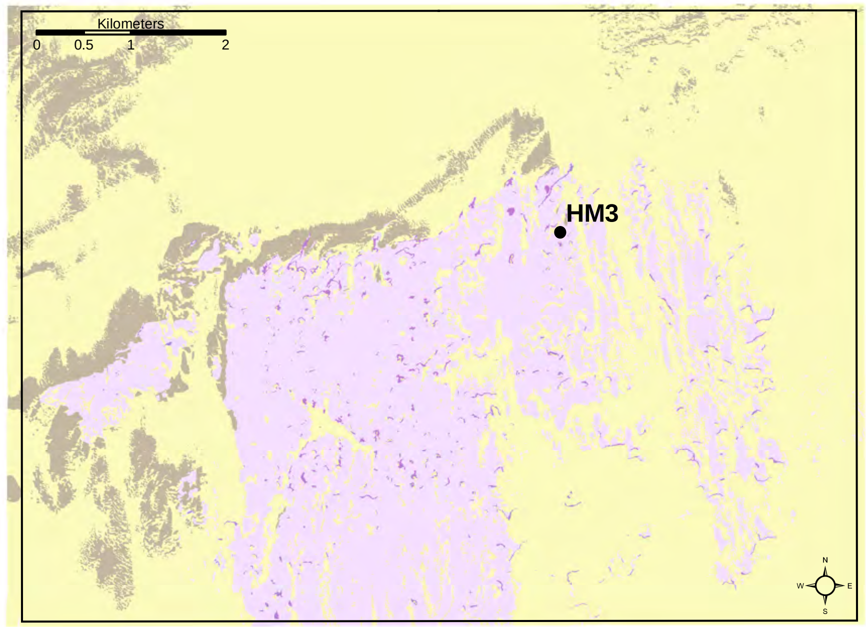
Year	Debris Type	Area (cm^2)	Entanglee	Fouling	Impacts/Notes
2008	None				
2009	Lead ball	120	None	Tunicates, algae	None observed; Item was not removed
2010					
2011					
2012					

HM3

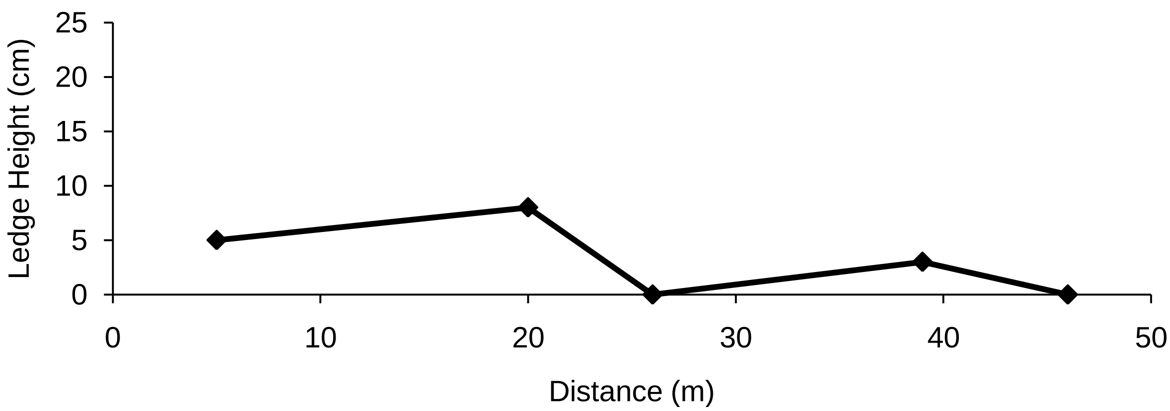
Longitude: -80.8611271

Latitude: 31.3998726

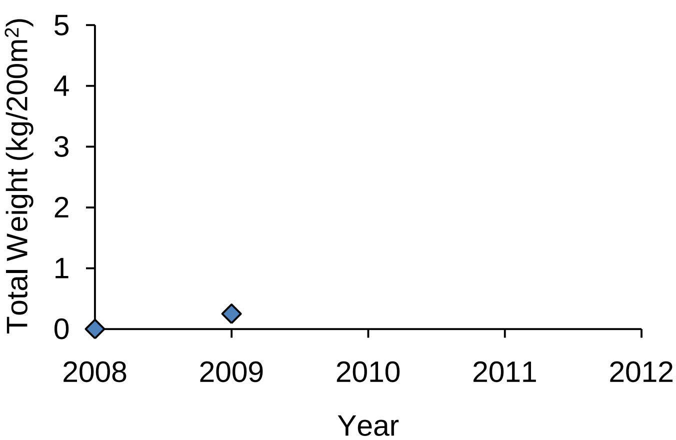


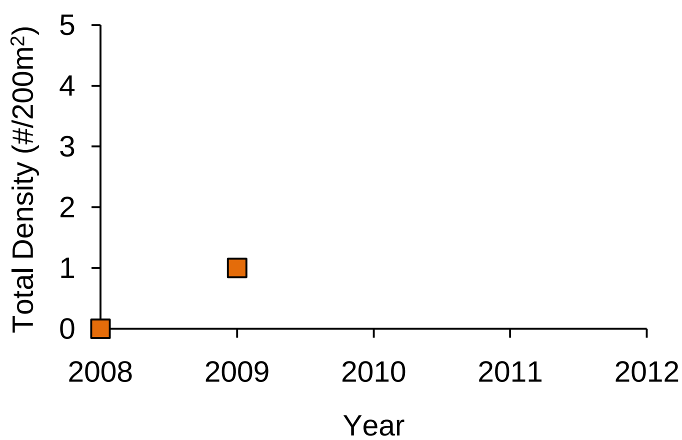


Ledge Height Profile



Time-series of debris accumulation





Summary of Debris Removed

Year	Debris Type	Area (cm^2)	Entanglee	Fouling	Impacts/Notes
2008	None				
2009	Wire	70	Substrate	Algae	None observed
2010					
2011					
2012					

HT1

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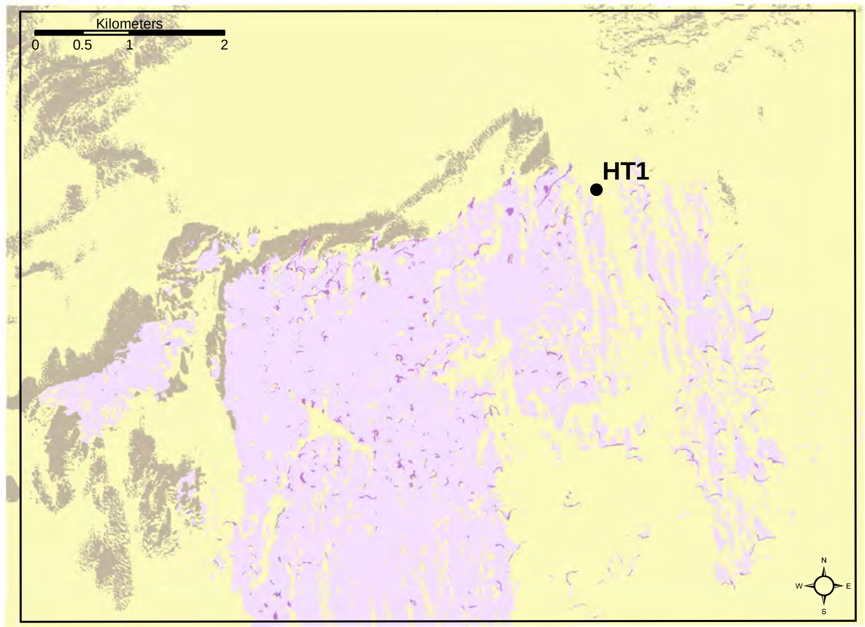
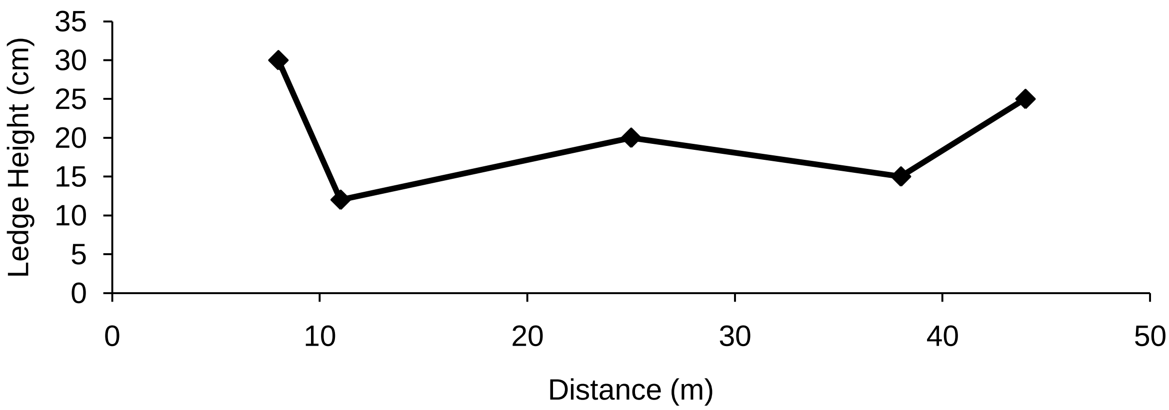
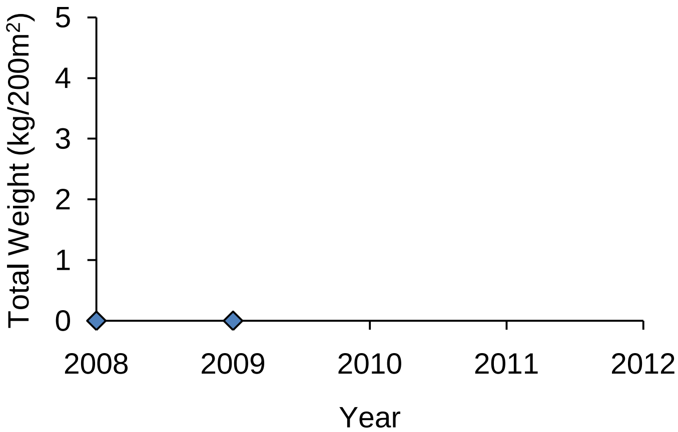
Latitude: 31.4039326

