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INFLUENCE OF MANGROVE DETRITUS IN AN ESTUARINE ECOSYSTEM

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ABSTRACT

This study has determined the relationship and extent of mangrove reduced carbon flow and its contribution to the diet of higher consumers in a nearby seagrass bed using stable isotope techniques. In a seagrass bed approximately 80 m from a riverine mangrove community, detritus from seagrass or other marine sources of carbon such as epiphytes (*Stilophora rhizodes*) or phytoplankton the major contributor of reduced carbon. Mangroves make only a localized contribution to the food chain, thus contributing a relatively low proportion of reduced carbon to this seagrass community.

The major primary producers in southern Florida fringe coastal communities are seagrasses and mangroves. *Thalassia testudinum* dominates the seagrass beds offshore, with *Halodule wrightii* as a secondary species. *Rhizophora mangle* dominates and *Avicennia germinans* and *Laguncularia racemosa* contribute significantly to the riverine and fringe forests. The detrital material formed by the partial decomposition of the leaves of these vascular plants may be the basis of trophic food chains in coastal ecosystems of southern Florida. Mangrove forests are net exporters of particulate organic carbon (Golley et al., 1962; Heald, 1969; Lugo et al., 1976). Further, mangrove carbon supports food chains within riverine and basin communities along the southwest coast of Florida (Odum and Heald, 1975; Zieman et al., 1984). In areas where seagrass and mangrove communities are in close association, however, the relative contribution of the seagrass and mangrove detritus to the food chain is difficult to determine. Mangrove estuarine environments are important nursery areas for fish populations, yet large numbers of organisms are supported by seagrass beds, the magnitude being related to the seagrass cover density (Zieman et al., 1984). This paper addresses the question of whether the influence of mangrove detrital flow is far reaching or localized. To answer this question we used stable carbon isotope abundance analysis of organisms from a mangrove riverine community and two seagrass communities, one of which was geographically close to a mangrove stand and the other was without any apparent mangrove detritus input. Stable isotope analysis provides a powerful tool to determine carbon flow in this particular ecosystem because there is a significant difference in the carbon-13 content of the primary producers in question (mangroves and seagrasses, Zieman et al., 1984). Further, consumers of mangroves and seagrass can be identified by isotopic analysis, because diet switching and turnover experiments for carbon clearly show that diet is the primary determinant of the animal isotopic composition (see Fry and Arnold, 1982). Unfortunately, nitrogen isotope analysis cannot be used in this situation since in some cases there are no differences in natural ¹⁵N abundances between seagrass and mangrove detritus (Zieman et al., 1984).

METHODS

The two study sites were located in the coastal areas of central Biscayne Bay, Florida (Fig. 1). The first site was a tidal stream in Matheson Hammock Park extending approximately 324 m into a fringe/

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riverine mangrove forest dominated by *R. mangle* with seagrass beds running parallel to the shore. Seagrass beds extend from about 3 to 4 m away from the shore to Biscayne Bay. The depth of the tidal stream averaged 1.4 m with extremes of 0.4 m and 2.4 m. The depth along the transect extension from the mouth of the stream averaged 0.6 m. The second site, located at Bill Baggs State Park (details not shown in Fig. 1), was a strip of beach with seagrass beds 8–10 m offshore and *Casuarina* (*Casuarina* sp.) stands 100–200 m from the beach. Samples were collected in the Bill Baggs site on 10 April 1987. At the first site a transect following the course of the tidal stream was established from the most inland accessible point to the mouth, and from the mouth to a point 180 m offshore perpendicular to the coast with 15 sampling locales approximately 30 m apart (Fig. 1). Samples from this transect were collected on 2 December 1986. In addition samples approximately 200 m south of the stream mouth were collected on 10 April 1986. Two random handfuls of detrital material were retained from each sample point in the first 480 m of the transect. Pieces of seagrasses and mangroves were separated from each other and cleaned of epiphytes for more accurate results. Samples were dried at 60°C, and each component was weighed before grinding and combustion. For the seagrass species equal weights of five leaves were ground and mixed together. Carbon isotope ratios were determined from an aliquot of this mixture. Organisms such as crabs, snails, fishes and oysters were collected within 18 m of each sample point by hand or with a sweep net. Tissue from birds from Florida Bay was collected from victims of storms or natural diseases. It was impossible, however, to determine their exact location because of their high mobility. Muscle tissue was dissected out, freeze dried, and combusted.

