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A COMPARISON OF PRIMARY PRODUCTION RATES IN INDIAN RIVER, FLORIDA SEAGRASS SYSTEMS

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Abstract: *Three sites in the Indian River, Florida were studied to determine primary production in seagrass meadows. Production rates were obtained for 3 species of seagrasses* (Thalassia testudinum, Syringodium filiforme *and* Halodule wrightii), *associated epiphytic flora, benthic microalgae and phytoplankton. Photosynthetic rates for Indian River seagrasses in March and July ranged between 0.009-0.395 mg C/g dry wt-h for* H. wrightii, *0.005-0.79 for* T. testudinum, *and 0.009-1.72 for* S. filiforme. *Epiphytic productivity per g dry wt varied considerably between stations and from season to season. Productivity maxima for* H. wrightii *and* S. filiforme *occurred at the Jim Island station;* Thalassia testudinum *demonstrated maximum photosynthetic response at Link Port. Phytoplankton, benthic microalgae and epiphytic production were similar at each station and increased slightly from March to July. However, their absolute importance in community productivity changed dramatically depending upon the contribution of the seagrass species.*

The Indian River is a broad, shallow coastal lagoon which harbors dense populations of seagrasses. It has been estimated that seagrasses cover 2% (2776 ha) of the river bottom between Merritt Island and the St. Lucie Inlet (Thompson, 1978). Of the 20 known seagrass species, 6 occur in the Indian River (Eiseman, 1980): *Halodule wrightii* Aschersen, *Thalassia testudinum* Banks ex Konig et Sims, *Syringodium filiforme* Kutzing, *Ruppia maritima* Linnaeus, *Halophila englemanii* Ascherson and *Halophila johnsonii* Eiseman. *Halodule wrightii, S. filiforme* and *T. testudinum* are the most abundant (Thompson, 1978).

Primary production is considered the most essential function of a seagrass meadow, and as a result, seagrass ecosystems support rich communities of plants and animals (McRoy, 1974; Topham et al, 1974; Thayer et al., 1975;

McRoy and McMillan, 1977; Jacobs, 1977. The role of seagrasses in coastal ecosystems has been summarized by Wood et al. (1969), Zieman and Wetzel (1974) and Topham et al. (1975). Because seagrasses are highly visible and most often the dominant primary producer, other autotrophic components of the community are often neglected. These include epiphytic algae, benthic microalgae and phytoplankton.

The number of *in situ* productivity studies on seagrass communities is small, and to our knowledge no single study has considered the contribution of the various primary producers to the total productivity in a seagrass meadow. The objects of this study were to determine the primary production rates of the 3 principal seagrasses in the Indian River and to investigate the contribution of seagrass epiphytes, benthic microalgae and phytoplankton to the total productivity in a seagrass meadow. At present, comparable information is not available on primary production of Indian River seagrasses. It is becoming increasingly important to obtain such information because Florida coastal areas are threatened by urban and industrial development.

Drift algal productivity was not considered in this study. The extent and persistence of large drift algal populations in the Indian River suggest that they are an important part of the total ecosystem (Eiseman & Benz, 1975; Gilmore, 1976; Thompson, 1978). However problems associated with 1) productivity measurements for a wide variety of algal species and 2) estimating drift algal biomass were beyond the scope of this study and the object of a separate study currently in progress (R. W. Virnstein, pers. comm.).