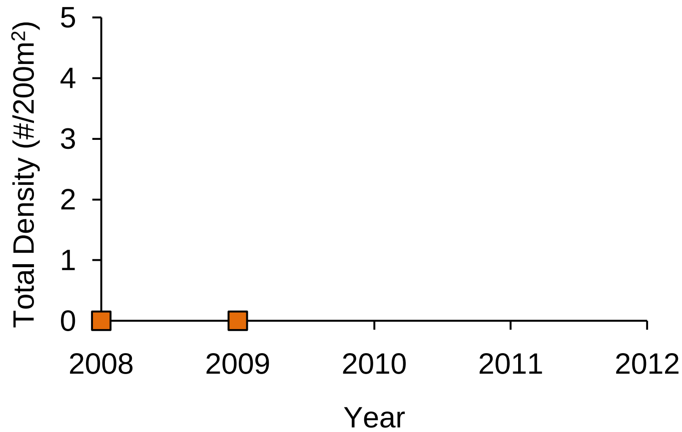


Ledge Height Profile



Time-series of debris accumulation





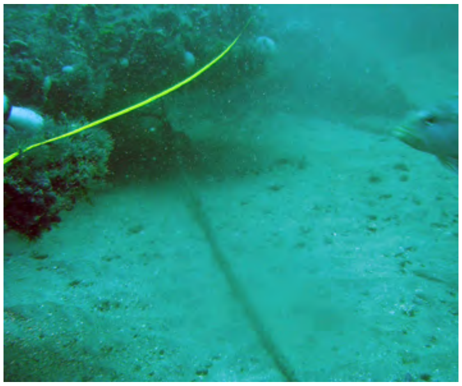
Summary of Debris Removed

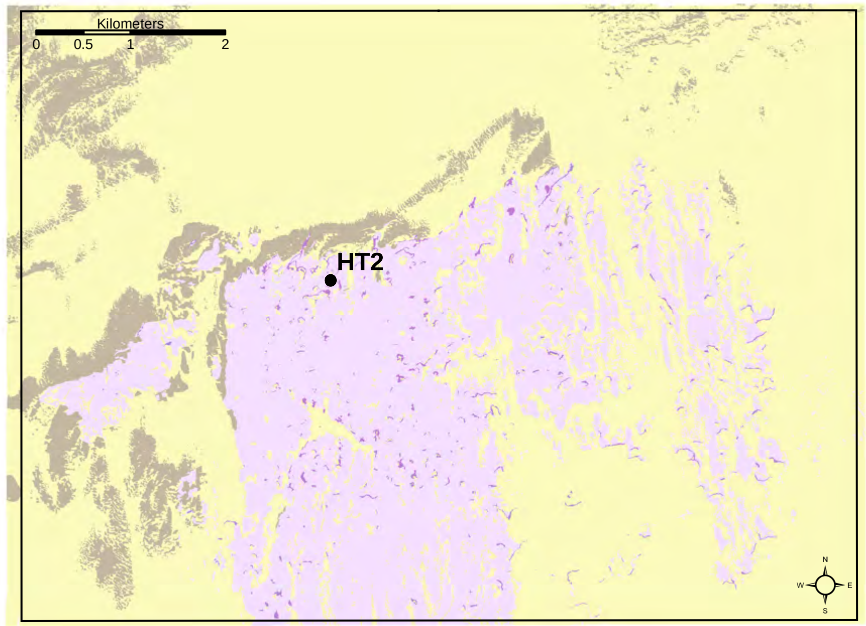
Year	Debris Type	Area (cm^2)	Entanglee	Fouling	Impacts/Notes
2008	None				
2009	None				
2010					
2011					
2012					

HT2

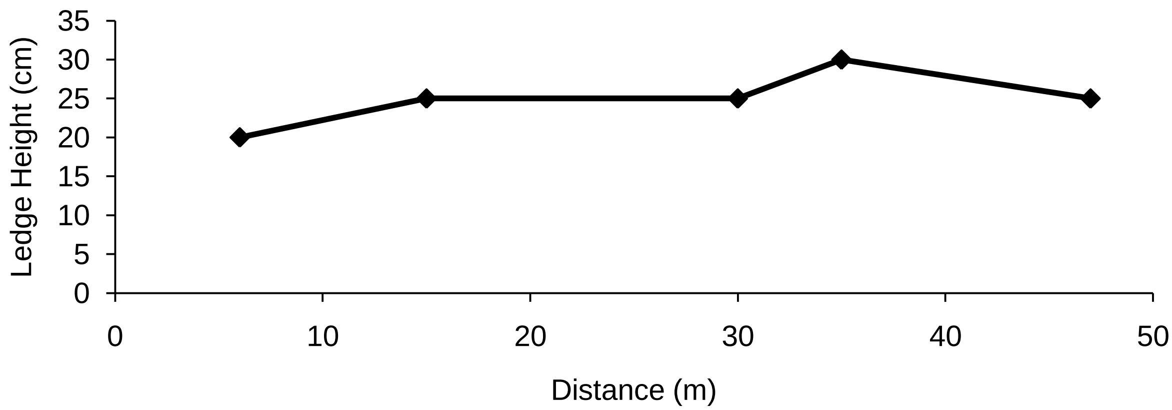
Longitude: -80.88682

Latitude: 31.395298

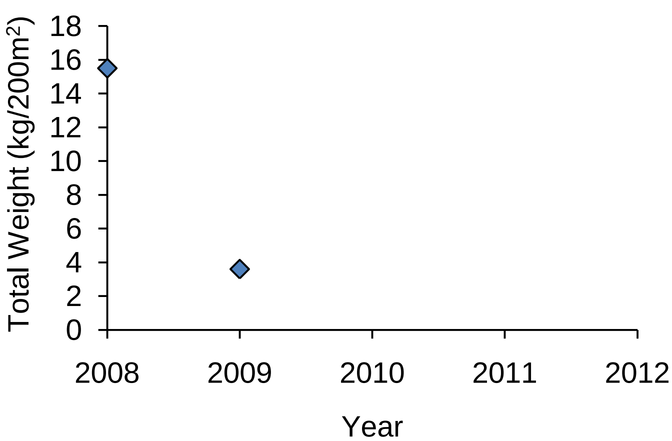


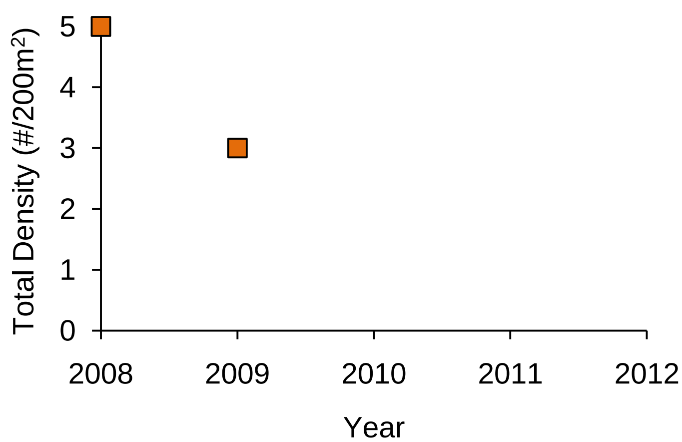


Ledge Height Profile



Time-series of debris accumulation





HT2 (Continued)

Summary of Debris Removed

Year	Debris Type	Area (cm^2)	Entanglee	Fouling	Impacts/Notes
2008	Rope	112000	Oculina, substrate	Oculina. sponges, barnacles, tunicates, algae	None observed; item was heavily colonized
	Wire w/ window sash weight	700	Substrate	Sponges, tunicates, algae	None observed
	Lead line	300	Substrate	Barnacles, tunicates, algae	None observed
	Wire leader	2500	Substrate	Tunicates, algae	None observed
	Wire leader	2500	Substrate	Tunicates, algae	None observed
2009	Wire leader	100	Oculina	Barnacles, sponges, tunicates, algae	None observed, but entangled in coral
	Rope w/ lead weights	30000	None	Barnacles, sponges, tunicates, mollusks, tube worms, algae	None observed
	Rope w/ lead weights	5000	Substrate	Oculina, barnacles, sponges, tunicates, calcareous algae, turf algae	None observed
2010					
2011					
2012					

