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Effects of No. 6 Oil and Selected Remedial Options in Tropical Seagrass Beds

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INTRODUCTION

On January 7, 1994, the barge *Morris J. Berman*, carrying 1.4 million gallons of No. 6 fuel oil, grounded on a reef north of San Juan Bay, Puerto Rico. The collision ruptured seven of nine compartments in the barge, spilling approximately 713,269 gallons of oil by January 9. On that date, the oil-contaminated area included an estimated five kilometers of coastline and over 30 square kilometers of sea surface. This impact area gradually grew during subsequent days. Operations to contain the spill and clean shorelines began almost immediately, and shoreline cleanup continued until May 28, 1994.

Within the impact area, Laguna del Condado was a point of particular interest, with respect to both socioeconomic and biological considerations. This body of water is near the barge grounding site (Figure 1), and its northern portion (where the mouth of the lagoon opens to the ocean) was heavily oiled. This section of Laguna del Condado includes a sandy beach popular with tourists and locals, patch reefs visited by snorkelers and scuba divers, a waterway frequented by recreational boat traffic, and seagrass beds and small mangrove communities.

Seagrasses play an important role in tropical, temperate, and Subarctic coastal ecosystems. They provide food, shelter, and nursery habitat for many organisms, including protected and endangered species (Vicente et al. 1980, McLaughlin et al. 1983, Kenworthy et al. 1988). Seagrass is an invaluable component of the local ecosystem; even sparse seagrass cover results in high rates of primary productivity.

In northern Puerto Rico, seagrass beds are less abundant and distributed more sparsely than in other parts of the island due to hydrodynamic and coastal characteristics (exposure to wave action of the Atlantic Ocean and an abundance of rocky shoreline). The seagrass beds in northern Puerto Rico are a sensitive and valuable resource because of these limitations and the inherent value of seagrass as food and habitat. This study used the *Morris J. Berman* spill as an opportunity to evaluate the effects of oil and selected remedial techniques on seagrass beds in Laguna del Condado.

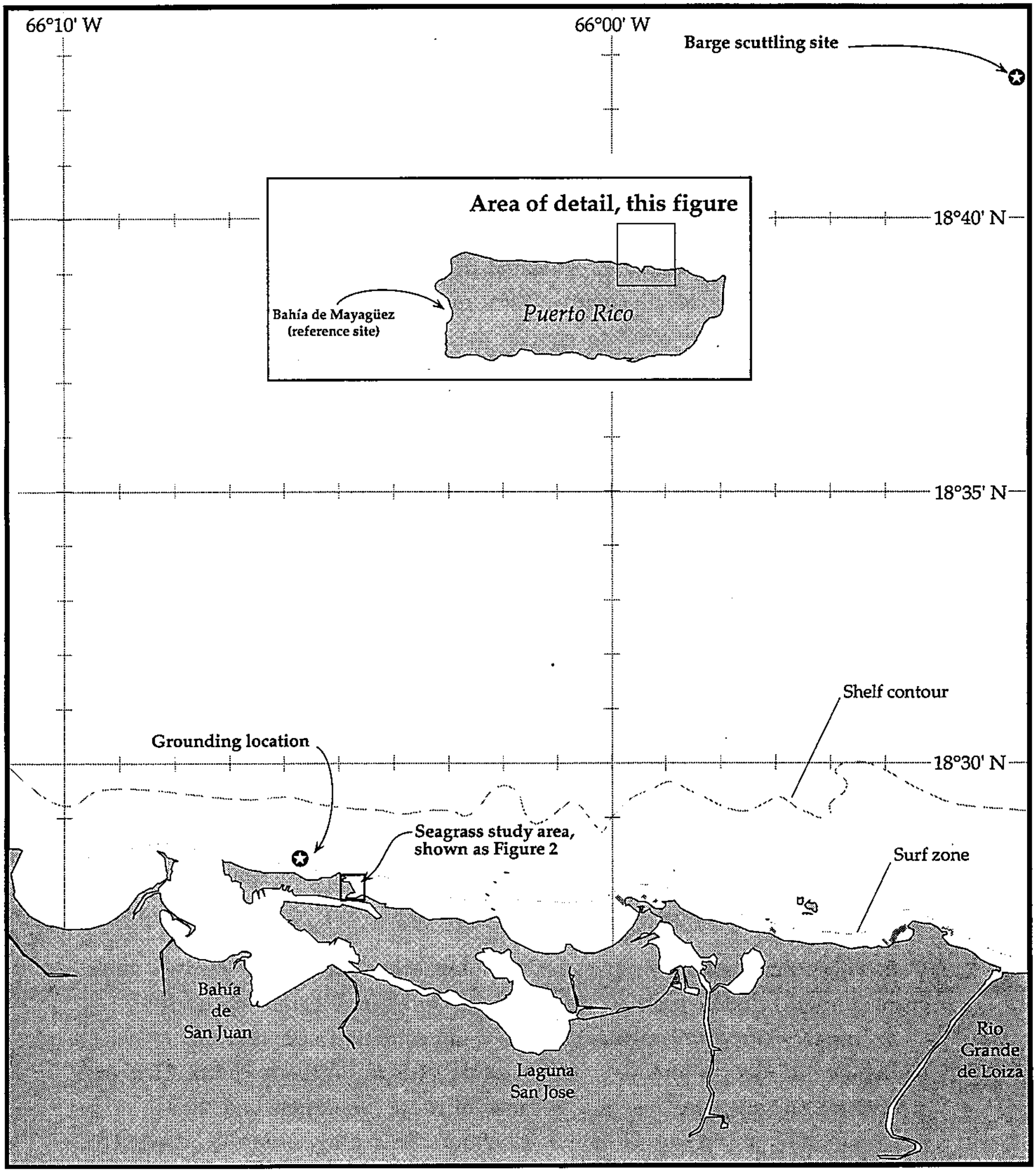

Figure 1. Map of the northern coastline of Puerto Rico, showing locations of the *Morris J. Berman* grounding and scuttling, the study area for the seagrass investigation, and the Mayagüez Bay reference site (above, inset).

MATERIALS AND METHODS

The main study site was near the mouth of Laguna del Condado, north of Dos Hermanos Bridge, in San Juan, Puerto Rico (Figure 2). This bay was approximately 300 m wide (east to west) and up to 5 m deep. The bottom substrate is mostly sand with occasional rock outcrops and supported seagrass beds, including the species most common in the West Indies: turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), sea vine (*Halophila decipiens*) and shoal grass (*Halodule wrightii*). *Thalassia* was the most abundant species. Seagrass beds in the middle section of the bay are relatively sparse, compared with those along the east and west sides. This difference can probably be attributed to the higher wave energy conditions in the central portion of the bay.

The barge spilled a heavy No. 6 fuel oil with a reported American Petroleum Institute gravity of 9.5. This suggested that the product was less dense than seawater when spilled, and therefore could be expected to float. However, *submerged* oil from the barge was later observed in many areas, including Laguna del Condado. (Petrae [1995] discusses possible explanations for the oil sinking.) Seagrass beds were thus exposed to both floating oil moving through blades exposed at lower tides, and also to submerged oil in contact with the bottom substrate.

Most of Laguna del Condado was exposed to oil from the barge spill on January 7, but the extent of contamination was not uniform when inspected two to three weeks after the spill. For example, although oil was not observed on seagrasses in the eastern third of the lagoon, much of the seagrasses observed in the western third were coated with oil.