LOCATION AND METHODS—The study area encompassed a 25 km section of the Indian River from the Ft. Pierce Inlet to the City of Vero Beach, Florida (Fig. 1). Three grassbed stations (from south to north) referred to as Jim Island, Link Port and Vero Beach were chosen to represent distinctly different physical-chemical environments. The Vero Beach station was located 6 km north of the City of Vero Beach at channel marker 118 on the west side of a spoil bank. The site was situated 25 km north of the Ft. Pierce Inlet and 25 km south of the Sebastian Inlet and was chosen as an area influenced primarily by land runoff and land-use practices. The area was characterized by salinities less than 32 ppt (annual average), high nutrient levels, wide temperature variations and minimal water movements (Table 1). Current velocities ranged between 9.0-15.0 cm/sec for a lunar cycle (M. Sternberger, pers. comm.), or approximately 30% of those at the Ft. Pierce Inlet. Tidal currents at this station are less significant in the net displacement of water due to the increased distance from the ocean inlets. Seagrass beds at Vero Beach are dominated by *H. wrightii* intermixed with sparse beds of *T. testudinum*. *Syringodium filiforme* was not found at this station. The Link Port station was located on the north side of the north spoil finger of Link Port channel, 9 km north of the Ft. Pierce Inlet. Link Port has physical-chemical characteristics intermediate between the Vero Beach and Jim Island stations (Table 1). The area is influenced to some extent by the salt wedge from the Ft. Pierce Inlet. *Halodule wrightii*, *S. filiforme* and *T. testudinum* occur consistently at this station. Grassbeds at Jim Island were chosen to represent an area influenced primarily by oceanic processes. The sampling site was a broad grassflat on the south side of the north bridge causeway near the Ft. Pierce Inlet. The grassflat is characterized by wide tidal fluctuations and maximal water movement. Current velocities range between 31.6-48.7 cm/sec for a lunar cycle (M. Sternberger, pers. comm.). Relatively low nutrient, high salinity oceanic water covers the area most of the time (Table 1). Water temperatures and salinities are more stable and fluctuate less than at the Vero Beach station. All 3 seagrasses were abundant at this station.

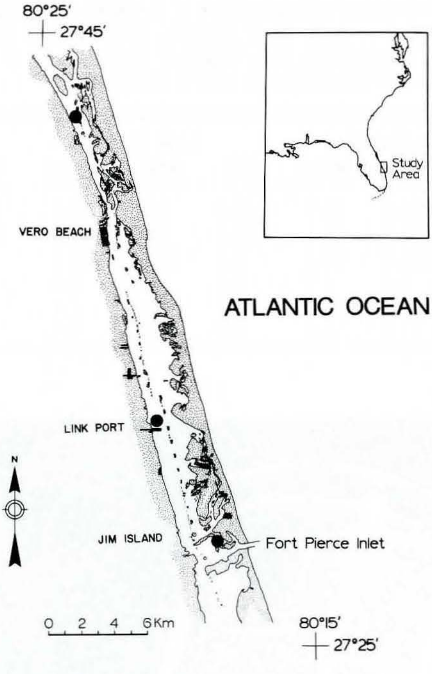

FIG. 1. Location of the study sites in the Indian River, Florida.

All productivity estimates were determined using radiocarbon techniques. Although use of ^{14}C in seagrass production measurements has recently been criticized due to possible internal recycling of CO_2 (Patriquin, 1973; Wetzel and Hough, 1973; McRoy, 1974) it remains the method of choice due to its high sensitivity, short incubation times, compatability with other autotrophic components and applicability to all seagrasses.

To obtain comparable data from the different components, productivity measurements must be performed under similar environmental conditions. An *in situ* incubation chamber was designed which allowed simultaneous measurements of phytoplankton, seagrass and epiphytic algal production (Fig. 2). The seagrass short shoot was inserted through the bottom of the chamber and sealed from the surrounding environment with non-porous neoprene rubber. By this method the short shoot remained intact *in situ*. A Savonius rotor was attached to the top of the incubation chamber (20 cm high, 4 cm ID) and coupled to an inner tube with magnets. Currents in the surrounding environment turn the Savonius rotor as well as the inner tube to insure constant mixing inside the chamber. Using a flow tank and measured flow rates it was possible to demonstrate that the incubation chamber was 85-90% efficient in imitating the current regime outside the chamber. Light transmission, as measured with a Biospherical Instruments PSL-10 Light Meter, was reduced 15% inside the chamber. Productivity levels were adjusted accordingly, assuming linearity between productivity and light energy levels below saturation. Such linearity has been noted for *T. testudinum* (Bittaker and Iverson, 1976) and *Zostera marina* (Dillon, 1974) and we have assumed linearity for *H. wrightii* and *S. filiforme*.

