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ENVIRONMENTAL IMPACTS OF THE 1990 BAL HARBOR BEACH RENOURISHMENT PROJECT: Mechanical and Sedimentation Impact on Hard-Bottom Areas Adjacent to the Borrow Area

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ENVIRONMENTAL IMPACTS OF THE 1990 BAL HARBOR BEACH RENOURISHMENT PROJECT: MECHANICAL AND SEDIMENTATION IMPACT ON HARD-BOTTOM AREAS ADJACENT TO THE BORROW AREA

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SUMMARY

Two modes of impact to hard-bottom reef areas occurred during the 1990 Bal Harbor renourishment project: mechanical fracturing and destruction of hard coral and benthic organisms caused by the dredging equipment making contact with the reef, and sedimentation impact resulting from the release of fine sediments from the dredge during the dredging operation.

The mechanical impact was the lesser of the two impacts relative to the area, and number of organisms involved. The impact was caused by the drag heads of the hopper barge "Atlantic American" being pulled up onto the reef. The area of mechanical impacted was found to be within the defined limits of the borrow area. Eight tracts of impact were identified, representing four to six incidences of contact of the drag heads with the reef. A total area of 105.85 m^2 of hard bottom reef were impacted, within which 85.3 m^2 were destroyed (all benthic organisms removed from the bottom). An estimated 155 hard corals, and an undetermined number of soft corals, sponges, algae, cryptic invertebrates and fish were destroyed by the impact.

Sedimentation impacted a total area of 24.7 acres (100,157 m^2) on two reef sites. The sites were located and north (site DLN) and south (site DLS) of the northern region of the borrow area. The sediment accumulation on the reefs was 0.5 to 12 cm above normal levels. The northern (site DLN) had approximately twice the level of sediment as the southern (site DLS), with the sediment depth commonly ranging between 6 and 8 cm on the reef at DLN site and 3 to 5 cm on the DLS site. Elevated sediment levels were estimated to occur on the reef as far as 360 m from the edge of the reef at DLN and 260 m from the reef's edge on DLS.

The data for the hard coral impact along the assessed transects (i.e., positioned at 20, 40 and 80 m from the reef edge) within the sedimentation zone showed that 61.1 to 78.1% of the colonies on the

reef at DLS were impacted (showed some tissue loss). The coral colonies on DLS had an average tissue loss of between 47.5 and 66.2%. The reef at DLN showed 35.7 to 88.9% of the hard corals had been impacted with an average tissue loss of between 24.0 and 85.3%. The lower values for the DLN site (35.7% of colonies impacted with a 24.0% tissue loss) were at the most distant transect (160 m). For equivalent areas (within 80 m of the reef's edge), the impact was greater on DLN than on DLS (83.3 to 88.9% impacted with 73.0 to 85.35% tissue loss on DLN versus 61.1 to 79.0% impacted with 47.5 to 66.2% tissue loss on DLS).

Assessment of the sediment impact to the hard corals showed the heaviest impact occurred on the 100 meters of reef closest to the borrow area. Within the entire area assessed for hard coral damage (i.e., 7.7 acres) slightly more than half (53.5 %) of the hard coral colonies were killed. The total loss of hard coral cover within the area assessed was 114.81 m^2. This area, given the average size of a coral colony in the region, is equivalent to a loss of 18,279 hard coral colonies.

Impacts to soft coral, sponges, cryptic invertebrates benthic and encrusting algae were also documented but not quantified. Impacts ranged from burial and subsequent death of encrusting and low lying sponges, algae and cryptic invertebrates. The impact to soft corals resulted in death of the lower portions of the colony through burial by accumulated sediment. This area will serve as a colonization site for epiphytic and epizoic organisms, some of which may further aggravate the impact to the soft corals.

Recent measurements of sediment levels indicate that the sediment is shifting around or moving off the reef areas. The shifting of the sediment will result in the exclusion of a portion of the reef from recovery through long term burial of previously exposed reef surface.

Recovery time for the impacted area is not known. The recovery will be affected by current regime of the area, storm events, future impacts and is specific to the group of organisms under consideration. As it is likely that future impacts (natural and human related) will occur, and in consideration of the present degradation of coastal water quality as a result of human activities, it is reasonable to assume that the reef will not recover to pre-impact conditions. It is probable, however, that the reef will recover to a point that will allow it to function as a productive resource that will provide necessary habitat for coastal reef associated organisms. The recovery may be expedited by a reef restoration project that focuses on the enhancement of the organisms requiring the greatest recovery time (e.g., hard and soft corals).

It is believed that the impact occurred through a combination of factors related to the quality of the material being dredged, the criteria used for predicting probable impact and the proximity of the reef to the borrow area. Recommendations for preventing similar impacts in the future include: select or develop an alternative sediment impact predictive monitoring parameter, as opposed to turbidity, that has relevance to the biological community; establish acceptable levels of "fines" (silt and fine sand) for material to be utilized for beach restoration projects; and increase the buffer area between the reef and the borrow area relative to the silt content of the material being dredged and the prevailing current regime in the area.

INTRODUCTION

Metropolitan Dade County Department of Environmental Resources Management (DC-DERM) is committed to preserving, enhancing, restoring and revitalizing the coastal beach and dune systems to provide enhanced storm protection for barrier island residents and recreational opportunities for county residents and visitors. This commitment has resulted in restoration of 15.4 miles of shoreline and revegetation of eight miles of coastal dune, through federal and state cost-shared programs.

During the summer of 1990, DC-DERM served as the local sponsor for the renourishment of a 0.8 mile stretch of beach south of Bakers Haulover Inlet. Construction (i.e., dredging) for the project occurred between May 7 and July 3, 1990. Weekly visual surveys of the hard-bottom reef were conducted primarily to examine for any mechanical impacts to the reef by the dredge equipment. During the third week of June, mechanical impacts and a considerable accumulation of sediment was noted on the reefs located south of the borrow (dredging) area. A subsequent survey of the reefs immediately to the north of the borrow area revealed another site where extensive sedimentation had also occurred.

Immediately after completion of the project an assessment was conducted to determine the areal extent of the mechanical impact and elevated sediment levels, and their effects on the benthic organisms, specifically, the hard (scleractinian) corals. The purpose of this report is to present the results of the sediment and mechanical impact assessments and give recommendations for modification of present monitoring and construction practices that might prevent similar impacts in the future.

METHODS

Borrow area and impact locations. The sand source, or borrow area, used for the Bal Harbor renourishment project, was identified, mapped and detailed in the General Design Memorandum for Beach Erosion Control and Hurricane Protection Project: Dade County, Florida, North of Haulover Beach Park (Army Corps of Engineers [ACOE] 1985). The borrow area is located 1.6 miles offshore of the northern Dade County community of Sunny Isles, between the second and third offshore reef tracts (Figure 1). The benthic communities found on the adjacent reef tracts have been described, in part, by Blair and Flynn (1989) and Goldberg (1973). The borrow area has hard-bottom reef areas within 100 meters (often within 50 m) of its boundary on the east (third reef), west (second reef), northeast (third reef) sides and the area south and southeast of the northern "dog-leg" (third reef) (Figure 2). The borrow area is irregularly shaped and roughly 1.99 statue miles long by 0.28 mile wide. The diagonally bordering latitudes and longitudes for the borrow area are: 25° 57.50'N, 80° 05.75'W (northeast corner); 25° 55.25'N, 80° 05.25'W (southwest corner).

The regions of mechanical and sediment impact are adjacent to the northern portion, or dog-leg, of the borrow area (Figure 2). Due to their location north and south of the dog-leg, the impact areas were designated as "Dog-Leg-North" (herein noted as "DLN") and "Dog-Leg-South" (herein noted as "DLS"). Reconnaissance of these areas revealed that the reef areas east of the impact regions and below 21 m (70 ft) depth, did not have appreciable accumulations of sediment. This was believed to be a result of the current regime on the outer reef slope, which kept the area free of sediment. Thus, for the purpose of this report, the area defined as the "reef area" will extend easterly to the 21 m (70 ft) isobath.

The DLN hard bottom reef is a low profile reef, varying between 17.6 and 18.9 m depth, dominated by soft corals, algae and sponges, with scattered hard corals (Blair and Flynn 1989). This region of the third reef has approximately 1-2 m of relief, rising out of the sand plane that forms the borrow area to the south and west. The reef extends north for a considerable distance (>10 miles) with minor discontinuities. The western edge of the reef in the DLN area is also bordered by a sand plain. The eastern reef edge slopes down to form the outer reef slope. This area is deeper than 21 m and beyond the area of concern.

The DLS hard bottom reef area has greater relief, rising 4 m off the sand plain that forms the borrow area to the north and west, and continues for an undetermined length to the south (> 10 miles). This third reef area, at a depth of 21.9 to 16.7 m, is also dominated by soft corals, algae and sponges, with scattered hard corals (Blair and Flynn 1989).

Mechanical impact assessment. The methods used to assess the level and magnitude of the impact are the same, with minor modifications, as those used for the assessment of the mechanical impact to the Sunny Isles reefs, described in "Sunny Isles Beach Restoration Project: Mechanical Damage to the reef adjacent to the borrow area. Metro-Dade Technical Report #88-14" (Blair and Flynn 1988). The methodology is summarized below.

A "baseline", or position reference line, was established roughly perpendicular to the impact tracts. This allowed for a detailed description of the distance and heading of the impact tracts relative to each other and the reef's edge. During the impact assessment, a metered line was placed along the length of an impact "tract" (for the purposes of this report, a "tract" will be defined as a noticeable linear path of impact within which some or all of the benthic organisms were physically damaged or removed from the bottom). A DC-DERM biologist, using scuba, swam the length of the metered line noting, at specified intervals, the width of the impact and the level of impact within the section being considered. The impact level was categorized into one of five levels: 0 impact; 1-25%; 25-50%; 50-75% or; 75-100% impacted. The width of the impact tract and the level of impact were recorded on underwater slates, and used to tally the overall impact on a specific impact tract. The impact described herein is of a much smaller magnitude than that documented in Blair and Flynn (1988). This allowed for a greater resolution in the enumeration of the impact. Thus smaller increments could be used when assessing the area impacted within an impact tract. Thus, during this assessment, intervals of 2.5 m were assessed (as opposed to 5 or 10 m used in the Sunny Isles impact assessment).

The area impacted was the sum of all areas showing any level of impact. The area destroyed was calculated by multiplying the decimal equivalent of the level of impact and the area within which that level of impact occurred. The individual areas were then summed to produce a total area destroyed.

Determination of sedimentation depth levels and areal extent. Sediment levels were measured along two transects (one each on DLN and DLS) by divers using scuba. Each transect started at the edge of the reef closest to the borrow area, and extended onto the reef in a north/south orientation, to a point where the depth of the sedimentation was within 0.5 cm of "background" or normal levels (i.e., sediment levels of <1.0 cm). The length of the sediment transect on DLN was 300 m, while the length of the sediment transect on DLS was 200 m long (Figure 3).

Sediment depth was measured and recorded to the nearest 0.1 cm at 3 m intervals along the length of each transect, using a stainless steel ruler. A notation was also made as to whether the measure was taken on top of the reef top (T), in a shallow depression on the top of the reef (D), or in a sand gully (G). The sediment level data for the top of the reef (T & D) were subjected to non-linear regression analysis (Systat 1988) to estimate the total length over which elevated sediment levels would be found.

The areal extent of the sedimentation was estimated by determining the width of the reef at various points along the length of the sediment impact. The distance from the reef's western edge to the 21 m isobath on the eastern edge was measured with a calibrated visual range finder. The reef edges (east and west) were located and marked using a recording fathometer on the surface vessel. Buoys were placed along the sediment transects at the 0 m, 100 m, 200 m, and 300 m marks. These buoys were used as references and provided accurate known distances for calibration and comparison with the reef width measurements.

Hard coral impact assessment. Transects, each 30 m long by 0.5 m wide, perpendicular to the previously established sediment transects, were used to assess the sediment impacts on the hard coral population. The information from the sediment measurements was used to determine the spacing and number of transects appropriate for the two sites. Three transects were assessed on the DLS site, while four transects were assessed on the DLN site. Transects were established at 20 m, 40 m and 80 m from the reef edge on DLS, and 20 m, 40 m, 80 m and 160 m from the reef edge on DLN. Each transect ran in a east/west direction centered (15 m mark) at the sediment transect (Figure 3).

The sediment on the reef within the transect area was removed by hand with the aid of small gardening hand tools (Figure 4). All hard corals within the transect corridor were identified, photographed and measured. Measurements (length and width) of the the live area, overall colony size (combined areas of "recently killed" and live tissue) and the general geometric shape of the colony were recorded on underwater paper. "Recently killed" areas were identified by: sharp definition of the calyx rays (i.e., no signs of abrasion, erosion or dissolution); a clean "bone white" color to the colony; and lack of any epiphytic or epizoic growths on the coral skeleton. The estimated pre-impact area of a coral colony was calculated using the field measurements in the appropriate equation for the geometric shape of the specific colony (i.e., area of a circle, triangle, ellipse). The impacted area was calculated by subtracting the area of live tissue from the estimate pre-impact area. The ratio of tissue loss for each colony was calculated by the following equation:

$$\text{Ratio loss} = 1 - (\text{live area}/\text{total area})$$

which is equal to the decimal equivalent of the percent tissue loss.