Four transect lines were established in the study area (Figure 2). Each transect line consisted of a 6-meter long string tied between two metal (rebar) stakes driven into the substrate at a water depth of about 2 m. Transects 1 and 2 were placed about 50 m from the eastern shore (Figures 2, 3, and 5) and first assessed on February 1994; no oil was observed in that area at that time. Transects 3 and 4 were placed and first assessed on February 17, 1994, about 30 m from the western shore (Figures 2, 4a, 4b, and 6). Shoreline assessment Zone 1B, delineated in Figure 2, was heavily oiled after January 7 and had

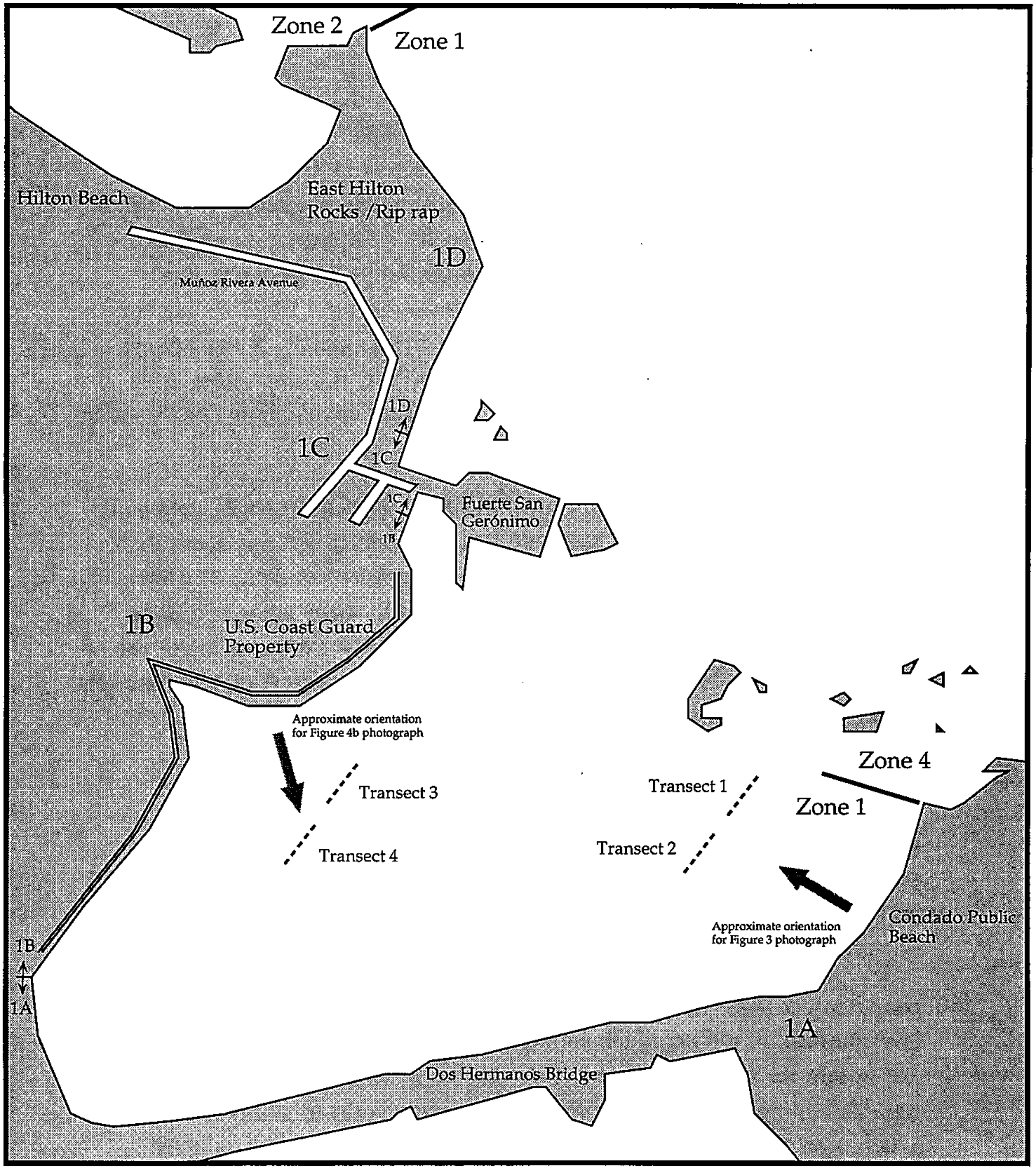

Figure 2. Map of entrance to Laguna del Condado, showing approximate location of seagrass study transects and orientation for photographs in Figures 3 and 4.

Figure 3. March 14, 1994 photograph from eastern shore of Laguna del Condado study area facing northwest. Transects 1 & 2 were located near center of photo on far side of buoys marking swimming area. Refer to Figure 2 for orientation.

been a site of intensive cleanup operations. Diver operations to manually remove submerged oil in Zone 1B were completed and discontinued on February 15. Seagrasses in Transects 3 and 4 appeared to be lightly oiled when the transect lines were established.

Selected remedial actions were tested on experimental plots at each transect and compared with control (untreated) plots. Generic oil cleanup options under consideration for seagrass beds included manual removal, vacuum pumping, dredging, flushing, sorption, vegetation cropping, and natural cleansing. The NOAA scientific advisory team discouraged using the more intrusive options on seagrass beds because of the potential to further damage the ecosystem.

Figure 4a. February, 1994 aerial photograph showing seagrass study area for Transects 3 and 4. View is facing to the southwest; Dos Hermanos Bridge is visible in upper left. Refer to Figure 2 for orientation within Laguna del Condado.

Figure 4b. March 19, 1994 photograph from western shore of Laguna del Condado study area facing south. Diver's head marks surface location of Transects 3 and 4. Refer to Figure 2 for orientation.

The current study examined sorption, vegetation cropping, and natural cleansing. Since natural cleansing constituted an absence of treatment, control plots fell into this category. Experimental plots were subjected to sorption (wiping with sorbent material) and vegetation cropping (cutting leaves at substrate level). The former option was tested by wiping grasses in a 20-cm by 2-m section at both Transects 1 and 3 with adsorbent polyethylene "pom-poms," a commonly used oil spill cleanup item. The latter option was tested by cutting grasses in 20-cm by 2-m section at both Transects 2 and 4 (one plot along Transect 2 is shown in Figures 7a and 7b). The remainder of each transect served as control plots. Parameters measured at experimental plots were compared with controls to assess the effects of each remedial option.

After initial assessments, seagrasses were monitored at biweekly intervals during March and April 1994. Thereafter, seagrass assessments were performed monthly through March 1995. For comparison, two transects (designated 5 and 6) were established in seagrass beds in Mayagüez Bay (western Puerto Rico, see Figure 1) in an area unaffected by the *Morris J. Berman* oil spill. These transects were established in September 1994 and monitored monthly through March 1995.

The study site in Mayagüez Bay was characterized primarily by a sandy bottom supporting seagrass beds of *Thalassia* and *Syringodium.* Transects 5 and 6 were 1.5 m and 3 m deep, and 10 m and 25 m from shore, respectively.

The following parameters were evaluated in the seagrass beds:

Shoot counts

Plant density was determined by counting the number of shoots per 20-cm^2 plot at regular 0.5 m intervals (12 replicates) along each transect.

Growth of leaves subjected to vegetative cropping

In each cut section at transects 2 and 4, the length of 20 *Thalassia* leaves was measured to the nearest 1 mm.

Figure 5. Transect 1 closeup on March 19, 1994, showing mix of *Thalassia testudinum* (broad flat blades) and *Syringodium filiforme* (narrower cylindrical blades).

Weight of above-ground biomass

Standing crop was quantified in selected plots near the transects on the east and west sides of Laguna del Condado. *Thalassia* leaves were cut above the substrate to determine biomass weights in two adjacent 20-cm^2 plots near Transects 2 and 4. To avoid cutting the same area during subsequent assessments and to avoid interfering with control and experimental plots, the cut sections were located a meter away from each transect line, and a different section was cut each time (Figure 5). Each cut sample was allowed to dry in a mesh bag overnight before weighing the biomass to the nearest gram.

Morphometry

External morphology was recorded as leaf length and width measured to the nearest millimeter. These data were recorded in the laboratory from

Figure 6. Transect 3 overview on March 16, 1994. Section marked by flagging tape was wiped with sorbent material on March 17, 1994.

25 randomly selected *Thalassia* blades from each sample of cut leaves (east and west sides of lagoon).

Growth rates

A metal staple was placed at the base of each of six *Thalassia* leaves at each transect to determine the subsequent amount grown between the staple and base of the leaf.

Statistical analyses were performed to detect the following differences:

- **a** seagrasses exposed to light versus heavy oil contamination (e.g., Zone 1A on the east side versus Zone 1B on the west side of Laguna del Condado);
- **b** remedial options (experimental treatments versus controls); and
- **c** oiled vs. non-oiled sites (Laguna del Condado versus Mayagüez Bay).

When the latter comparisons were made, the Condado data were limited to those collected between September 1994 and March 1995 (the period during which the Mayagüez data were collected). Simple regressions were used to detect changes in seagrasses over time. Mann-Whitney U was used to test for differences between two groups, and Kruskal-Wallis test with Dunn's multiple comparison was used when analyzing more than two groups. All values were corrected for ties. An alpha of 0.05 was taken to indicate statistical significance, and all tests were two-tailed.

RESULTS

Transect 1 included the seagrasses *Thalassia testudinum* and *Syringodium filiforme*. All other transects consisted of *Thalassia* only. For consistent comparisons, only measurements of *Thalassia* leaves were analyzed. Attempts to measure growth using metal staples placed on *Thalassia* blades during February and March were unsuccessful; stapled blades could not be relocated. It was suspected that the staples fell out or that stapled blades broke off before later assessments.