Organic material from consumers was frozen for storage prior to cleaning, sorting, identification, and processing. Animal flesh was extracted (in some cases a HCl wash was necessary to remove carbonate material), freeze-dried, and ground before combustion. Approximately 5 mg of ground sample was sealed with copper and cupric oxide in evacuated Vycor cuvettes and combusted at 800°C as in Northfelt et al. (1981). Carbon-13 abundance is expressed in δ units where

$$\delta^{13}\text{C}\text{‰} = \left[\frac{R_{\text{sample}}}{R_{\text{standard}}} - 1 \right] 1,000, \quad (1)$$

and R is the $^{13}\text{C}/^{12}\text{C}$ ratio of sample and standard, respectively. The standard used was PDB carbonate, and the precision of analysis was $\pm 0.2\text{‰}$. Carbon isotope ratios were measured in a PRISM mass spectrometer (VG) in the Department of Geology of the University of Miami.

RESULTS

The percentage of mangrove detritus present relative to seagrass detrital material and other vegetative matter along the transect decreased from an average of 80% ($N = 6$) along the stream to about 10% at 90 m beyond the mouth of the stream (Fig. 2a). The location of this sharp drop in mangrove detritus, however, probably varies somewhat with tidal influences and the season of the year. There was a large difference between $\delta^{13}\text{C}$ values of mangrove ($-26.7 \pm 0.3\text{‰}$) and seagrass detritus ($-15.3 \pm 1.2\text{‰}$, Fig. 2b). $\delta^{13}\text{C}$ values of flesh from heterotrophic organisms increased along the transect from the mangrove estuary to the seagrass bed. There was a highly significant difference of 4.6‰ between the average $\delta^{13}\text{C}$ value of the organisms living in the riverine forest and those living in the flat beyond the mouth ($T = 11.9$, $P < 0.01$). Unlike mangrove detritus abundance, the differences between $\delta^{13}\text{C}$ values of mangrove and seagrass organisms are less sensitive to tidal and seasonal effect, since the carbon isotope ratio of an organism is an integrative indicator of the diet over a longer period of time. A smaller but significant difference was observed between $\delta^{13}\text{C}$ values of organisms sampled in front of the effluent flow (approximately 20 m to 180 m away, $-19.6 \pm 1.0\text{‰}$) and those sampled away from the effluent flow ($-18.6 \pm 1.5\text{‰}$, $T = 2.42$, $P < 0.05$).

The average $\delta^{13}\text{C}$ value of seagrass at Matheson ($-15.3 \pm 1.2\text{‰}$) was significantly less than that of seagrass at Bill Baggs ($-8.7 \pm 0.5\text{‰}$, $T = 8.4$, $P < 0.01$, Table 1). Also shown in Table 1 are the $\delta^{13}\text{C}$ values of organisms living at Matheson Hammock Park and Bill Baggs. $\delta^{13}\text{C}$ values of organisms living in the seagrass beds of Bill Baggs ($-15.4 \pm 1.0\text{‰}$) were significantly higher than those living in seagrass beds in Matheson Hammock Park ($T = 6.2$, $P < 0.01$). In both cases,