HT3

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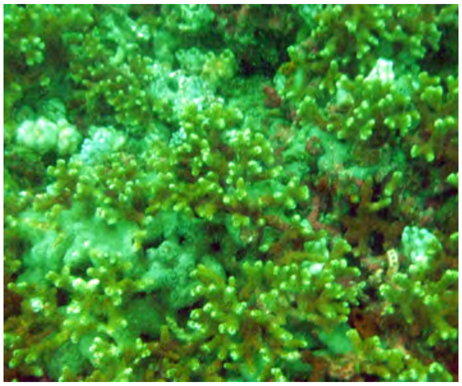
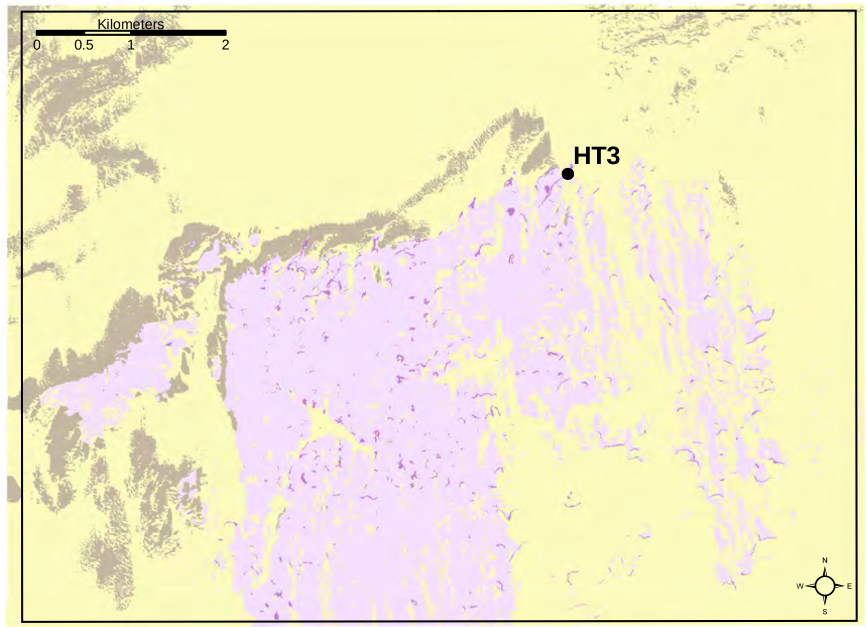
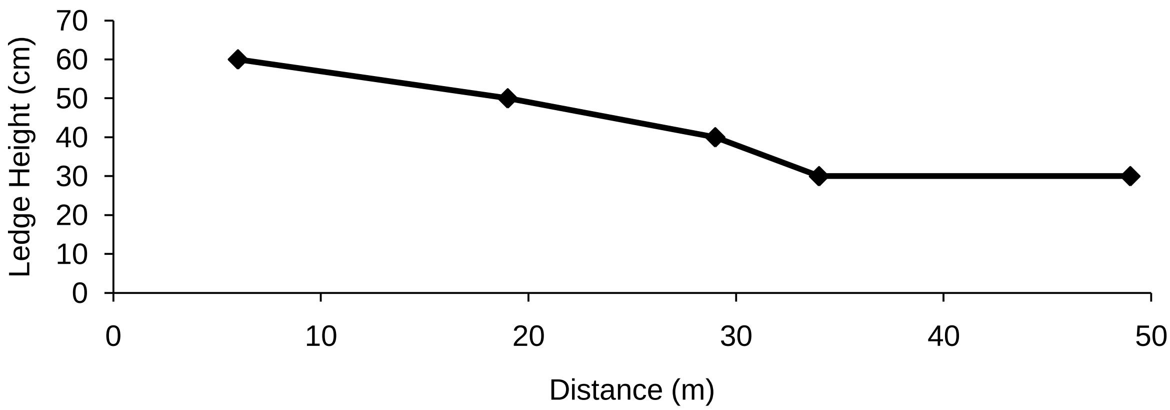
Latitude: 31.4054308

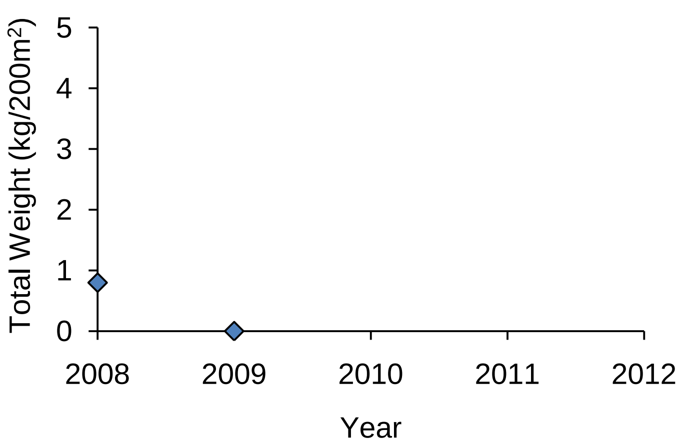


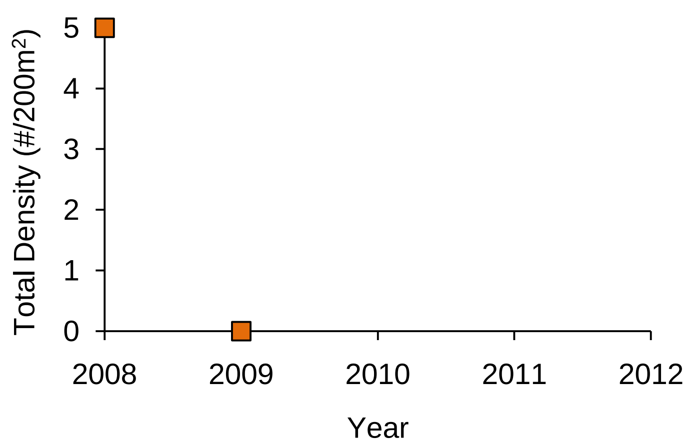


Ledge Height Profile



Time-series of debris accumulation





HT3 (Continued)

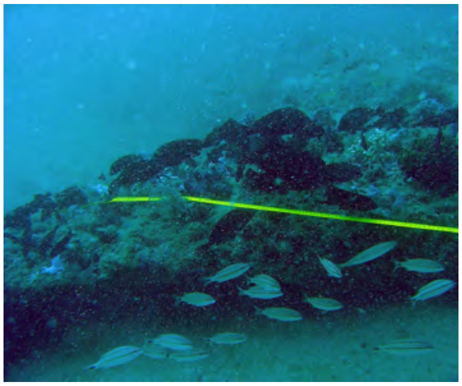
Summary of Debris Removed

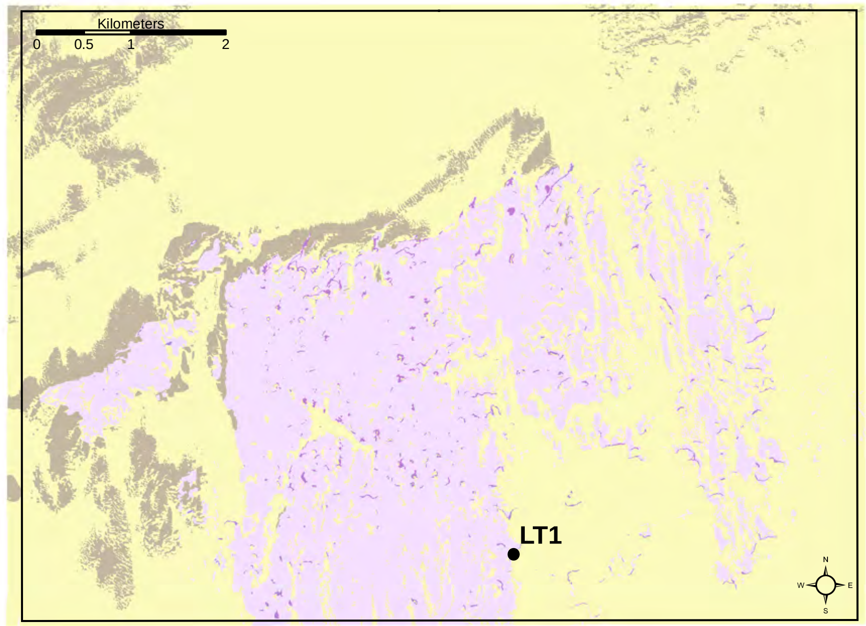
Year	Debris Type	Area (cm^2)	Entanglee	Fouling	Impacts/Notes
2008	Hook and wire	30	Substrate	Algae	None observed
	Wire	60	None	Algae	None observed
	Fabric	150	Oculina	Tunicates	Resting on top of dead Oculina
	Plastic	120	None	Algae	None observed
	Plastic	180	None	Barnacles, tunicates, mollusks, gorgonians, tube worms, algae	None observed
2009					
2010					
2011					
2012					