During mid-March, markers for Transect 1 disappeared (probably dragged away by a boat anchor) and were replaced in the same area. At the end of March, one-third of Transect 1 was missing (again, probably due to boat traffic). The remaining portion of the transect was assessed at that time. Transect 1 subsequently disappeared again and was not assessed during April. In May, the transect was re-established in the same area, and shoot counts were resumed. Both Transects 2 and 4 disappeared in July. The general vicinity of these transects was known so that shoot densities and cut sample measurements were continued. However, the exact locations of cut plots at those two transects were indistinguishable from the surrounding grassbeds, and measurements of blade in cut plots had to be abandoned. All data from monthly assessments through March 1995 are presented for Laguna del Condado in Appendix 1, and for Mayagüez Bay in Appendix 2.

Seagrass plots subjected to surface wiping appeared indistinguishable from untreated areas, both before and after being wiped with sorbent material. Shoot densities in wiped plots did not differ from those in control plots within the same transect ($p = 0.9590$ for Transect 1 and $p = 0.8773$ for Transect 3). However, shoot densities differed significantly among transects (Table 1a). Both transects in Zone 1B had higher densities than those in Zone 1A. During the period of September 1994-March 1995, shoot densities in Mayagüez Bay were the same as Zone 1B and greater than Zone 1A. When comparisons were made among all six transects, Transect 1 had significantly lower shoot densities than all others.

Thalassia shoots decreased significantly in density over time in all four transects in Laguna del Condado (Table 1b). In contrast, both transects in Mayagüez increased in shoot density between September 1994 and March 1995, although this increase was not significant at Transect 5. When Condado transects were analyzed for this time period, the decrease in shoot density was still evident, although this decrease was not significant at Transect 2. On closer inspection of the data, it was noted that all Condado transects actually increased in shoot density between February and April 1994. During May 1994, the trend of decreasing shoot density became clearly evident. This phenomenon was observed at all transects regardless of location in Laguna del Condado.

Growth of *Thalassia* blades in plots subjected to vegetative cropping were significantly greater in Zone 1B than in 1A (Table 2a). During the time that blade lengths were measured in cut plots (March to June 1994), leaves increased in length through March, then decreased in April, resulting in a significantly negative trend for the entire time period in both zones (Table 2b).

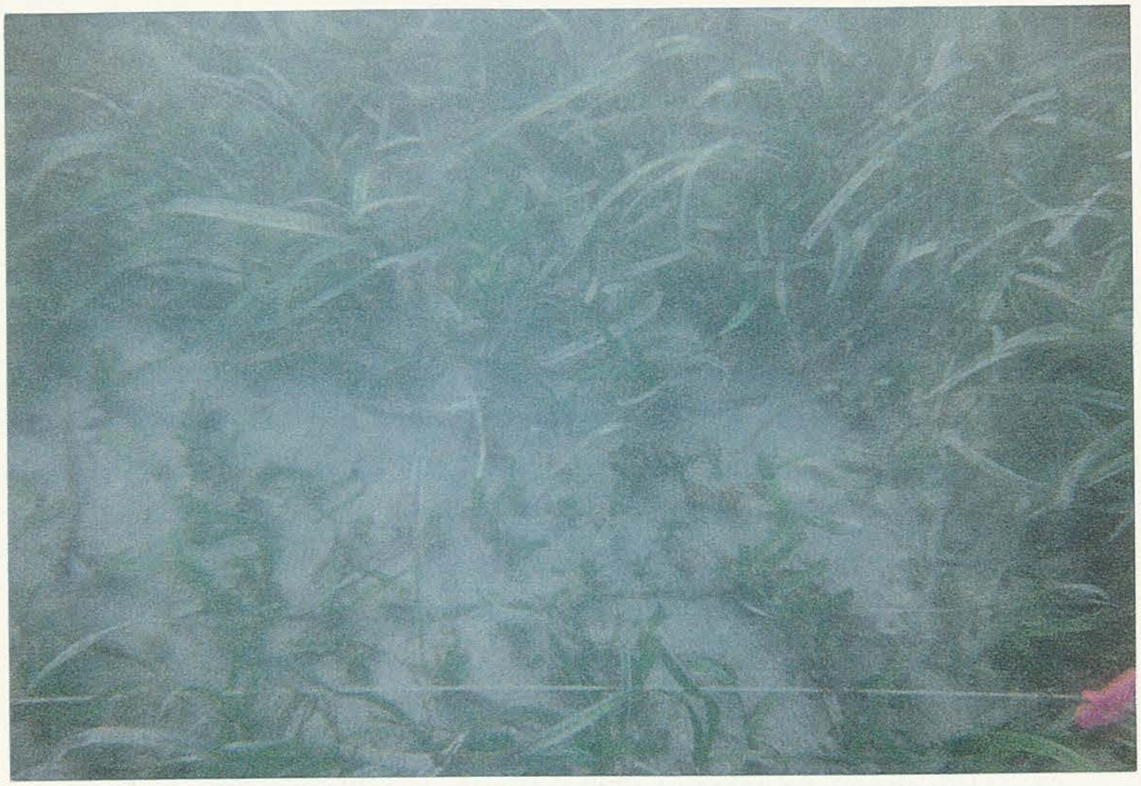

Figure 7a. Transect 2, 2 m X. 20 cm section of vegetation cropping cut on February 16, 1994.

Figure 7b. Transect 2, 2 m X. 20 cm section of vegetation cropping, March 19, 1994. Note new growth over one month elapsed since Figure 7a.

Table 1. Analyses of *Thalassia* shoot densities in 20- x 20-cm plots (12 plots per transect on each day assessed). Laguna del Condado, divided into Coast Guard-designated Zone 1A (lightly oiled) and Zone 1B (heavily oiled), was assessed on 17 dates during February 1994 to March 1995. Zone 1A included Transects 1 and 2; Zone 1B included Transects 3 and 4. The Mayagüez Bay zone (not oiled) included Transects 5 and 6 and was assessed on seven dates during September 1994 to March 1995.

a. Results of Mann Whitney-U tests (comparisons of two groups) and Kruskal Wallis-Dunn tests (comparisons of more than two groups). In the Test Result column, sites with the same letter are not significantly different at p = 0.05.

Site	Dates	Median # Shoots	Test Result	p
Zone 1A	Feb 94-Mar 95	9	A	0.0001
Zone 1B	Feb 94-Mar 95	10	B	
Transect 1	Feb 94-Mar 95	9	A	0.0001
Transect 2	Feb 94-Mar 95	10	A	
Transect 3	Feb 94-Mar 95	10	B	
Transect 4	Feb 94-Mar 95	11	B	
Zone 1A	Sep 94-Mar 95	8	A	0.0008
Zone 1B	Sep 94-Mar 95	9	B	
Mayagüez	Sep 94-Mar 95	9	B	
Transect 1	Sep 94-Mar 95	8	A	0.0001
Transect 2	Sep 94-Mar 95	9	B	
Transect 6	Sep 94-Mar 95	9	B	
Transect 4	Sep 94-Mar 95	9	BC	
Transect 3	Sep 94-Mar 95	9	C	
Transect 5	Sep 94-Mar 95	9	C	

b. Results of simple regression analysis of changes in shoot density over time.

Site	Dates	r^2	Equation	p
Transect 1	Feb 94-Mar 95	0.5345	y = -0.40x + 13.36	0.0001
Transect 2	Feb 94-Mar 95	0.3899	y = -0.32x + 12.99	0.0001
Transect 3	Feb 94-Mar 95	0.4641	y = -0.44x + 15.23	0.0001
Transect 4	Feb 94-Mar 95	0.4469	y = -0.40x + 14.54	0.0001
Transect 5	Sep 94-Mar 95	0.0131	y = 0.06x + 8.08	0.3392
Transect 6	Sep 94-Mar 95	0.2453	y = 0.30x + 2.88	0.0001
Transect 1	Sep 94-Mar 95	0.1666	y = -0.24x + 10.95	0.0004
Transect 2	Sep 94-Mar 95	0.0164	y = -0.07x + 9.55	0.2843
Transect 3	Sep 94-Mar 95	0.0902	y = -0.20x + 11.81	0.0104
Transect 4	Sep 94-Mar 95	0.1124	y = -0.21x + 11.84	0.0041
Transect 1	Feb 94-Apr 94	0.2205	y = 0.93x + 9.92	0.0008
Transect 2	Feb 94-Apr 94	0.0626	y = 0.33x + 10.99	0.0344
Transect 3	Feb 94-Apr 94	0.0499	y = 0.32x + 12.44	0.0591
Transect 4	Feb 94-Apr 94	0.3062	y = 0.77x + 11.22	0.0001

Table 2. Analyses of growth of *Thalassia* blades from 20 x 20 cm plots subjected to vegetative cropping in Transect 2(Zone 1A) and Transect 4 (Zone 1B) in Feb 1994. Measurement of blade growth began in Mar 1994 and was assessed on eight dates until June 1994. Laguna del Condado was divided into Coast Guard designated Zone 1A (lightly oiled) and Zone 1B (heavily oiled).

a. Results of Mann Whitney-U test (comparisons of two groups). Under the Test Result column, sites represented by the same letter are not significantly different at p = 0.05.