Statistical analysis. Statistical analysis of the sediment and hard coral impact assessment data was conducted utilizing the "SYSTAT: The System For Statistics" (Wilkinson 1988) software package. Hard coral data was log (natural) transformed to reduce variance, and subjected to Tukey's HSD Test to determine significant differences between species, sites and transects.

Sediment grain size analysis. Grain size analysis was conducted on two samples taken from the reef top of approximately 40 m from the reef's edge at the DLN site. The samples were analyzed using standard Ro-tap sediment apparatus. The sorting apparatus used 14 screened pans. The screen sizes, in mm and (Phi), were: 4.0 (-2), 2.8 (-1.5), 2.0 (-1), 1.4 (-0.5), 1.0 (0.0), 0.71 (0.5), 0.5 (1.0), 0.355 (1.5), 0.25 (2.0), 0.18 (2.5), 0.125 (3.0), 0.09 (3.5), 0.075 (3.75), 0.063 (4.0).

Sedimentation rates. The rate of sedimentation was measured during the dredging project using samplers, positioned 0.5 m off the bottom, on the edge of the reef adjacent to the borrow area. The samplers were made of 6.35 cm (2.5 in.) diameter PVC tube, 56.0 cm in length. A one liter plastic jar was taped to the bottom of the PVC tube to act as a collection jar. The samples were collected, washed, dried and weighed.

RESULTS

Area of mechanical impact. The mechanical impact areas were confined to the region of the DLS site that is within the defined limits of the borrow area. The damage was first recognized on June 19, 1990, by fractured rubble, dislodged benthic organisms and areas (often linear paths) of denuded hard bottom. Closer examination of the bottom revealed unusually flat surfaces within the linear paths. The flattened areas were visible despite approximately 1.5 to 2.5 cm of sediment on top of the reef surfaces. The sediment on the flattened surfaces was smooth and even, whereas adjacent surfaces showed irregularities caused by underlying benthic organisms (i.e., algae, sponges, tunicates). Removal of the sediment revealed freshly scraped or fractured reef surface. The scrapes and fractures were a cream or bone color, devoid or any epilithic (growing on rock) biota, and were easily distinguishable from the surrounding bottom. The scrape marks often exhibited areas of apparent compression of the rock, similar to those described for the Sunny Isles impact (Blair and Flynn 1988). However, the parallel grooves attributed to the wear pads of the drag head at the Sunny Isle impact sites were not evident here. Rather, areas showing the widest impact tracts had even or level scrape marks. Occasionally, smaller linear scrapes, approximately 3 to 4 cm wide were seen within the tract. These were determined to be caused by metal "teeth" on the bottom of the drag head of the dredge "Atlantic American". In tracts 1.5 m wide and greater, a gap of 35 cm was evident. The gap corresponded to the split-head drag head used by the dredge ("Atlantic American") during the project.

As with the impact at Sunny Isles, the recent impact was often confined to the higher points of the reef, with rubble and dislodged benthic organisms found in the depressions along the impact tract. The scrape marks were either continuous, when there was little to no relief to the surface, or confined to the higher portions of the reef. Scrape marks were not found on the sides of the prominences or in the depressions. At certain locations, 90° angle cuts, at the edge of the impact tract, 1-3 cm deep, were seen. These were usually in areas where the reef surface sloped away from the impact tract. It appeared that the object creating the impact made contact with only a portion of the reef, resulting in a narrow impact tract at these areas.

Eight impact tracts were identified. The tracts varied in length between 5.0 m and 20.8 m, and in width between 0.1 m and 2.7 m. The heading (or bearing) of the impact, length, width (at each 2.5 m interval) and area destroyed for each impact tract is given in Appendix 1 and illustrated in Figure 5. Table 1 summarizes the extent of impact on the documented impact tracts.

Table 1. Summary of mechanical impact to hard bottom reef areas at DLS along the eight impact tracts identified.

Impact tract	Overall length(m)	Area (m^2) impacted	Area (m^2) destroyed	Position of Baseline (m)	Heading of tract
DLS-1	18.9	16.80	14.24	16.9	150-160°
DLS-2	8.4	4.81	4.21	+3.4	150-160°
DLS-3	18.4	17.70	12.33	11.4	150-160°
DLS-4	14.7	18.08	15.82	10.5	180-190°
DLS-5	5.0	6.25	4.47	+6.1	185-190°
DLS-6	9.8	8.17	6.58	2.8	190°
DLS-7	10.5	17.25	14.60	No intercept	20°
DLS-8	20.8	16.75	13.10	0.0	60°
TOTALS	106.5	105.81	85.35		

A total of 105.81 m^2 were impacted at the DLS site over the eight identified tracts. Within that area 85.35 m^2 were destroyed. By "destroyed" it is meant that all epilithic organisms (including Montastrea annularis [star coral], M. cavernosa [mountainous star coral], Xestospongia muta [barrel sponge], Eunicea spp. [knobby soft corals]. Cliona spp. [boring sponge], tunicates [sea squirts], and numerous other species of encrusting and up right

Table 2. Sediment depths along the sediment transects on DLN and DLS.

	DLN		DLS	
Dist. (m)	Depth (cm)	Cont.*	Depth (cm)	Cont.
3	7.5	T	3.8	T
6	10.2	T	3.0	T
9	12.6	G	17.9	G
12	16.0	G	7.0	T
15	4.8	D	8.0	D
18	5.5	T	5.1	D
21	7.5	T	0.3	T
24	6.3	T	19.4	G
27	3.5	T	2.6	T
30	7.1	T	4.5	T
33	12.1	T	5.0	T
36	11.6	D	2.8	T
39	8.0	T	3.7	D
42	3.8	T	2.5	T
45	1.4	D	0.6	T
48	7.0	T	3.5	D
51	7.3	T	20.3	G
54	7.9	T	3.3	T
57	9.2	T	7.7	D
60	6.8	T	1.0	T
63	5.0	D	12.8	D
66	5.0	T	5.3	T
69	8.1	D	1.9	T
72	27.1	G	2.3	T
75	8.1	D	13.3	D
78	4.2	T	4.2	T
81	12.2	D	16.8	G
84	6.1	T	1.4	T
87	9.2	D	1.3	T
90	1.9	T	9.8	T
93	6.1	T	1.8	T
96	3.0	T	4.3	D
99	3.0	T	1.7	T
102	2.9	T	13.4	G
105	5.0	T	2.0	T
108	17.0	G	2.5	D
111	7.9	T	1.5	D
114	5.2	T	1.5	T
117	2.9	T	1.8	T
120	9.2	D	1.4	T
123	9.1	G	2.7	D
126	2.8	T	1.3	G
129	3.9	T	1.0	G
132	3.1	T	2.7	G
135	2.8	T	8.0	T
138	4.8	T	1.5	G
141	3.0	T	1.8	T
144	5.2	T	2.3	D
147	6.4	T	1.1	T
150	6.2	T	1.6	T
153	13.4	G	6.0	D
156	10.4	G	0.1	T
159	6.6	T	4.6	G
162	8.2	D	0.4	T
165	4.2	T	0.1	T
168	5.4	T	1.0	T
171	5.8	T	9.3	G
174	5.8	T	0.5	T
177	6.4	G	0.9	T
180	9.8	G	0.5	T
183	17.0	G	7.6	G
186	3.4	D	1.5	T
189	2.2	T	3.0	D
192	4.8	T	1.9	D
195	4.2	T	0.6	T
198	4.2	T	0.1	T
201	4.2	T		
204	5.5	D		
207	2.2	T		
210	2.3	T		
213	2.5	T		
216	1.2	T		
219	2.5	T		
222	55.8	D		
225	3.7	T		
228	2.7	T		
231	3.8	T		
234	2.6	T		
237	0.5	T		
240	2.8	D		
243	3.0	T		
246	1.2	T		
249	1.8	T		
252	4.4	T		
255	14.0	T		
258	0.5	T		
261	2.4	T		
264	3.2	T		
267	7.6	G		
270	2.2	T		
273	0.0	T		
276	2.0	G		
279	2.0	T		
282	1.0	T		
285	0.5	T		
288	2.4	T		
291	1.0	T		
297	0.0	T		
300	2.5	T		

algae and invertebrates) were fractured, crushed or dislodged.

Sediment levels. The accumulation of sediment at sites DLN and DLS was sufficient to bury the majority of the low lying and encrusting benthic organisms, completely cover the limestone bedrock, and mask the irregular surface contours of the rock (Figures 4 and 6). The raw data (Table 2) indicated the sedimentation on DLN was greater than on DLS. Comparatively, the sediment on DLN was approximately twice the depth than measured on DLS for an equivalent distance from the reef's edge. The maximum sediment depth (measured on the reef tops and shallow depressions) on DLN was 12.2 cm, 81 m from the edge of the reef, with sediment depths commonly ranging between 4 and 8 cm. The maximum sediment depth for DLS was slightly higher (13.3 cm, 75 m from the edge of the reef), however, the common range was appreciably less (2 to 4 cm). The level of sedimentation was sufficient to fill the barrel sponges (*Xestospongia muta*) within 50 to 100 m of the reef's edge (Figure 7).

The sediment data were grouped to yield 10 m incremental averages. Non-linear regression analysis of the 10 m average sediment levels and the distance from the reef's edge revealed that the decreasing sediment levels would best fit a linear function. The linear function was used to estimate the distance from the reef's edge where the level of sediment would be equivalent to the background level. This point was at 360 m from the reef's edge for DLN and at 240 m for DLS (Table 3). Figure 8 illustrates the 10 m averages for DLN, DLS, and the linear functions for the averaged sediment levels for both sites.

Sedimentation rates. Two sediment samplers were recovered from the DLS site. The sediment collected in the samplers corresponded to sedimentation rates of 54.6 mg cm^{-2} day^{-1}. For comparison, sedimentation rates at DERM biological monitoring control stations, outside the influence of the dredging effects, range between 4.0 and 6.0 mg cm^{-2} day^{-1}. Thus, the sedimentation rate during the dredging was approximately 10 times the normal rate.

Table 3. Average (10 m) sediment depths, the linear regression estimates of the sediment depths and distance of elevated sediment levels on the two impact sites.

DLS Average Sediment Depths.

Dist. (m)	Sediment depth (cm)	Lin. regress. depth est. (cm)
10	3.4	4.8
20	6.7	4.6
30	2.5	4.4
40	3.8	4.2
50	2.2	4.0
60	4.0	3.8
70	6.7	3.6
80	6.6	3.4
90	1.4	3.2
100	2.6	3.0
110	2.2	2.8
120	1.6	2.6
130	2.0	2.4
140	1.7	2.2
150	1.7	2.0
160	3.0	1.8
170	0.5	1.6
180	0.7	1.4
190	1.6	1.2
200	0.9	1.0
210		0.8
220		0.6
230		0.4
240		0.2

DLN Average Sediment Depths.

Dist. (m)	Sediment depth (cm)	Lin. regress. depth est. (cm)
10	8.8	7.6
20	5.2	7.4
30	6.1	7.2
40	10.6	7.0
50	4.1	6.8
60	7.8	6.6
70	6.0	6.3
80	6.2	6.1
90	7.4	5.9
100	4.0	5.7
110	4.0	5.5
120	6.3	5.3
130	3.4	5.1
140	3.6	4.9
150	5.2	4.7
160	6.6	4.5
170	5.9	4.2
180	5.8	4.0
190	2.8	3.8
200	4.3	3.6
210	3.6	3.4
220	1.8	3.2
230	4.1	3.0
240	2.4	2.8
250	2.0	2.6
260	2.4	2.4
270	2.6	2.1
280	1.0	1.9
290	1.3	1.7
300	1.6	1.5
310		1.3
320		1.1
330		0.9
340		0.7
350		0.5
360		0.3

Sediment analysis. The composition of the sediment on the reef at DLN was of fine sand and silt. A total of 95% (by weight) of the sample was of material smaller than 0.2 mm diameter (fine sand), with only 0.5% greater than 0.5 mm diameter (medium and coarser sand). Fine sand made up 63% of the sample and 32% was silt.

Figure 9 shows a cumulative component plot, or gradation curve, of the sediment samples collected from the DLN reef surface, and a pre-construction gradation curve for a sediment core boring taken from the borrow area adjacent to the impact sites. The gradation curve for the sediment on the reef represents the portion of the material taken up by the dredge but not retained. This material was released (i.e., "skimmed off") into the water column as suspended material. The released material, which creates the measured turbidity, will later settle out of the water column and accumulate on the bottom. The location onto which the material will accumulate is largely dependent on the current regime in the area.

Area of sediment impact. The information from the measurements of the reef width at specific points along the sediment transect and the distance along the reef that the sediment depths were elevated were used to estimate the area impacted by the sediment. At the DLN site, the width of the reef was narrowest near the southern point (120 m wide), and averaged approximately 150 m wide within the area of impact. The DLS site was wider, being approximately 200 m wide along the majority of the distance of impact (Fig. 3). Planimetric measurement of the areas represented in Figure 3, revealed that 57,347 m^2 (14.17 acres) were impacted on the DLN site, while 42,810 m^2 (10.58 acres) were impacted on the DLS site, for a total area of impact of 100,157 m^2 (24.75 acres) (Table 4).

