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Effects Of Space Shuttle Launches STS-1 Through STS-9 On Terrestrial Vegetation Of John F. Kennedy Space Center, Florida

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Space Administration

John F. Kennedy Space Center

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Abstract

Space Shuttle launches cause acute vegetation damage in an area of about 22 ha near the launch pad. Damage results from exposure to the exhaust ground cloud which contains hydrochloric acid (HCl), aluminum oxide (Al_2O_3), and other substances; acidities of <0.5 pH have been measured routinely in association with the launch cloud. Vegetation changes have been followed on 42 permanent 20 m vegetation transects within the impact zone. The vegetation changes which have occurred from STS-1 through STS-9 include loss of sensitive species, loss of plant community structure, reduction in total cover, and replacement of some species by weedy invaders. Community level changes define a retrogressive sequence.

Impacts to strand and dune vegetation up to 1.2 km northeast of the launch pad occurred after the launches of STS-8 and STS-9. Acute vegetation damage in these areas occurred especially to sensitive species. Within six months, however, recovery was nearly complete as shown by examination of permanent plots. Sensitivity of strand and dune species to the launch cloud was partially predicted by previous laboratory studies.

Far-field acidic and dry fallout from the launch cloud as it rises to stabilization and moves with the prevailing winds causes vegetation spotting. Damage from this deposition is minor; typically at most 1% to 5% of leaf surface area is affected. No plant mortality or community changes have occurred from far-field deposition.

The area impacted by Shuttle launches will probably increase with increased launch frequency and operation of a second launch pad. Potential problems requiring monitoring include dune stability and erosion, nutrient leaching, and wildlife effects.

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Acknowledgements

This project was conducted under the direction of Dr. William M. Knott, III, Biological Sciences Officer and Dr. Albert M. Koller, Jr., Chief, Environmental Sciences Operations and Research Branch, The Biomedical Office, John F. Kennedy Space Center (KSC) under NASA Contract NAS10-10285. We thank Technicolor Graphic Services, Inc., Florida Operations for photographic support and members of The Bionetics Corporation Environmental Monitoring team, particularly Lee A. Maull, for field assistance. Terry Layer of EG&G Florida, Inc. provided graphics assistance. Thomas W. Dreschel, Charles T. Gaetz and Carlton R. Hall reviewed an earlier version of this paper. We thank Alice Hudson and Tami Skidmore for typing the manuscript.

Introduction

Launches of the Space Shuttle from John F. Kennedy Space Center produce environmental impacts resulting from the formation of an exhaust cloud (Bowie 1981, Knott et al. 1983). Major constituents of the exhaust cloud are carbon dioxide (CO_2), water (H_2O), aluminum oxide (Al_2O_3), and hydrogen chloride (HCl) (NASA 1979). The formation of the exhaust cloud occurs as a result of the combined effects of the ignition of the Solid Rocket Motors (SRM), the Space Shuttle Main Engines (SSME) and the simultaneous dumping of several thousand kiloliters of sound suppression and cooling water onto the launch pad. In the turbulence of the rocket exhausts, atomization of the deluge water occurs; these droplets coagulate with aluminum oxide particulates and rapidly scavenge hydrogen chloride gas producing acidic deposition (Anderson and Keller 1983).

Typically this cloud, termed the ground cloud, is directed northward by the structure of the flame trench and begins to rise as the horizontal velocity decreases (Knott et al. 1983). As the cloud rises it entrains ambient air until reaching a stabilization height (Bjorklund et al. 1982). This cloud together with portions of the column cloud produced as the Space Shuttle ascends are carried by prevailing winds.

Near-field acute effects are produced by the ground cloud sweeping turbulently across the ground, vegetation, and lagoonal waters. Generally near-field effects occur within 0.5 km of the launch pad although they have extended up to 1.0 km away (Knott et al. 1983). Since the pH of droplets in this cloud can be <0.5 (Anderson and Keller 1983), near-field effects can be severe and include acute vegetation damage (Bowie 1981, Knott et al. 1983) and fish kills (Knott et al. 1983, Milligan and Hubbard 1983, Hawkins et al. 1984).

Far-field effects are produced after the cloud rises and moves with the prevailing winds. Deposition from this cloud occurs as spotting on vegetation and structures; spotting may include acid burns from "wet" deposition or may be dry residue, primarily Al_2O_3 (Knott et al. 1983, Anderson and Keller 1983). Deposition has been detected up to 22 km from the launch site.

Near-field deposition has been quantified for three launches, STS-11 (41-B), STS-13 (41-C) and STS-14 (41-D) (Dreschel and Hinkle 1984, Dreschel, Hall, and Hinkle 1985, Dreschel et al. 1985). In a typical launch such as STS-11 (41-B), approximately 3000 kg of chlorides and 7000 kg of particulates are deposited in the 22 ha near-field environment (Figure 1). Isopleths of this deposition indicate 100 g/m^2 or more of chlorides (Figure 2) and 200 g/m^2 or more of particulates (Figure 3) can be deposited in

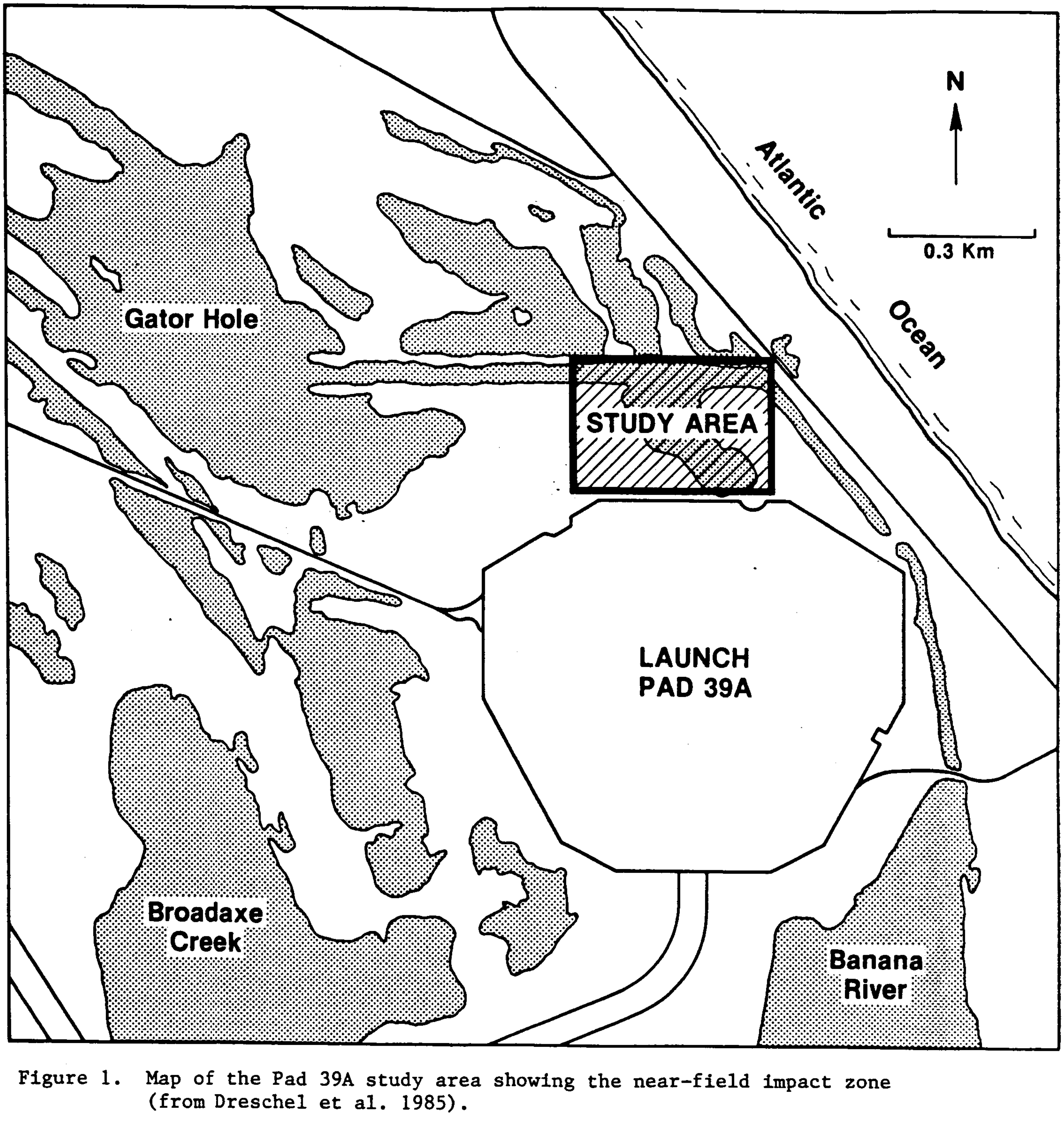


Figure 1. Map of the Pad 39A study area showing the near-field impact zone (from Dreschel et al. 1985).