LT1

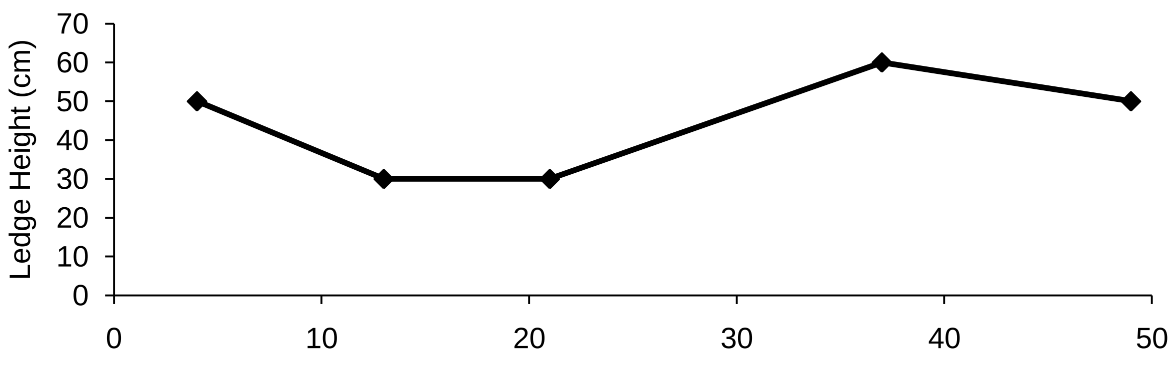
Longitude: -80.8663893

Latitude: 31.3690415

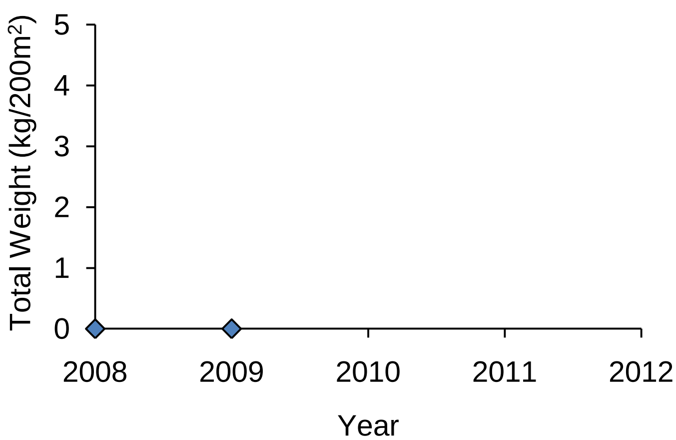


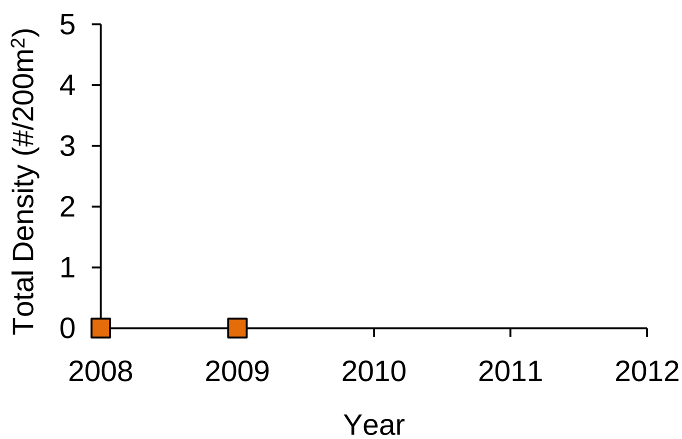


Ledge Height Profile



Time-series of debris accumulation





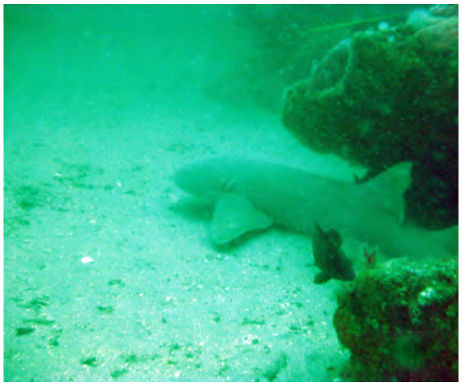
Summary of Debris Removed

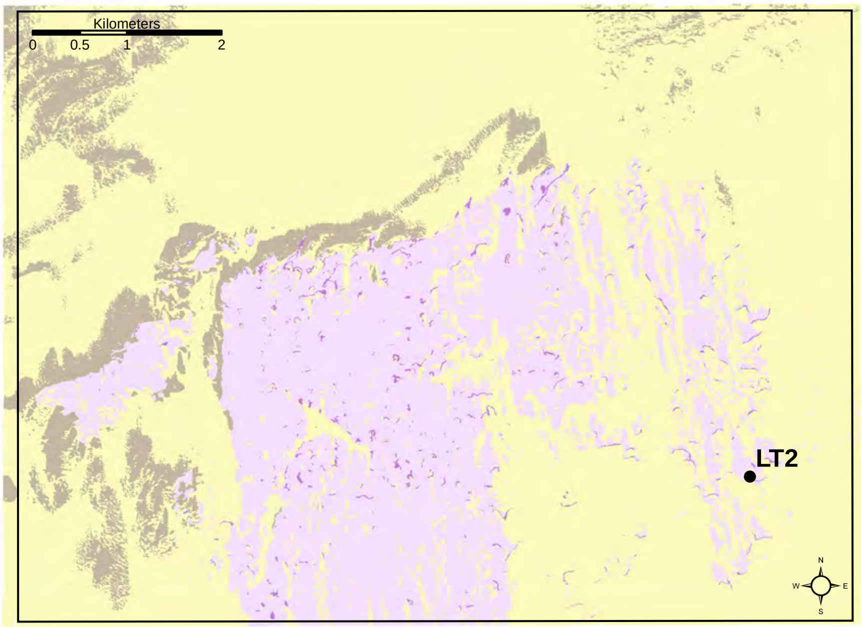
Year	Debris Type	Area (cm^2)	Entanglee	Fouling	Impacts/Notes
2008	None				
2009	None				
2010					
2011					
2012					