Sedimentation related hard coral impact assessment. Seven transects were assessed for impact to the hard corals by sedimentation at sites DLN and DLS. Table 5 presents summary of the estimated pre-impact and the post-impact data for density, diversity, average percent tissue loss to colonies by transect, and number of colonies and species per transect. Overall, twelve species of hard corals were found on the transects, with four to eight species found on any single transect. *Stephanocoenia michelini* was the most common hard coral species, followed by *Siderastrea siderea* (Table 5).

Table 4. Area extent of elevated sediment levels on reefs adjacent to the borrow area.

Site	Equivalent Units	Area	Ave. density of hard corals	Estimated number of hard corals
DLN	ft-sq. m-sq. Acres	617,278 57,347 14.17	$1.2m^{-2}$	68,816
DLS	ft-sq. m-sq. Acres	460,803 42,810 10.58	$1.5m^{-2}$	64,215
TOTALS	ft-sq m-sq Acres	1,078,081 100,157 24.75	$1.4m^{-2}$	133,031

Table 5. Number of colonies of each species found on hard coral assessment transects.

TRANSECT

SPS*	DLN-20	DLN-40	DLN-80	DLN-160	DLS-20	DLS-40	DLS-80
AS	-	-	-	-	1	-	-
AG	-	-	1	1	1	-	1
DI	-	-	3	-	3	3	3
MA	-	-	-	-	-	1	1
MC	-	-	3	2	4	4	3
MD	-	-	-	3	1	2	2
MM	-	2	3	-	2	-	-
MY	-	-	-	-	-	1	-
P-sp	1	1	2	-	2	1	-
SC	-	-	1	-	-	-	-
SS	5	3	2	4	7	1	4
ST	17	4	10	4	13	7	4

* AS = Astrangia solitaria; AG = Agaricia spp.; DI = Dichocoenia stokesii; MA = Montastrea annularis; MC = Montastrea cavernosa; MD = Madracis decactis; MM = Meandrina meandrites; MY = Mycetophyllia aliciae; P-sp = Porites sp.; SC = Scolymia sp.; SS = Siderastrea siderea; ST = Stephanocoenia michelini.

Impact to the corals within 80 m of the reef edge was high at both sites, with 83.3 to 87.5% of the coral colonies on DLN showing some degree of impact (partial or total tissue loss) and 61.1 to 79.0% of the corals on DLS showing impact. An appreciable decrease in hard coral impact levels did not occur until 160 m for the DLN site (Table 6). With respect to mortality of the coral heads (i.e., 100% tissue loss) along the transects assessed, 53% of the coral colonies were killed.

Table 6. Summary of estimated pre-impact and post impact parameters relating to density, diversity and coverage by hard corals on the transects assessed.

Transect	(Coral cover - m^2/m^{-2}) pre-impact	post impact	Ave. %tissue loss per colony	% corals impacted
DLN-20	36.6	7.8	85.3	87.5
DLN-40	59.9	51.0	73.0	88.9
DLS-80	70.3	19.7	81.4	83.3
DLN-160	75.8	43.7	24.0	35.7
DLS-20	127.8	52.0	55.8	78.1
DLS-40	62.1	51.0	66.2	79.0
DLS-80	145.8	88.4	47.5	61.1

Transect	Coral density (colonies/m^2) pre-impact	post-impact	No. colonies (sps/Tran.) pre-impact	post-impact	Percent of colonies killed
DLN-20	1.6	0.3	24(4)	4(2)	83.3
DLN-40	0.6	0.2	9(4)	3(3)	66.7
DLS-80	1.6	0.6	24(7)	10(5)	58.3
DLN-160	0.9	0.9	14(5)	14(5)	0.0
DLS-20	2.1	1.5	32(8)	22(8)	31.2
DLS-40	1.3	0.5	19(7)	8(6)	57.9
DLS-80	1.2	0.9	18(8)	14(8)	22.2

CORAL COVERAGE LOSS BY REGION

Region	Area (m^2)	Est. # Coral col.	Ave. coral col. size (cm^2)	Ave. impact w/in region	Equivalent col. loss
DLN 0-80m	8,819	10,583	43.9	81.7	8,646
DLN 80-160m	12,144	14,523	81.2	24.0	3,490
DLS 0-80m	7,722	11,583	73.0	57.4	6,649
	28,685	36,689			18,785

Pre-impact coral cover ranged from 549.5 cm^2 m^{-2} to 2186 cm^2 m^{-2}. Post-impact coral cover decreased on all transects, and ranged from 117.5 cm^2 m^{-2} to 1326.2 cm^2 m^{-2}, corresponding to average impact (i.e., tissue loss per colony) per transect of between 24.0 and 85.3% (Table 6). With the exception of DLN-160, density of living coral colonies decreased between 33.3 and 81.2% on the transects (Table 6).

At site DLN, transects DLN-20, DLN-40 and DLN-80 had severe tissue loss per colony (i.e., >73%) while the lowest level of tissue loss occurred on the transect most distance from the edge of the reef (DLN-160). The average tissue loss on the DLS transects was generally less (i.e., <67%), with the most distance transect (DLS-80) again having the least loss (Table 6).

Statistical analysis of the data revealed the pre-impact levels of coral coverage on each of the transects were equivalent (i.e., did not show statistically significant differences). Significant differences did occur between the transects with respect to the level of impact (ratio of tissue loss). With regard to the tissue loss, DLN-160 was significantly lower than all transect but DLS-80 and DLN-40. The latter two, however, were not significantly different from each other.

Eight species of hard coral had sufficient numbers of colonies on the transects to test for significant differences in their impact level. Only Madracis sp. consistently showed significant differences in level of impact from the other species (Table 7). The level of impact was lower for Madracis sp. than for all other species tested except Porites sp. and Dichocoenia stokesii. The latter two species, however did not show consistent differences from other species.

Table 7. Matrix of significant level for differences in tissue loss of the species found on the hard coral assessment transect.

SPS*	AG	DI	MC	MD	MM	P-SP	SS
AG	-						
DI	NS	-					
MC	NS	NS	-				
MD	NS	NS	NS	-			
MM	NS	NS	.05	NS	-		
P-SP	NS	NS	NS	NS	NS	-	
SS	NS	NS	NS	<.001	NS	.05	
ST	NS	NS	NS	<.01	NS	NS	NS

* AS = Astrangia solitaria; AG = Agaricia spp.; DI = Dichocoenia stokesii; MA = Montastrea annularis; MC = Montastrea cavernosa; MD = Madracis decactis; MM = Meandrina meandrites; MY = Mycetophyllia aliciae; P-sp = Porites sp.; SC = Scolymia sp.; SS = Siderastrea siderea; ST = Stephanocoenia michelini.

DISCUSSION

Reported impacts to reef systems associated with dredging projects can be generalized into one of three categories: mechanical, turbidity or sedimentation. Mechanical impact is often the most dramatic, being easily visible to observers of the impacted reef area (Blair et al. 1990, Barry et al. 1988, Marszalek 1981, Britt Associates 1979, Goldberg 1988).

The characteristics of the mechanical impacts presented in this report are consistent with what would be caused by heavy objects or equipment (i.e., a drag head of a dredge) being pulled across the reef. The scrape markings and their location (only on the reef tops, not in any depressions) would indicate that the impact was caused by a drag head of a dredge. The dredge "Atlantic American" was the only dredge working in the area since the Sunny Isles Project of 1988. The freshness of the scrape marks would preclude the impacts being made in 1988. The scrape marks made in 1988 are presently a grayish-brown color and have a limited algal and sponge growth over them. Therefore, it is believed that the dredge "Atlantic American" was the cause of the impacts described herein.

The pattern of the mechanical impact tracts would indicate the impact was the result of 4 to 6 different passes (incidences of impact) by the dredge. During an informal conversation about the dredging operations of the "Atlantic American", Larry Devicco (American Dredging, Co.) stated the drag heads are approximately 24 meters apart. Examination of Figure 5 show impact tracts DLS-1 and DLS-3, as well as DLS-6 and DLS-5 are approximately 24 to 25 m apart. Further, the tracts paired above are on the same headings. Tracts DLS-2 and DLS-4, however, do not appear to have a "paired" tract. This would not be inappropriate, as the dredge has been observed, operating with only one drag head functioning. From the spacing and relative heading of the impact tracts, it appears that the impacts were caused during 6 separate instances or passes. Tracts DLS-1 and DLS-3 in one pass, DLS-6 and DLS-5 in a second, DLS-2, -4, -7, and -8 during seperate passes (order of presentation is arbitrary).

It should be noted that the reef's edge was known to be in close proximity to the borrow area. Metro-Dade DERM divers had marked the reef edge with buoys. Both the contractor's field office and the dredge operator were notified as to the location of the buoys and the proximity of the reef relative to the dredging area. Subsequent to this, the location (i.e., coordinates) of the reef edge was determined using the trisponder positioning system on the dredge's support vessel, The "Captain Tom". The position "fix" revealed the reef edge, and the impact areas, were within the confines of the borrow area as described and delineated in the General Design Memorandum utilized for this project (ACOE 1985). This was independently confirmed by the U.S. Army Corps of Engineers, (personal communication with Douglas Rosen, U.S. Army Corps of Engineers, Jacksonville, Florida).

Hard corals and soft corals have very limited abilities to survive after being broken or removed from the substrate. The presence of high levels of suspended material and sedimentation in the area, due to the dredging associated with the renourishment project, further reduces the probability of survival of any dislodged or fractured organisms. The mechanical impact associated with the dredge's equipment coming in contact with the reef is significant. Although the area impacted is approximately two orders of magnitude lower than that documented during the Sunny Isles Restoration Project (i.e., 85.3 m^2 [present report] versus 6,006 m^2 [Blair and Flynn 1988]), these additional impacts serve to further degrade the overall health and productivity of the reef system, and delay the recovery of the reef from the previous impacts.

The impacts from sediment and turbidity, although often encompassing larger areas than the mechanical damage, are not as apparent (Goldberg 1985). Thus the overall level, magnitude and effect of the impacts are not always presented. Turbidity and sedimentation impacts are often treated together, without designation of which component may be more critical. Turbidity and sedimentation have been documented to reduce light levels reaching the benthos (Bak 1978, Dallmeyer et al 1982, Cintron et al. 1974, Loya 1976), interfere with feeding activity of hard corals (Logan 1988), reduce growth rates of hard corals (Dodge et al. 1974, Dodge and Vaisnys 1977, Bak 1978), and when severe enough, bury and kill hard corals (Bak 1978, Marszelek 1981, Rogers 1983, Goldberg 1988).

Although often discussed and presented together because of their intuitive correlation, the level of turbidity does not always correlate to the level of sedimentation. The sediment impacts presented herein provide an example of this. The dredging company contracted to conduct the beach nourishment project was required to conduct turbidity monitoring at both the borrow site (150 m behind the working dredge and 100 m to either side of that point) and at the disposal site (the beach). Present state regulations allow for increased turbidity of up to 29 NTU's (Nephlometric Turbidity Units) above background or normal levels. The turbidity monitoring reports (monitoring and reporting were conducted by a firm subcontracted by the dredge company) showed the turbidity was usually only 1 to 4 NTU's above the background levels (Appendix 2). The turbidity levels of the water closest to the reef (100 m either side of the reading directly behind the dredge) were seldom over 3.0 NTU's, or roughly 10% of the allowable turbidity level. This may be the result of the static nature of the turbidity measurement. Samples represent the turbidity in a small region of the water column, at preselected depth levels or increments. Thus, increased or decreased turbidity levels between the sampling depths will go undetected. Parameters that utilize measures that can integrate throughout the water column (i.e., light penetration) may provide a more appropriate measure of possible impact. The low level of turbidity measured during the project, however, corresponded to the 1 to 13 cm of sediment deposited over 24.75 acres on the reef at sites DLN and DLS (Fig. 3; Table 2).

It should be noted that the "standing" level of sediment on the reef may not truly reflect the sedimentation rate, or the sedimentation pressure, experienced by the benthic organisms. Other site-specific factors (i.e., slope of substrate, relief of substrate, current regime) can effect the "standing" level of the sediment while having little to no effect on the sedimentation rate affecting the organisms on the bottom. This could help explain the apparent discrepancy between the amount of sediment on the reef and the level of impact documented at sites DLS and DLN (Table 6). The DLS site (16.8 to 21.9 m [55 to 72 ft.] depth) has a greater relief, raising 5 meters within a 40 m distance from the edge of the reef. The slope of the reef is moderately steep and the top of the reef remains 4 to 5 meters above the level of the sand plain that makes up the borrow area. In contrast, the DLN site (17 to 18 m [57 to 60 ft.]) has low relief, raising only 1 to 2 meters above the borrow area sand plain. The predominant current over the reefs flows northerly. Thus, the DLS site, with its greater relief, may serve to buffer, shield, or deflect some of the current that would otherwise reach DLN and help remove sediments. The greater depth of reef top at the DLN site means the area has exposure to a greater portion of the water column carrying sediment (i.e., the portion from 55 ft. to 62. This portion of the water column (the lowest portion) would carry the highest suspended sediment load (i.e., the result of the combination of the draghead plum and the released fines from the dredge) and the material would have a tendency to fall out closer to the borrow area. Further, the general current in the region (i.e., northerly) would carry this sediment laden water over the DLN site, aggravating sediment loading there.