Triplicate 3-hr incubations were made on individual short shoots for each seagrass species. Each chamber was injected with 1.0 ml of 10-15 μCi of $NaHC^{14}O_3$. Incubations were made between 1000 and 1300 h. Each site was sampled in the spring (March) and summer (July) of 1981. After incubation, the chamber with short shoot was removed from the sediment. The chamber water was filtered onto 0.4 μm Nucleopore filters for determination of phytoplankton productivity. To remove any unincorporated ^{14}C, 0.5 ml of 0.5N HCL was added to each filter and allowed to evaporate (Williams et al., 1974). After each filter was digested with 1.0 ml of NCS tissue solubilizer (Amersham Corp.), 10 ml of scintillation cocktail (ACS-Amersham Corp.: toluene:water — 7:3:1) was added and the sample counted using a Searle Mark III LSC with ESR

TABLE 1. Physical and chemical characteristics of the three sampling sites. Values represent weekly measurements of a 2.5 yr study from January, 1976 through June, 1978 (Indian River Coastal Zone Study, M. J. Youngbluth, pers. comm.). Temperature of surface water is in °C; Salinity in ppt and the nutrient concentration unit is micromolar.

	Vero Beach			Link Port			Jim Island		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Temperature	10.5	31.6	23.7	10.0	31.0	23.1	12.5	29.0	23.1
Salinity	15.0	37.0	28.0	18.1	37.5	30.8	27.0	37.0	34.5
Silicate	8.2	354.0	36.5	2.6	268.4	26.2	0.6	29.8	7.1
Phosphate	0.3	6.1	1.3	0.1	3.5	0.9	0.1	6.0	0.4
Nitrate	0.1	83.6	2.6	0.1	63.3	1.4	0.1	51.8	1.1
Ammonia	0.3	31.0	4.4	0.3	19.7	2.7	0.3	8.1	1.9

FIG. 2. *In situ* incubation chamber used to determine seagrass productivity.

counting techniques at 85-90% efficiency. The seagrass short shoot was quick frozen in a dry ice/acetone slurry. Epiphytes were separated from the seagrass blade using the freeze-drying technique of Penhale (1977). Solubilization of the seagrasses and epiphytes followed a modification of the methods of Gagne et al. (1979). Each sample was ground to a powder using a "wiggle bug" grinder (Crescent Dental Manufacturing Co.). One-half ml of 30% H_2O_2 was added to 5-10.0 mg of plant tissue. Vials were capped and placed in an oven at 50°C for 24 h. One ml of NCS was then added and the vial reheated at 50°C for approximately 3 hr. After cooling, cocktail was added and the sample counted as before.

To determine solubilization efficiency, non-labeled freeze-dried seagrasses were ground to a powder. Approximately 9000 DPMs of sucrose ^{14}C was added to the powder as an internal standard. The sample was digested and counted. The solubilization technique was 100 ± 2.5% efficient in recovering labeled ^{14}C (Table 2).

TABLE 2. Recovery of ^{14}C from seagrasses and epiphytes of known radioactivity using the solubilization technique (Weight in mg).

Species	N	Weight	% Recovery
Thalassia testudinum	6	25-64	99 ± 2.4
Syringodium filiforme	5	19-52	98 ± 2.7
Halodule wrightii	4	18-37	101 ± 2.5
Epiphytes	6	20-56	98 ± 2.4

Productivity of benthic microalgae was determined for the upper 2.5 cm of sediment. Sediment cores (2.0 cm ID) were taken in the grassbeds and one ml of $NaHC^{14}O_3$ (10-15 μCi) was injected into each corer. The corer was capped and returned to the grassbed for 3 hr. The water was decanted from the sampler and the sediments immediately extracted and frozen. Productivity was determined using a modification of the method of Van Raalte et al. (1974). Unlabeled ^{14}C was removed from the sediment by washing with 2N HCL. The sediment was centrifuged (10,000 RPMS) and the supernatant discarded. The sample was then digested for 12 h with 10 ml of concentrated HNO_3. After centrifugation (10,000 RPMS), 1 ml of supernatant was buffered with 9 ml of 0.75 M Tris buffer. One ml of buffered sample was added to 10 ml of cocktail and counted. Van Raalte et al. (1974) recovered 94-98% of algal-fixed ^{14}C using this acid digestion method. They also found little variation in percent recovery between sandy and fine organic mud sediments.

Seagrass biomass was determined using a modified post-hole digger (Indian River Coastal Zone Study Annual Report, 1974-1975: 92). Three replicate seagrass plugs, 15 x 15 cm and 20 cm deep, were made at each station for each species. Sampling was stratified, i.e., an area with maximum *Halodule* cover was chosen to sample biomass of that grass assuming this to represent the maximum production potential of the locality with respect to this species. These plugs were also used to determine epiphytic biomass. This was determined by finding mean epiphytic biomass of 9-12 seagrass blades and converting to an areal basis by a determination of the number of seagrass blades per m^2.