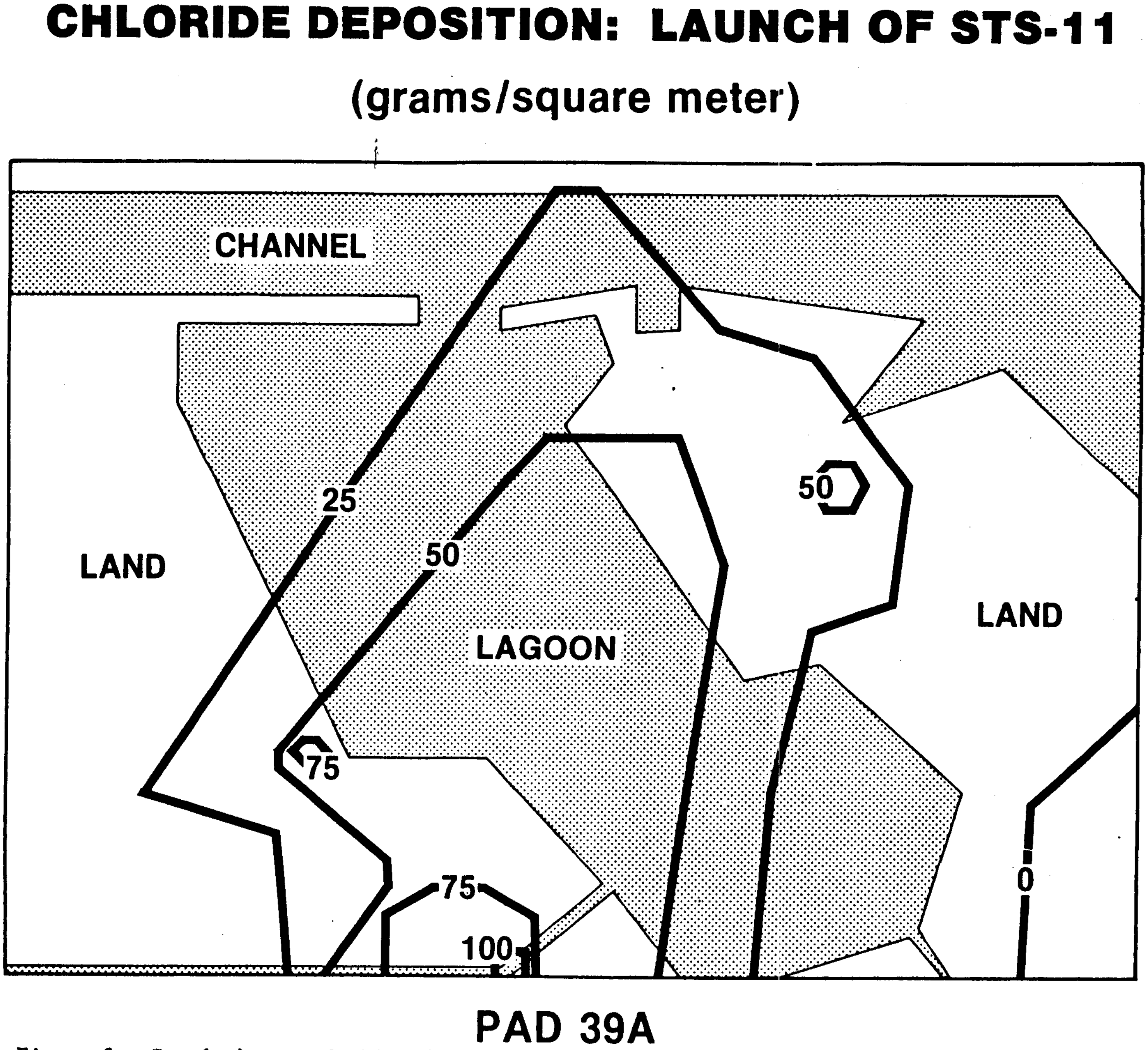
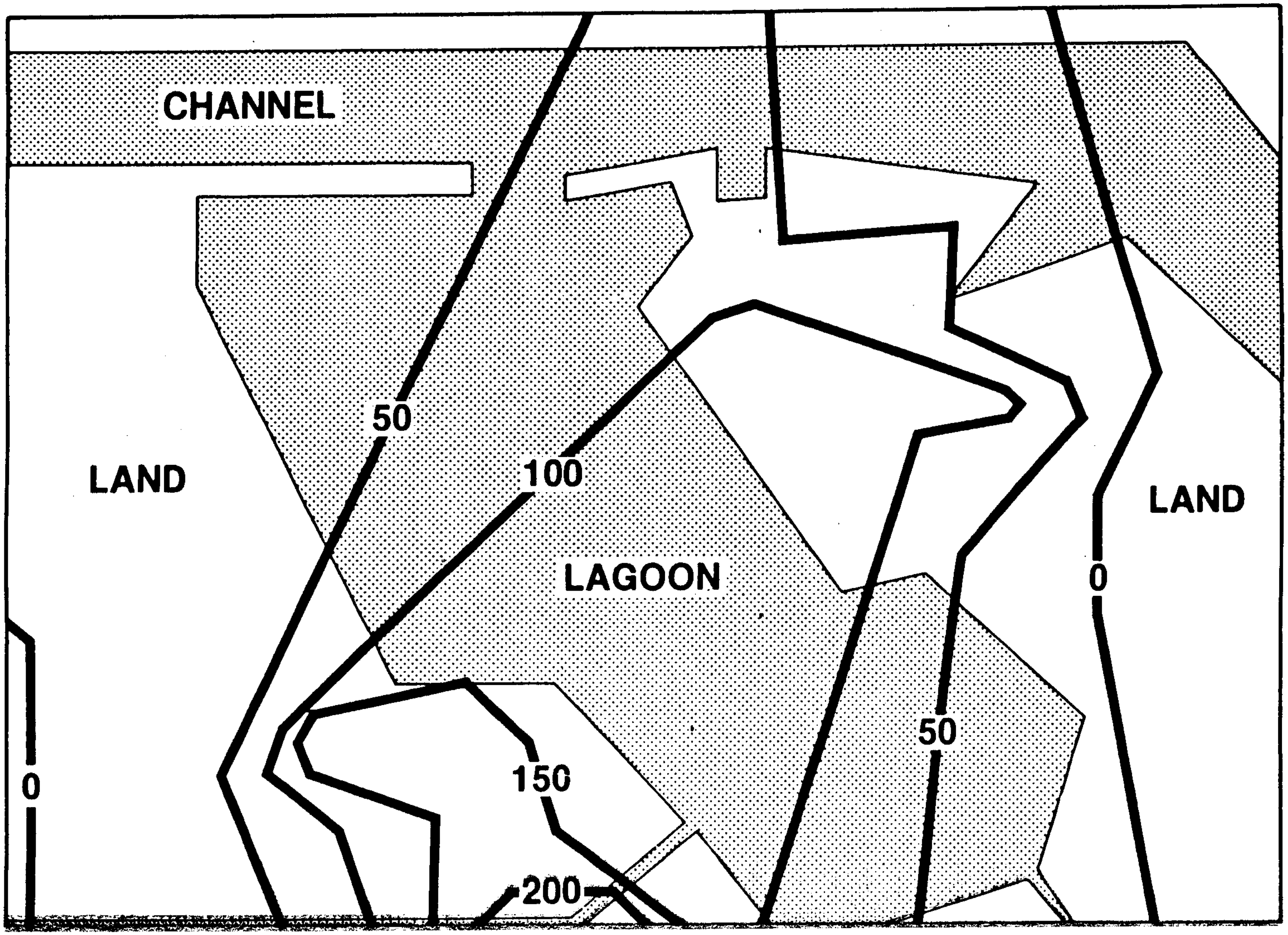


Figure 2. Isopleth map of chloride deposition in the near-field environment from STS-11 (41-B) (from Dreschel, Hall and Hinkle 1985).

PARTICULATE DEPOSITION: LAUNCH OF STS—11

(grams/square meter)



PAD 39A

Figure 3. Isopleth map of particulate deposition in the near-field environment from STS-11 (41-B) (from Dreschel, Hall and Hinkle 1985).

the near-field environment (Dreschel, Hall, and Hinkle 1985). This typical pattern occurs under conditions of light surface winds. With stronger surface winds, particularly if from the north (e.g., during STS-13), the ground cloud is blown off its usual path (Dreschel, Hall, and Hinkle 1985).

This paper reports the effects on terrestrial vegetation of the first nine Space Shuttle launches in both the near-field and far-field environments. From the first launch on April 12, 1981 through the ninth launch on November 28, 1983 the near-field environment was impacted. The frequency of these launches has increased and subsequently the time for vegetation recovery between launches has decreased. There were two launches in 1981, three in 1982, and four in 1983. Since the first launch in 1981, the shortest interval between any two consecutive launches has been 63 days and the longest period has been seven months; therefore, this constituted a maximum recovery time of seven months and a minimum time of 63 days for vegetation exposed to the launch exhaust cloud.

The launch exhaust cloud from two of nine launches, STS-8 (August 30, 1983) and STS-9 (November 28, 1983), crossed over nearby dunes which had previously not been impacted. These events allowed for the assessment of vegetation damage from a single launch onto previously unaffected areas of strand and dune vegetation. The launch of STS-8 occurred on August 30, 1983 at 2:32 a.m. At the time of the launch surface temperature was 23.9°C, relative humidity was 95.0%, surface wind speed was 3.09 m/sec and wind direction was 230.0° (Knott 1983a). Thunderstorms had occurred a few hours before launch. Vegetation damage was more extensive following this launch than from any previous one, perhaps due to the high humidity and wet condition of the vegetation. The launch of STS-9 occurred on November 28, 1983 at 11:00 a.m. At the time of launch, surface temperature was 21.4°C, relative humidity was 80.0%, surface wind speed was 6.18 m/sec, and wind direction was 180° (Knott 1983b). Vegetation damage was similar to that from STS-8.

Prior to any Space Shuttle launches several plant communities occurred in the near-field area. These communities included shrub dominated types, graminoid communities and mud flats. Specific types (named by dominant species) were sea oxeye (*Borrichia frutescens*), saltwort-glasswort (*Batis maritima-Salicornia* spp.), wax myrtle-groundsel (*Myrica cerifera-Baccharis* spp.), mixed grasses-sedge (e.g., *Fimbristylis castanea*, *Andropogon* spp.), black mangrove (*Avicennia germinans*), mud flat-sea purslane (*Sesuvium portulacastrum*), sea oats-slender cordgrass (*Uniola paniculata- Spartina patens*), groundsel-sea oxeye and saw palmetto-sea grape (*Serenoa repens - Cocoloba uvifera*) types. (Unpublished vegetation map, M.J. Provancha).

Methods

Near-Field Vegetation

After the launch of STS-1 but before the launch of STS-2, sampling of the vegetation in the impact zone north of Pad 39A was conducted. A rectangular grid sampling system was established in an area approximately 427 m (1400 ft) along the east-west axis and 305 m (1000 ft) along the north-south axis. Eight north-south grid lines were established approximately 60 m (200 ft) apart. These were labeled A,B,C,D,E,F,G, and H. Six east-west running grid lines were also established and labeled 1,2,3,4,5, and 6 (Figure 4). Grid coordinates were marked with metal posts except for those occurring in the lagoon. North-south and east-west trending vegetation transects were established along these transects. Transects were established in the central 20 m on the line between two grid posts. A total of 46 vegetation sampling transects were established with the grid system. Percent cover by species was determined along each transect using the line-intercept method. (Mueller-Dombois and Ellenberg 1974). The initial vegetation survey was conducted in October, 1981 (Breininger 1981).

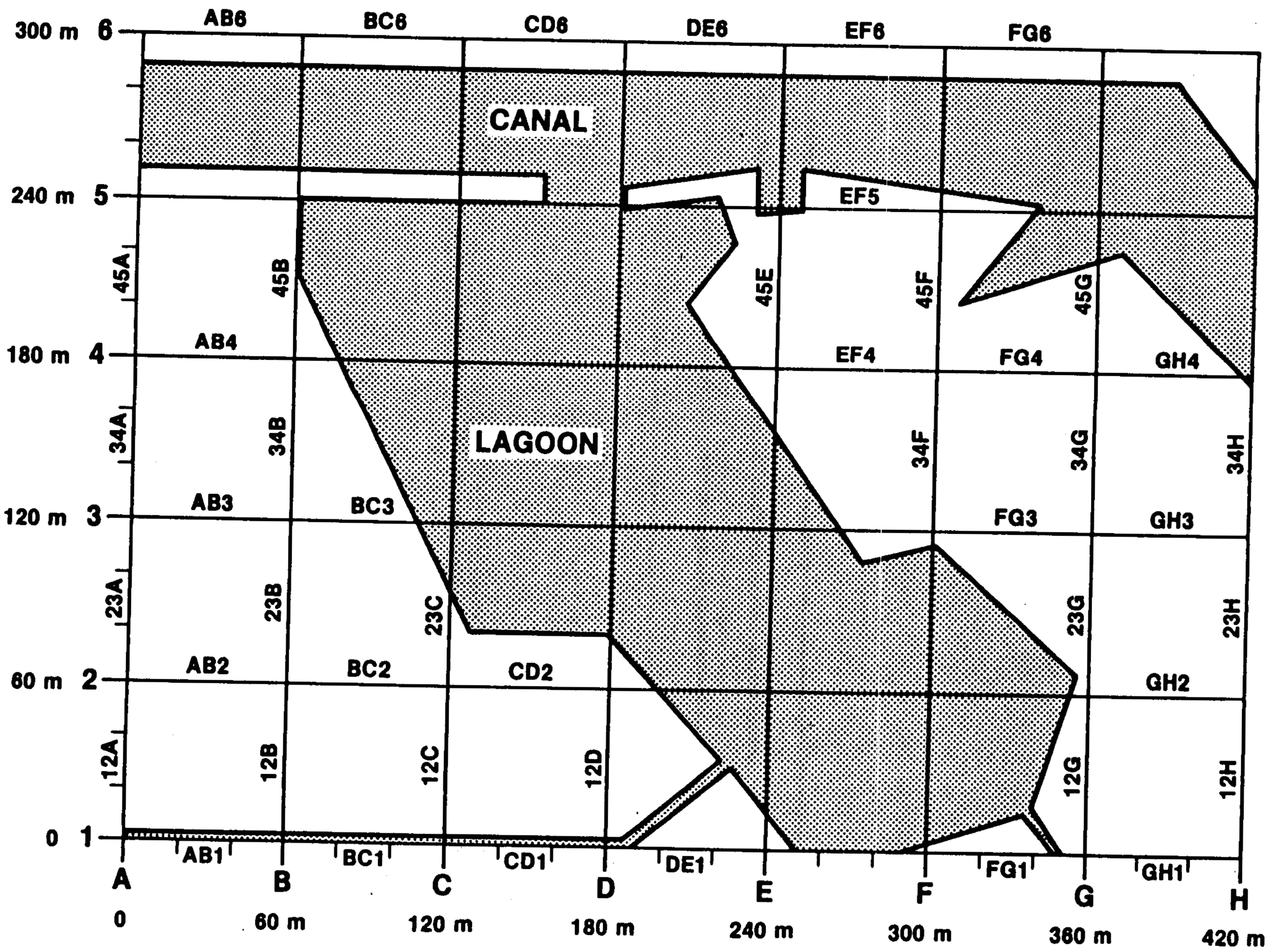
In January, 1984 subsequent to the launch of STS-9 these transects were resurveyed. Percent cover by species was determined along each transect. Four of the original transects had been destroyed by groundskeeping operations leaving 42 for comparison to the original survey. Soil samples were taken at 0-15 cm and 15-30 cm depth. Frequency, percent frequency, mean cover and mean relative cover were determined for all plant species occurring in each transect. Species richness and the number of species lost, gained and persisting through the period were calculated. Total cover was also compared between the post-STS-1 and post-STS-9 periods.