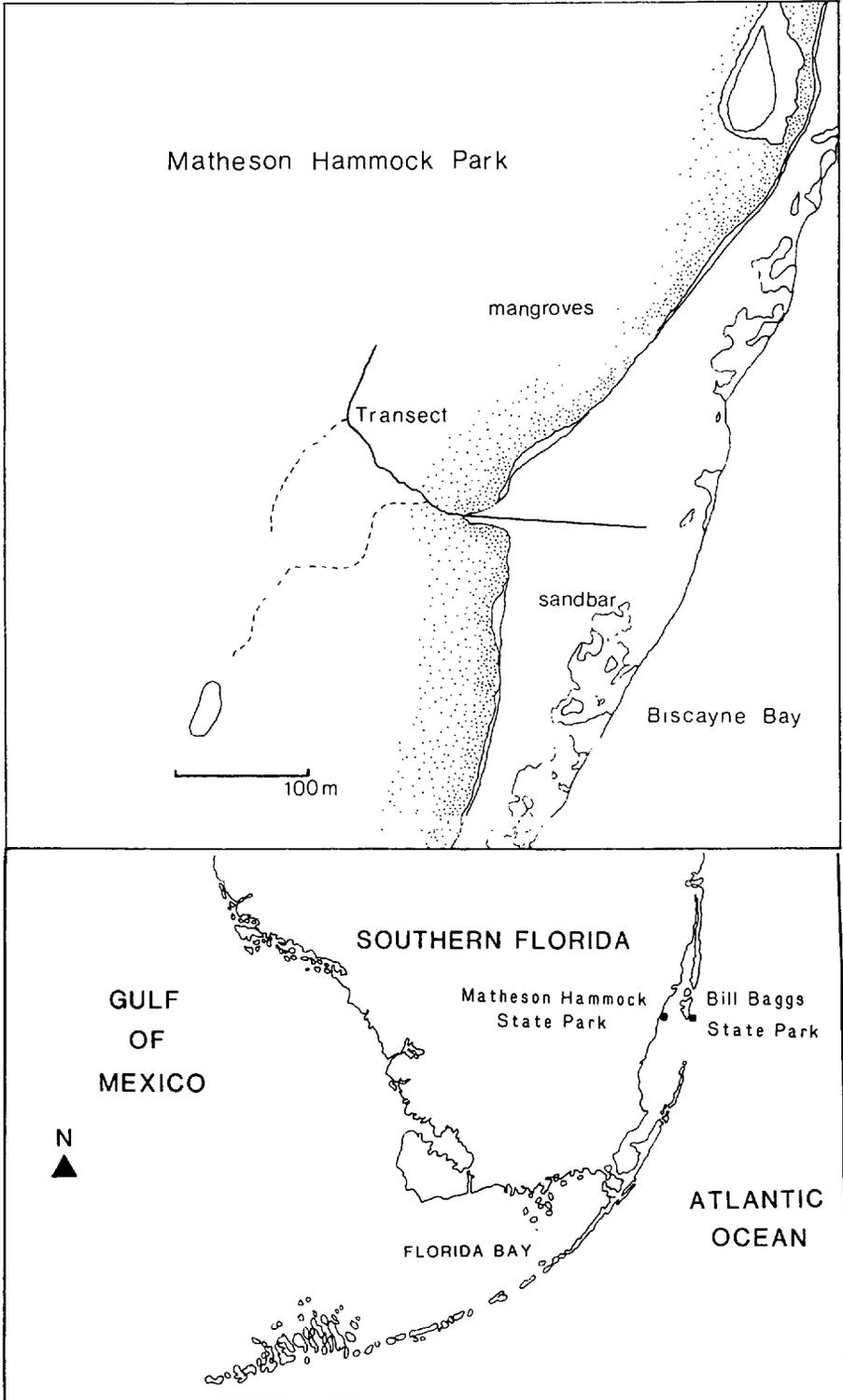


Figure 1. Location of sampling sites in southern Florida, and a detailed map of the Matheson Hammock Park site.

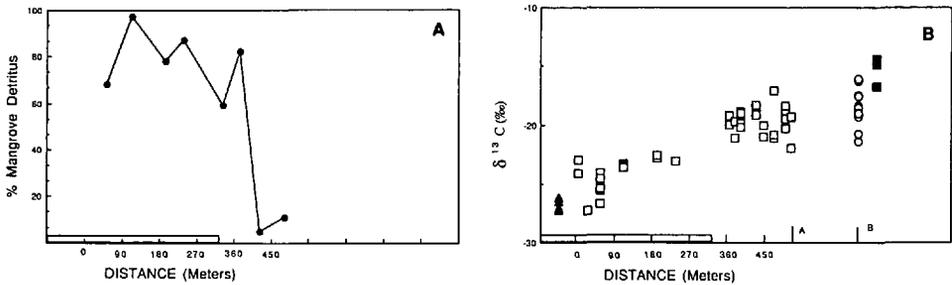


Figure 2. Percentage of identifiable mangrove detritus along the Matheson Hammock Park transect (Fig. 2a). $\delta^{13}C$ values of mangrove (▲), seagrass (■), several organisms collected along the Matheson Hammock Park transect (□), and organisms collected away from the mouth of the estuary (○) (Fig. 2b). White rectangle at the bottom of graph indicates the length of the transect occurring within the mangrove forest.

however, the $\delta^{13}C$ values of the organisms were significantly lower than those of seagrasses at each site ($T = 6.96$, $P < 0.01$ for Bill Baggs, $T = 3.7$, $P < 0.01$ for Matheson Hammock Park). The isotope ratios of two species of birds (*Ardea herodias* and *Ajaja ajaja*) occupying a higher trophic level together with $\delta^{13}C$ values of their potential food are shown in Figure 4.