Site	Dates	Median Length (mm)	Test Result	p
Zone 1A	Mar 94-Jun 94	190	A	0.0001
Zone 1B	Mar 94-Jun 94	215	B	

b. Results of simple regression analysis of changes in growth over time.

Site	Dates	r^2	Equation	p
Zone 1A	Mar 94-Jun 94	0.0527	$y = -3.40x + 204.87$	0.0117
Zone 1B	Mar 94-Jun 94	0.1524	$y = -7.54x + 249.43$	0.0001

Biomass weight differed significantly among zones (Table 3a). *Thalassia* biomass was greater in Zone 1B than 1A, although this difference was near the borderline of significance. When biomass weighed during September 1994 to March 1995 were compared among study sites, seagrasses in Mayagüez had weights intermediate between Zones 1A and 1B. While Mayagüez data did not differ between the two Condado zones, Zone 1B weighed significantly more than 1A.

Biomass decreased in weight over time at both Condado zones, although this change was not significant at 1B (Table 3b). This same trend was evident in both zones during September 1994 to March 1995. In contrast, biomass increased significantly in weight in Mayagüez.

Table 3. Analyses of biomass of *Thalassia* blades cut from two adjacent 20 x 20 cm plots in each zone on each date of assessment. Laguna del Condado was divided into Coast Guard designated Zone 1A (lightly oiled) and Zone 1B (heavily oiled) and was investigated on 17 dates during February 1994 to March 1995. The zone in Mayagüez Bay (not oiled) was investigated on seven dates during September 1994 to March 1995.

a. Results of Mann Whitney-U tests (comparisons of two groups) and Kruskal Wallis-Dunn tests (comparisons of more than two groups). Under the Test Result column, sites represented by the same letter are not significantly different at $p = 0.05$.

Site	Dates	Median Weight (g)	Test Result	p
Zone 1A	Feb 94-Mar 95	120	A	0.0563
Zone 1B	Feb 94-Mar 95	139	B	
Zone 1A	Sep 94-Mar 95	102	A	0.0193
Mayagüez	Sep 94-Mar 95	123	AB	
Zone 1B	Sep 94-Mar 95	136	B	

b. Results of simple regression analysis of changes in biomass weight over time.

Site	Dates	r^2	Equation	p
Zone 1A	Feb 94-Mar 95	0.4553	$y = -3.83x + 149.58$	0.0058
Zone 1B	Feb 94-Mar 95	0.2383	$y = -2.33x + 157.29$	0.0649
Mayagüez	Sep 94-Mar 95	0.7204	$y = 4.52x + 37.02$	0.0157
Zone 1A	Sep 94-Mar 95	0.7746	$y = -4.71x + 161.21$	0.0090
Zone 1B	Sep 94-Mar 95	0.3116	$y = -5.36x + 193.43$	0.1928

Blade morphology differed significantly during the study period (Tables 4a and 5a). Blade length was greater in Zone 1B while blade width was greater in Zone 1A. However, during September 1994 to March 1995, both measurements were greater in Zone 1A. When length measurements were compared among all study sites for this time period, median blade length in Zone 1A was the same as Transect 6; Zone 1B and Transect 5 had shorter blade lengths. Both Zones 1A and 1B blades were wider than those in Transects 5 and 6.

Blade morphology also varied significantly over time (Tables 4b and 5b). From February 1994 to March 1995, *Thalassia* blade lengths decreased in both Condado zones (although this change was not significant in Zone 1A).

Between September 1994 and March 1995, both transects in Mayagüez increased in blade length (not significant in Transect 6). During the same period in Condado, Zone 1B decreased in length while 1A showed an insignificant increase. *Thalassia* blades decreased in width between February 1994 and March 1995 in Zone 1A and increased in Zone 1B. Between September 1994 and March 1995, both Condado zones and both Mayagüez transects increased significantly in blade width.

DISCUSSION

The results of this study indicated several general trends. Shoot density, growth of cut plots, and biomass weight were greater in the heavily oiled west side of Laguna del Condado than in the lightly oiled east side. Shoot density and biomass weight in the west side did not differ from those in the unoiled site in Mayagüez Bay. Moreover, both of these sites had greater *Thalassia* density and biomass than the east side of Laguna del Condado. After an initial increase in density and biomass during early spring, these parameters decreased over time in both Condado zones while they increased in Mayagüez.

Blade length was greater in the west than in the east side of Laguna del Condado early in the study period, but during the last half of the investigation, the west side decreased in length over time until it was less than the east side.

Meanwhile, blade length in the east side did not change over time. In contrast, blade width was greater in the east than the west side of Laguna del Condado, but over time, width decreased in the east and increased in the west until there was little difference between them. In general, length and width of *Thalassia* blades in Mayagüez were less than or equal to those in Laguna del Condado. Over time, blade length decreased in the west side while it did not change in the east side of Laguna del Condado and increased over time in Mayagüez.

Variations among the three sites cannot be attributed entirely to exposure to oil. The degree of water motion (i.e., current or surge) appeared to vary considerably across the Laguna del Condado as well as between north and west sides of Puerto Rico; this parameter strongly influences community structure in the marine environment (McGehee 1991; 1994). Additionally, some of the findings may be due to seasonal trends. Spring growth, for example, may be at least partially responsible for increases in growth and density early in the study period.

Table 4. Analyses of *Thalassia* blade lengths of cut specimens (25 blades per zone on each date of assessment). Laguna del Condado was divided into Coast Guard designated Zone 1A (lightly oiled) and Zone 1B (heavily oiled) and was investigated on 17 dates during February 1994 to March 1995. Zone 1A included Transects 1 and 2; Zone 1B included Transects 3 and 4. The zone in Mayagüez Bay (not oiled) included Transects 5 and 6 and was investigated on seven dates during September 1994 to March 1995.

a. Results of Mann Whitney-U tests (comparisons of two groups) and Kruskal Wallis-Dunn tests (comparisons of more than two groups). Under the Test Result column, sites represented by the same letter are not significantly different at $p = 0.05$.

Site	Dates	Median Length (mm)	Test Result	p
Zone 1A	Feb 94-Mar 95	290	A	0.0033
Zone 1B	Feb 94-Mar 95	296	B	
Zone 1A	Sep 94-Mar 95	287	A	0.0018
Zone 1B	Sep 94-Mar 95	275	B	
Zone 1A	Sep 94-Mar 95	287	A	0.0001
Transect 6	Sep 94-Mar 95	287	AB	
Zone 1B	Sep 94-Mar 95	275	BC	
Transect 5	Sep 94-Mar 95	267	C	

b. Results of simple regression analysis of changes in blade length over time.

Site	Dates	r^2	Equation	p
Zone 1A	Feb 94-Mar 95	0.0068	$y = -0.62x + 297.31$	0.1004
Zone 1B	Feb 94-Mar 95	0.1805	$y = -4.12x + 338.06$	0.0001
Transect 5	Sep 94-Mar 95	0.0807	$y = 4.54x + 179.61$	0.0004
Transect 6	Sep 94-Mar 95	0.0066	$y = 1.45x + 254.01$	0.3213
Zone 1A	Sep 94-Mar 95	0.0114	$y = 1.84x + 260.14$	0.1944
Zone 1B	Sep 94-Mar 95	0.2240	$y = -7.07x + 370.01$	0.0001

Table 5. Analyses of *Thalassia* blade widths of cut specimens (25 blades per zone on each date of assessment). Laguna del Condado was divided into Coast Guard designated Zone 1A (lightly oiled) and Zone 1B (heavily oiled) and was investigated on 17 dates during February 1994 to March 1995. Zone 1A included Transects 1 and 2; Zone 1B included Transects 3 and 4. The zone in Mayagüez Bay (not oiled) included Transects 5 and 6 and was investigated on seven dates during September 1994 to March 1995.

a. Results of Mann Whitney-U tests (comparisons of two groups) and Kruskal Wallis-Dunn tests (comparisons of more than two groups). Under the Test Result column, sites represented by the same letter are not significantly different at p = 0.05.