LT2

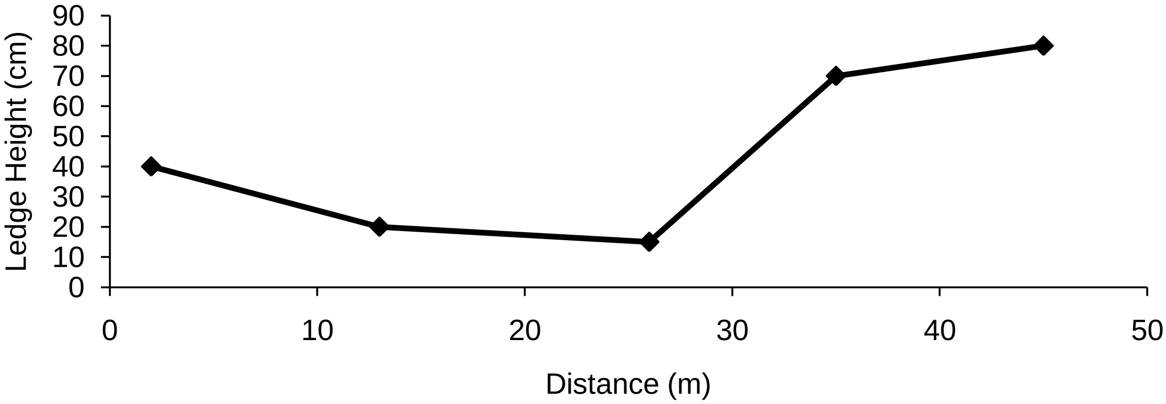
Longitude: -80.8395354

Latitude: 31.3764615

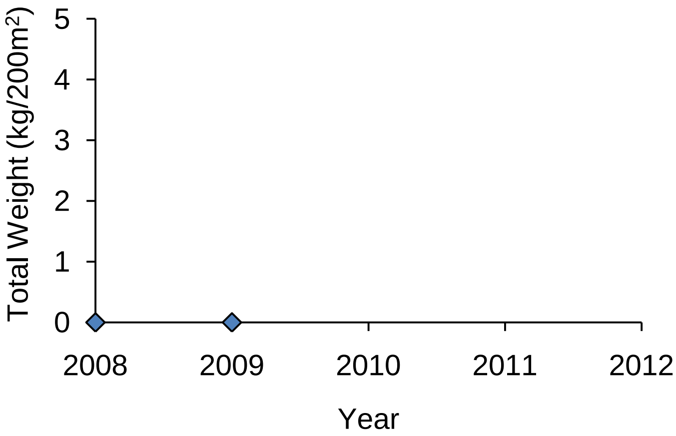


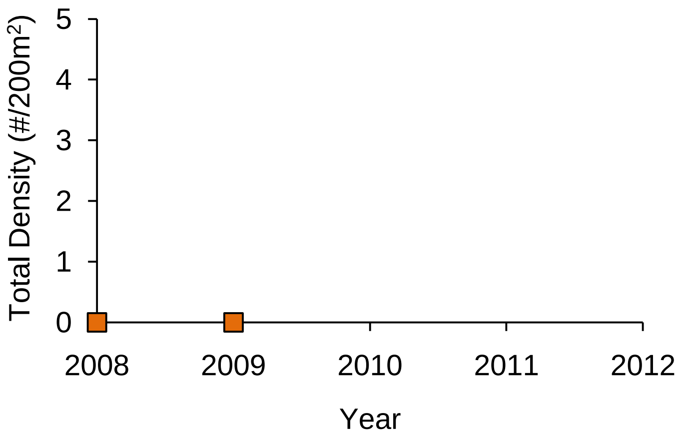


Ledge Height Profile



Time-series of debris accumulation





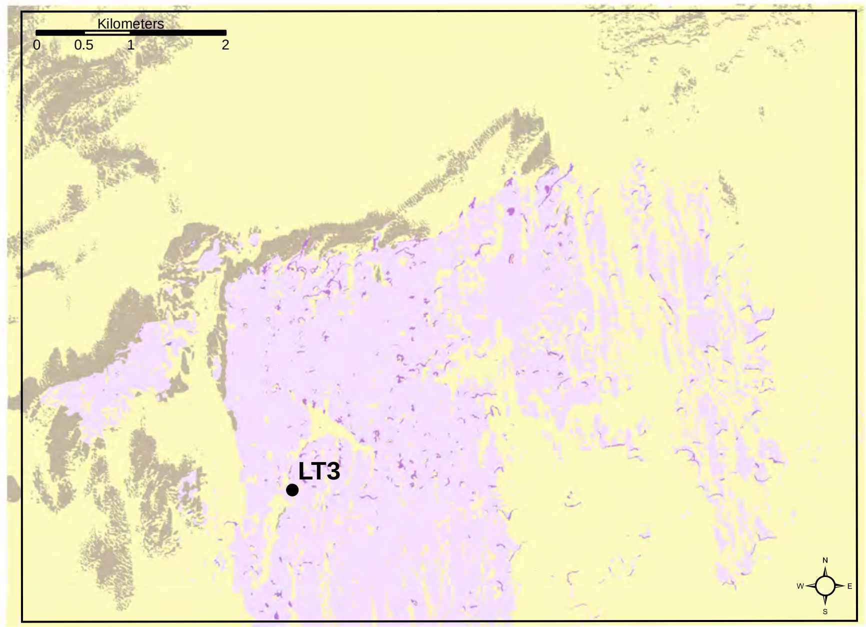
Summary of Debris Removed

Year	Debris Type	Area (cm^2)	Entanglee	Fouling	Impacts/Notes
2008	None				
2009	None				
2010					
2011					
2012					

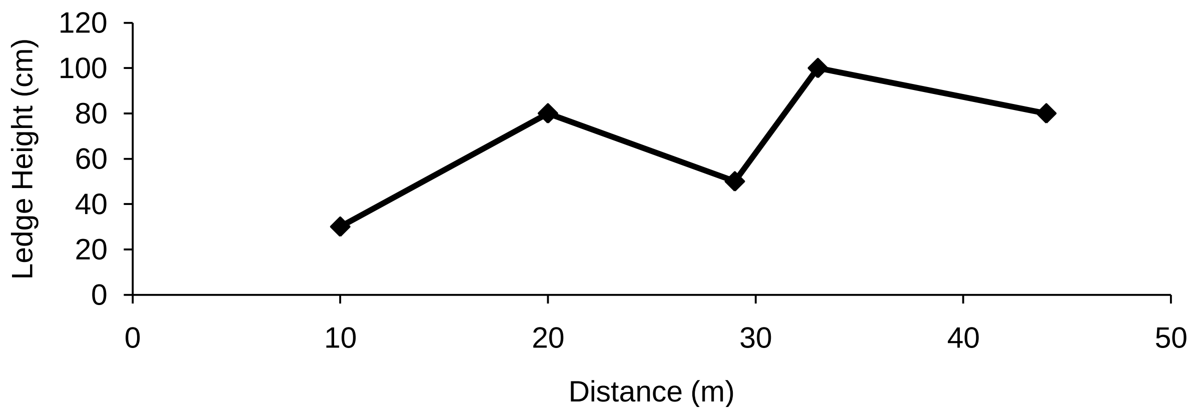
LT3

Longitude: -80.8910095

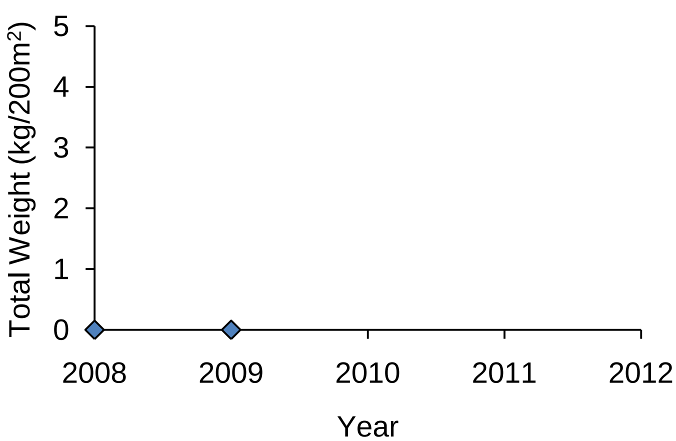
Latitude: 31.375283

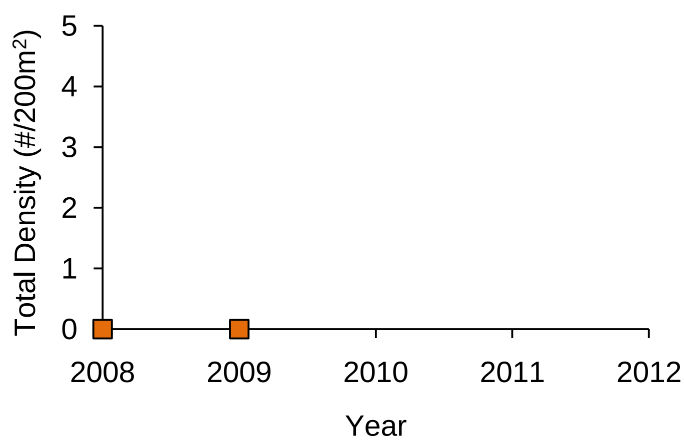


Ledge Height Profile



Time-series of debris accumulation





Summary of Debris Removed

Year	Debris Type	Area (cm^2)	Entanglee	Fouling	Impacts/Notes
2008	None				
2009	None				
2010					
2011					
2012					

APPENDIX B: SURVEY INSTRUCTIONS FOR MARINE DEBRIS MONITORING IN GRNMS

OBJECTIVE

To monitor nine long term monitoring sites within Gray's Reef National Marine Sanctuary to characterize the types, abundance, and accumulation rates of marine debris within the sanctuary. Ledge sites were selected to compare debris metrics between regions with differing relative use (low, high) and among ledge height classes (tall, medium). Nine sites were initially marked and surveyed in September 2007 and May 2008; these sites were revisited during June 2009. Subsequent monitoring should take place at approximately the same time on an annual basis. This will require a minimum of nine dives although additional dives may be needed to survey complex or heavily fouled sites, or if any sites need to be re-marked. Dive time is expected to be ~30 minutes per site.

SURVEY SITES

See attached map (Figure B.1) and table (Table B.1) for site locations. A data sheet is provided for each monitoring site. The following abbreviations are used:

HT= High boat use area, Tall
HM = High boat use area, Medium height
LT = Low boat use area, Tall

METHODOLOGY

The boat captain will navigate to the survey sites using a hand held GPS unit. Once on site, two divers will be deployed and will maintain contact with one another throughout the entire census. The GPS location is generally located 2-4 m away from the lip of the ledge in the sand, rather than on top of the ledge itself. On each data sheet, there is information on which direction the ledge should be located if it is not visible once the divers descend.

The survey will be conducted within a 50 x 4 m transect for a total survey area of 200 m^2. Previously, sites were marked on either end of the 50 m transect using sand anchors. Once on bottom, divers will find the first ground anchor, which marks the beginning of the survey. Once the first pin is located, refer to the data sheet for instructions on the survey compass bearing. One diver will tie off the transect tape to the first anchor and string it along the ledge in the specified direction, using the curve of the ledge as a guide (Figure A.2). At ~50m, the divers should encounter the second pin, which marks the end of the transect.