Within the 7.1 acre area assessed during the hard coral impact survey (80 m from the reef edge on DLS; 160 m from the reef edge on DLN) an estimated 36,689 coral colonies were estimated to be found (Table 6). Given the percent loss of living tissue and the average colony size within those areas (Table 6), an equivalent of 18,785 colonies were destroyed by the sediment impact. This impact, however, does not take into account the impacted region outside of the hard coral transect assessment areas (i.e., 17.67 acres or 71.4% of the impacted area), within which an excess of 96,000 additional hard coral colonies could have received varying degrees of impact or stress.

A common mode of impact to the hard corals was death of the marginal or lowest portions of the coral colony due to a build up of the sediment (Fig. 10). This is believed to be a direct result of the coral's attempts to rid the colony of the settling sediment. Hard coral species vary in their ability to rid themselves of sediment. Most corals, however, have greater success removing finer grained sediments (fine sand, silt and clay) (Hubbard and Pocock 1972). In this respect the documented level of impact to the hard corals could be considered minimal relative to the level of sedimentation, as the grain size of the sediment causing the impact (Figure 9) is mostly "favorable" for removal by the hard corals.

Hard corals can rid themselves of sediment by one of four methods: distention of the polyp by uptake of water; tentacular action; ciliary action; and mucus entanglement (Hubbard and Pocock 1972). The method used by a given coral species is augmented or exacerbated by the shape of calyx and colony. For the majority of species observed in the impacted reef areas, mucus entrapment and, secondarily, polyp distention appeared to be the predominant methods of sediment removal. Mucus entrapmnent is successful when the sediment load is periodic (short term) and sufficient current is present to move the mucus-bound sediment away from the colony. When the sediment loading is long term (i.e., 4 to 6 weeks in this case), the mucus-bound sediment accumulates around the base of the coral. This can be, and was, aggravated by an extended period of low current velocities during the project, decreasing the removal of sediment. The result was that coral colonies literally buried themselves in an attempt to rid the sediment accumulating on the living tissues of the colony (Fig. 10). Colonies with some degree of slope or mounding (i.e., Montastrea cavernosa, M. annularis, Stephenocoenia michelini, Siderastrea siderea) were able to keep the sediment off the central, elevated portions of their colony. The species with flattened or plate-like shapes (i.e., Meandrina meandrites, Agaricia spp.) were less successful, often showing pockets or areas of tissue death where sediment had accumulated, or had been moved to, by more elevated polyps. Thus, although the majority of hard corals were able to remove the sediment falling out of the water column and onto the surface of the colonies, the length of time over which the otherwise survivable sedimentation rates occurred, proved to be lethal to a significant portion of the hard coral colony. Rogers (1983) found similar results with multiple applications of sediment on Diploria clivosa. A single application of up to 400 mg cm^{-2} was tolerated without observable impact. Daily applications of 200 mg cm^{-2}, however, resulted in approximately 50% loss of tissue through burial as described above. It should be noted that the impacts described herein are associated with a sedimentation rate of approximately 50 mg cm^{-2} day^{-1} over a four to six week period.

The decrease in the number of colonies and live tissue area on each transect does not always correspond to a proportional variation in average impact (tissue loss) per colony, or the percentage of colonies killed (i.e., DLN-40, DLN 160, DLS-80; Table 6). This results from the presence of one or more large, somewhat elevated coral colonies on the transect, along with numerous smaller colonies with minimal relief. The larger colonies account for the majority of the live tissue present on the transect. Although they sustain varied levels of impact, due to the greater relief of their colonies, they survive with a relatively large portion of their living tissue. The majority of coral colonies found were small, (<0.4 m in diameter) with low cover (surface area). Thus, that very small areal impact to these colonies produce a high impact level (ratio). Further, the smaller colonies are more easily buried, destroying or killing the entire colony. Thus the decrease in live tissue cover of hard coral alone does not reflect the level of impact to the population of hard corals. This fact has relevance when considering possible recovery of the impacted regions. The decreased number of colonies can result in a reduced overall rate at which hard coral cover will accumulate as fewer colonies will be adding (growing) living tissue. The reduced number of coral heads would mean less larvae would be produced and settling of hard coral recruits would be diminished. The combination of these factors would prolong the period of recovery. An area, for example, with high remaining live tissue cover, but severe impact and mortality (i.e., DLN-40), would be expected to show slower recovery than an area with moderate live tissue loss and either low or moderate colony loss (i.e., DLS-20).

It was hoped that the hard coral assessment and sedimentation transects would allow definition of the hard coral mortality versus sedimentation level, but the data did not lend itself to such evaluation. A decrease in the percentage of coral impacted and the tissue loss was evident at the furthest transects assessed, however, the average sediment level did not correlate with the level of impact on the transect. Although a correlation could not be defined, it was apparent that an appreciable impact occurred with accumulations of as little as 2.3 cm of sediment (Table 6; DLS-80).

The total impact of the sediment on the benthic community is not known. This is in part due to the techniques used in the assessment which focused on the impact to the hard corals. Numerous sponges, such as barrel (Xestospongia muta), erect (Callyspongia spp., Haliclona spp., Niphates spp., Agelas spp., Verogula spp.), encrusting (Mycale sp., Ulosa spp.), vase (Ircinia companata), ball (Ircinia spp., Specieospongia sp.) and boring (Cliona spp., Scyphonodictyon sp.) sponges were coated and/or buried by the sediment. During the sediment removal it was common to have dead, bleached sponges dislodge from the substrate.

Soft corals received impact to the portions of the colony that were covered by the sediment. The tissues of the buried part of the colony were destroyed, leaving only the central axis or "axial rod" of the soft coral (Figures 4 [foreground] and 11). This area will serve as a site for colonization of various epiphytes and epizoids, some of which (i.e., Millepora alcicornis) may result in the overgrowth and subsequent death of the soft coral. Thus, the long term impact to the soft corals will most likely go beyond the level presently noted.

The time it will take for the impacted reef areas to recover from this sedimentation is unknown. Much will depend on the amount of time it will take for the sediment to move off the reef, and the duration of the resuspension periods associated with the sediment transport. In October of this year, tropical storm "Klaus" passed over the upper Florida Keys-Miami area. The winds associated with the storm generated seas above 8 feet for 3 to 4 days including 1 to 2 days of 10 to 15 foot seas. Observations made on the reef the week following the storm at the two impact sites revealed that a large portion of the sediment had been moved off or shifted around on the reef surface (Table 8). Sediment depths were commonly below 1 cm across the top of the reefs at both sites. Along the first 100 m of the reef at the DLS site, the sediment levels decreased on the top, in depressions and in the gullies of the reef. This would indicate that the sediment was transported off the reef, presumably to the neighboring sand plains (possibly to neighboring reef areas). On the DLN site, the sediment level decreased significantly on the top of the reef, but increased slightly in the depression and the gullies of the reef (Table 8). This would indicate that the sediment is shifting around on the reef and not necessarily being transported off the reef.

The sediment shifting has further implications for recovery of the reef. The resuspension and shifting of sediments on the reef can shade, bury or abrade the sporeling and larval recruits of the organisms attempting to settle in the impacted regions. Further, the sediment on the rock surfaces of the reef will make the area unsuitable for settlement and attachment of the (larval) organisms. This substrate pre-emption will continue throughout the period of resuspension.

Table 8. Sediment levels on reefs during assessment (July) and after the passing of tropical storm "Klaus" (Sept.).

Average Sediment Depths (cm)

	July	September
DLN		
Top (T)	6.3 ±2.5	1.1 ±0.2
Depressions (D)	7.5 ±3.9	8.1 ±4.5
Sand gullies (G)	18.6 ±7.6	21.2 ±5.1
DLS		
Top(T)	2.8 ±1.7	0.4 ±0.3
Depressions (D)	7.3 ±3.9	4.0 ±1.9
Sand gullies (G)	16.8 ±4.2	7.2 ±3.7

The shifting of the sediment into the depressions and gullies will exclude a portion of the reef surface that was previously available (prior to impact) and used by benthic organisms. Therefore, although the sediment is moving off the top of the reef surface, a smaller area of reef is exposed for settlement and re-establishment of benthic organisms. Thus, even if the area available were to recover to pre-impact levels of benthic organism cover, diversity and density, there would remain a net loss of habitat and associated productivity on the reef.

The appearance of the reef surface during the October visit, especially at the DLN site, reflected the period of time significant sediment cover had remained on the reef (approximately 8 to 12 weeks). Bleached patches of dead sponge and crustose coralline algae were apparent on the limestone bedrock. Further, there was an obvious lack of encrusting and benthic algae, sponges and invertebrates (Fig. 12). The movement of the sediment off the reef may create additional stress and impact to neighboring reef areas that receive the sediment. The "chronic" aspect of the sediment is more difficult to measure and detect, as it will most likely be manifested in reduced productivity and slowed growth rates of impacted organisms rather than the dramatic loss of living tissue, or organisms as documented here.

There are certain parameters and actions that are believed to have served as aggravating factors for the sedimentation. The primary factor is associated with the quality of the material being dredged from the borrow area. "Fines" (i.e., fine sand, silt and clay) will not be retained in the hopper dredge. This material will be "skimmed off" with excess water from the collection bins on the dredge and released into the water column as suspended materials. The higher the level of "fines" the greater the amount of material suspended, released and ultimately settling out of the water column.

No minimal or maximal standards have been established for silt and fine sand content of borrow material used in beach nourishment projects. Experience from south Florida beach renourishment projects, indicate that a silt level of less than 2-3% is needed to minimize the sediment loading to neighboring areas (Goldberg 1988). The sediment analysis of the core borings taken in the dredging area by the Army Corps of Engineers (Table 9) shows the silt level to vary between 4 and 16% with fine sand comprising 35 to 80% of the material in the portion of the borrow area used.

Three additional factors had significant contributions to the sediment impact: the proximity of the neighboring reef to the borrow area, the concentration of the dredge activities to a small portion of the borrow area and the prevailing currents of the region. Due to the previous use of the borrow area for a project that occurred in 1988 and constraints of the dredging equipment used during the Bal Harbor project, a large portion of the borrow area was excluded from use. This was due to a combination of unusable material (i.e., high rock content) remaining in the unused protion of the borrow area and the inability of the dredging equipment to recover the material. The result of this was to

Table 9. Fine sand and silt content of material in borrow area adjacent to the damaged areas. Cores were all taken within the "Dog-Leg" of the borrow area.

Core #	% Fine Sand	% Silt
CB-ND-6	35	4
CB-ND-7	80	8
CB-ND-9	79	10
CB-ND-10	64	14
CB-ND-12	65	16

concentrate the dredging operations in the northern portion or "dog-leg" of the borrow area. The concentration of dredging operations also meant a concentration of the resultant sedimentation associated with the release of the "fines" during the dredging operations on to a smaller area of reef.

A "buffer zone", or minimum distance between the borrow area and the reef is required to protect the reefs from sediment impacts as well as inadvertent mechanical impacts. The distance necessary between reef areas and the borrow area will vary with the project, quality of the borrow area material, and the type and efficiency of the equipment used and prevailing current regime. Buffer zone sizes that have been suggested are 100 m (Goldberg 1981), 400 m (U.S. Fish and Wildlife Service - letter from D. R. Ekberg to U. S. Army Corps of Engineer, December 9, 1981) and 0.5 nmi (Griffin 1974). The buffer zone for Bal Harbor project was 45 m. As elevated sediment levels were documented 350 m distant to the borrow area, and estimated to continue to to 400 m from the borrow area, the present buffer zone size (45 m) would appear grossly inadequate for protection of the reef system from adverse impact associated with turbidity and sedimentation.

The prevailing north-south currents in the dredging area resulted in the sediment laden waters released from the dredge and stirred up on the bottom by the drag-head, to be carried dirrectly over the hard-bottom reef areas. If the lower portion of the borrow area had been used or included in use, the sedimentation level would have been substaintially less. The north-south orientation of the lower portion of the borrow area in conjunction with the sand areas to the north and south of the borrow area would have allowed the suspended sediment to settle-out either back into the borrow area or onto the sand areas, rather than onto the reefs. Thus, when currents are consistant, they may have a compensation effect for the buffer zone in circumstances where the current can keep, or carry, the suspended sediments away from the hard-bottom reef areas.

The limitations on of the use of turbidity as a measure of possible impact to biological systems has been raised in the past (Bak 1978, Goldberg 1988). This results from a lack of consistent correlation between the turbidity units and level of impact, and the "static" nature of the measure. It would seem intuitive that the greater the turbidity, the greater the amount of material in the water column that could fall out onto the reef and subsequently impact the reef. Turbidity readings, however, are a measure of the amount of light scattered in a water column, rather than an indication of the amount of material in suspension. Further, this reasoning, does not take into account the size of the water column over the possible impact area, nor the composition of the suspended material. Thus, a reading of 10 N.T.U.'s over a reef that is in 10 feet of water may have little to negligible impact, while the same level of turbidity over a reef in 60 feet of water could result in severe impact from settling of suspended materials on the biological components of the benthic community. Further, high turbidity may not relate to impact level. Britt Assoc. (1977) illustrated an apparent correlation between turbidity measures (N.T.U.) and suspended solids levels (mg/1), however, they later stated "it appears that no correlation can be made between excessive turbidity and reef damage".