The area receiving acute vegetation damage from the ground cloud was mapped after each launch. Maps showing cumulative impacts were prepared by overlaying maps of individual launches.

Dune and Strand Vegetation

Transects were established through the damaged strand and dune vegetation after the launch of STS-8. The dune transect established was 1150 m long and oriented northwest-southeast through the impacted area of dune vegetation. Along the sampling transect, 17 plots (1 m^2) were located; of these 1 was in an area of no damage, 5 were in areas of light damage (<5% leaf area), 2 were in moderate damage (5-10% leaf area), and 9 were in heavily damaged areas (>10% leaf area). Within each plot, percent cover by species was estimated. Percent damage to each species was

VEGETATION TRANSECTS-PAD 39A IMPACT ZONE



PAD 39A

Figure 4. Location of vegetation transects in the Pad 39A near-field impact zone.

also estimated visually. Prior to launch this area was relatively undisturbed native dune vegetation dominated by sea oats in association with beach sunflower (Helianthus debilis), camphorweed (Heterotheca subaxillaris), sea grape, and other species.

A transect 1050 m long was established through the strand vegetation after STS-8 and was oriented north-south through the damaged vegetation. Sixteen plots were established along this transect; meter square plots were used in open areas of grasses and herbs and .004 ha (.01 ac) circular plots were used to sample shrub vegetation with nested meter square plots for the herb layer. One plot was in an area of no damage, 4 in an area of light damage, 4 in an area of moderate damage and 7 in a heavily damaged area. Percent cover and percent damage by species were estimated visually on a continuous scale for each plot. Strand vegetation adjacent to the primary dune had previously been affected by road and railroad construction. Shrubs such as wax myrtle, sea oxeye, and groundsel dominate much of the area but openings dominated by grasses (e.g., Chloris petrae, Andropogon spp.) and herbs (e.g., Monarda punctata, Bidens pilosa) occurred.

A weighted mean percent damage was determined for each plot by multiplying the percent cover of each species by the percent damage of that species, summing over all species, and dividing by the total cover. In order to determine the sensitivities of individual species, plots were divided into those in areas of moderate damage and those in areas heavily damaged. Mean percent damage for each species within these groups was calculated.

Assessment of STS-9 vegetation damage was made in a similar fashion to that from STS-8. In the dune vegetation a 450 m transect was established and 11 plots (1 m^2) were distributed along it. Two plots were in undamaged areas, 2 in areas of light damage, 2 in moderate damage and 5 in heavily damaged areas. Six of these plots were selected to be permanently marked and used to evaluate vegetation recovery. Percent cover and percent damage were recorded visually on a continuous scale by species on each plot.

In the strand vegetation a 350 m transect was established and eight plots were placed along it; 0.004 ha plots with nested plots (1 m^2) for the herb layer (if present) were used. Six of these plots were permanently marked to follow recovery. Permanent plots were photographed initially and rephotographed in January, March, April and June. The original estimates of percent cover and percent damage were repeated in June, six months after the launch of STS-9.

Far-Field Vegetation

After each launch, the area receiving far-field deposition was mapped using deposition spotting on vegetation and structures (Knott et al. 1983). Cumulative maps showing areas repeatedly hit by the launch cloud were prepared by overlaying maps of individual launches.

Results

Near-Field Vegetation

Launch effects have not been uniform across the near-field study area in terms of frequency of being hit (Figure 5) or intensity of the deposition if hit (Figures 2 and 3). Changes in species and cover are apparent for the entire impact zone (22 ha). Among the trees and shrubs, groundsel, sea oxeye and saltwort have declined in frequency and cover (Table 1). Three species have disappeared from the study transects; persimmon (Diospyros virginiana) and beautybush (Callicarpa americana) were relatively uncommon to begin with but lantana (Lantana camara) was more common initially. Wax myrtle and black mangrove have maintained their frequency and increased in cover. These species appear more resistant to the ground cloud than many other shrubs. Wax myrtle has been lost or damaged at some sites but is still dominant at others; its relative cover has increased from 20.3% to 32.2% probably due to the decline in cover of more sensitive shrubs such as groundsel and sea oxeye. Black mangrove is apparently very resistant to the exhaust cloud but it was damaged by the December 1983 freeze. (Provancha, et al. 1985).

Grasses and sedges have undergone less obvious changes in frequency and cover than the shrubs (Table 2). Some of the more common species have increased in frequency (e.g., Fimbristylis castanea, 17.5% to 35.0%) or cover while others have decreased somewhat (e.g., Eragrostis elliottii, 10.0% to 2.5% frequency). In general, grasses and sedges seem fairly resistant to effects of the launch cloud and have in some cases increased in dominance as more sensitive species have been eliminated.

Herbaceous species which include succulents and subshrubs constitute the largest species group in the Pad 39A vicinity. Responses of these species are variable. Twenty one species have disappeared from the study transects (e.g., Ambrosia spp.) while ten others (e.g., Rivina humilis) have declined in frequency or cover (Table 3). Seasonal difference between the time of the original and the second survey may have had some influence on the presence or abundance of some species, particularly annuals. Some herbaceous species have increased in frequency and cover; Parietaria floridana has apparently invaded and become

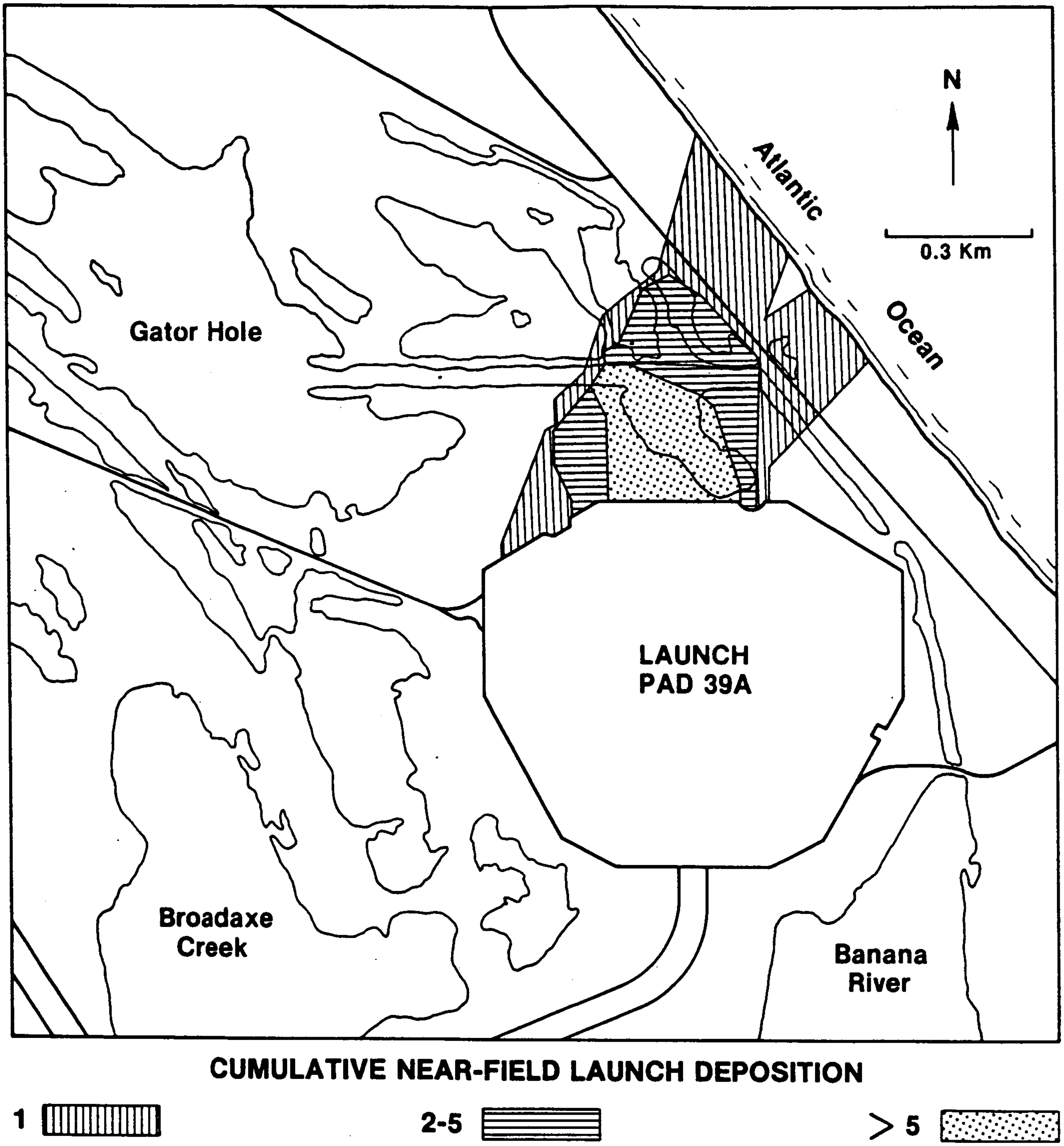


Figure 5. Cumulative near-field launch deposition from STS-1 through STS-9.

Table 1. Changes in frequency (F) and percent cover of trees and shrubs from STS-1 through STS-9 in the near-field impact zone

TREES/SHRUBS	POST STS-1		POST STS-9		POST STS-1		POST STS-9	
	F	%F	F	%F	$\bar{x}$ Cov	$\bar{x}$ Rel Cov	$\bar{x}$ Cov	$\bar{x}$ Rel Cov
Avicennia germinans	5	12.5	5	12.5	17.8	11.9	24.6	26.6
Baccharis halimifolia	20	50.0	12	30.0	20.9	17.4	18.8	19.5
Batis maritima	8	20.0	5	12.5	25.1	18.8	2.6	3.2
Borrichia frutescens	26	65.0	21	52.5	47.8	34.6	29.3	33.3
Callicarpa americana	2	5.0	0	0.0	7.5	4.7	--	--
Diospyros virginiana	1	2.5	0	0.0	1.0	0.7	--	--
Lantana camara	7	17.5	0	0.0	11.0	8.5	--	--
Myrica cerifera	19	47.5	19	47.5	26.0	20.3	29.3	32.2
Schinus terebinthifolius	0	0.0	1	2.5	--	--	3.0	3.4

Table 2. Changes in frequency (F) and percent cover of grasses and sedges from STS-1 through STS-9 in the near-field impact zone

Grasses & Sedges	Post STS-1		Post STS-9		Post STS-1		Post STS-9	
	F	%F	F	%F	$\bar{x}$ Cov	$\bar{x}$ Rel Cov	$\bar{x}$ Cov	$\bar{x}$ Rel Cov
Andropogon spp.	12	30.0	10	25.0	4.2	4.7	5.3	6.8
Cenchrus spp.	1	2.5	--	--	1.0	1.1	--	--
Chloris petrae	6	15.0	7	17.5	6.0	6.4	6.2	9.4
Cladium jamaicense	1	2.5	1	2.5	5.0	4.5	5.0	8.3
Cyperus brevifolius	--	--	1	2.5	--	--	3.5	7.0
Cyperus esculentus	--	--	2	5.0	--	--	4.5	7.8
Cyperus spp.	4	10.0	--	--	20.8	15.0	--	--
Distichlis spicata	2	5.0	3	7.5	10.0	1.7	13.2	24.2
Eragrostis elliottii	4	10.0	1	2.5	18.5	18.0	10.5	28.2
Fimbristylis castanea	7	17.5	14	35.0	55.6	39.3	23.5	27.7
Fimbristylis spathacea	--	--	6	15.0	--	--	10.2	15.0
Fimbristylis spp.	4	10.0	1	2.5	13.3	10.8	36.0	36.0
Muhlenbergia capillaris	--	--	1	2.5	--	--	2.5	2.2
Poaceae unknown	--	--	2	5.0	--	--	2.3	4.4
Scirpus spp.	2	5.0	--	--	1.0	1.1	--	--
Sorghum halepense	1	2.5	--	--	1.0	0.6	--	--
Spartina bakerii	--	--	1	2.5	--	--	12.5	15.6
Sphenopholis obtusata	--	--	1	2.5	--	--	8.5	17.0
Sporobolus domingensis	--	--	1	2.5	--	--	3.5	3.5
Sporobolus virginicus	2	5.0	2	5.0	9.5	11.2	8.3	9.0
Sporobolus spp.	2	5.0	--	--	1.0	1.1	--	--

established on 25% of the transects. Some differences in taxonomy also influence the results; Salicornia bigelowii (annual glasswort) was not originally distinguished from Salicornia virginica (perennial glasswort); its presence in the second survey results from this and not from new invasion. There is a greater loss of species than gain from new invasion.