Divers will quantify and remove debris from 2 m on either side of the ledge lip, using the tape measure as a guide. All debris will be photographed and removed (unless the size of the object would render it unsafe to do so) and detailed information will be taken on the types of debris, quantity, and associations with benthic fauna. Information on associations with benthic fauna include degree of entanglement, type of organism with which it is entangled or resting on, degree of fouling, and visible impacts such as tissue abrasions. In addition, the following ledge characteristics will be measured at each location where debris is found: ledge height, undercut width, and undercut height. A photo will be taken of each debris item at 1 m height to later approximate the percent cover. Commercial gear such as pots and fishing nets are not allowed in the sanctuary and are not expected to be found. However, in the rare event that a diver should come upon a heavy item that cannot be safely removed, they will note it on the datasheet, leave it in place, and report it to sanctuary management.

The debris removed from each site should be kept in separate buckets/bags with the site name and weighed upon return to shore. Total debris weight will be recorded on the data sheet for each site.

Materials to bring on boat:

- Sand anchors, for use in case any anchors need to be replaced (some w/ ends cut on angle in case they need to be hammered into the substrate, typically they are screwed into the substrate)
- Hammer
- Mesh bags
- PVC pole w/ measured increments (1 m total length, 10 cm increments)
- Buckets (2-3)

Table B.1. GPS coordinates (decimal degrees) of monitoring site locations.

Site ID	Longitude	Latitude
HM1	-80.869749	31.387953
HM2	-80.862573	31.397819
HM3	-80.861127	31.399873
HT1	-80.856932	31.403933
HT2	-80.886675	31.395251
HT3	-80.860281	31.405431
LT1	-80.866389	31.369041
LT2	-80.839535	31.376462
LT3	-80.891009	31.375283

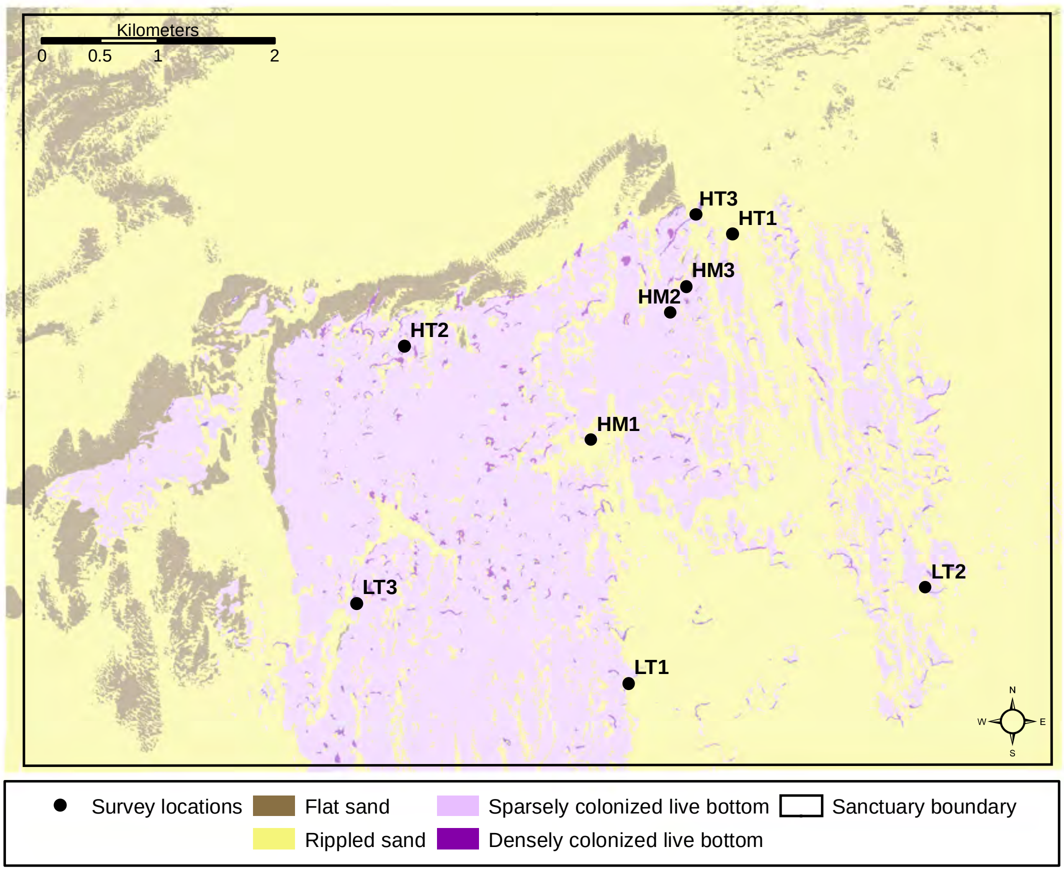


Figure B.1. Location of permanent marine debris monitoring sites.

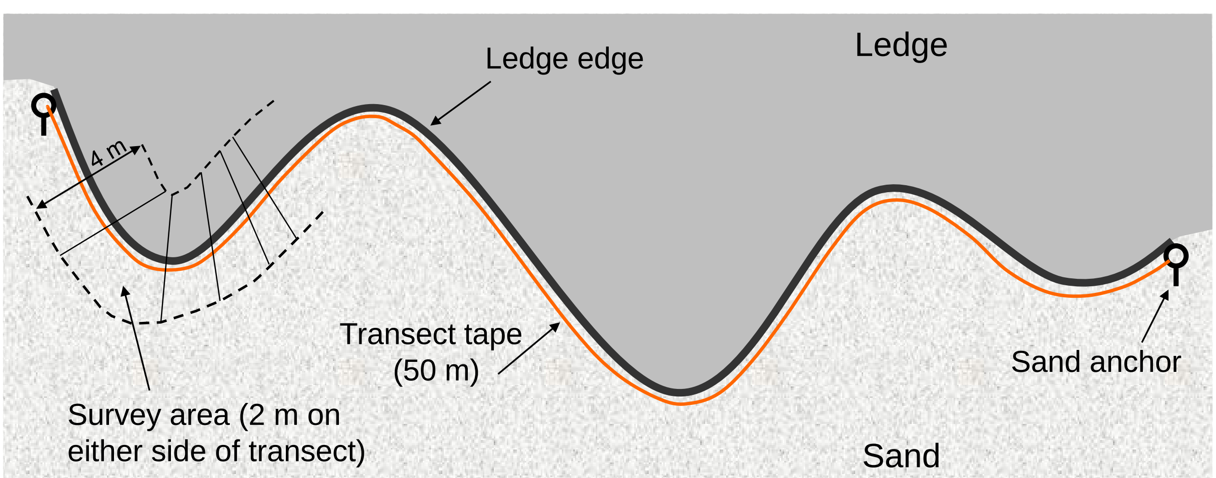
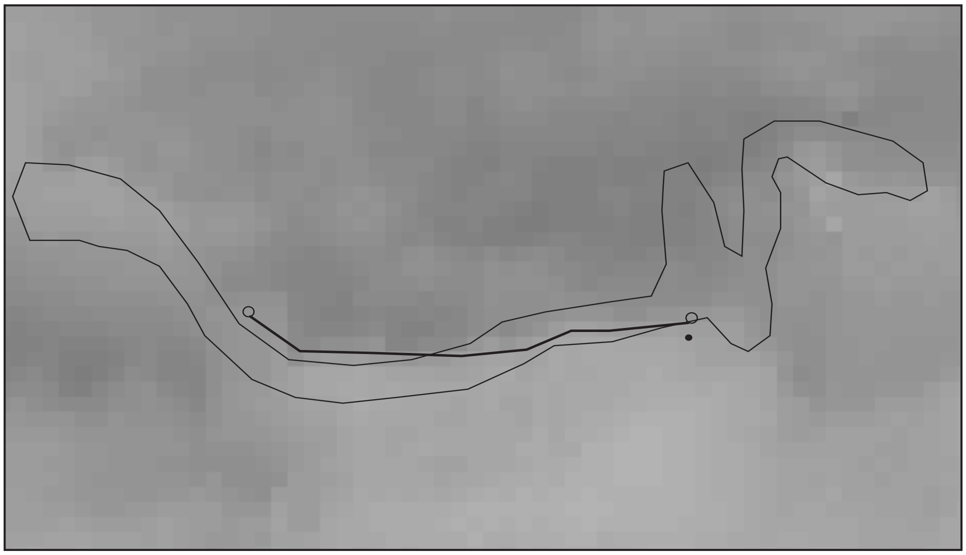


Figure B.2. Schematic of how survey transect should be placed along the edge of a ledge.