RESULTS AND DISCUSSION — Table 3 shows seagrass and epiphyte productivity (mg C/g dry wt-h) at the three sampling sites in March and July, 1981. Primary production of both components was low during March (<0.1 mg C/g dry wt-h) but increased 1-3 fold in July. Epiphytic production ranged between 0.003 mg C/g dry wt-h in March to 1.02 in July. Penhale (1977) found a similar response of epiphytic algae on *Zostera* leaves. Over a 12 mo period the productivity rate of *Zostera* epiphytes averaged 0.88 mg C/g dry wt-h. Data in Table 3 show that the photosynthetic response of epiphytes can equal or exceed that of seagrasses. Epiphytic productivity is highly dependent upon the composition of the epiphytic community. If large animal biomass is present, especially species with calcified exoskeletons, the result is an underestimation of photosynthetic rate on an areal basis and

TABLE 3. Seagrass and epiphyte productivity of the above ground portions at various locations. The data represent mean values in mg C/g dry wt-h. Percent relative standard deviations are in parenthesis. Asterisk indicates only enough material for 1 sample.

Station	Jim Island		Link Port		Vero Beach
Date	March	July	March	July	July
Halodule wrightii	$1.0\ 10^{-2}$ (48.5)	0.40 (90.3)	$8.6\ 10^{-3}$ (15.5)	0.36 (22.7)	0.29 (102.7)
Epiphytes	$8.36\ 10^{-3}$ (117.5)	0.17 (94.2)	$1.0\ 10^{-2}$ (138.6)	0.30 (8.9)	0.09 (71.7)
Thalassia testudinum	$5.42\ 10^{-4}$ (10.18)	0.32 (41.3)	$5.42\ 10^{-3}$ (4.5)	0.79 (44.8)	0.09 (80.6)
Epiphytes	$1.39\ 10^{-3}$(*)	0.64 (137.4)	$5.58\ 10^{-3}$ (47.5)	0.75 (49.6)	0.33 (138.0)
Syringodium filiforme	$9.2\ 10^{-2}$ (138.3)	1.72 (96.1)	$9.82\ 10^{-4}$ (5.1)	0.46 (16.7)	—
Epiphytes	$5.4\ 10^{-2}$ (132.3)	0.52 (81.0)	$9.3\ 10^{-3}$ (139.8)	1.02 (103.2)	—

overestimation on a gravimetric basis. *Thalassia testudinum*, with its broad leaf, is an especially good substrate for foraminiferans, bryozoans and other animal species. Estimates of epiphytic productivity is, therefore, more subject to error on this species than *H. wrightii* and *S. filiforme*. Until methods are devised to adequately separate epifaunal and epifloral biomass, true epiphytic photosynthetic rates and contribution to community productivity cannot be determined.

TABLE 4. Changes in seagrass standing crop (g dry wt/m^2) from March to July, 1981 at each sampling site.

Station	Jim Island		Link Port		Vero Beach
Date	March	July	March	July	July
Halodule wrightii	123.5	197.6	20.4	72.0	45.0
Thalassia testudinum	64.3	124.0	97.9	160.3	85.0
Syringodium filiforme	19.1	11.9	48.8	57.7	0.0

On a g dry wt basis, *Syringodium filiforme* demonstrated the highest productivity rates of all 3 species in both March (0.09 mg C/g dry wt-h) and July (1.72) at Jim Island (Table 3). During this study, ranges in photosynthetic rates for Indian River seagrasses were 0.009-0.395 mg C/g dry wt-h for *H. wrightii*, 0.005-0.79 for *T. testudinum* and 0.009-1.72 for *S. filiforme*. No comparable data are available on *Syringodium* production rates, however, carbon uptake rates for *T. testudinum* and *H. wrightii* have been measured elsewhere at 0.13-6.3 and 1.8 mg C/g dry wt-h respectively (Pomeroy, 1960; Odum, 1963; Jones, 1968; Brylinsky, 1971).

Table 4 shows seagrass biomass values exclusive of epiphytes. At Jim Island and Link Port the standing crop of *H. wrightii* and *T. testudinum* increased at least 60% from March to July while *S. filiforme* showed constant values. *Halodule wrightii* had the highest standing crop values at Jim Island, *T. testudinum* at Link Port and Vero Beach, and *S. filiforme* the lowest values at all 3 stations. These trends held true for both sampling periods within the sampling sites.