Overall changes in species richness are apparent (Table 4). For all of the transects resurveyed, the mean number of species per transect declines from 7.8 to 5.1 indicating a significant net loss of species (Table 5). This is the result of both species loss ranging from 0 to 14 species per transect (0-100%, $\bar{x}$=4.3 species) and species gain ranging from 0 to 7 species (0-100%, $\bar{x}$=1.7 species). It is evident that considerable turnover, replacement, and loss of species have occurred; the number of species in common ranges from 0 to 9 (Tables 4 and 5).

It is evident that the changes in species composition are not uniform across the site and that some areas have been more heavily impacted than others. Two indices have been calculated to attempt to quantify the changes in species composition. Jacard's index of similarity (IS_j) was applied to these data (Mueller-Dombois and Ellenberg 1974). As applied to these data, a high index of similarity indicates that little change in species composition (presence-absence) has taken place. Indices calculated range from 0 to 100% indicating changes from complete turnover to no change in species composition (Table 4). The index of similarity tends to be low for plots in the areas hit most often or most severely by the launch cloud. For example, transect DE1 (Figure 4) is in an area frequently hit (Figure 5); its index of similarity is 7.7% (Table 4) while transect GH4 is at the edge of the impact zone (Figure 4) and its similarity index is 100% (Table 4).

In order to more carefully define the changes in species composition in these transects, an index of change, I_c was developed.

Table 3. Changes in frequency (F) and percent cover of herbs from STS-1 through STS-9 in the near-field impact zone

Herbs	Post STS-1		Post STS-9		Post STS-1		Post STS-9	
	F	%F	F	%F	$\bar{x}$ Cov	Rel Cov	$\bar{x}$ Cov	Rel Cov
Acrostichum danaeifolium	1	2.5	2	5.0	2.0	1.2	7.0	7.4
Ambrosia spp.	6	15.0	--	--	2.8	2.9	--	--
Bacopa spp.	2	5.0	1	2.5	1.0	1.2	0.5	1.5
Catharanthus roseus	2	5.0	--	--	3.5	3.1	--	--
Ceratophyllum demersum	--	--	1	2.5	--	--	22.5	67.2
Chamaesyce spp.	2	5.0	--	--	1.0	0.6	--	--
Crotolaria spp.	1	2.5	--	--	10.0	6.3	--	--
Gaillardia pulchella	1	2.5	--	--	7.0	7.8	--	--
Galactia spp.	1	2.5	--	--	1.0	0.9	--	--
Gaura spp.	1	2.5	--	--	13.0	14.4	--	--
Heliotropium curassavicum	1	2.5	--	--	1.0	0.8	--	--
Hydrocotyle spp.	4	10.0	5	12.5	1.3	1.1	1.7	2.2
Hypericum spp.	1	2.5	--	--	2.1	1.8	--	--
Ipomoea pes-caprae	1	2.5	--	--	1.0	1.1	--	--
Lachnanthes caroliniana	3	7.5	--	--	1.3	0.9	--	--
Limonium carolinianum	1	2.5	--	--	1.0	1.2	--	--
Lippia nodiflora	1	2.5	--	--	1.0	1.1	--	--
Melothria pendula	4	10.0	--	--	3.6	2.7	--	--
Mentzelia floridana	6	15.0	6	15.0	17.0	11.8	3.3	6.8
Mikania scandens	6	15.0	4	10.0	8.2	7.2	0.8	1.0
Momordica charantia	5	12.5	--	--	16.2	12.1	--	--
Monarda punctata	1	2.5	--	--	7.0	7.8	--	--
Parietaria floridana	--	--	10	25.0	--	--	17.8	38.0
Passiflora spp.	2	5.0	--	--	12.5	9.9	--	--
Physalis viscosa	7	17.5	7	17.5	5.0	3.6	5.3	9.6
Phytolacca americana	--	--	1	2.5	--	--	1.3	2.2
Pluchea rosea	1	2.5	--	--	1.0	0.6	--	--
Portulaca pilosa	8	20.0	--	--	2.5	2.0	--	--
Rivina humilis	9	22.5	2	5.0	22.1	13.6	9.5	18.0
Rubus spp.	2	5.0	2	5.0	5.0	5.1	14.3	16.2
Salicornia bigelowii	--	--	6	15.0	--	--	8.3	8.1
Salicornia virginica	6	15.0	11	27.5	23.3	15.7	17.4	20.6
Salicornia spp.	9	22.5	5	12.5	28.6	24.3	17.8	19.3
Samolus ebracteatus	3	7.5	1	2.5	1.0	0.7	0.5	0.6
Sesuvium portulacastrum	4	10.0	4	10.0	22.3	17.9	7.5	7.4
Solidago spp.	16	40.0	11	27.5	7.1	5.4	6.0	7.2
Suaeda linearis	8	20.0	--	--	1.2	1.2	--	--
Typha domingensis	3	7.5	5	12.5	14.0	17.4	6.1	11.2
Unknown herb	3	7.5	3	7.5	5.0	3.2	1.8	2.7
Vigna luteola	2	5.0	--	--	1.0	0.8	--	--

Table 4. Changes in species richness and percent cover from STS-1 through STS-9 in the near-field impact zone

Plot	No. of Species Post STS-1	No. of Species Post STS-9	No. of Species Lost	Percent Species Lost	No. of Species Gained	Percent Species Gained	No. of Species In Common	Percent Species In Common	IS_j[1]	I_c[2]	Total Cover Post STS-1	Total Cover Post STS-9	IS_{mo}[3]
12H	7	6	3	42.9	2	28.6	4	57.1	44.4	35.0	156.0	107.0	71.5
23H	5	7	2	40.0	4	80.0	3	60.0	33.3	27.0	179.0	101.5	66.7
34H	7	4	3	42.9	0	0	4	57.1	57.1	37.0	125.2	121.8	89.8
12G	15	7	10	66.7	2	13.3	5	33.3	29.4	62.0	90.0	80.0	20.0
23G	10	5	5	50.0	0	0	5	50.0	50.0	45.0	123.0	91.5	58.3
34G	4	3	1	25.0	0	0	3	75.0	75.0	19.0	107.0	100.0	80.7
45G	6	5	1	16.7	0	0	5	83.3	83.3	14.0	169.0	107.0	71.7
34F	4	3	1	25.0	0	0	3	75.0	75.0	19.0	135.0	96.0	74.5
45F	4	3	1	25.0	0	0	3	75.0	75.0	19.0	131.0	67.0	62.6
45E	5	1	4	80.0	0	0	1	20.0	20.0	64.0	113.0	76.5	80.7
FG1	11	8	4	36.4	1	9.1	7	63.6	58.3	33.0	113.5	74.2	67.6
GH1	13	12	4	30.8	3	23.1	9	69.2	56.3	27.0	168.0	115.5	60.7
GH2	10	9	7	70.0	6	60.0	3	30.0	18.8	62.0	84.0	90.5	9.2
FG3	9	11	5	55.6	7	77.7	4	44.4	25.0	47.0	108.0	89.0	67.0
GH3	4	3	2	50.0	1	25.0	2	50.0	40.0	35.0	109.0	80.0	67.7
EF4	5	3	2	40.0	0	0	3	60.0	60.0	27.0	128.0	78.5	76.0
FG4	6	3	3	50.0	0	0	3	50.0	50.0	42.0	102.0	76.0	66.3
GH4	6	6	0	0	0	0	6	100.0	100.0	0	196.0	100.0	68.0
EF5	4	2	2	50.0	0	0	2	50.0	50.0	37.0	118.9	88.4	85.3
12D	11	8	9	81.8	6	54.5	2	18.2	11.8	74.0	165.2	50.25	2.8
12C	19	8	14	73.7	3	15.8	5	26.3	22.7	70.0	111.0	37.3	37.1

Table 4. (continued)

Plot	No. of Species Post STS-1	No. of Species Post STS-9	No. of Species Lost	Percent Species Lost	No. of Species Gained	Percent Species Gained	No. of Species In Common	Percent Species In Common	IS_j[1]	I_c[2]	Total Cover Post STS-1	Total Cover Post STS-9	IS_{mo}[3]
23C	5	4	5	100.0	4	80.0	0	0	0	80.0	121.3	60.0	0.0
12B	12	5	8	66.7	1	8.3	4	33.3	30.8	61.0	130.0	94.0	82.6
23B	10	7	5	50.0	2	20.0	5	50.0	41.7	44.0	171.0	61.5	40.0
34B	3	2	2	66.7	1	33.3	1	33.3	25.0	42.0	196.0	28.0	2.2
45B	3	2	2	66.7	1	33.3	1	33.3	25.0	48.0	118.0	81.5	75.2
12A	6	4	2	33.3	0	0	4	66.7	66.7	28.0	108.0	109.0	89.4
23A	11	8	6	54.5	3	27.3	5	45.5	35.7	49.0	83.0	79.0	33.3
34A	1	2	0	0	1	100.0	1	100.0	50.0	-50.0	100.0	100.0	98.5
45A	10	4	7	70.0	1	10.0	3	30.0	27.3	63.0	141.0	88.0	74.2
AB1	9	8	3	33.3	2	22.2	6	66.7	54.5	28.0	112.0	60.0	64.0
BC1	9	4	6	66.7	1	11.1	3	33.3	30.0	59.0	67.0	33.5	21.9
CD1	8	6	3	37.5	1	12.5	5	62.5	55.6	32.0	139.0	53.0	25.3
DE1	11	3	10	90.9	2	18.2	1	9.1	7.7	82.0	160.0	66.75	50.3
AB2	10	3	8	80.0	1	10.0	2	20.0	18.2	72.0	92.0	95.5	78.9
BC2	7	5	6	85.7	4	57.1	1	14.3	9.1	73.0	125.0	68.5	44.4
CD2	7	7	5	71.4	5	71.4	2	28.6	16.7	60.0	150.0	53.75	12.0
AB3	2	2	0	0	0	0	0	100.0	100.0	0	100.0	100.0	99.5
BC3	2	3	0	0	1	50.0	2	100.0	66.7	-17.0	106.0	24.0	4.6
AB4	7	6	3	42.9	2	14.3	4	42.9	44.4	35.0	150.0	112.5	69.7
EF6	14	7	7	50.0	0	0	7	50.0	50.0	46.0	76.0	42.25	37.5
FG6	14	6	10	71.4	2	14.3	4	28.6	25.0	66.0	106.0	61.0	43.1

1 ISj = Jacard's index of similarity (Mueller-Dombois and Ellenberg 1974)
2 Ic = Index of change (see text)
3 IS_{mo} = Sorenson's index (quantitative modification) (Mueller-Dombois and Ellenberg 1974)

Table 5. Mean species richness and mean percent cover from STS-1 through STS-9 in the near-field impact zone

	All Plots (N=42)	Severe Impact (N=23)	Moderate Impact (N=19)
Mean Number of Species Post STS-1	7.8	9.2	6.0
Mean Number of Species Post STS-9	5.1*	5.2*	4.9
Mean Number of Species In Common	3.4	2.9	4.0
Mean Number of Species Lost	4.3	6.3	1.9
Mean Number of Species Gained	1.7	2.3	0.9
Mean Total Cover Post STS-1 (%)	125.8	118.8	134.2
Mean Total Cover Post STS-9 (%)	78.6*	69.9*	89.2*

*differences between means are significant at $p < 0.05$

It is defined as

$$I_c = 100 - \left[\frac{P}{T} + \left[\frac{L+G}{\frac{T+G}{T}} \right] \times 100 \right]$$

where T is the number of species present at time one, L is the number of species lost, G is the number of species gained, and P is the number of species persisting from time one to time two (C.T. Gaetz, pers. com.). Thus, this index explicitly includes the numbers of species lost, gained, and persisting relative to the original.