Site	Dates	Median Width (mm)	Test Result	p
Zone 1A	Feb 94-Mar 95	11	A	0.0001
Zone 1B	Feb 94-Mar 95	10	B	
Zone 1A	Sep 94-Mar 95	10	A	0.0252 *
Zone 1B	Sep 94-Mar 95	10	B	
Zone 1A	Sep 94-Mar 95	10	A	0.0001
Zone 1B	Sep 94-Mar 95	10	A	
Transect 5	Sep 94-Mar 95	9	B	
Transect 6	Sep 94-Mar 95	9	B	

* Mean blade width in Zone 1A > Zone 1B (1A x = 10.1; 1B x = 9.8)

b. Results of simple regression analysis of changes in blade width over time.

Site	Dates	r^2	Equation	p
Zone 1A	Feb 94-Mar 95	0.0415	$y = -0.06x + 11.02$	0.0001
Zone 1B	Feb 94-Mar 95	0.0568	$y = 0.06x + 9.01$	0.0001
Transect 5	Sep 94-Mar 95	0.0796	$y = 0.17x + 5.97$	0.0005
Transect 6	Sep 94-Mar 95	0.0466	$y = 0.14x + 6.68$	0.0079
Zone 1A	Sep 94-Mar 95	0.0260	$y = 0.11x + 8.63$	0.0486
Zone 1B	Sep 94-Mar 95	0.0796	$y = 0.18x + 7.41$	0.0005

It is also possible that the introduction of the petroleum hydrocarbons into the seagrass beds may have played an indirect role in the increased growth and density. That existing "native" populations of microorganisms can degrade oil constituents is both well-known and well-described (Atlas 1981; Riser-Roberts 1992; Venosa et al. 1996). Biodegradation of oil itself can release constituents that may serve as nutrients to plants, resulting in increased plant growth. This enhanced growth would diminish as nutrients are used up (Nadathur personal communication 1996). Similarly, the influx of oil into a seagrass environment could also serve as a major carbon source for nitrogen-fixing bacteria. Increased nitrogen-fixing activity by bacterial populations feeding on this carbon source could possibly account for the initial high density, biomass, and length that decreased over time in the west side of Laguna del Condado (Nyman personal communication 1996). The results of the present study clearly cannot elucidate which physical or biological factors were responsible for the initial trends observed in the seagrass beds. They do, however, suggest some relevant topics for further investigation.

OIL AND SEAGRASS LITERATURE

Previous studies conducted after oil spills and under more controlled conditions have indicated that seagrass beds are generally resilient following exposure to petroleum, provided there is little or no prolonged direct contact between plant and oil. The plant community recovers quickly (within a year), while the associated faunal communities (epifauna and benthic) show a short-term decrease and then recover over the course of about two years.

Jacobs (1980) investigated seagrass (*Zostera marina*) community impacts for two years following the *Amoco Cadiz* spill off the coast of Brittany in 1978. Direct effects on the seagrass itself were local and short-term, consisting of the appearance of blackened leaves. However, production of new and apparently unaffected leaf material continued, and the oil-affected leaves were quickly replaced. A sharp numerical decrease was noted in the seagrass-associated benthic community of crustaceans, echinoderms, and other invertebrates, but these recovered over a period of about a year and a half.

In 1984, the American Petroleum Institute sponsored a study of both oil and dispersed oil effects in a tropical ecosystem that included mangroves, corals, and seagrass (*Thalassia testudinum*) beds (Ballou et al. 1989). In 1994, the sites were revisited by members of the original research team to assess long-term effects (Dodge et al. 1995). The primary parameters measured in seagrass beds were plant density, growth rate, leaf area, and invertebrate abundance. All parameters were highly variable. In contrast to other potential effects studied (particularly those in oiled mangrove stands), there were no significant long-term impacts noted in seagrass beds. Although numbers of invertebrates associated with seagrass beds were reduced after oil exposure, these communities had recovered after two years.

Following the Gulf War oil spills in 1991, Kenworthy et al. (1993) examined the distribution, species composition, abundance, and productivity of seagrasses (*Halodule uninervis* and *Halophila* spp.) in several oil-contaminated bays on the Saudi Arabian coast. Despite the relatively recent (one year) history of heavy oiling, the seagrasses studied showed no evidence of degradation as a consequence of that exposure. The authors also conducted laboratory experiments and found that short-term exposure of seagrasses to the water-soluble fraction of a one-percent aqueous solution of crude oil caused no apparent acute toxicity.

More relevant to the *Morris J. Berman* spill, past experiences with seagrass oiling in Puerto Rico have resulted a varying degree of observed effect. One of the few instances where a serious effect on seagrass beds was documented occurred in 1962, when the tanker *Argea Prima* grounded off Guayanilla Bay on Puerto Rico's southern coast. Crude oil dumped by the tanker in an effort to refloat itself impacted the nearshore zone, and beds of *Thalassia testidinum* deteriorated over several months (Diaz-Piferrer 1962). Longer-term effects of the spill, and the nature of seagrass recovery from it, have not been reported.

Nadeau and Bergquist (1977) reported on the effects of Venezuelan crude from the 1973 *Zoe Colocotronis* spill off the southern coast of Puerto Rico, and noted that *Thalassia* seagrass flats were contaminated by oil entrained into the water column by surf action and that oil coated leaves. Much of the *Thalassia* thus affected subsequently died and washed away, exposing the underlying substrate and rhizome matrix. However, ten months later the authors recorded "rejuvenated" *Thalassia* growth; by 1976 the flat had returned to a state comparable to that existing at the time of the spill.

In December 1978, the barge *Peck Slip* grounded and spilled Bunker C oil off the northeast corner of Puerto Rico. Red mangroves were oiled and several months later were observed to have suffered both defoliation and mortality

(NOAA 1992). While oil was observed to be carried through *Thalassia* meadows by the tide, it did not adhere and no damage to the seagrass was noted (Zieman et al. 1984).

In the laboratory, Thorhaug et al. (1986) tested the tolerance of the three seagrass species of interest in Puerto Rico to both crude oil and chemical dispersants by documenting mortality as well as growth rates. They found that of the three, *Thalassia testudinum* was more resistant to both dispersed oil and oil alone than *Halodule wrightii* and *Syringodium filiforme.* As might be expected, dispersed oil had a greater toxic effect than oil alone.

One of the most extensive reviews of oiling effects on seagrass communities is that of Zieman et al. (1984). The authors suggest that the comparatively minor oil spill damage documented in seagrass systems is in part due to the subtidal location of the beds–resulting in a reduced exposure to oil on the surface of the water. This conclusion was supported by observations made by Foster et al. (1971) during the Santa Barbara oil spill in 1969, in which oil heavily damaged intertidal stands of *Phyllospadix torreyi* , while subtidal and extreme lower intertidal beds were unaffected.

Zieman et al. noted that a large portion of the seagrass plant biomass (a range of 50-85 percent is given) is located below the surface of the substrate and thus is well-protected from water column or substrate-surface impacts. The buried rhizomes provide storage for the plants, and so even when oil damages leaves, seagrasses are readily able to generate new growth.

Potential exists for indirect oiling effects related to seagrass oiling. While it appears that the seagrasses themselves may be less susceptible to direct toxic impacts than other portions of the affected ecosystem, oiled leaves that remain attached to the plants or break off and become part of the floating wrack may serve as a source of contamination to other organisms and other areas. The importance of seagrass beds as both food and habitat has been discussed previously. Lopez (1978) noted the importance of *Thalassia* beds as grazing areas for sea turtles, but also pointed out that 90 percent or more of the energy content of the beds is passed on to higher trophic organisms via detritus. In addition, Chan (1977) found that oiled seagrass wrack in the Florida Keys persisted in the intertidal zone at least one month longer than clean seagrass, which broke down in three weeks.

SUMMARY AND CONCLUSIONS

The results from the *Morris J. Berman* seagrass study are consistent with those observed in many, if not most, seagrass oiling investigations in that little long-term adverse effect from oiling has been documented. Moreover, although problems were encountered in maintaining the integrity of study transects in the more highly trafficked areas, there appeared to be no significant difference in the rate of seagrass bed recovery when remedial actions of surface wiping and vegetation cropping were employed. These observations have two response-related implications:

1. Natural recovery of oiled seagrass beds is a viable response strategy for seagrass beds and, in the absence of other resource or secondary oiling issues, even a preferred approach; and

2. Should concerns about potential exposure of birds, turtles, and other users of seagrass habitat arise, carefully implemented wiping and cropping can reduce the degree of oiling remaining in the bed without adversely affecting the long-term recovery of the seagrass.