Station	HM1
Date	
Time	
Longitude	-80.869749
Latitude	31.387953
Diver #1	
Diver #2	

Number debris items	
Total debris weight	
height of pin (cm) - 1	
height of pin (cm) - 2	



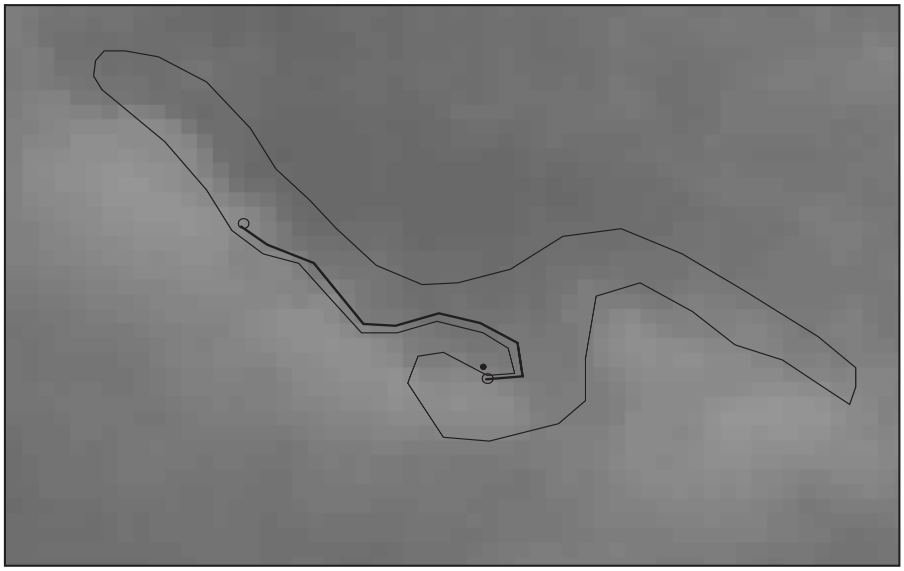
Site info:
Directions to site: swim 2-4 m north to ledge
Surevy bearing: Turn left (West)
Approx. depth: 19m (62 ft)

Debris type	Distance	Area (cm^2)	Entanglee	Impacts?	Fouling?	Ledge hgt	Und. Wth	Und hgt.	% cover

Notes

Station	HM2
Date	
Time	
Longitude	-80.8625731
Latitude	31.3978187
Diver #1	
Diver #2	

Number debris items	
Total debris weight	
height of pin (cm) - 1	
height of pin (cm) - 2	



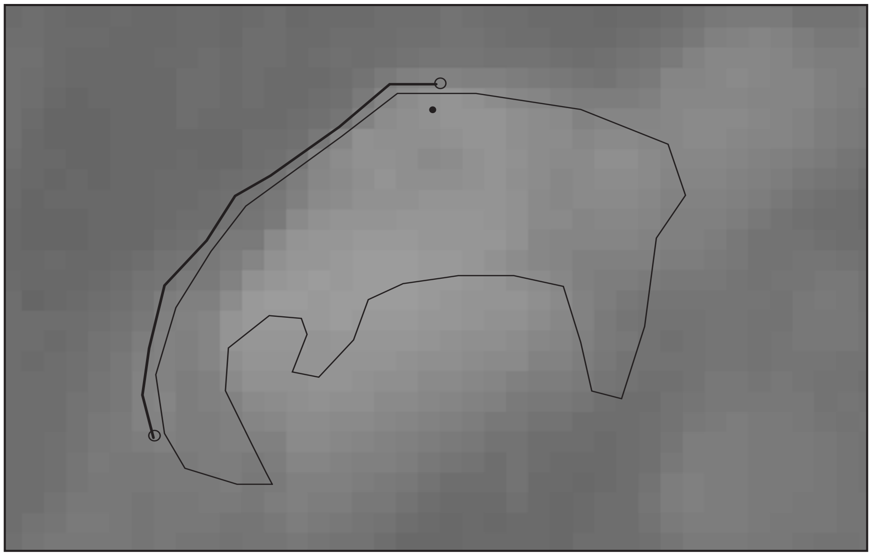
Site info:
Directions to site: swim 2-4 meters S-SE
Survey bearing: Turn left (west, then NW)
Approx depth: 18 m (59 ft)

Debris type	Distance	Area (cm^2)	Entanglee	Impacts?	Fouling?	Ledge hgt	Und. Wth	Und hgt.	% cover

Notes
Smallish for a medium-height ledge, has obviously been filled in with sand

Station	HM3
Date	
Time	
Longitude	-80.8611271
Latitude	31.3998726
Diver #1	
Diver #2	

Number debris items	
Total debris weight	
height of pin (cm) - 1	
height of pin (cm) - 2	



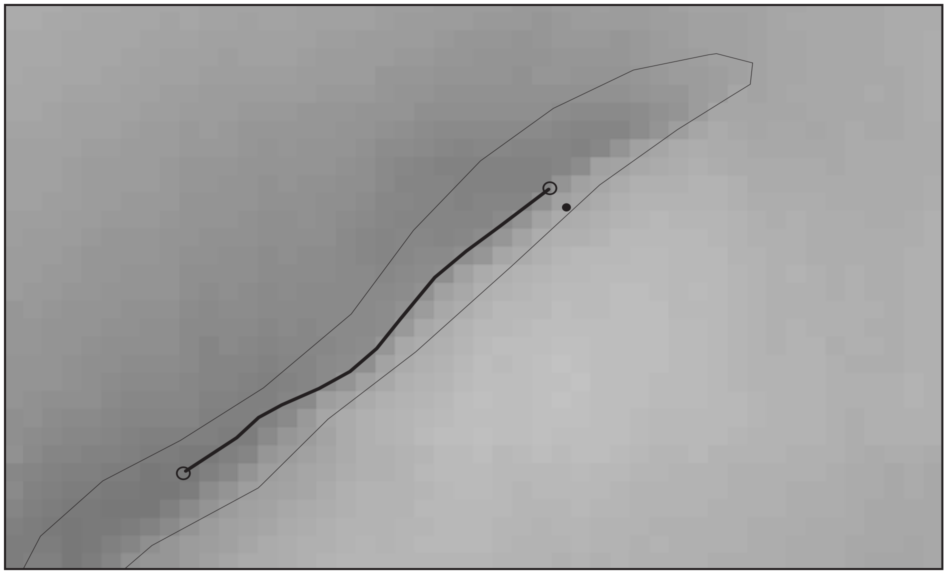
Site info:
Directions to site: swim 2-4 meters north to ledge
Survey bearing: Turn left (west-SW)
Approx depth: 18 m (59 ft)

Debris type	Distance	Area (cm^2)	Entanglee	Impacts?	Fouling?	Ledge hgt	Und. Wth	Und hgt.	% cover

Notes
small ledge, interdispersed with sand patches

Station	HT1
Date	
Time	
Longitude	-80.8569318
Latitude	31.4039326
Diver #1	
Diver #2	

Number debris items	
Total debris weight	
height of pin (cm) - 1	
height of pin (cm) - 2	



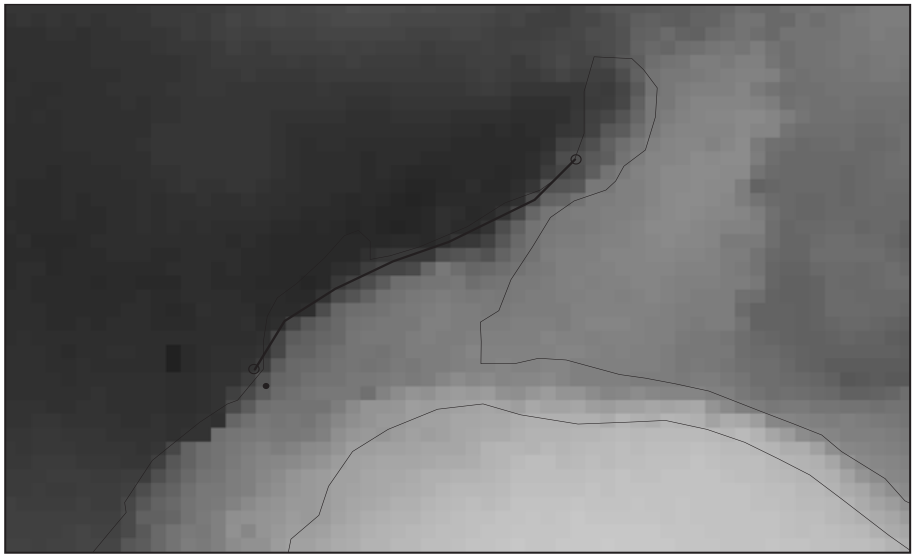
Site info:
Directions to site: swim 2-4 meters W-NW to ledge
Survey bearing: Turn left (S-SW)
Approx depth: 18-19 m (59-62 ft)

Debris type	Distance	Area (cm^2)	Entanglee	Impacts?	Fouling?	Ledge hgt	Und. Wth	Und hgt.	% cover

Notes
shorter than expected

Station	HT2
Date	
Time	
Longitude	-80.88682
Latitude	31.395298
Diver #1	
Diver #2	

Number debris items	
Total debris weight	
height of pin (cm) - 1	
height of pin (cm) - 2	