This index was calculated for the sample transects (Table 4) and ranges from -50.0 through 0 to 82.0. The two negative indices occur in plots 34A and BC3 which gained species but did not lose any. An index of zero indicates no change in species composition while positive indices indicate species change. This index indicates considerable changes in species composition. Those transects with the largest positive indices are generally those nearest to the usual cloud path and most frequently or severely affected; for example, transect DE1 has an index of change of 82.0%. Transects with small indices are in areas less frequently or severely impacted by the cloud as, for example, transect GH4 which has an $I_c = 0$.

All of the measures discussed so far depend totally on changes in species composition; changes in cover of a species without it being added or lost to the transect are not included. Total cover for the transects is given in Table 4. Mean total cover declined from 125.8% post-STS-1 to 78.6% post STS-9, a significant ($p < .05$) decline (Table 5). This indicates that there has been a loss of cover as well as a loss of species. This loss of cover results from the complete or partial killing of shrubs and small trees removing the shrub layer and changing the structure of the community.

In order to compare individual transects on a basis which incorporates changes in cover, a quantitative modification of Sorensen's index was used (Mueller-Dombois and Ellenberg 1974). This index weights dominance more heavily than species presence - absence and so responds somewhat differently than the other two indices (Table 4). An example is transect DE1 which is in an area nearly always hit by the exhaust cloud. Its species richness has declined from eleven species to three losing ten of the original eleven species. Jacard's similarity index reflects this change, IS_j=7.7%, as does the index of change, I_c=82.0% (Table 4). However, the dominant plant in this transect, Fimbristylis castanea, had remained the same so that the quantitative index reflects greater similarity (less change), IS_{mo}=50.3%.

In general, the index of change (I_c), which incorporates species lost, species gained and species persistent, seems to provide the best general index of community changes at this site. The transects may be separated into two distinct groups, one group with I_c>40% can be considered the area of "severe" impact and the second group with I_c<40% is considered the area of "moderate" impact. Only two transects had I_c=0 indicating no change and these were grouped with the moderate impact transects.

The two groups show somewhat different responses. The mean number of species per transect declined from 9.2 to 5.2 in the severe impact group which was significant at $p < .05$; the mean number declined in the moderate impact group from 6.0 to 4.9 but this decline was not significant (Table 5). Declines in mean total cover were significant in both groups.

Changes in species composition and dominance have been sufficient to change community types of some of the sample transects (Figure 6). The wax myrtle-groundsel type in the area of severe impact has lost its shrub component and is now dominated by grasses and sedges; in the area of moderate impact some shrubs persist although shrub cover is generally reduced. Groundsel or sea oxeye may be lost from this type while wax myrtle persists. The grass-sedge type is relatively resistant to the cloud impacts and has not changed in classification; sensitive herbaceous species have been lost from it and percent cover has declined.

Moderate impact to the sea oxeye type has resulted in reduction of cover of sea oxeye while severe impact has eliminated it altogether (Figure 6). Where sea oxeye is eliminated herbaceous species such as Parietaria floridana and Physalis viscosa have become dominant. The invading herbs are typical of disturbed sites.

In summary, the community level changes resulting from repeated exposure to the Shuttle exhaust cloud are: 1) reduction in species richness particularly by the elimination of sensitive species, 2) loss of shrubs and small trees which cannot survive repeated defoliation and their replacement by grasses and sedges or by weedy herbs, and 3) a decline in total cover as strata and individual species are lost. As cover declines, the area of bare ground increases, possibly increasing the potential for erosion.

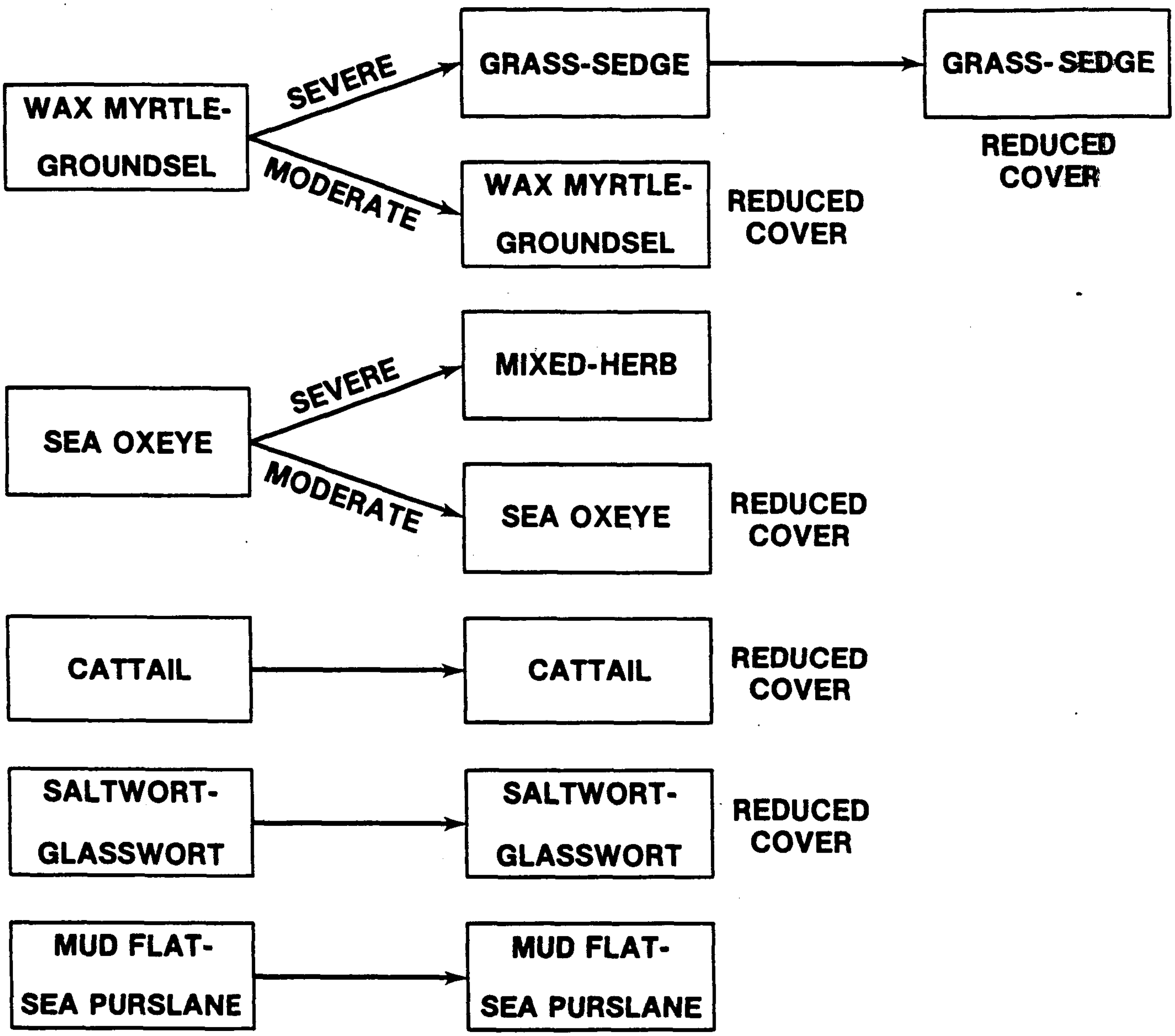


Figure 6. Retrogressive changes in plant communities in the Pad 39A near-field impact zone from STS-1 through STS-9.

Dune and Strand Vegetation

Acute damage to dune and strand vegetation occurred up to 1.2 km northeast of the launch pad from the launches of STS-8 and STS-9. Mean total damage to the strand vegetation from STS-8 ranged from 0% to 81%; the most intense damage was in a strip about 300 m wide (Figure 7). Species showed widely ranging sensitivities to the launch cloud (Tables 6 and 7). Results for the area of heavy damage were probably more reliable given the larger sample size (Table 6). In general, herbaceous species with thin leaves were very sensitive (e.g., *Monarda punctata*, *Bidens pilosa*) while grasses and sedges were fairly resistant (e.g., *Chloris petrae*, *Andropogon* spp.). Shrubs varied in their sensitivities with *Borrichia* > *Baccharis* > *Myrica* in sensitivity.

Mean total damage to the dune vegetation ranged from 0% to 27% and the pattern was less consistent from plot to plot than in the strand (Figure 7). This probably results from the dunes being farther away from the launch pad and from the generally greater resistance of the dominant dune grasses to launch cloud effects. Thin-leafed herbaceous species (e.g., camphorweed, beach sunflower) were generally sensitive to the cloud as were some shrubs with succulent leaves (e.g., *Scaevola plumieri*, (beachberry), *Iva imbricata* (marsh elder)) while the dune grasses (e.g., sea oats, beach grass (*Panicum amarum*), slender cordgrass) were quite resistant (Tables 8 and 9).

The launch of STS-9 produced a similar pattern of damage followed by recovery. Mean percent damage to the strand vegetation ranged from 0% to 76%; major damage was in a strip about 250 m wide. (Figure 8). Species sensitivities were similar to those of STS-8 (Table 10). Some species had already become dormant at the time of launch and were thus unaffected (e.g., *Monarda punctata*). Mean percent damage to the dune vegetation ranged from 0% to 58%; heavy damage on the dunes was restricted to a strip about 250 m wide (Figure 9). Sensitive and resistant species were similar to those of STS-8 (Table 11). Initial recovery of the damaged vegetation was slow probably due to the season of the launch. In fact, the severe freeze of December 25-26, 1983 damaged species such as sea grape and beachberry which were in control plots unaffected by launch (Provancha et al. 1985). By April, however, substantial regrowth was evident and by June conditions appeared close to those pre-launch. This was confirmed by a resurvey of the permanent plots which indicated only a small remaining mean percent damage (0-5%) attributable to launch (Figures 8 and 9). Not all species in all plots had yet recovered their pre-launch cover. Some plots also had minor changes in species composition; seasonal differences (late fall to late spring) complicate the interpretation of these results.