DISCUSSION

The ability to trace the carbon flow in an estuarine ecosystem by stable isotope techniques is possible because of large differences between the $\delta^{13}C$ values of mangroves and seagrasses. Further, there is little change in $\delta^{13}C$ values during the decomposition of mangrove and seagrass, thus their isotopic identity is maintained (Zieman et al., 1984). Atmospheric CO_2 , the source of carbon for plants, has a $\delta^{13}C$ value of about -7.6‰ (Francey et al., 1985), yet terrestrial plants that utilize the Calvin Cycle to fix carbon have an average $\delta^{13}C$ value of -27‰ . This degree of fractionation occurs because of the isotopic selectivity of the enzyme (ribulose-1,5-bisphosphate carboxylase) initially responsible for fixing atmospheric carbon dioxide (Estep et al., 1978) and to a minor extent because of fractionations associated with diffusion resistance (Farquhar and Richards, 1984). Carbon fixation in aquatic plants such as seagrasses, on the other hand, may be substantially affected by rate-limiting diffusion barriers that prevent isotopic selectivity and cause much smaller isotopic depletions relative to environmental CO_2 than in terrestrial plants (Fry and Sherr, 1989). The isotopic composition of the dissolved inorganic carbon (DIC) pool also affects the $\delta^{13}C$ value of aquatic plants since the DIC pool is their sole carbon source. The seagrass beds at the Bill Baggs site are well flushed by relatively clear water, but seagrass beds in Matheson Hammock Park are in shallow and relatively immobile water that may accumulate isotopically light CO_2 from the degradation of particulate organic material from the man-

Table 1. Average $\delta^{13}C$ values of seagrass and consumers at various locations (mean \pm SE (n))

Location	$\delta^{13}C$ of seagrass	$\delta^{13}C$ of consumers
Matheson Hammock (mangrove forest)	—	$-24.2 \pm 1.4\text{‰}$ (14)
Matheson Hammock (mouth of effluent)	$-15.3 \pm 1.2\text{‰}$ (3)	$-19.6 \pm 1.0\text{‰}$ (24)
Matheson Hammock (away from effluent)	$-15.3 \pm 1.2\text{‰}$ (3)	$-18.6 \pm 1.5\text{‰}$ (11)
Bill Baggs (beach)	$-8.7 \pm 0.5\text{‰}$ (3)	$-15.4 \pm 1.0\text{‰}$ (8)

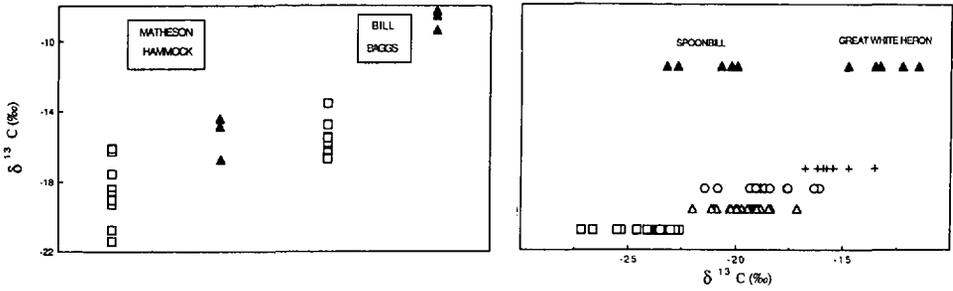


Figure 3 (left). $\delta^{13}\text{C}$ values of seagrasses (\blacktriangle) and heterotrophic organisms (\square) in Matheson Hammock Park and Bill Baggs Park.

Figure 4 (right). $\delta^{13}\text{C}$ values of organisms in mangroves and at several seagrass beds sampled in Matheson Hammock and Bill Baggs State Park as well as from several individuals from two bird species (Great White Heron and Roseate Spoonbill) collected in Florida Bay. Symbols are (\square) for organisms living within the mangrove forest, (\triangle) organisms living in a seagrass bed at the mouth of the mangrove estuary, (\circ) organisms living in a seagrass bed within Biscayne Bay but away from the mouth of the mangrove estuary, (+) organism living in a seagrass bed at Bill Baggs without any terrestrial input, and (\blacktriangle) the two bird species.

grove tidal stream. Thus at Matheson Hammock Park an input of isotopically light respired CO_2 may be the cause of the lower $\delta^{13}\text{C}$ values in seagrass relative to those found at Bill Baggs. Zieman et al. (1984) observed similar variations between seagrasses in different localities in Florida Bay and proposed a similar cause for this variation.