More aggressive remedial techniques were considered and ruled out during the *Berman* incident. This decision was at least partially attributable to concerns about disrupting the seagrass and its surrounding substrate and causing greater damage than could be expected from the degree of oiling that occurred. The guidance offered by Zieman et al. (1984) remains very relevant, and should be factored into the oil cleanup decision-making process when seagrass beds are potentially affected:

> Based on the damage that has occurred to seagrass beds from past oil spills, any attempt to utilize oil cleanup procedures around seagrasses should be approached with extreme caution because many cleanup procedures are potentially far more harmful than the damage from the oil...If seagrass leaves are damaged or removed by oil, the system has the capacity for rapid recovery of the leaf canopy if the rhizome-sediment complex is not disturbed. The plants have the capacity to put out new leaves using the stored starch reserves of the rhizomes. Also, the leaves grow from basal meristems that are relatively protected. However, the total destruction of the bed can easily be accomplished if the sediments are sufficiently

disturbed. Thus, all attempts at cleanup should in no case compact, remove, or in any way disturb the rhizome-sediment complex. This will inevitably cause more damage, perhaps of an irreparable nature.

We can summarize the findings of this study to include the following:

- Little evidence of either short- or long-term damage to seagrass beds oiled by the *Morris J. Berman* spill was observed.
- Non-intrusive remedial techniques (sorbent wiping, vegetation cropping) for removing oiled seagrass appeared to have no adverse effect.
- The scope of this study does not permit determining whether the increase in growth of oiled seagrass was attributable to the introduction of spill-related hydrocarbons in the beds.

The *Morris J. Berman* seagrass study was a relatively modest "spill-of-opportunity" research effort initiated to generate useful, response-related information on a resource–seagrass beds–acknowledged to be an extremely important ecosystem component in waters ranging from tropical to Subarctic. As a spill-of-opportunity project implemented during cleanup operations, it was not intended to be a rigorously designed investigation. Nevertheless, we feel that the results are both scientifically sound and consistent with the available literature.

The response-relevant conclusions previously discussed should be integrated into the larger response decision-making context and not viewed in isolation. That is, they are most appropriately considered as part of the overall evaluation of practical and environmental tradeoffs that are common to every spill response. The *Berman* cleanup experience, the subsequent seagrass study, and the available literature suggest the following from a response perspective:

- Direct oiling effects to seagrass beds themselves appear to be less of an environmental concern for response personnel than other resource priorities;
- However, while apparently not harmful to seagrass plants, the presence of oil on attached leaves and floating wrack may present an exposure hazard

to more sensitive organisms and may justify efforts to remove the source of exposure;

- Oil removal techniques more intrusive than wiping and clipping may not be advisable or necessary in seagrass beds unless special and extreme circumstances exist; and

- Regardless of cleanup approach used, disturbance to the seagrass bed substrate and root-rhizome matrix should be studiously avoided.

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APPENDIX I

Table 1. Shoot densities (number of Thalassia plants per 20 by 20 cm plot). Transects 1 and 2 were located in Zone 1A (lightly oiled); Transects 3 and 4, in heavily oiled Zone 1B (east and west sides of Condado Lagoon, respectively).

Date	16 Feb 1994	2 Mar 1994	16 Mar 1994	30 Mar 1994	10 Apr 1994	24 Apr 1994	14 May 1994	11 Jun 1994	17 Jul 1994	27 Aug 1994	4 Sep 1994	14 Oct 1994	20 Nov 1994	10 Dec 1994	14 Jan 1995	11 Feb 1995	27 Mar 1995
Transect 1	15	9	11	12	*	*	11	8	7	8	9	9	8	8	7	7	8
	14	8	12	14	*	*	12	10	8	10	9	9	7	7	8	8	7
	11	10	11	14	*	*	12	11	7	11	8	8	9	9	6	7	6
	12	11	15	13	*	*	13	12	10	11	8	8	8	8	9	6	7
	11	10	9	16	*	*	12	10	9	9	7	9	6	6	8	6	8
	10	10	12	14	*	*	15	13	10	9	8	7	7	7	7	7	8
	13	14	11	12	*	*	14	11	10	8	9	6	8	8	8	8	9
	13	8	13	14	*	*	16	9	9	9	9	8	9	7	6	6	7
	12	14	14	14	*	*	12	9	10	9	8	9	8	9	7	7	8
	9	11	16	16	*	*	12	8	9	8	8	7	7	6	8	8	6
	9	13	12	14	*	*	14	11	9	10	10	7	8	8	9	7	7
	8	14	15	15	*	*	14	12	11	11	9	9	6	7	8	8	7
Transect 2	13	10	11	11	10	11	10	12	11	9	9	10	9	10	9	9	8
	8	11	10	12	12	11	11	13	7	9	8	10	8	8	8	8	9
	14	12	12	14	12	10	10	12	8	8	10	9	9	9	9	9	8
	11	8	11	14	11	9	10	11	8	10	10	7	6	9	10	7	7
	14	12	10	15	12	10	11	9	9	11	9	6	7	8	10	9	6
	8	14	10	16	12	12	9	13	8	8	8	8	8	9	8	9	6
	12	13	11	16	15	16	14	13	9	9	8	9	9	8	7	9	8
	10	11	11	13	17	12	12	12	8	8	10	9	9	7	9	9	6
	15	12	13	13	17	13	13	11	9	7	9	10	8	8	7	8	6
	13	7	13	14	15	12	12	11	9	10	8	10	9	9	8	7	8
	11	8	9	15	16	10	11	13	11	8	8	9	9	10	8	8	9
	12	11	12	14	15	15	12	9	10	8	9	8	9	9	9	9	8

Table 1, cont.

Date	17 Feb 1994	2 Mar 1994	16 Mar 1994	30 Mar 1994	10 Apr 1994	24 Apr 1994	14 May 1994	11 Jun 1994	17 Jul 1994	27 Aug 1994	4 Sep 1994	14 Oct 1994	20 Nov 1994	10 Dec 1994	14 Jan 1995	11 Feb 1995	27 Mar 1995
Transect 3	15	12	15	18	15	16	15	8	8	11	10	10	11	10	9	11	9
	15	14	14	17	15	14	14	8	10	10	11	10	9	10	9	9	10
	13	14	13	16	14	12	13	10	9	11	10	9	8	8	8	10	8
	9	9	15	17	16	10	11	9	8	10	9	8	8	9	9	8	9
	10	10	13	16	15	12	12	12	8	12	8	11	9	8	10	9	8
	9	11	12	15	16	12	12	13	9	11	10	11	10	7	10	7	8
	14	10	9	16	14	13	13	9	10	9	12	10	9	9	9	9	9
	9	15	14	16	13	14	13	12	11	8	12	9	8	8	8	8	8
	12	16	16	15	12	12	13	12	9	9	11	8	7	9	9	9	6
	16	11	11	18	13	11	11	11	9	8	10	7	9	10	7	10	7
	11	10	13	17	16	10	12	12	10	10	9	9	10	9	9	9	8
	15	13	15	18	16	13	11	11	10	11	8	9	9	9	8	8	7
Transect 4	12	9	14	16	16	17	18	12	8	11	10	9	9	10	9	8	8
	9	15	13	17	16	14	16	11	9	8	11	9	8	9	8	9	9
	14	14	11	15	15	14	15	12	8	9	8	8	10	8	9	7	10
	16	10	10	14	17	16	15	13	7	10	9	7	9	9	10	10	9
	13	12	15	17	16	14	14	13	8	8	9	8	8	7	10	10	9
	12	8	16	17	17	13	14	12	8	11	10	9	9	8	9	9	8
	14	11	13	18	16	16	14	14	9	10	10	7	10	9	8	8	7
	8	14	13	15	14	14	15	15	10	8	8	10	10	9	9	9	8
	12	13	14	17	14	16	14	11	11	10	11	11	8	7	7	9	6
	10	10	11	16	13	13	16	13	9	9	11	10	9	8	9	8	8
	12	12	16	16	16	14	16	15	8	11	12	10	8	10	9	7	7
	14	13	12	18	15	16	14	15	9	10	10	9	9	9	8	9	7

Table 2. Growth of Thalassia blade lengths in mm in plots subjected to vegetative cropping at Transects 2 and 4 (lightly oiled Zone 1A and heavily oiled Zone 1B, respectively, in Laguna del Condado). By July 1994, markers indicating locations of cut plots had disappeared, and cut areas were indistinguishable from surrounding grassbeds.