RECOMMENDATIONS

Based on the documentation and observations made during this assessment of mechanical and sediment impacts to the benthic hard-bottom reef community, the following recommendations are made to limit hard-bottom reef impacts during future dredging-related projects.

A. Increase the buffer zone between the borrow area and surrounding hard-bottom reef areas. The distance should be sufficient to reduce sediment accumulation on the reef areas. The actual distance may vary relative to the composition of the material being dredged (i.e., amount of silt and fine sand) and direction and speed of prevailing currents. From past projects in south Florida, when currents are not favorable, the minimum distance recommended are: 100 m (Goldberg, 1988) when the silt content is low (<3%), 500 m (this report) when the content is moderate (5-9%) and 1000 m (Griffin 1974) when the silt content is high (above 10%).

B. Acceptable levels of silt content should be established for borrow material used for beach renourishment. This would facilitate reductions of impact at the deposition site, nearshore reefs and any reefs adjacent to the borrow area. Establishment of silt content levels would allow for optimal use of borrow areas through minimization of necessary buffer zones.

C. A more significant and appropriate measure of the impact potential of the suspended and resuspended sediments needs to be established. Turbidity does not show consistent correlation with suspended solids, sedimentation rates or biological impact. Its use as an environmental protection measure, especially with respect to nearshore habitats, is inappropriate and presently unsubstantiated. For marine biological systems utilization of percent reduction of diel (daylong) light levels reaching the bottom, for example, in conjunction with daily sedimentation rate measurments could provide a more appropriate, albeit a more involved, measure of possible impact to the benthic community.

LITERATURE CITED

Army Corps of Engineers, U.S. 1985. Beach erosion control and hurricane protection. Dade County, Florida north of Haulover Beach Park. Design Memorandum (CP&E). U.S. Army Corps of Engineers, Jacksonville. 171 PP.

Bak, R. P. M. 1978. Lethal and sublethal effects of dredging on reef corals. Mar. Pol. Bull. 9:14-16.

Barry, J. J., C. Vare, P. Davis and R. Clinger. 1989. Reef restoration off Boca Raton, Florida. Proc. Beach Presv. Technology 1989, Tampa, FL: 101-108.

Blair, S., B. S. Flynn. 1988. Sunny Isles Beach Restoration Project: Mechanical damage to the reefs adjacent to the borrow area. Metro-Dade Tech. Rpt. #88-14:23 pp.

Blair, S., B. S. Flynn. 1989. Biological monitoring of hard-bottom reef communities off Dade County, Florida: Community description description. In: Diving for Science... 1989. M. Lang and W. Jaap (Eds.), Proc. Amer. Acad. of Underwater Science 9th Annual Scientific Diving Symposium, pp. 9-24.

Blair, S. M., B. S. Flynn and S. Markley. 1990. Characteristics and assessment of dredge related mechanical impact to hard-bottom reef areas off northern Dade County, Florida. In: Diving for Science... 1990. W. Jaap (Ed.). Proc. Amer. Acad. of Underwater Science 10th Annual Scientific Diving Symposium, pp 5-20.

Britt Associates. 1977. Final Report. Biological Monitoring of the John U. Lloyd Beach Restoration Project. Submitted to Broward County Environmental Quality Control Board, 41 pp + 12 pls.

Britt Associates. 1979. Final Report. Reef damage report. Submitted to Broward County Environmental Quality Control Board, Erosion Prevention Division. 64 pp.

Cintron, G., F. McKenzie and R. Olazogasti. 1974. Studies at the PRINUL site. Final Report: Mission 3 and 5. Department of Natural Resources, San Juan, Puerto Rico.

Dallmeyer, D. G., J. W. Potter and G. J. Smith. 1982. Effects of particulate peat on the behavior and physiology of the Jamaican reef-building coral Montastrea annularis. Marine Biol. 68: 229-233.

Dodge, R. E., R.C. Aller and J. Thompson. 1974. Coral growth related to resuspension of bottom sediments. Nature 247: 574-577.

Dodge, R E., and J. R. Vaisnys. 1977. Coral populations and growth patterns: responses to sedimentation and turbidity associated with dredging. J. Mar. Res. 35: 715-730.

Goldberg, W. 1973. The ecology of the coral-octocoral communities off the southeast Florida coast: Geomorphology, species composition and zonation. Bull. Mar. Sci. 23:465-487.

Goldberg, W. 1981. A resurvey of coral communities adjacent to a beach restoration area in south Broward County, Florida. Report to Broward County Environmental Quality Control Board and Erosion Prevention District. pp 1-23.

Goldberg, W. 1985. Long term effects of beach restoration in Broward County, Florida. A three year overview. Coral Reef Associates, Miami, FL. 31 pp.

Goldberg, W. 1988. Biological effects of beach restoration in South Florida: The good, the bad and the ugly. Proc. Beach Preservation Technology Conference '88. Gainesville, FL. pp 19-28.

Griffin, G. M. 1974. Case history of a typical dredge-fill project in the northern Florida Keys - effects on water clarity, sedimentation rates and biota. Harbor Branch Foundation, Inc., Publication No. 33. Fort Pierce, Florida 138 pp.

Hubbard, J. A. E. B. and Y. P. Pocock. 1972. Sedimentation rejection by recent scleractinian corals: A key to palaeo-environmental reconstruction. Geol. Randsch. 61: 598-626.

Logan, A. 1988. Sediment-shifting capability in the recent solitary coral Scolymia cubensis (Milne-Edwards and Haime) from Bermuda. Bull Mar. Sci. 43:241-247.

Loya, Y. 1976. Effects of water turbidity on the community structure of Puerto Rican corals. Bull. Mar. Sci. 26:450-466.

Marszalek, D. S. 1981. Impact of dredging on a subtropical reef community, southeast Florida, U. S. A.. Proc. Fourth Internat. Coral Reef Symp. Vol. 1: 147-153.

Rogers, C. S. 1983. Sublethal and lethal effects of sediments applied to common Caribbean reef corals in the field. Mar. Pollution Bull. 14:378-382.

Wilkinson, L. 1988. SYSTAT: The system for statistics. Evanston, Il.

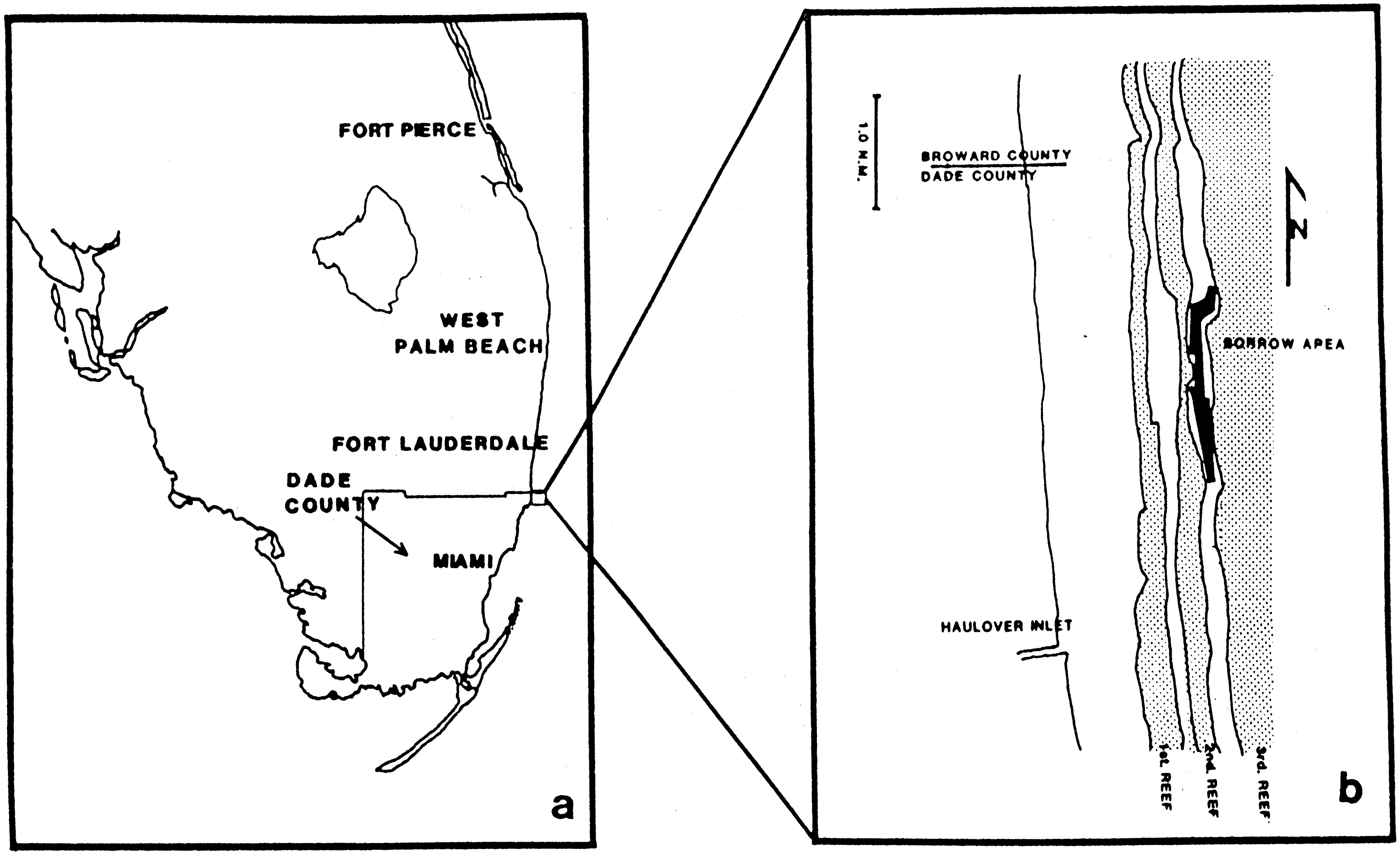

Figure 1. Map of Florida showing the location of the borrow area and its position relative to the neighboring reef tracts.

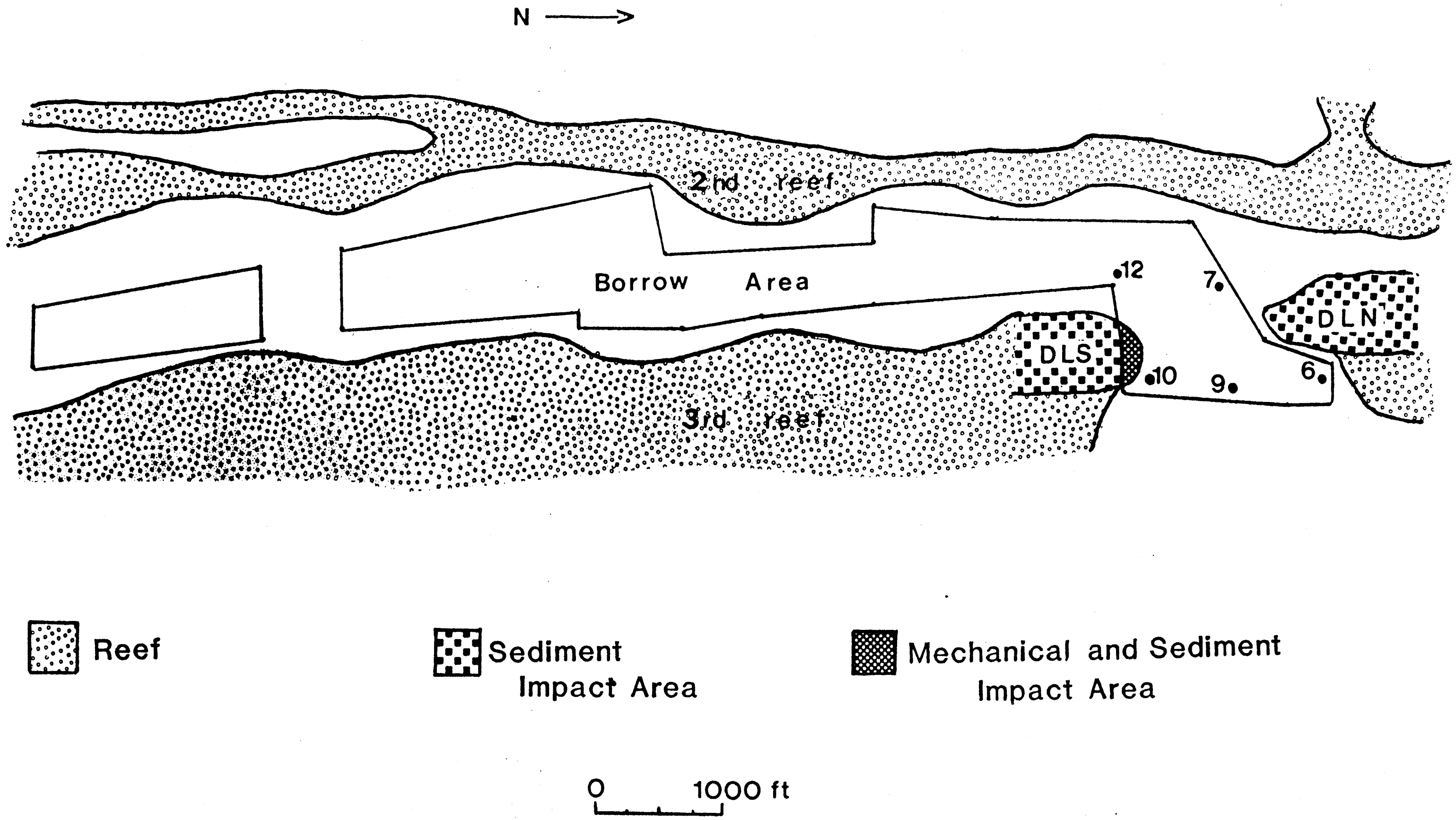

Figure 2. Map of the borrow area showing the location of the mechanical and sediment impact areas.