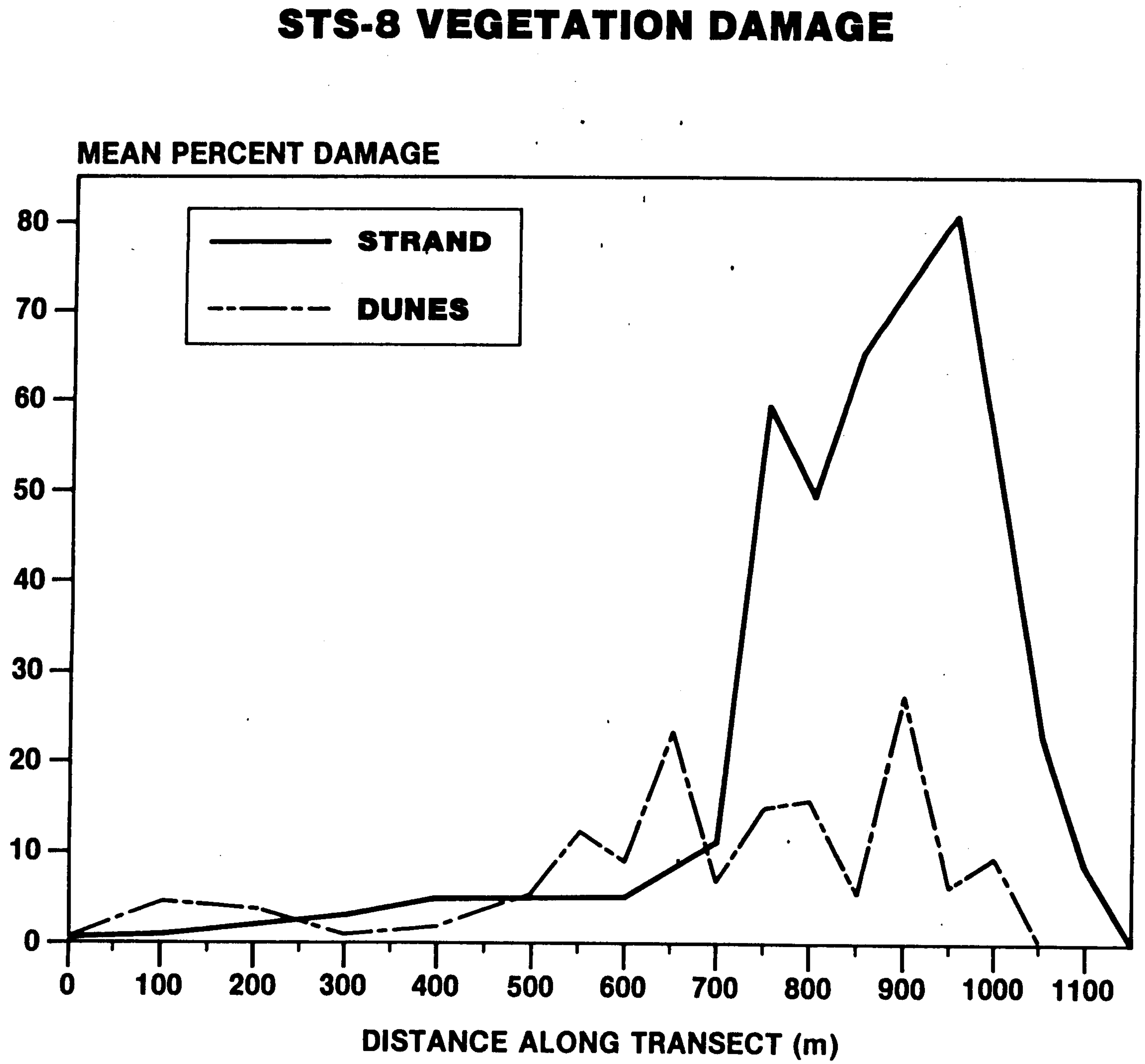


Figure 7. Damage to strand and dune vegetation from STS-8.

Table 6. Sensitivity of species to damage based on transect data from strand vegetation - Zone of heavy damage from STS-8

SPECIES	Mean % Damage	Std. Dev.	N
Monarda punctata	97.5	5.0	4
Bidens pilosa	82.5	10.6	2
Borrichia frutescens	63.3	34.0	3
Conyza canadense	50.0	----	1
Vitis rotundifolia	35.0	21.2	2
Baccharis halimifolia	31.0	10.2	5
Croton punctatus	20.0	----	1
Myrica cerifera	17.5	3.5	2
Lantana camara	10.0	----	1
Catharanthus roseus	10.0	----	1
Rubus sp.	10.0	----	1
Solidago sp.	10.0	----	1
Acrostichum danaeifolium	10.0	----	1
Lippia nodiflora	7.5	3.5	2
Opuntia stricta	6.3	2.5	4
Chloris petrae	5.3	4.5	3
Cyperus sp.	5.0	----	1
Andropogon spp.	5.0	----	1
Scirpus sp.	5.0	----	1
Cenchrus longispinus	3.0	2.8	2

Table 7. Sensitivity of species to damage based on transect data from strand vegetation - Zone of moderate damage from STS-8

SPECIES	Mean % Damage	Std. Dev.	N
Borrichia frutescens	7.5	3.5	2
Myrica cerifera	5.0	0.0	2
Baccharis halimifolia	5.0	0.0	4
Lantana camara	5.0	----	1
Ambrosia artemissifolia	5.0	----	1
Heterotheca subaxillaris	5.0	----	1
Monarda punctata	2.5	3.5	2
Opuntia stricta	1.0	0.7	2
Andropogon spp.	1.0	----	1
Cyperus sp.	1.0	----	1
Chloris petrae	1.0	----	1
Lippia nodiflora	1.0	----	1
Batis maritima	0	0.0	2
Euphorbia sp.	0	----	1
Mikania scandens	0	----	1

Table 8. Sensitivity of species to damage based on transect data from dune vegetation - Zone of heavy damage from STS-8

SPECIES	Mean % Damage	Std. Dev.	N
Heterotheca subaxillaris	35.0	24.6	8
Scaevola plumieri	25.0	----	1
Helianthus debilis	20.0	----	1
Iva imbricata	15.0	7.1	2
Yucca aloifolia	10.0	----	1
Chamaesyce bombensis	5.5	6.4	2
Uniola paniculata	5.5	1.7	9
Panicum amarum	5.0	0.0	4
Andropogon spp.	5.0	----	1
Croton punctatus	5.0	----	1
Commelina diffusa	5.0	----	1
Coccoloba uvifera	5.0	----	1
Rapanea punctata	5.0	----	1
Spartina patens	1.0	----	1

Table 9. Sensitivity of species to damage based on transect data (N=1) from dune vegetation - Zone of moderate damage from STS-8

SPECIES	Mean % Damage
Agave neglecta	15.0
Scaevola plumieri	10.0
Heterotheca subaxillaris	5.0
Lippia nodiflora	5.0
Licania michauxii	5.0
Gaillardia pulchella	3.0
Ipomoea stolonifera	2.0
Uniola paniculata	2.0
Opuntia stricta	1.0

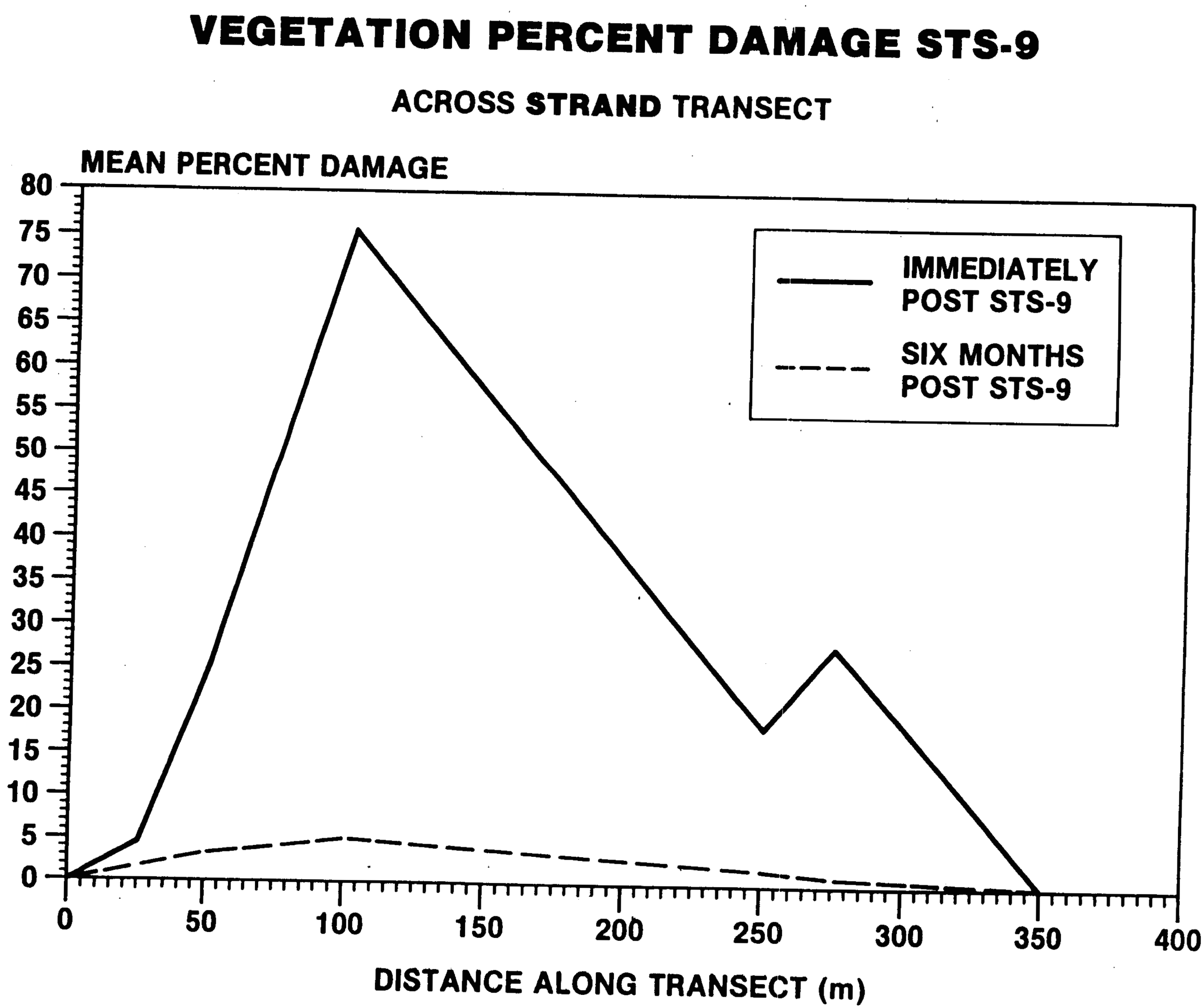


Figure 8. Damage to strand vegetation from STS-9 and subsequent recovery.