As indicated in Figure 2b, there is a steady increase in $\delta^{13}\text{C}$ values of organisms proceeding along the transect from mangrove to seagrass at the Matheson Hammock site. Assuming that mangrove and seagrass detritus are the sole contributors of carbon to organisms at the site in front of the estuary, then the relative carbon contribution of each can be determined with a mass-balance equation: $\delta^{13}\text{C}_c = n\delta^{13}\text{C}_m + (1 - n)\delta^{13}\text{C}_s$, where $\delta^{13}\text{C}_c$, $\delta^{13}\text{C}_m$, and $\delta^{13}\text{C}_s$ are the $\delta^{13}\text{C}$ values for consumers, seagrass, and mangroves, respectively, and n is the proportion of carbon derived from mangrove detritus. For the Matheson Hammock Park site this equation becomes $-19.6\text{‰} = n(-27\text{‰}) + (1-n)(-15.3\text{‰})$, and n equals 37%. Under this scenario, mangroves are providing 37% and seagrasses are supplying 63% of the carbon to organisms beyond the mouth of the stream in the seagrass bed. This scenario, however, may not be realistic. Results of carbon isotope analysis at the Bill Baggs site, which does not have a terrestrial input, indicate that there may be other marine sources with isotopically light carbon contributing to the food chain (Fig. 3). $\delta^{13}\text{C}$ values of seagrass and epiphytes at Bill Baggs were -8.7‰ and -12‰ , respectively, and yet $\delta^{13}\text{C}$ values of organisms living in the seagrass beds there averaged -15.4‰ . This discrepancy suggests that other marine sources, probably phytoplankton with an average $\delta^{13}\text{C}$ value of -20‰ (Peterson and Fry, 1987), are also important carbon sources. If the contribution by phytoplankton at the Matheson Hammock is as extensive as that observed in Bill Baggs, then the contribution of reduced carbon to organisms living in the seagrass beds by mangroves is much less than 37%. As has been observed in seagrass beds in other areas (Kitting et al., 1984), mangrove carbon may be further diluted by the extensive epiphytic growth in the seagrass beds at Matheson Hammock Park which has an average $\delta^{13}\text{C}$ value of -24‰ . Thus, we conclude that mangrove may be a major contributor of carbon on a very localized scale, such as within the riverine forest. Beyond the forest, seagrass and other

marine sources such as phytoplankton or seagrass epiphytes are the major suppliers of reduced carbon. Our conclusions about the localized contribution of reduced carbon by mangrove ecosystems are in agreement with those reported by Rodelli et al. (1984) in a study of Malaysian mangroves. Rodelli et al.'s (1984) results indicate that at distances as close as 2 km offshore, mangrove carbon is no longer an important contributor to the food chain and is replaced by phytoplankton.

The implications of these findings are also important for organisms at higher trophic levels. The same contrast between the two major sources of reduced carbon for the food chain has been previously observed in Florida Bay by Zieman et al. (1984). Thus isotopic ratios of organisms collected in the Florida Bay can be interpreted using our data. Analysis of stable carbon isotope ratios of muscle tissue of Great White Herons (*Ardea herodias*) collected in Florida Bay (Fig. 4) indicates that its diet is mainly dependent on seagrass organisms. The $\delta^{13}\text{C}$ values of its muscle tissue are only a few ‰ higher than small organisms living in a seagrass bed as observed in Bill Baggs. This small isotopic enrichment is probably caused by a trophic level effect (Mizutani and Wada, 1988). In contrast to the isotope ratios of the Great White Heron, flesh from Roseate Spoonbills (*Ajaja ajaja*) also collected in Florida Bay, which forage mostly in mangrove muds, have $\delta^{13}\text{C}$ values similar to those observed in organisms growing within the mangrove forest ecosystems.

ACKNOWLEDGMENTS

We thank G. Powell and F. Schaffner for the muscle tissue from Great White Heron and Roseate Spoonbill, T. Banks for technical assistance, T. Fleming for helpful discussion and logistic support during the course of this research, K. Sullivan for the initial aerial survey of this area, and C. R. Robins for help in the identification of fish species. This research was supported in part by a NIH biomedical research support grant (L. da S.L.S.). This is publication number 351 from the program in Ecology, Behavior, and Evolution of the Department of Biology, University of Miami, Coral Gables, Florida.

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DATE ACCEPTED: December 15, 1989.

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