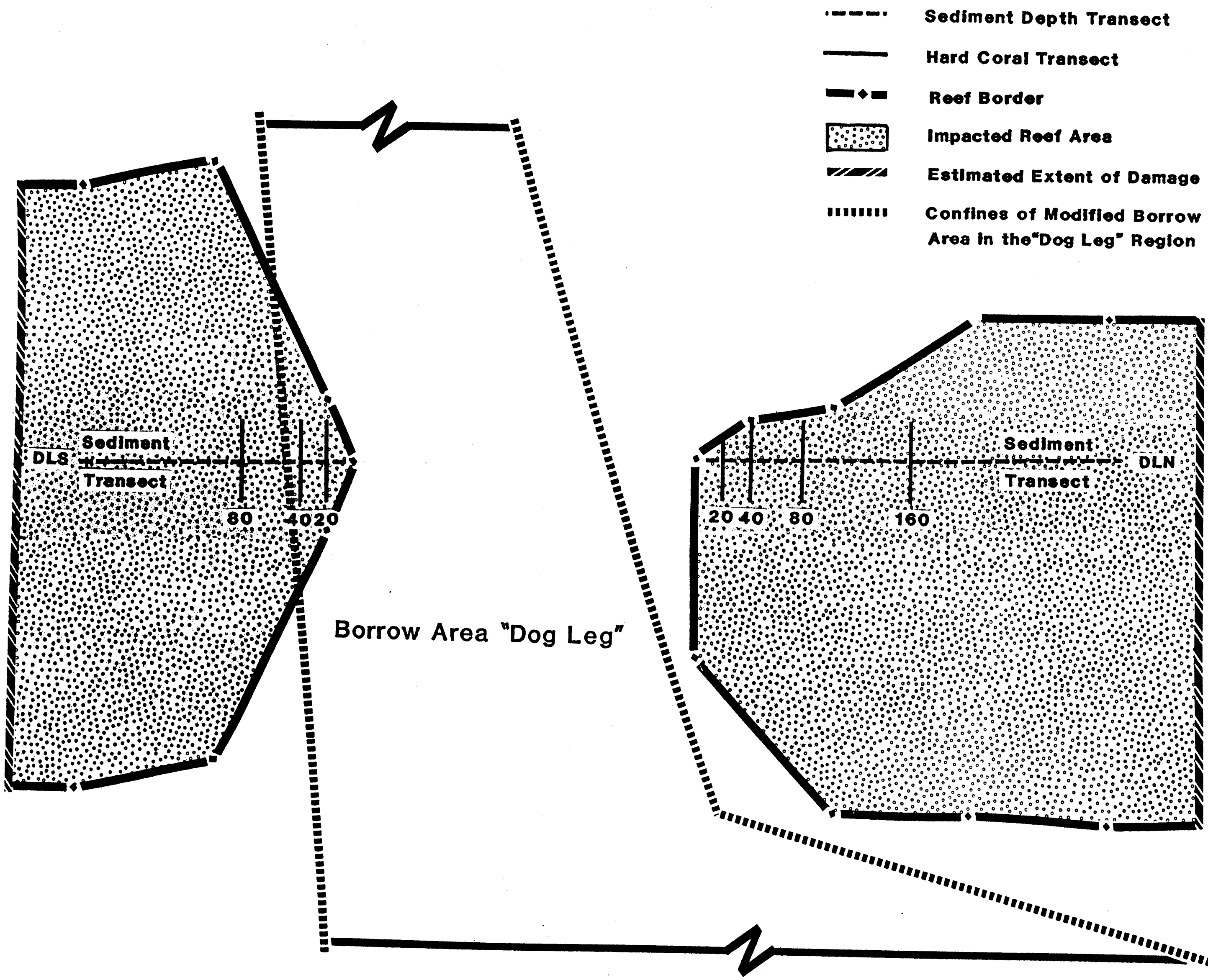

Figure 3. Schematic of the sediment impact areas, illustrating the position and location of the sediment and hard coral impact assessment transects.

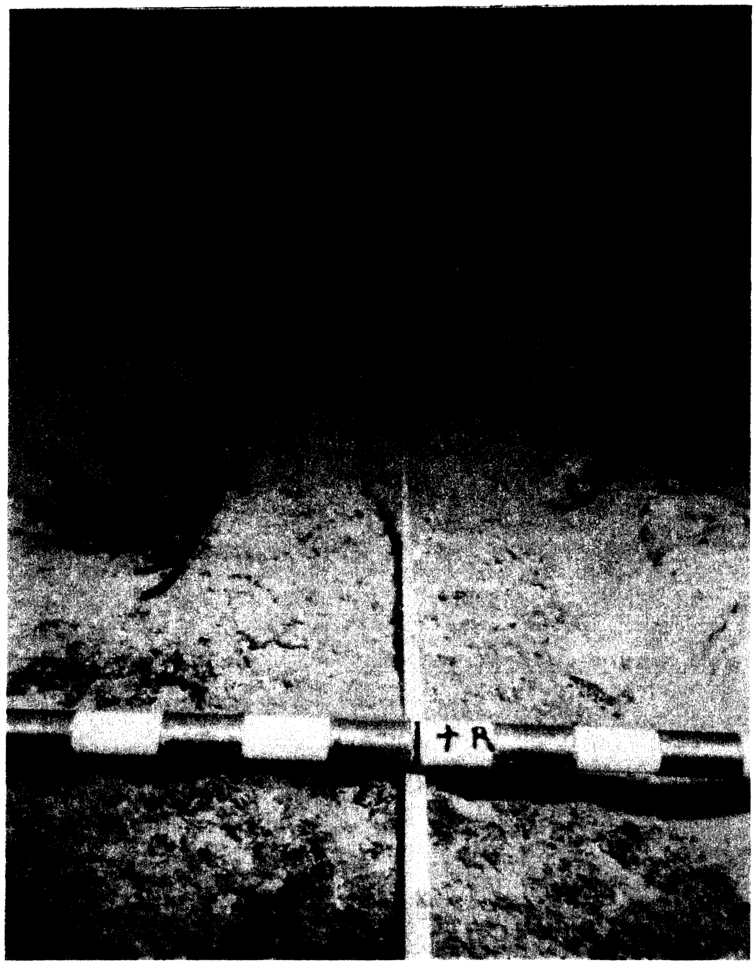

Figure 4. A hard coral assessment transect after removal of the sediment (scale: 1 band = 5 cm).

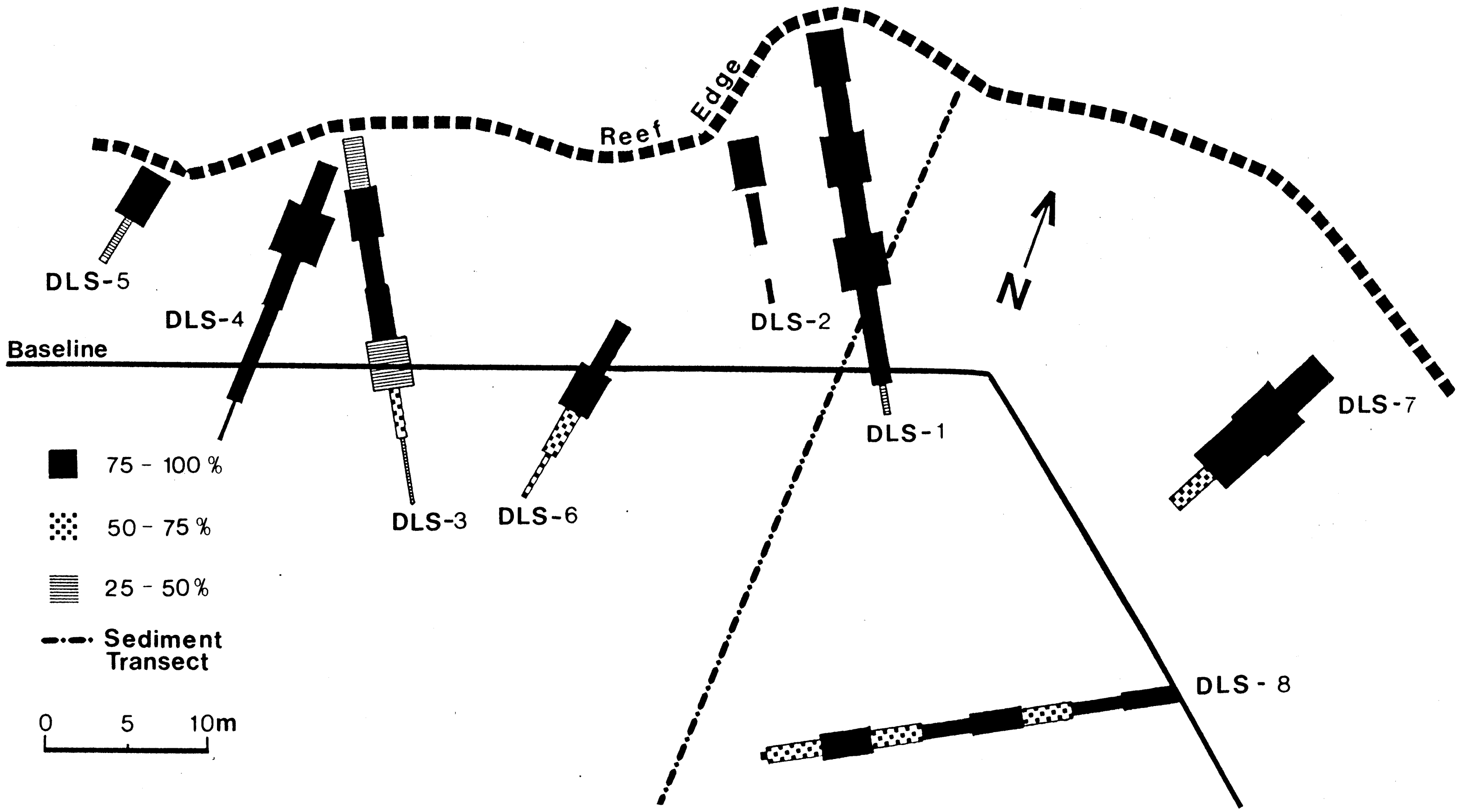

Figure 5. Schematic of the impact level and position of mechanical impact tracts identified on the DLS site.

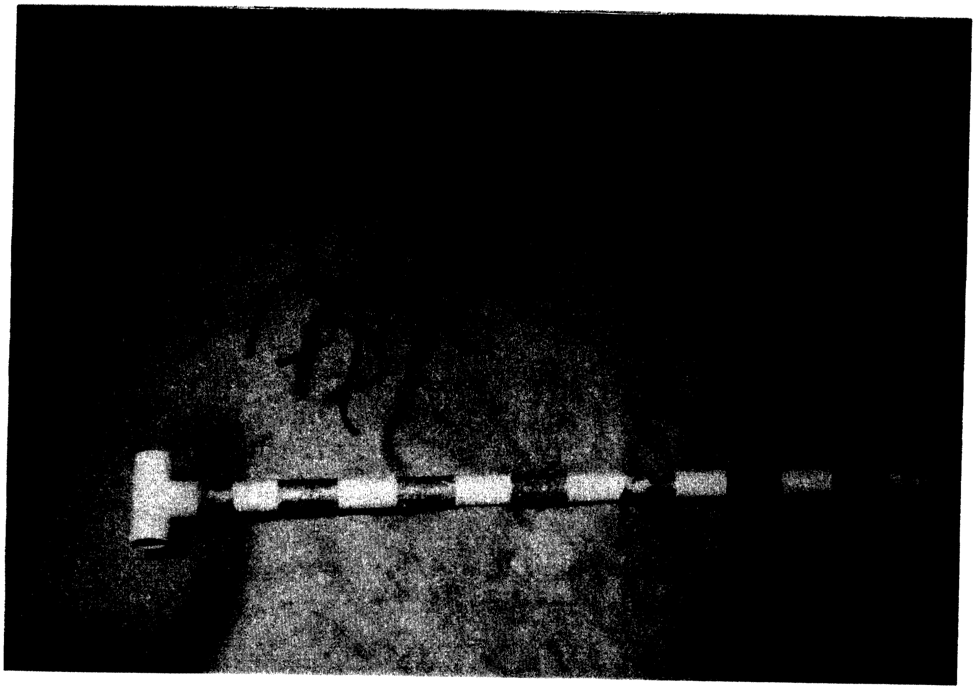

Figure 6. Reef surface at DLN site showing sediment on the reef. Note the lack of surface relief features, which are masked by the sediment (scale: 1 band = 5 cm).