The contribution of various photosynthetic components at each station is shown in Table 5. Seagrasses appear to be the dominant autotrophic component in July and benthic microalgae dominant in March. Productivity rates (mg C/m^2-h) for *Halodule* and *Syringodium* were highest at Jim Island during both sampling periods. *Thalassia*, on the other hand, showed the highest rates at Link Port. Although *S. filiforme* weight-specific production rates were the highest measured (Table 3), the standing crop of this species was the lowest (Table 4) which accounts for its low areal production.

Epiphytic productivity varies considerably between stations and from season to season (Table 5). As stated previously, this variation may be a result of the incrustation of various epifauna. Epiphytic populations can vary considerably within the year, the growing season and among short

TABLE 5. Contribution of the various photosynthetic components at each sampling location during the spring and summer of 1981. Values are mg C/m^2-h^1 and represent the means of 3 seagrass and epiphyte replicates, 4 benthic microalgae replicates and 6 phytoplankton replicates. Percent relative standard deviations are in parenthesis. Asterisk indicates only enough material for 1 sample.

Station	Jim Island		Link Port		Vero Beach
Date	March	July	March	July	July
Halodule wrightii	1.22 (43.5)	47.00 (50.1)	0.18 (14.8)	2.63 (19.8)	13.15 (102.7)
Epiphytes	0.56 (36.3)	8.75 (55.3)	1.00 (138.9)	2.46 (26.9)	0.40 (116.1)
Thalassia testudinum	0.04 (10.4)	30.30 (94.7)	1.32 (4.4)	128.1 (44.9)	8.39 (80.6)
Epiphytes	0.05 (*)	0.42 (135.1)	1.94 (0.0)	0.70 (52.1)	0.32 (131.6)
Syringodium filiforme	1.75 (138.29)	20.4 (96.18)	0.05 (6.0)	2.66 (18.8)	———
Epiphytes	0.28 (138.8)	0.32 (41.85)	0.12 (155.1)	0.11 (83.8)	———
Benthic microalgae	1.66 (22.9)	3.30 (21.5)	33.8 (24.2)	28.9 (23.6)	15.0 (19.2)
Phytoplankton	0.21 (20.6)	2.48 (19.0)	1.43 (51.5)	2.99 (20.0)	7.22 (4.9)

shoots (Brown, 1962; Hargrave, 1965). Epiphytic productivity rates on Indian River seagrasses ranged from 0.5-8.75 mg C/m^2-h. These values are considerably less than the 200-900 mg C/m^2-h reported by Jones (1968) for epiphytes on *Thalassia* in Biscayne Bay, Florida. However, production rates of Indian River seagrass epiphytes on a wt specific basis (Table 3) are comparable to other seagrass systems (see Penhale, 1977).

Benthic microalgae contribute significantly to community productivity in Indian River seagrass beds. During March this fraction accounted for 89-95% of the primary productivity within the various seagrass beds at Jim Island and Link Port (Table 5). During July this group was the largest contributing component in Vero Beach grassbeds. Benthic microalgae had a greater impact on primary productivity at Link Port and Vero Beach than at Jim Island. Sites farther from ocean inlets (i.e., Link Port and Vero Beach) typically have reduced light regimes and current velocities. Sediment microflora proliferate in shallow, sluggish backwater areas with little water movement, high nutrient concentrations and poor light regimes, and may actually be adapted to seemingly stressful conditions (Round, 1971; Jones, 1980). Vero Beach and Link Port more closely satisfy these conditions than Jim Island which characteristically exhibits high flushing rates, low nutrient concentrations (Table 1) and high light penetration.

Phytoplankton had their greatest productivity rates and contribution to overall community production in July at Vero Beach. Phytoplankton values were also higher at Link Port than Jim Island. Though the number of sampling periods was limited, this agrees with trends of chlorophyll a, phytoplankton cell abundance and productivity measurements taken during the Indian River Coastal Zone Study (Gibson, unpubl. data). Weekly measurements of these parameters from 1976 through 1978 showed values consistently highest at Vero Beach, lowest at Jim Island and intermediate at Link Port.