Date	30 Mar 1994	10 Apr 1994	24 Apr 1994	14 May 1994	11 Jun 1994
Transect 2	204	190	196	186	190
	182	160	190	210	203
	193	175	182	190	186
	187	181	169	176	174
	242	220	196	200	214
	200	226	202	194	202
	197	160	205	198	196
	222	220	211	185	184
	194	160	180	176	173
	185	169	193	198	190
	167	172	180	183	180
	182	164	170	175	141
	177	165	176	180	210
	160	198	169	166	203
	195	210	181	165	176
	170	160	169	180	179
	157	185	143	160	181
	182	190	191	210	193
	243	210	202	205	197
	198	160	210	210	186
Transect 4	174	190	220	224	201
	206	185	210	201	203
	251	280	262	240	186
	296	290	196	206	193
	203	160	210	198	187
	232	202	225	189	176
	214	214	230	212	174
	212	212	221	240	165
	213	213	210	210	196
	189	189	215	223	186
	287	287	260	213	203
	215	215	230	208	214
	223	223	215	218	206
	206	206	206	209	196
	243	243	232	240	176
	222	222	241	230	182
	255	255	236	236	214
	198	198	220	218	216
	162	162	200	210	220

Table 4. *Thalassia* blade lengths (mm) of cut specimens. Zone 1A (lightly oiled) and Zone 1B (heavily oiled) were located on east and west sides of Condado Lagoon, respectively.

Date	16 Feb 1994	2 Mar 1994	16 Mar 1994	30 Mar 1994	10 Apr 1994	24 Apr 1994	14 May 1994	11 Jun 1994	17 Jul 1994	27 Aug 1994	4 Sep 1994	14 Oct 1994	20 Nov 1994	10 Dec 1994	14 Jan 1995	11 Feb 1995	27 Mar 1995
Zone 1A	343	258	312	316	300	296	285	295	305	320	294	290	245	245	312	240	260
	323	252	321	252	240	250	240	390	280	290	302	310	302	312	323	270	245
	311	256	282	293	280	263	260	356	295	268	306	287	310	304	276	320	285
	332	268	352	377	360	280	275	402	245	260	294	260	267	287	287	345	301
	242	250	348	395	310	320	300	300	258	290	286	278	235	256	289	330	236
	350	263	258	328	290	275	285	341	265	310	274	280	308	276	265	320	215
	254	262	319	353	316	310	305	270	260	310	294	295	287	298	312	295	292
	232	296	330	306	290	319	310	265	305	280	266	258	246	267	276	297	275
	230	270	296	269	280	296	285	350	260	296	273	302	268	287	323	255	325
	244	304	343	268	285	270	260	280	265	310	296	298	249	298	289	249	276
	290	262	327	298	290	286	290	346	290	315	284	287	312	257	278	370	248
	245	250	387	260	360	282	296	256	310	260	269	257	256	289	265	315	255
	327	270	299	301	290	296	285	273	305	246	270	258	245	278	276	300	294
	285	259	329	348	340	361	312	298	296	286	301	259	231	265	299	453	283
	278	246	295	322	310	346	340	400	280	304	266	298	234	278	300	270	213
	277	213	334	292	290	285	310	304	270	310	294	287	235	287	270	285	246
	325	252	371	281	280	270	290	345	303	296	282	289	265	290	325	230	298
	340	302	380	298	360	310	315	325	304	280	276	268	276	297	296	228	248
	282	217	287	339	350	340	330	384	270	282	284	298	278	309	276	265	294
	269	215	335	252	296	280	270	310	283	320	290	301	298	303	296	240	301
	321	248	279	298	291	310	305	394	260	276	286	305	312	307	287	190	308
	287	263	268	267	260	295	265	283	255	284	310	298	265	268	312	250	296
	330	252	262	398	310	365	346	293	303	290	304	275	287	287	298	268	266
	286	256	233	271	300	310	312	364	245	310	286	265	254	342	328	310	221
	252	214	286	300	321	329	313	293	263	282	290	245	268	312	342	300	296

Table 4, cont.

Date	17 Feb 1994	2 Mar 1994	16 Mar 1994	30 Mar 1994	10 Apr 1994	24 Apr 1994	14 May 1994	11 Jun 1994	17 Jul 1994	27 Aug 1994	4 Sep 1994	14 Oct 1994	20 Nov 1994	10 Dec 1994	14 Jan 1995	11 Feb 1995	27 Mar 1995
Zone 1B	346	298	354	332	340	352	365	280	365	290	268	287	265	245	234	260	302
	367	260	340	274	290	285	335	374	377	270	302	259	234	254	254	270	319
	392	257	344	369	350	336	296	370	290	306	310	268	245	312	237	273	286
	322	272	301	380	360	342	338	280	303	290	296	298	265	306	312	227	274
	367	341	268	392	280	310	306	391	336	306	325	292	276	267	276	253	256
	365	313	260	405	402	366	355	308	344	315	298	315	287	287	287	260	283
	312	252	178	280	335	390	381	345	335	286	302	301	289	234	287	253	291
	350	309	332	324	330	312	320	340	275	281	274	285	259	256	265	255	313
	365	297	282	393	410	365	298	337	360	292	270	325	236	276	285	295	265
	384	261	276	268	350	323	268	368	314	314	280	312	312	245	245	290	234
	266	296	338	396	290	296	310	318	285	325	294	298	302	287	269	280	269
	258	312	325	368	250	288	334	334	336	330	275	287	298	298	324	255	284
	269	242	245	337	335	350	363	352	276	286	268	269	276	269	265	300	306
	255	306	356	331	294	312	312	387	260	294	310	247	287	304	278	287	251
	288	269	364	402	287	296	308	355	277	268	320	314	265	265	258	239	232
	290	261	293	320	371	338	339	450	280	275	303	284	287	243	275	268	212
	292	307	260	339	376	276	326	329	255	274	294	275	297	276	248	265	298
	365	259	261	348	403	410	394	314	230	283	296	256	269	258	245	275	271
	320	302	277	392	280	296	323	333	276	289	304	265	258	287	236	215	264
	272	312	337	273	354	359	337	290	293	330	275	245	248	234	225	255	236
	248	345	263	325	360	312	308	412	282	300	283	312	298	265	287	238	246
	264	298	302	418	400	396	401	350	266	306	291	332	312	246	246	242	310
	336	208	290	264	390	360	384	392	276	296	282	296	302	276	266	250	286
	304	248	268	365	340	382	364	410	290	284	284	294	312	239	254	210	275
	271	243	206	391	340	365	370	290	332	312	261	289	305	240	265	225	241

Table 5. *Thalassia* blade widths (mm) of cut specimens. Zone 1A (lightly oiled) and Zone 1B (heavily oiled) were located on east and west sides of Condado Lagoon, respectively.

Date	16 Feb 1994	2 Mar 1994	16 Mar 1994	30 Mar 1994	10 Apr 1994	24 Apr 1994	14 May 1994	11 Jun 1994	17 Jul 1994	27 Aug 1994	4 Sep 1994	14 Oct 1994	20 Nov 1994	10 Dec 1994	14 Jan 1995	11 Feb 1995	27 Mar 1995
Zone 1A	11	11	14	10	9	10	9	11	14	11	11	10	10	9	12	10	9
	12	11	13	8	9	11	10	12	12	11	10	9	10	9	11	11	10
	13	10	11	9	10	9	9	9	12	12	8	8	11	10	10	11	10
	12	11	11	13	12	10	10	12	14	11	12	8	12	10	9	7	12
	9	12	13	13	12	11	11	10	15	12	12	9	11	11	10	11	11
	11	11	12	11	11	12	11	10	10	10	10	11	10	12	10	12	10
	12	11	14	10	9	9	9	12	10	8	9	10	10	10	11	11	11
	12	8	12	10	9	8	9	12	11	10	8	10	9	10	12	11	9
	10	9	12	11	8	10	10	11	13	11	10	9	11	9	9	8	10
	10	11	12	10	10	9	8	6	13	10	11	8	12	9	10	10	11
	11	13	12	11	10	10	9	10	13	12	11	11	10	12	11	12	10
	11	10	12	12	10	11	10	13	13	10	12	9	11	11	10	11	12
	11	8	12	10	11	9	10	12	10	11	10	9	9	10	10	11	10
	11	10	14	12	9	10	11	10	10	12	11	8	10	10	11	10	11
	11	10	13	10	12	11	11	9	11	11	9	8	10	12	10	11	11
	12	9	10	10	12	12	11	10	12	11	10	10	9	9	9	11	11
	12	11	12	12	9	10	10	10	13	10	11	10	8	9	9	10	10
	12	11	11	10	10	9	9	11	12	9	12	11	9	8	11	12	9
	11	12	12	12	9	9	8	11	11	9	12	9	9	12	10	10	8
	10	13	11	9	8	8	11	12	12	11	10	8	10	11	10	10	10
	11	10	10	10	8	9	11	9	10	10	9	8	11	11	11	10	10
	13	10	12	12	7	9	10	11	12	11	9	9	10	10	9	10	11
	12	10	13	12	9	10	12	12	11	10	11	7	12	12	10	10	9
	10	11	11	9	11	12	11	10	12	11	10	10	10	10	11	11	11
	11	12	13	11	12	12	11	9	11	11	11	11	9	10	10	11	10

Table 5, cont.