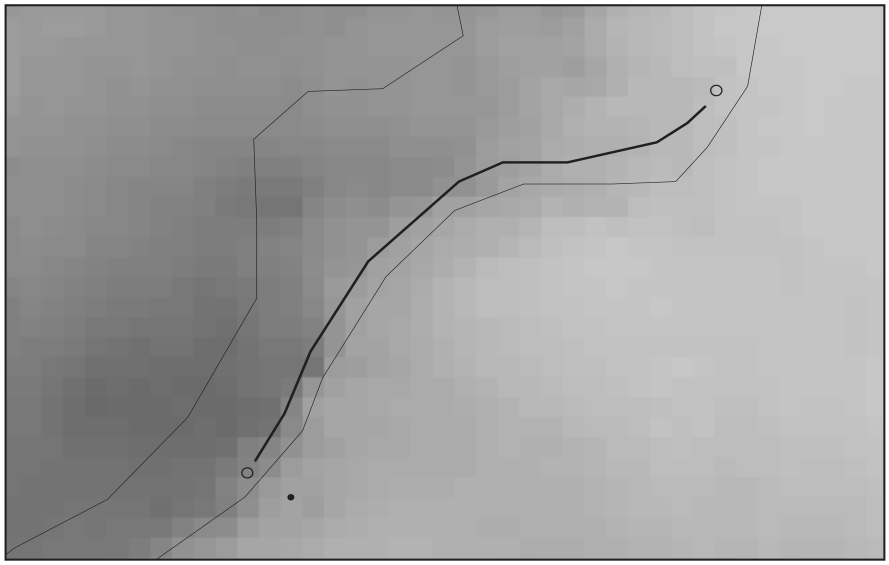


Site info:
Directions to site: swim 2-4 meters W-NW to ledge
Survey bearing: Turn right (N-NE)
Approx depth: 17-18 m (56-59 ft)

Debris type	Distance	Area (cm^2)	Entanglee	Impacts?	Fouling?	Ledge hgt	Und. Wth	Und hgt.	% cover

Notes
nice ledge

Station	HT3
Date	
Time	
Longitude	-80.8602809
Latitude	31.4054308
Diver #1	
Diver #2	



Number debris items	
Total debris weight	
height of pin (cm) - 1	
height of pin (cm) - 2	

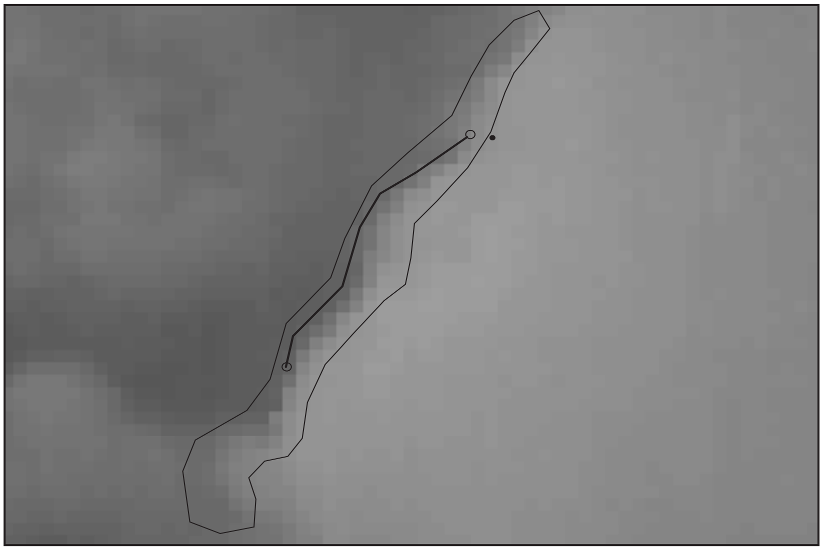
Site info:
Directions to site: swim 2-4 meters West-NW to ledge
Survey bearing: Turn right (NE)
Approx depth: 18-19 m (59-62 ft)

Debris type	Distance	Area (cm^2)	Entanglee	Impacts?	Fouling?	Ledge hgt	Und. Wth	Und hgt.	% cover

Notes
Site marked in September 2007- gap of sand at 35-45 m.

Station	LT1
Date	
Time	
Longitude	-80.8663893
Latitude	31.3690415
Diver #1	
Diver #2	

Number debris items	
Total debris weight	
height of pin (cm) - 1	
height of pin (cm) - 2	



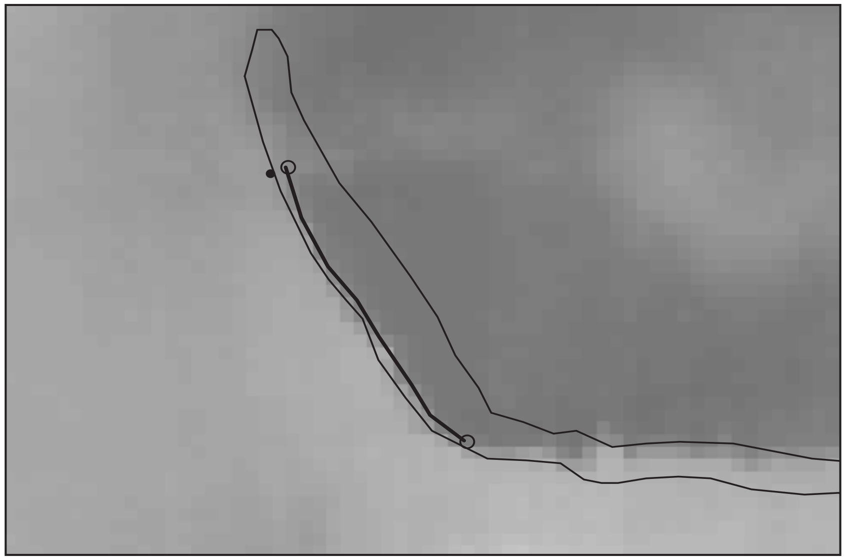
Site info:
Directions to site: swim 2-4 meters west to ledge
Survey bearing: Turn left (S-SW)
Approx depth: 18-19 m (59-62 ft)

Debris type	Distance	Area (cm^2)	Entanglee	Impacts?	Fouling?	Ledge hgt	Und. Wth	Und hgt.	% cover

Notes
Site marked an initially surveyed in September 2007, *pins not found in May 2008*; diffciulty finding ledge/pins in June 2009. New second pin inserted on 6/13/09

Station	LT2
Date	
Time	
Longitude	-80.8395354
Latitude	31.3764615
Diver #1	
Diver #2	

Number debris items	
Total debris weight	
height of pin (cm) - 1	
height of pin (cm) - 2	



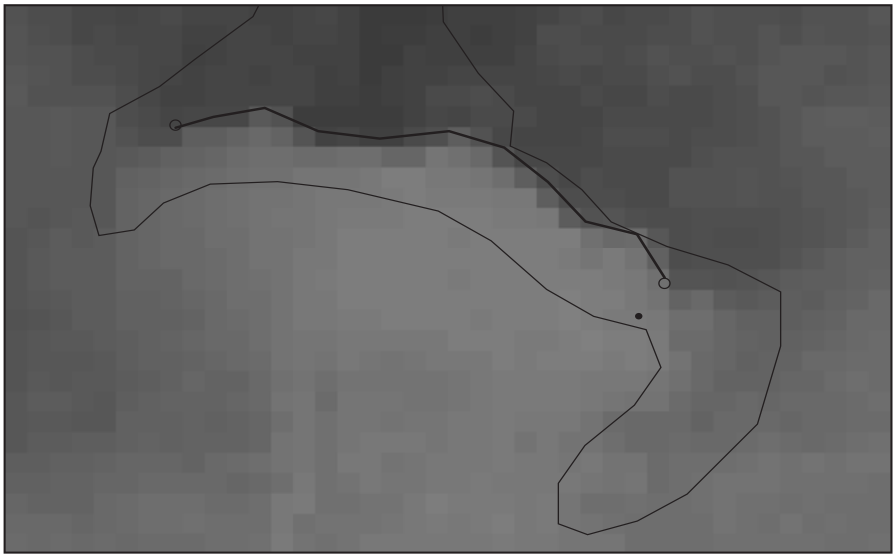
Site info:
Directions to site: swim 2-4 meters east to ledge
Survey bearing: Turn right (south)
Approx depth: 18-19 m (59-62 ft)

Debris type	Distance	Area (cm^2)	Entanglee	Impacts?	Fouling?	Ledge hgt	Und. Wth	Und hgt.	% cover

Notes
Site marked and initially surveyd in September 2007

Station	LT3
Date	
Time	
Longitude	-80.8910095
Latitude	31.375283
Diver #1	
Diver #2	

Number debris items	
Total debris weight	
height of pin (cm) - 1	
height of pin (cm) - 2	



Site info:
Directions to site: swim 2-4 meters N-NE to ledge
Survey bearing: Turn left (W-NW)
Approx depth: 18-19 m (59-62 ft)

Debris type	Distance	Area (cm^2)	Entanglee	Impacts?	Fouling?	Ledge hgt	Und. Wth	Und hgt.	% cover

Notes

Site marked and initially surveyed in September 2007- many curves (alternating concave and convex)

United States Department of Commerce

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Under Secretary of Commerce for Oceans and Atmopsheres

National Ocean Service

David Kennedy
Acting Assistant Administrator