Table 10. Sensitivity of species to damage based on transect data from strand vegetation - Zone of heavy damage from STS-9

SPECIES	Mean % Damage	Std. Dev.	N
Flaveria linearis	96.7	5.8	3
Asteraceae-Unknown	92.5	3.5	2
Unknown Herb #1	90	----	1
Baccharis halimifolia	83.3	18.1	6
Lantana camara	75	----	1
Hypericum sp.	74.0	42.5	3
Solidago sp.	50	----	1
Iresine diffusa	40	----	1
Schinus terebinthifolius	22.5	24.7	2
Myrica cerifera	19.0	5.5	5
Serenoa repens	15	----	1
Smilax auriculata	15	----	1
Quercus virginiana var. geminata	11.7	2.9	2
Rubus sp.	8.8	2.5	4
Opuntia stricta	8.8	4.8	4
Spartina patens	7.5	3.5	2
Cyperaceae-Unknown	5.0	0.0	2
Juncus sp.	5	----	1
Poaceae-Unknown	5	----	1
Casuarina litorea	1	----	1

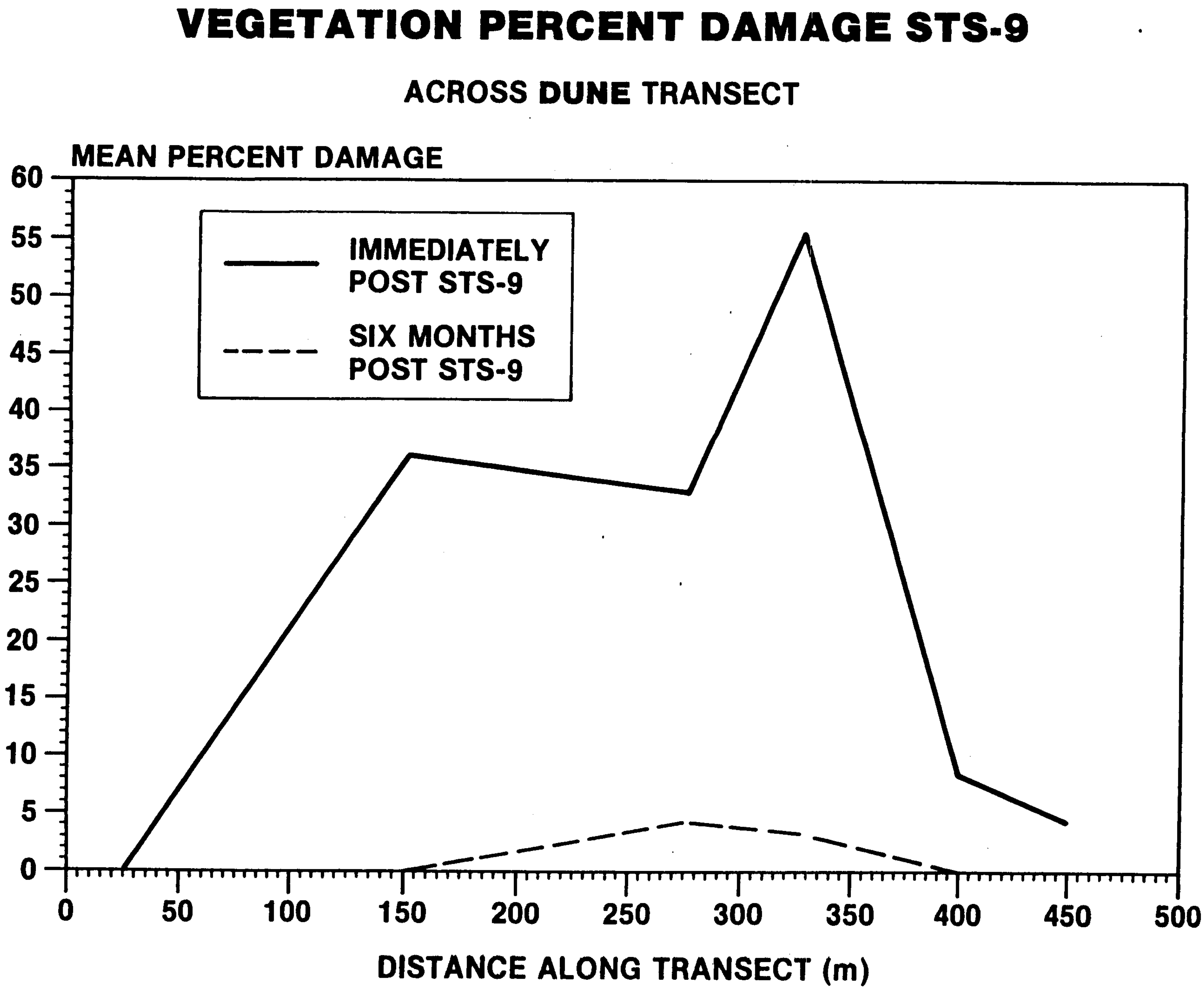


Figure 9. Damage to dune vegetation from STS-9 and subsequent recovery.

Table 11. Sensitivity of species to damage based on transect data from dune vegetation - Zone of heavy damage from STS-9

SPECIES	Mean % Damage	Std. Dev.	N
Helianthus debilis	70.4	28.3	2
Heterotheca subaxillaris	53.3	35.1	3
Iva imbricata	45.0	20.8	4
Ipomoea stolonifera	20.0	----	1
Croton punctatus	20.0	----	1
Opuntia stricta	16.7	5.8	3
Coccoloba uvifera	10.0	----	1
Uniola paniculata	5.0	0.0	5
Chloris petrae	5.0	----	1
Euphorbia sp.	1.0	----	1

A one-time exposure to the severe near-field effect of the launch cloud can result in considerable vegetation damage particularly to dune and strand types dominated by relatively sensitive species. However, if this impact is not repeated considerable recovery will occur within about six months. No structural changes occurred in these dune and strand communities with only one exposure to the launch exhaust cloud.

Far-field Vegetation

The map of cumulative far-field deposition (Figure 10) shows that different areas are affected by this deposition depending on the cloud behavior. The frequency of impact for areas >3 km from Pad 39A has been low. Based on visual surveys of vegetation and structures, deposition has occurred as far as 22 km from the launch pad and the cloud track has been up to 3 km in width. Vegetation damage from far-field deposition consists of acid spotting and dry deposition of aluminum oxide on leaves. Deposition on any one surface may be mixed so that a spot of aluminum oxide will include a ring of acid burn around it on a leaf. Typically the amount of leaf surface involved will be about 1-5% occasionally ranging up to 10%.

Although deposition persists on leaf surfaces for considerable periods, no mortality of these plants has been observed from this minor loss of photosynthetic tissue. No changes in community composition or structure have been observed in the far-field related to launch effects. The chronic effect of such deposition is unknown at this time. Evaluation of the actual amounts of deposition could provide considerable insight into potential effects.

Discussion

Considerable experimental data are available from laboratory exposures of plants to hydrogen chloride (HCl), aluminum oxide (Al_2O_3), mixtures of HCl and Al_2O_3, and the combustion products of solid rocket fuel (Heck et al. 1980). Ratings of the sensitivities of both plants native to Merritt Island and cultivated species to HCl have been developed. In the launch cloud, however, hydrogen chloride gas is quickly scavenged by water to form a hydrochloric acid aerosol. Effects on plants differ somewhat between exposure to dry HCl gas and to hydrochloric acid aerosols (Heck et al. 1980, Granett 1984). Environmental factors such as relative humidity and soil moisture also influence the amount of plant damage. High relative humidity or misting of plants prior to exposure to HCl increased plant damage compared to dry exposure to HCl gas (Heck et al. 1980). Thus, the high relative humidity occurring at STS-8 and STS-9 and the rain which preceded STS-8 would be expected to increase vegetation damage.

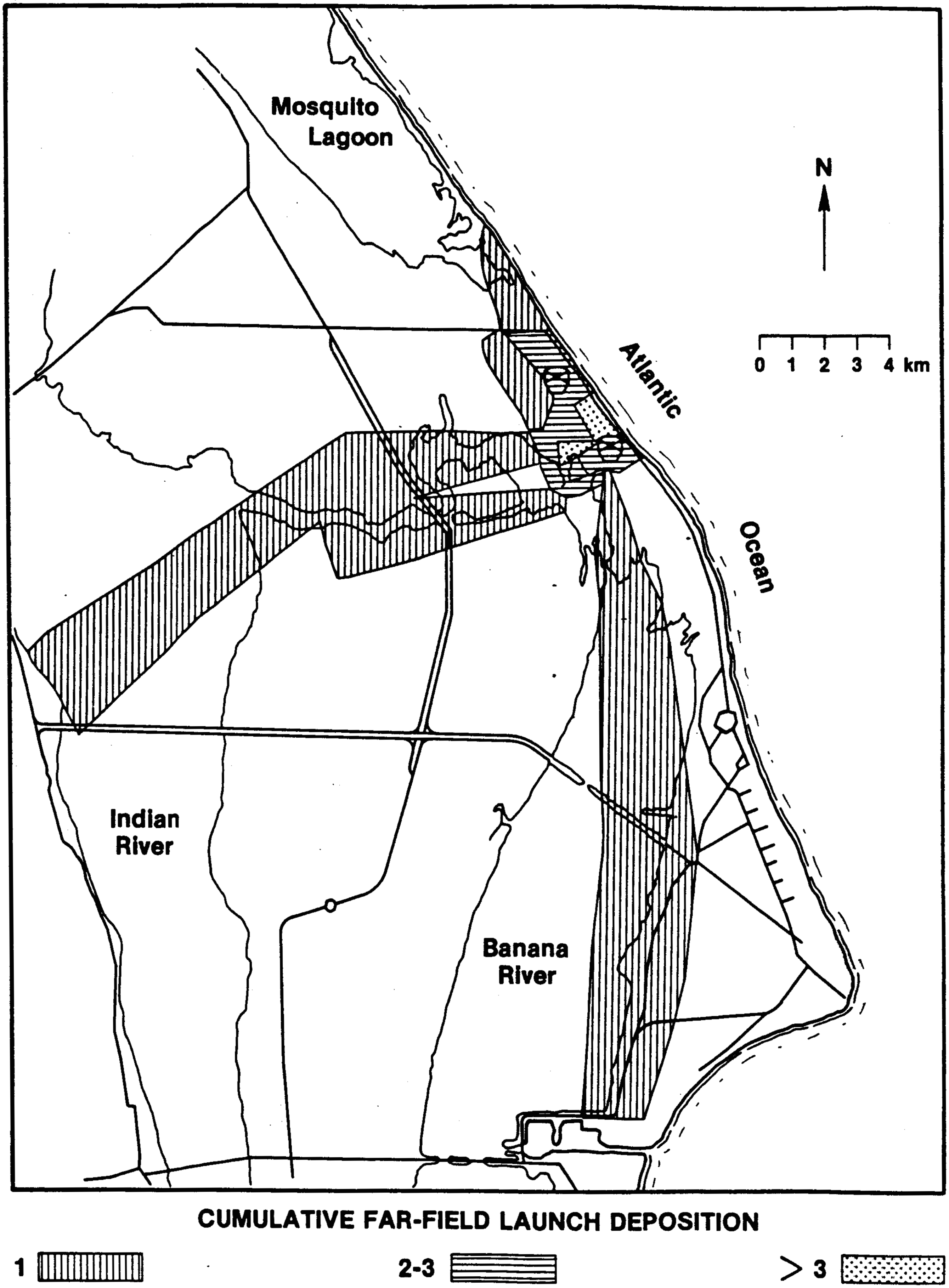


Figure 10. Cumulative far-field launch deposition from STS-1 through STS-9.

The responses of plants resulting from laboratory exposures to HCl and field exposures to the launch cloud are generally comparable. For example, sea oats and slender cordgrass were uninjured by exposures of >40 ppm HCl for one hour (Heck et al. 1980), and these species are very resistant to exposure to the launch cloud in the field. On the other hand, camphorweed, sea oxeye and beach sunflower appear to be much more sensitive to the launch cloud than predicted by laboratory studies. This is probably due to the difference in response to dry HCl gas (used in laboratory experiments) as compared to aqueous aerosol hydrochloric acid. Field data are complicated somewhat by the lack of control of amount and time of exposure, varying environmental conditions of temperature, humidity, and other factors; in some cases, the upper strata of the vegetation intercepts the launch cloud and partially shields the ground-level vegetation.

Community and ecosystem level effects are produced by the Shuttle exhaust cloud. Smith (1981) has divided the interactions between air contaminants and forest ecosystems into three classes. A Class I relationship occurs under conditions of low dose where the forest ecosystem functions as a sink and source for air pollutants. Under intermediate doses, a Class II relationship, particular species or individuals may be subtly and adversely affected. Exposure to high doses, a Class III relationship, may result in acute morbidity or mortality of particular plants. Although developed originally for forests, this classification seems generally applicable to interpreting launch effects on terrestrial ecosystems.