Figure 7. Sediment accumulation in a barrel sponge (Xestospongia muta) on the DLS site.

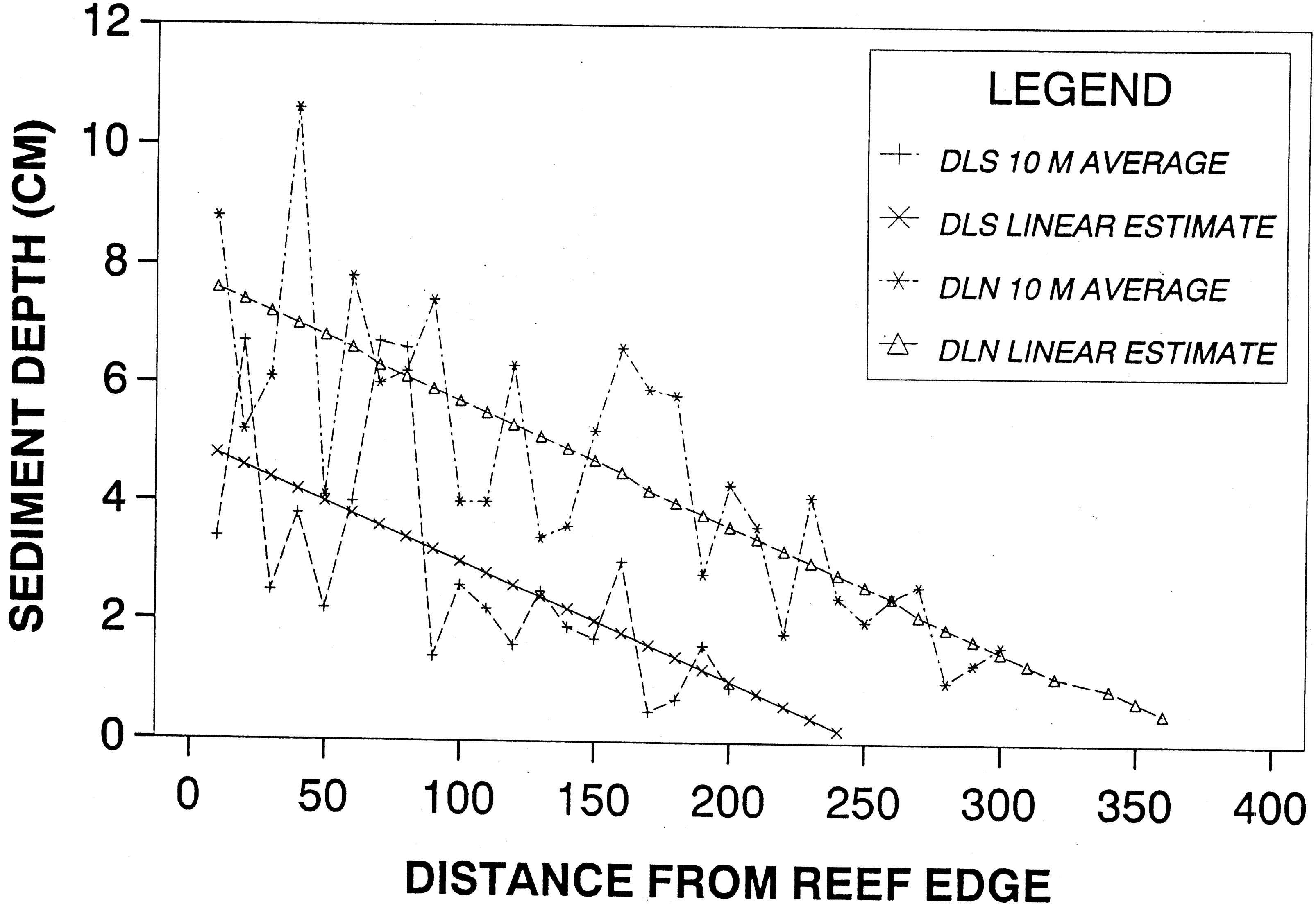

Figure 8. Sediment depths averaged over 10 m increments and a plot of the linear model used to estimate the distance over which elevated sediment levels occurred.

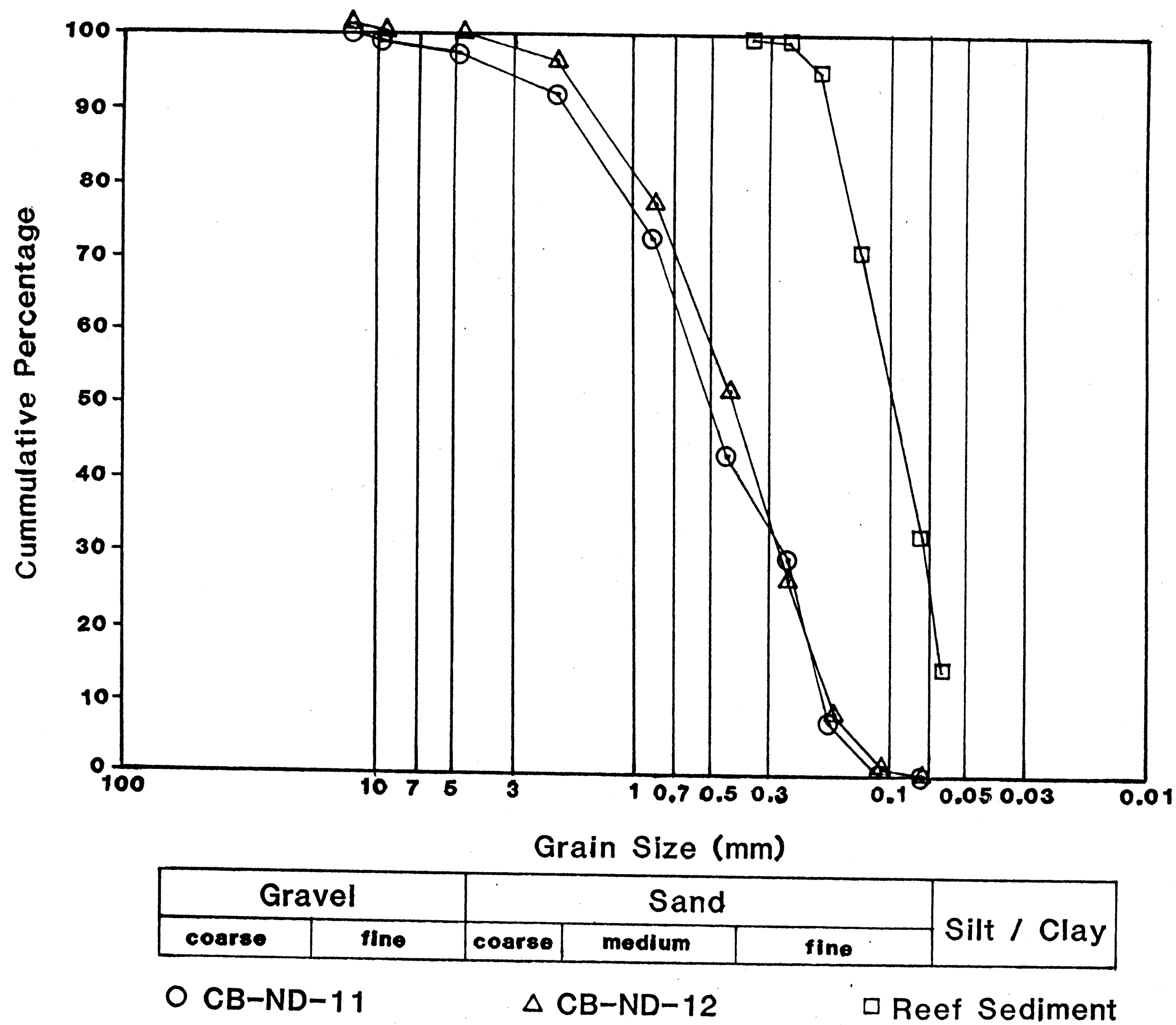

Figure 9. Gradation curves for sediment taken from the DLN site and for sediment core borings taken from an adjacent region of the borrow area (core borings taken prior to any dredging of the borrow area.

Figure 10a. A hard coral (Montastrea cavernosa) with sediment build-up around the base. The build-up is associated with the coral's attempts to rid itself of sediment falling onto the colony.

Figure 10b. The same coral after removal of the sediment exposing the portion of the coral head killed (white area) by the build-up of the sediemnt (scale: 1 band = 5 cm).

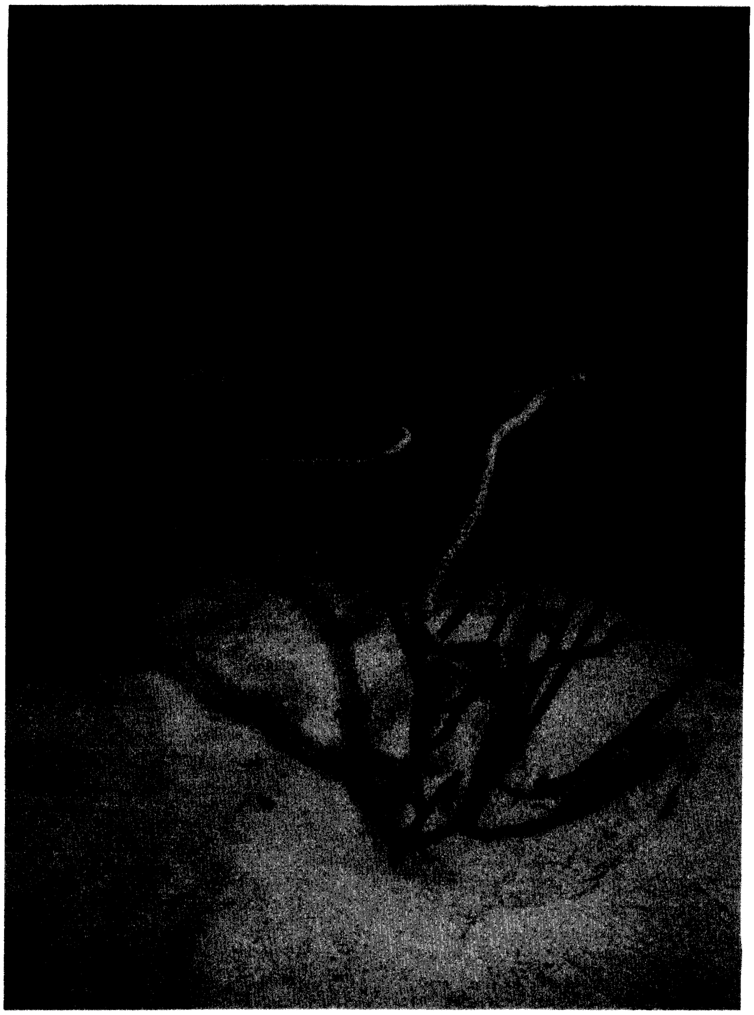

Figure 11. A soft coral (Eunicea sp.) illustrating the type of impact caused by the sediment build-up. Note the lower (black) portion of the colony. All tissue has eroded away, leaving only the central axial rod.

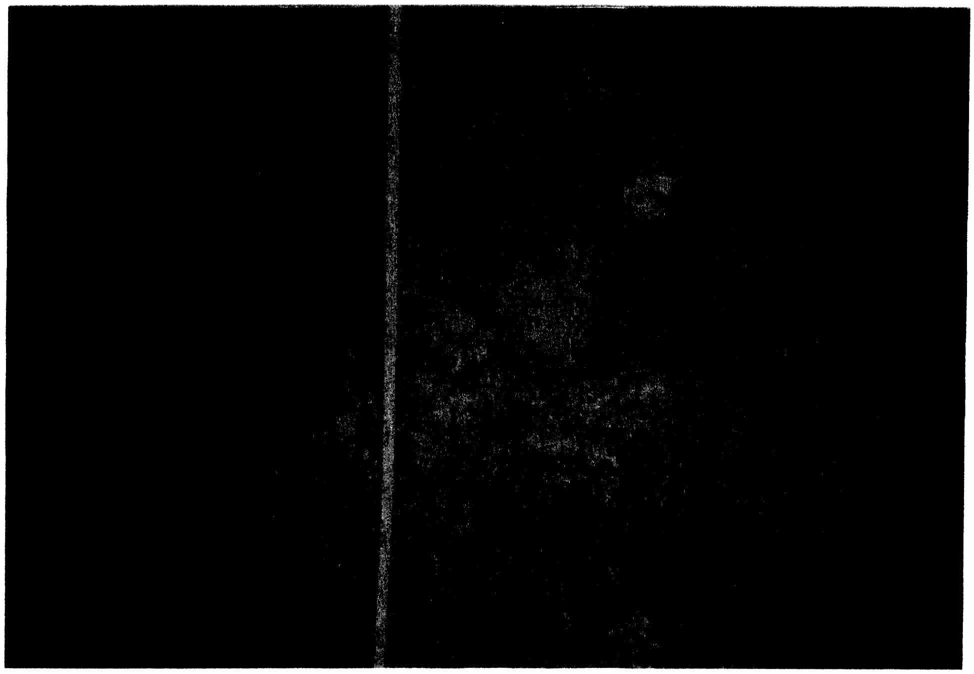

Figure 12. An area of DLN in October of 1990, after the sediment had moved off the reef top. Note the lack of algal, sponge and invertebrate cover on the bottom.