Date	17 Feb 1994	2 Mar 1994	16 Mar 1994	30 Mar 1994	10 Apr 1994	24 Apr 1994	14 May 1994	11 Jun 1994	17 Jul 1994	27 Aug 1994	4 Sep 1994	14 Oct 1994	20 Nov 1994	10 Dec 1994	14 Jan 1995	11 Feb 1995	27 Mar 1995
Zone 1B	9	11	11	8	9	10	9	11	10	9	8	8	10	9	11	10	10
	8	9	10	9	9	10	9	10	10	11	10	9	9	9	12	8	8
	11	9	9	8	8	9	10	10	10	7	7	7	7	11	10	10	8
	9	11	10	8	6	8	12	8	9	11	11	8	9	11	9	11	10
	9	8	8	8	10	8	9	10	10	10	10	9	11	12	10	10	10
	8	10	11	9	9	9	10	9	11	10	9	8	12	10	11	10	11
	11	10	9	10	8	10	11	10	10	8	10	7	11	10	10	11	10
	11	9	11	9	7	6	11	10	11	9	11	9	10	10	9	11	11
	12	10	9	9	7	8	8	11	10	10	10	10	10	9	12	10	12
	10	8	10	7	6	8	9	9	11	11	9	8	9	11	11	10	12
	8	9	10	8	8	9	10	9	10	10	7	9	10	12	10	10	11
	9	8	10	7	9	10	8	8	12	10	10	10	11	10	10	10	11
	11	10	7	10	10	11	12	12	13	7	8	11	10	9	9	10	10
	9	9	8	8	10	8	11	12	9	11	9	10	11	10	10	11	10
	8	11	11	11	7	9	8	12	10	6	8	10	10	10	10	9	9
	9	9	11	7	9	10	9	11	10	10	9	12	9	11	9	10	11
	8	10	9	10	11	9	10	8	10	6	10	9	9	12	10	11	10
	8	8	10	11	10	10	8	9	9	10	9	9	8	10	11	10	10
	9	10	11	10	9	11	11	8	9	11	11	8	11	9	10	11	10
	9	8	10	8	9	11	10	9	10	9	10	10	10	9	12	10	10
	8	8	10	10	9	9	8	10	11	8	8	10	10	10	10	9	11
	10	11	7	11	10	10	11	10	10	11	11	11	9	10	9	9	9
	8	10	9	7	8	8	9	9	9	12	9	10	10	9	10	10	10
	8	9	8	10	8	10	11	10	10	10	10	10	10	10	10	10	11
	9	10	9	10	8	10	11	11	10	10	11	10	10	10	10	10	12

APPENDIX 2

Table 1. Shoot densities (number of *Thalassia* plants per 20 x 20 cm plot) at each transect in Mayagüez Bay.

Date	17 Sep 1994	6 Oct 1994	25 Nov 1994	17 Dec 1994	21 Jan 1995	17 Feb 1995	11 Mar 1995
Transect 5	9	9	10	10	9	9	8
	7	10	11	9	10	10	9
	8	10	9	9	10	10	9
	8	11	8	8	9	9	10
	8	9	10	9	8	8	9
	10	8	9	10	9	9	10
	10	8	9	10	9	9	10
	10	7	10	10	9	10	7
	8	8	9	9	10	9	10
	9	9	10	8	11	9	9
	11	10	9	9	10	10	10
	10	10	9	10	9	9	10
Transect 6	7	8	9	10	9	9	10
	6	9	9	9	9	10	10
	7	7	8	8	9	10	9
	7	6	9	9	8	9	10
	8	8	10	8	10	8	9
	10	7	9	9	9	9	8
	7	10	10	10	9	9	9
	8	10	9	9	8	10	8
	7	8	8	8	10	9	9
	8	9	9	9	9	9	10
	9	8	10	9	9	8	11
	7	7	9	9	10	9	10

Table 2. Biomass weight (g) of *Thalassia* blades cut from two adjacent 20 x 20 cm plots at each transect in Mayagüez Bay.

Date	17 Sep 1994	6 Oct 1994	25 Nov 1994	17 Dec 1994	21 Jan 1995	17 Feb 1995	11 Mar 1995
Transect 5	103	113	123	134	124	132	132
Transect 6	100	103	145	133	143	140	126

Table 3. *Thalassia* blade lengths (mm) of cut specimens at each transect in Mayagüez Bay.

Date	17 Sep 1994	6 Oct 1994	25 Nov 1994	17 Dec 1994	21 Jan 1995	17 Feb 1995	11 Mar 1995
Transect 5	263	287	245	289	243	321	289
	243	259	234	276	235	265	311
	262	254	287	245	223	234	294
	263	248	256	234	198	214	286
	227	228	287	237	311	290	275
	185	224	249	245	309	298	246
	250	256	312	311	234	312	286
	226	278	276	306	265	342	294
	235	289	223	276	276	287	301
	245	258	245	287	287	234	296
	302	268	236	276	248	276	215
	294	259	245	235	276	289	236
	265	298	278	256	287	206	294
	243	265	254	287	278	260	296
	256	236	231	298	290	298	286
	235	315	254	296	312	289	274
	246	285	275	287	278	305	291
	249	245	243	311	296	296	304
	262	268	267	304	267	258	268
	302	295	289	265	259	287	291
	286	265	257	278	245	285	283
	264	245	235	287	269	309	268
	235	287	286	290	287	296	271
	290	274	275	268	298	289	246
	248	256	265	297	265	287	298
Transect 6	340	245	321	245	325	290	261
	250	285	311	265	311	265	294
	240	247	290	278	276	314	255
	334	325	256	234	256	243	244
	310	312	287	321	298	287	231
	315	318	293	306	276	306	296
	320	298	289	265	287	234	281
	334	278	256	321	314	345	310
	220	256	265	256	287	276	305
	215	316	256	276	245	298	294
	314	285	311	289	289	287	281
	306	268	325	265	274	287	264
	225	247	342	287	247	298	294
	250	245	243	265	249	259	215
	268	289	287	298	250	245	218
	310	312	245	209	312	312	276
	308	246	316	322	300	267	243
	246	325	276	245	265	298	255
	248	318	276	276	269	315	266
	301	289	265	287	245	314	281
	268	247	312	257	284	324	294
	243	285	268	287	234	331	236
	208	296	287	298	254	300	294
	217	314	276	296	287	298	286

284 285 307 303 299 295 273

Table 4. *Thalassia* blade widths (mm) of cut specimens at each transect in Mayagüez Bay.

Date	17 Sep 1994	6 Oct 1994	25 Nov 1994	17 Dec 1994	21 Jan 1995	17 Feb 1995	11 Mar 1995
Transect 5	9	9	9	9	10	9	8
	10	8	8	8	10	9	9
	9	8	10	7	10	11	10
	9	9	9	8	11	11	9
	11	10	8	9	11	10	10
	10	9	9	11	9	8	11
	7	8	11	11	8	11	10
	11	9	10	10	10	10	11
	10	10	10	9	10	10	10
	8	11	9	9	9	10	9
	10	10	8	8	9	10	9
	10	9	9	10	8	9	10
	9	8	9	7	9	8	10
	9	9	11	10	11	9	11
	8	8	11	10	10	11	10
	8	7	10	9	10	10	10
	9	9	9	10	10	10	10
	10	8	8	10	10	10	11
	10	10	7	11	9	9	9
	10	10	9	10	11	11	10
	10	9	8	9	11	10	9
	8	8	9	9	10	10	10
	8	9	9	10	9	10	10
	7	9	9	10	9	9	11
	10	7	8	10	10	10	10
Transect 6	9	7	9	9	9	11	9
	8	10	9	9	9	10	9
	7	11	10	9	9	9	10
	10	9	10	12	8	9	11
	9	8	9	11	11	8	9
	11	7	11	10	12	7	8
	10	8	11	9	10	9	9
	11	9	11	10	10	9	7
	10	9	12	8	9	8	10
	10	8	10	10	8	10	10
	9	10	10	10	10	10	9
	10	8	9	9	10	10	11
	9	7	8	10	9	9	9
	8	9	9	9	11	9	10
	8	9	9	9	11	10	10
	9	8	9	8	12	10	10
	7	10	10	11	9	9	9
	10	10	10	10	9	9	11
	9	8	10	10	9	10	10
	10	9	11	9	8	12	11
	9	11	9	9	10	11	10
	8	8	8	11	10	10	10
	9	9	9	10	10	9	10

8	9	8	10	10	9	10
9	8	9	10	9	10	10