The near-field acute impacts of the Shuttle exhaust cloud clearly qualify as a Class III interaction given the plant mortality and community changes which have occurred in this area. Other examples of vegetation damage of this type have been associated with certain point sources of pollution. Smelting operations for copper, nickel, or iron have produced extensive zones of vegetation destruction at Copper Basin, Tennessee, Sudbury, Ontario and Wawa, Ontario resulting from sulfur dioxide emissions (Smith 1981, Gordan and Gorham 1963). Fluoride emissions from aluminum ore processing facilities have produced similar patterns of vegetation damage (Smith 1981). Gordan and Gorham (1963), in a detailed study of the Wawa, Ontario site, showed that zones of decreasing intensity of vegetation damage to the boreal forest existed away from the iron sintering plant. Near the source, nearly all plants had been eliminated. Farther away the ground layer of vegetation persisted but trees and shrubs were eliminated. In the next zone, the shrub layer was dominant but the canopy had been nearly eliminated. Next was a zone where trees were still present but showed signs of damage. Finally a zone of no apparent damage was reached. Species richness also declined on a gradient approaching the sintering plant. These zones of damage extended more than 20 miles (32 km) in the direction of the prevailing winds and affected thousands of acres of forest. In contrast, the effects of the Shuttle exhaust are localized.

Similar patterns of vegetation response have been described for chronic exposure to radiation (Woodwell 1967, 1970, Whittaker and Woodwell 1978) a very different kind of disturbance. Woodwell (1970) described common features that result from these and other disturbances to ecosystems. These changes are first a reduction in diversity by the elimination of sensitive species; then elimination of the tree canopy and survival of resistant shrubs and herbs, usually species recognized as "seral" or "generalist." Along with this simplification in community structure, occurs a reduction in standing crop biomass and the amount of nutrients held within the system. Whittaker and Woodwell (1978) termed these sequence of changes retrogression and contrasted them to successional changes which typically add species and increase structure through time.

The effects of Shuttle launches differ from many environmental perturbations in that it is a pulsed system; major acute impacts are separated by some weeks or months which allow some recovery. More typical point sources (e.g., smelters) produce essentially continuous emissions. The early Shuttle flights (STS-1 to STS-9) were two to seven months apart; the shortest interval between launches in this period was 63 days.

Although there are unique features of Shuttle launch effects, the vegetation changes caused by the Shuttle exhaust cloud in the near-field area exhibit many of the characteristics associated with smelters and radiation sources. Sensitive species have been lost and reduction in species richness has occurred. No tree canopy existed at this site but the shrub layer has been removed in the most heavily damaged areas and reduced at the less impacted sites. Grasses, sedges and herbs persist within the impact zone; many of these are typical of disturbed sites. Standing crop biomass has undoubtedly declined with elimination of the shrub layer.

The area influenced by the near-field exhaust cloud effects, about 22 ha, is much smaller than the hundreds to thousands of hectares damaged by large smelters. The interval between Shuttle launches has allowed some recovery and regrowth to occur; however, this interval is expected to decrease to perhaps two weeks in the future as launch rates increase.

The increased frequency will result in permanent removal or change of several plant communities. Changes can be expected to continue to occur within the impact zone. The area currently considered moderately damaged will become more like the area of severe damage. The area of severe damage will continue to be stressed; an endpoint cannot be predicted with complete certainty, but at some point all vascular plants may be eliminated, especially with increased exposure by frequent launches. The total area within the impact zone may increase with differing meteorological conditions at future launches. An area larger than the present impact zone may eventually be damaged.

With reduced cover and increased areas of bare ground, the potential for erosion will increase. Increased leaching of soil nutrients may occur as plants are no longer present to take them up. Runoff and leaching may contribute greater nutrient and sediment loads to nearby surface waters. Increased nutrient loading could contribute to eutrophication of the aquatic system while increased amounts of sedimentation could impact benthic organisms.

Loss of the shrub layer from plant communities changes their value as wildlife habitat. The changes in habitat structure within the near-field impact area suggest that species requiring shrub vegetation will be replaced by species preferring graminoid vegetative cover. In addition, the interactions of wildlife with contaminants produced by Shuttle launches may be a major factor responsible for impacts on wildlife. Since the near-field terrestrial area at Pad 39A is limited in size and is not critical habitat for species of special concern, the effects on wildlife due to vegetational change are probably minimal.

Dune vegetation has been impacted by two launches, STS-8 and STS-9; if impacts to the dune system become frequent the loss of dune stability and erosion could occur. Since severe storms do occur along this coast, loss of the protecting dunes would pose a risk to areas and structures inland from them.

Long-term effects to dune vegetation are also of concern because of the mouse Peromyscus polionotus niveiventris. This subspecies of beach mouse is restricted primarily to dune vegetation along the central stretch of Florida's Atlantic coast. Given the rapid development along this coastline, lands of Kennedy Space Center and Cape Canaveral Air Force Station are likely to retain the only significant acreage for the survival of this animal (Jack Stout, pers. comm.). The effects on wildlife of contaminants from Shuttle operations in near-field or far-field areas are unknown and may be as significant or more significant than changes in vegetation.

Far-field deposition is considered a much less serious environmental impact because of the much smaller amount of deposition which occurs over a relatively large area. No plant mortality or community changes have been associated with far-field deposition. However, absence of acute effects does not imply that long term chronic effects are not occurring. More careful quantification of far-field deposition is necessary to evaluate this potential.

For far-field areas, the magnitude of vegetation change has not appeared significant enough to perceive any permanent shifts in habitat structure that would affect wildlife. However, the deposition rates have not yet been quantified for long term evaluation.

Conclusions and Recommendations

There have been significant acute vegetation changes in a 22 ha near-field area resulting from Space Shuttle launches at Pad 39A. Launch effects are minor with respect to the whole barrier island system. Effects will increase in the near-field area depending on launch frequency which dictates vegetation recovery time, conditions at each launch and the sensitivity of the various species. The area affected will probably increase with time to include more than 22 ha. Further monitoring is required to determine if these changes are adversely impacting other components of this ecosystem and to determine the maximum extent of damage. More subtle chronic effects (e.g., leaching of soil nutrients, nutrient loading to aquatic systems, etc.) are occurring and should be quantified.

Dune and strand vegetation exposed to the launch cloud on a one-time basis can recover to a large degree in about six months. However frequent exposure of dune vegetation to the launch cloud could result in elimination of vegetation cover and lead to serious erosion problems. Continued monitoring of dune vegetation should be conducted to evaluate these impacts and contingency plans for revegetation should be established.

Far-field deposition also occurs with each launch. Acute effects of this deposition are minor but continued monitoring is required to determine long-term chronic effects. A more careful quantification of far-field deposition amounts is necessary for evaluating potential chronic effects.

The effects of contaminants from Shuttle launches on wildlife utilizing areas receiving deposition is currently unknown. This issue requires further study.

Operation of Pad 39B can be expected to produce an area of acute impact similar to that of Pad 39A. More of the expected impact zone at Pad 39B is water than land but impacts to terrestrial vegetation will occur. It can be predicted that sensitive plant species will be eliminated from the near-field zone and shrubs will be eliminated. Additional areas of dune vegetation will be exposed to damage by launches from Pad 39B. If the dune vegetation is repeatedly damaged a problem of dune stability and erosion will develop. Monitoring is required to determine these effects.

Literature Cited

Anderson, B.J. and V.W. Keller. 1983. Space Shuttle exhaust cloud properties. NASA Technical Paper 2258. Marshall Space Flight Center, Alabama.

Bjorklund, J.R., R.K. Dumbauld, C.S. Cheney and H.V. Geary. 1982. Users manual for the REEDM (Rocket Exhaust Effluent Diffusion Model) computer program. H.E. Cramer Co. NASA Contractor Report 3646. Marshall Space Flight Center, Alabama.

Bowie, W.H. 1981. Environmental effects of the STS-1 flight readiness firing and launch. Medical Directorate, NASA, Kennedy Space Center, Florida.

Breininger, D.R. 1981. Analysis of vegetation north of LC39A prior to STS-2. Unpublished paper.

Dreschel, T.W. and C.R. Hinkle. 1984. Acid deposition, pH and inorganic carbon interactions: Laboratory simulation of Space Shuttle launch cloud effects on estuarine systems. NASA TM 83094. John F. Kennedy Space Center, Florida. 13pp.

Dreschel, T.W., C.R. Hall and C.R. Hinkle. 1985. Near-field deposition patterns of chlorides and particulates resulting from launches of the Space Transportation System. In preparation.

Dreschel, T.W., C.T. Gaetz, C.R. Hall, and C.R. Hinkle. 1985. An evaluation of statistical relationships between the near-field atmospheric deposition patterns of Space Transportation System related substances. In preparation.

Gordan, A.G. and E. Gorham. 1963. Ecological aspects of air pollution from an iron-sintering plant at Wawa, Ontario. Can. J. Bot. 41:1063-1078.

Granett, A.L. 1984. The phytotoxicity of designated pollutants on plant species. Third Annual Report, AFAMRL-TR-83-96, Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio. 81 pp.

Hawkins, W.E., R.M. Overstreet and M.J. Provancha. 1984. Pathological effects of Space Shuttle exhaust plumes on gills of some estuarine fish: A light and electron microscopic study of acute environmental stress. Gulf Research Reports 7:297-309.

Heck, W.W., W.M. Knott, E.P. Slahel, J.T. Ambrose, J.N. McCrimmon, M. Engle, L.A. Romanov, A.G. Sawyer and J.D. Tyson. 1980. Response of selected plant and insect species to simulated solid rocket exhaust mixtures and to exhaust components from solid rocket fuels. NASA Technical Memorandum 74109. NASA, J.F. Kennedy Space Center, Florida. 146 pp.

Knott, W.M. 1983a. STS-8-Environmental effects: Quick look report. Biomedical Office, NASA, J.F. Kennedy Space Center, Florida.

Knott W.M. 1983b STS-9-Environmental effects: Quick look report. Biomedical Office, NASA, J.F. Kennedy Space Center, Florida.

Knott, W.M.,III, A. Koller, Jr., and J. Puleo. 1983. Environmental effects of STS-1 through STS-4 launches: Comprehensive report. pp.1-30. In: A. Potter (ed.) Space Shuttle Environmental Effects: The First Five Flights. NASA, L.B. Johnson Space Center, Houston, Texas.

Milligan, J.E. and G.B. Hubbard. 1983. STS-5 fish kill, Kennedy Space Center, Florida. pp.59-80. In: A. Potter (ed.) Space Shuttle Environmental Effects: The First Five Flights. NASA, L.B. Johnson Space Center, Houston, Texas.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, New York. 547 pp.

NASA. 1979. Final environmental impact statement for the Kennedy Space Center. NASA, J.F. Kennedy Space Center, Florida.

Provancha, M.J., P.A. Schmalzer and C.R. Hall. 1985. Effects of the December 1983 and January 1985 freezing air temperatures on select aquatic poikilotherms and plant species of Merritt Island, Florida. Unpublished manuscript.

Smith, W.H. 1981. Air pollution and forests. Springer-Verlag, New York. 379 pp.

Whittaker, R.H. and G.M. Woodwell. 1978. Retrogression and coenocline distance. pp. 51-70. In: R.H. Whittaker (ed.) Ordination of plant communities. Dr. W. Junk. The Hague, The Netherlands.

Woodwell, G.M. 1967. Radiation and the patterns of nature. Science 156:461-470.

Woodwell, G.M. 1970. Effects of pollution on the structure and physiology of ecosystems. Science 168:429-433.

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15. Abstract

Space Shuttle launches produce a launch cloud which contains hydrochloric acid (HCl), aluminum oxide (Al_2O_3), and other substances. Acidities of <0.5 pH have been measured routinely in association with the launch cloud. In an area of about 22 ha regularly exposed to the exhaust cloud during most Shuttle launches, acute vegetation damage has resulted from the first nine Shuttle launches. Changes include loss of sensitive species, loss of plant community structure, reduction in total cover, and replacement of some species by weedy invaders. Community level changes define a retrogressive sequence. One-time impacts to strand and dune vegetation occurred after launches of STS-8 and STS-9. Acute vegetation damage occurred especially to sensitive species. Within six months, however, recovery was nearly complete. Sensitivity of species to the launch cloud was partially predicted by previous laboratory studies. Far-field acidic and dry fallout from the cloud as it rises to stabilization and moves with the prevailing winds causes vegetation spotting. Damage from this deposition is minor; typically at most 1% to 5% of leaf surface area is affected. No plant mortality or community changes have occurred from far-field deposition.

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