APPENDIX 1

Enumeration of level and extent of impact within the 6 impact tracts identified.

DLS-1 - heading 150-160°/ 330°-340°

Distance from reef edge (m)	Width of tract (m)	% destroyed	Area (m^2) impacted	Area (m^2) Destroyed	Comment
5.0	1.2	75-100	6.0	5.25	Tract as wide as1.8m.
10.0	1.2	"	6.0	5.25	Tract as wide as 2.1 m
15.0	0.8	"	4.0	3.25	Tract as wide as 2.45 m
18.9	0.2	50-75	0.8	0.49	End of damage

Baseline @ 16.9m.
Area impacted = 16.80m^2; area destroyed = 14.24m^2.
A 30 cm gap (no scrape marks present) appears in the approximately 1 to 1.3 m from the edge of the damage tract.

DLS-2 - this is a small damage tract. The area has numerous gullies and impact was confined to the higher parts of the reef. Therefore each area of impact (3 in total) was measured (length and width) rather than the interval method used on the other tracts.

Distance from reef edge (m)	Length of impact (m)	Width of impact (m)	% destroyed	Area (m^2) impacted	Area (m^2) destroyed
0.0	2.20	1.40	75-100	3.08	2.70
2.3	2.70	0.50	"	1.35	1.18
6.8	1.50	0.25	"	0.38	0.33

Baseline @ 10.34m. - damage ended @ 8.3m.
Area impacted = 4.81 m^2; area destroyed = 4.21m^2.

DLS-3 - bearing 150-160°/330°-340°

Distance from reef edge (m)	Width of tract (m)	% destroyed	Area (m^2) impacted	Area (m^2) destroyed	Comments
2.5	1.00	25-50	2.50	0.94	
5.0	1.70	75-100	4.25	3.72	35cm gap @ 1.00-1.35m
7.5	1.05	" "	2.62	2.30	
10.0	1.20	" "	3.0	2.62	
12.5	2.00	25-50	5.0	1.88	
15.0	0.50	50-75	1.25	0.78	
18.4	0.10	25-50	0.34	0.09	End of dam.

Baseline @ 11.45m.
Area impacted = 17.701 m^2; Area destroyed = 12.33 m^2

DLS-4 - bearing 0-10°/180-190°

Distance from reef edge (m)	Width of tract (m)	% destroyed	Area (m^2) impacted	Area (m^2) Destroyed	Comments
2.5	0.9	75-100	2.25	1.97	
5.0	2.4	"	6.00	5.25	
7.5	1.0	"	2.50	2.19	
10.0	0.7	"	1.75	1.53	
12.5	0.7	"	1.75	1.53	
13.5	1.5	"	3.75	3.28	
14.7	0.1	"	0.08	0.07	End of dam.

Baseline @ 10.5m.
Area impacted = 18.08m^2; area destroyed = 15.82m^2.

DLS-5 - bearing 5-10°/185-190°

Distance from reef edge (m)	Width of tract (m)	% destroyed	Area (m^2) impacted	Area (m^2) destroyed	Comments
2.5	1.7	75-100	4.25	3.72	Path ext. to 3.5m w/ width of 1.7m.
5.0	0.4	25-50	2.00	0.75	End of damage

Baseline @ 11.1m. (+6.1m from end of damage).
Area impacted = 6.25 m^2; area destroyed = 4.47 m^2.

DLS-6 - bering 0-10°/180-190°

Distance from reef edge (m)	Width of tract (m)	% destroyed	Area (m^2) impacted	Area (m^2) destroyed	Comments
2.5	0.7	75-100	1.75	1.51	
5.0	1.7	75-100	4.25	3.72	
7.5	0.7	50-75	1.75	1.09	
9.8	0.2	50-75	0.42	0.26	End of dam.

Baseline @ 2.8
Area impacted 8.17m^2; area destroyed = 6.58m^2.

DLS-7 - bearing 20°/200°

Distance from reef edge (m)	Width of Impact (m)	% Destroyed	Area (m^2) impacted	Area (m^2) destroyed	Comments
2.5	1.7	75-100	4.2	3.72	
5.0	2.4	"	6.00	5.25	
7.5	2.0	"	5.00	4.38	
10.0	0.8	50-75	2.00	1.25	
10.5					End of damage

Baseline @ +4m.
Area impacted = 17.25m^2, area destroyed = 14.60m^2.

DLS-8 - bearing 60°/120°

Distance from reef edge (m)	Width of Impact (m)	% Destroyed	Area (m^2) impacted	Area (m^2) Destroyed	Comments
2.5	0.8	75-100	2.00	1.75	
5.0	0.6	"	1.50	1.31	
7.5	0.8	50-75	2.00	1.25	
10.0	1.0	75-100	2.50	2.19	
12.5	0.7	"	1.75	1.53	
15.0	0.9	50-75	2.25	1.41	
17.5	1.1	75-100	2.75	2.41	
20.0	0.8	50-75	2.00	1.25	End of damage

Baseline @ 0.0m.
Area impacted = 16.75m^2, area destroyed = 13.10m^2

APPENDIX 2

Turbidity measurements in N.T.U.'S (Nephlometric Turbidity Units) for each dredge load, taken from a depth of 0.5 feet at three points: 150 m behind the dredge (150M), 100 m to the left of point 150M (100ML), 100 m to the right of point 150M (100MR) and control sample (NTRL).

LOAD #	DATE	150M	100ML	100MR	CNTRL
1	-	-	-	-	-
2	MAY 7	1.3	0.7	0.7	0.4
3	MAY 8	0.8	0.6	1.5	0.5
4	MAY 8	1.5	1.9	1.1	0.4
5	MAY 8	0.6	1.1	1.3	0.5
6	MAY 9	1.7	0.6	2.2	0.9
7	MAY 9	1.5	1.9	2.0	0.5
8	MAY 10	0.8	0.4	0.4	0.4
9	MAY 10	1.6	1.4	1.0	0.4
10	MAY 10	-	-	-	-
11	MAY 11	1.7	1.1	1.0	0.7
12	MAY 12	3.3	4.4	0.4	0.3
13	MAY 11	1.2	1.6	0.4	0.3
14	MAY 12	0.7	0.7	0.7	0.5
15	MAY 12	0.8	0.6	1.4	1.4
16	MAY 13	3.8	0.8	0.8	0.4
17	MAY 13	-	-	-	-
18	MAY 14	1.7	1.0	1.0	0.6
19	MAY 14	4.3	4.1	6.6	0.5
20	MAY 15	1.8	1.5	3.1	0.9
21	MAY 15	4.9	4.0	3.4	1.2
22	MAY 16	2.1	2.7	3.1	0.9
23	MAY 16	3.5	2.2	1.5	1.1
24	MAY 17	3.5	1.2	0.9	-
25	MAY 19	4.7	2.8	1.7	0.8
26	MAY 20	4.7	2.0	2.5	3.5
27	MAY 20	2.8	1.8	2.0	1.1
28	MAY 20	9.7	3.5	3.4	0.7
29	MAY 21	-	-	-	-
30	MAY 21	1.0	0.9	0.8	0.6
31	MAY 21	4.3	3.5	5.8	2.1
32	MAY 22	2.5	1.4	0.8	0.7
33	MAY 22	3.6	2.0	1.1	0.8
34	MAY 22	2.7	1.6	1.7	0.5
35	MAY 23	4.1	1.0	1.2	0.6
36	MAY 23	3.5	2.3	2.8	1.7
37	MAY 23	3.8	2.9	1.6	1.1
38	MAY 24	2.6	1.2	1.3	0.8
39	MAY 24	-	-	-	-
40	MAY 25	3.6	4.1	4.4	4.6
41	MAY 25	3.9	4.9	1.8	2.2
42	MAY 26	4.7	4.5	4.0	1.2
43	MAY 26	3.3	4.0	1.4	0.9
44	MAY 26	3.4	1.8	2.7	0.8
45	MAY 27	-	-	-	-

LOAD #	DATE	150M	100ML	100MR	CNTRL
46	MAY 27	4.7	1.7	3.2	1.1
47	MAY 28	-	-	-	-
48	MAY 28	8.8	4.2	1.5	1.2
49	MAY 29	1.1	1.3	0.8	0.6
50	MAY 29	2.9	1.9	1.7	0.9
51	MAY 30	2.2	2.0	3.0	0.8
52	MAY 28	4.7	2.8	2.6	8.6
53	JUNE 1	3.7	2.4	2.3	1.9
54	JUNE 1	-	-	-	-
55	JUNE 2	2.1	2.4	1.1	1.4
56	JUNE 2	2.2	1.1	2.2	1.0
57	JUNE 3	4.8	2.0	1.4	1.0
58	JUNE 3	3.0	1.8	2.1	1.0
59	JUNE 3	1.8	1.2	1.4	1.0
60	JUNE 4	1.0	2.0	2.7	1.0
61	JUNE 4	3.0	5.9	2.4	0.6
62	JUNE 4	5.8	5.0	1.2	1.0
63	JUNE 5	2.5	1.1	0.8	-
64	JUNE 5	6.7	1.2	2.4	0.9
65	JUNE 6	1.9	1.4	5.2	0.8
66	JUNE 6	7.7	1.3	2.9	0.8
67	JUNE 7	3.8	1.0	1.8	1.0
68	JUNE 7	12.0	1.6	1.5	0.9
69	JUNE 8	5.3	1.6	2.8	2.3
70	JUNE 8	7.7	2.7	3.7	1.1
71	JUNE 9	3.1	1.8	1.3	0.8
72	JUNE 9	17.0	1.0	1.7	1.5
73	JUNE 10	4.5	1.3	2.0	1.4
74	JUNE 10	3.3	1.1	1.2	0.8
75	JUNE 11	-	-	-	-
76	JUNE 11	4.3	1.8	2.2	0.8
77	JUNE 11	12.0	8.1	3.4	2.1
78	JUNE 12	0.7	1.2	0.6	0.7
79	JUNE 12	1.7	1.6	1.1	0.7
80	JUNE 13	1.2	1.8	1.7	0.8
81	JUNE 13	4.7	1.2	1.4	0.8
82	JUNE 13	8.8	3.4	2.6	1.8
83	JUNE 14	1.8	1.1	1.7	0.7
84	JUNE 14	3.1	2.8	2.1	0.8
85	JUNE 15	1.8	1.2	1.4	0.7
86	JUNE 15	2.6	1.9	2.9	1.6
87	JUNE 16	2.1	1.1	0.9	0.7
88	JUNE 16	3.5	2.9	2.1	0.8
89	JUNE 17	6.4	54.3	2.3	-
90	JUNE 17	1.2	3.1	1.0	0.8
91	JUNE 18	2.3	1.9	2.3	1.3
92	JUNE 18	1.5	1.0	1.7	0.7
93	JUNE 18	0.8	0.9	1.3	0.6
94	JUNE 19	-	-	-	-
95	JUNE 19	2.6	1.8	2.6	0.9
96	JUNE 20	6.5	3.0	2.8	1.5

LOAD #	DATE	150M	100ML	100MR	CNTRL
97	JUNE 21	2.6	2.1	1.4	1.2
98	JUNE 21	1.9	1.4	1.7	1.3
99	JUNE 22	7.2	2.1	1.8	1.1
100	JUNE 22	7.0	1.2	1.1	0.6
101	JUNE 23	1.8	5.4	3.0	1.3
102	JUNE 23	4.3	2.1	0.8	0.7
103	JUNE 23	-	-	-	-
104	JUNE 24	3.4	1.7	1.1	0.8
105	JUNE 24	6.5	2.0	1.9	0.9
106	JUNE 25	5.6	3.1	2.7	0.9
107	JUNE 26	6.5	4.1	2.6	1.3
108	JUNE 26	-	-	-	-
109	JUNE 27	3.1	2.8	5.1	2.1
110	JUNE 27	11.0	2.6	1.7	0.7
111	JUNE 27	1.2	1.8	2.4	1.6
112	JUNE 28	-	-	-	-
113	JUNE 28	1.2	1.4	1.1	1.3
114	JUNE 28	4.3	2.1	1.6	0.7
115	JUNE 29	3.9	3.0	1.9	0.9
116	JUNE 30	2.4	1.3	0.9	0.7
117	JUNE 30	2.7	1.9	1.3	1.1
118	JULY 1	1.2	3.2	1.1	0.7
119	JULY 1	-	-	-	-
120	JULY 2	6.1	2.2	1.7	-
121	JULY 2	3.6	2.8	1.9	1.2
122	JULY 3	5.5	1.7	3.4	0.7