Of the photosynthetic components shown in Table 5, phytoplankton and epiphytic algae contribute the least to community productivity. The phytoplankton population appears to play a more important role farther from the ocean inlet (Jim Island) which may be a reflection of increased nutrient concentrations at Vero Beach (Table 1). Seagrass and benthic microalgae were the dominant primary producers of the system during the study period. However, the changes in seagrass productivity account for most of the variation in production in the grass meadows. The other components were either relatively stable or relatively low in their photosynthetic rates.

The summer period (May-September) appears to encompass the time span of maximum seagrass growth in the Indian River. Table 6 provides the salinity and temperature data for this time period. Seagrass productivity is regulated in a complex manner by environmental factors such as light, temperature and salinity. Studies have shown the optimum temperature for seagrass growth to be near 29°C and sublethal temperatures (i.e., low pro-

TABLE 6. Mean and standard deviation of integrated water column salinity and surface temperatures from May through September in 1976 and 1977. Values were compiled from weekly measurements taken during the Indian River Coastal Zone Study (M. J. Youngbluth, pers. comm.).

Station	Jim Island		Link Port		Vero Beach	
Date	1976	1977	1976	1977	1976	1977
Integrated Salinity (ppt)	22.1 ±4.24	28.9 ±4.6	26.9 ±4.75	33.6 ±2.57	32.64 ±2.46	35.6 ±2.13
Surface Temperature (°C)	29.5 ±1.52	29.1 ±1.75	28.3 ±0.88	28.01 ±1.29	26.5 ±1.56	26.7 ±1.24

ductivity) between 29-32°C (Zieman, 1968; Thorhaug, 1971; Zieman and Wetzel, 1980; Zieman, 1975). Salinity tolerances are more broad, yet there is a definite optimum between 33-36 ppt (Jones, 1968; McMahan, 1968; McMillan and Moseley, 1969; Zieman and Wetzel, 1974; Zieman, 1975). It is apparent from Table 6 that Jim Island and Link Port offer the best conditions for seagrass growth in this section of the Indian River. Water temperatures and salinities at Vero Beach are not at optimum levels which is reflected in the reduced biomass and productivity of the seagrasses. Thompson (1979) felt the reduced salinities, increased temperatures and reduced light levels (caused by tannins from the freshwater runoff) were partially responsible for the poor conditions of the grassbeds in the Vero Beach area.

Seagrass production is likely to be very significant in supporting foodwebs in the Indian River (Young, 1976; Zimmerman et al., 1979; Stoner, 1980a, 1980b). Our estimates indicate that seagrass communities may contribute a major portion of the total primary production in the River. While the seagrass species may be the driving component of the system it is only one of many primary producers. The influence of the phytoplankton, benthic microalgae and epiphytes must be examined if the total productivity of the system is to be determined. Other plant communities such as mangroves, salt marshes, algal mats and drift algae are also important and should be examined as well.

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A CHECK-LIST OF THE BENTHIC MACROINVERTEBRATES OF KENNEDY SPACE CENTER, FLORIDA

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Abstract: *A quarterly baseline study of benthic macroinvertebrates was conducted from December 1979 to March 1981 in the brackish lagoons surrounding Launch Complex 39A (LC-39A) of the John F. Kennedy Space Center. This was performed as part of the NASA Environmental Effects Program for Space Shuttle activities. A baseline monitoring study was also conducted in the Banana River from December 1979 to December 1980 to monitor benthic community recovery at 2 sites in the Banana River following removal of silt by shallow water dredging. A check-list of the macroinvertebrates found in the 2 areas is given. One hundred and twenty-two species were collected from both studies: 67 species from the lagoons and 108 species from the Banana River; 53 species were common to both areas.*

A Marine Benthic Program was initiated by NASA at the John F. Kennedy Space Center, Florida, in August 1979 for 2 purposes: 1) to establish a baseline of pre-Shuttle operation conditions in the lagoons surrounding Launch Complex 39A (LC-39A) to ascertain possible adverse impact of Shuttle launch activities, and 2) to monitor benthic community recovery at 2 sites in the Banana River following removal if silt by shallow water dredging. The lagoon baseline study was conducted from December 1979 to March 1981 (the first Shuttle launch occurred 12 April 1981). The Banana River siltation recovery study was conducted from December 1979 to December 1980.

While no previous benthic studies have occurred in the lagoonal waters adjacent to LC-39A or the upper Banana River, studies have been conducted