



Short Communication

Hydrodynamic transport of drifting macroalgae through a tidal cut

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Abstract

Drifting macroalgae are unattached seaweeds that are commonly found in many South Florida and Gulf of Mexico shallow-water seagrass habitats. They are primarily comprised of species of red algae (Rhodophyta) and some brown algae (Phaeophyta). Because of the unattached nature of these species, drift algae have the ability to be moved around the landscape primarily by tidal, as well as wind-driven and alongshore currents. Numerous invertebrates and some fish species are typically found associated with drift algal clumps and aggregations. Transport of drift algae is an important dispersal mechanism for both the plants and their associated fauna. Dispersal distances have been studied in numerous locations over a range of spatial scales. However, little is known about quantities of algal material that are involved. In this study I report on composition and biomass of drifting algae that are transported through a tidal inlet in Biscayne Bay, Florida. *Sargassum* (a brown alga) and about 12 genera of red algae were found in three seasonal collections (Aug., Dec., May). Total biomass collected varied among seasons, with larger average amounts of drift algae collected in May than the other two months sampled. From this data, I calculate the approximate quantities of drift algae that are potentially moving in, or out of, Biscayne Bay, about a half to one ton of biomass per day.

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1. Introduction

Most seaweeds are attached by a holdfast to the substrate, which prevents their being swept away by waves and tide. Unlike most plants, seaweeds do not need to be rooted as their nutrients are derived primarily from the surrounding water, not the substrate (Lobban and Harrison, 1994). The development of communities of unattached macroalgae is often promoted under high nutrient, high light, low energy conditions that are commonly found in sheltered lagoonal waters (Norton and Mathieson, 1983); in the tropics and subtropical Florida these are often dominated by seagrass habitats. In Biscayne Bay and other similar Florida estuaries, clumps of drift macroalgae vary in size (10–40 cm diameter) and are typically comprised of rhodophyte

(red algal) taxa (Virstein and Carbonara, 1985; Bell and Hall, 1997; Holmquist, 1997).

Drift algae can originate from hard substrates such as coral reefs or rocky shores, alternatively they can break off after epiphytic growth on seagrass and mangrove roots (Dawes et al., 1978; Bell and Hall, 1997). Regardless of the original source, drift algae are moved via wave activity and water currents. Passive movement of drift algae implies that the hydrodynamic regime of a body of water may be critical in determining the transport of algae through the landscape. Bell and Hall (1997) found that spatial variation in drift distribution was highly correlated with the local energy regime in Tampa Bay, with passive transport and deposition of algal clumps strongly linked to the bay-wide hydrodynamic regime. In that system, algal movement was heavily dictated by waves and currents, with hydrodynamically less active environments favoring accumulations of drift algae in the seagrass beds at a greater rate than sites with high current velocity (e.g., inlets) or extensive exposure to waves (Bell and Hall, 1997;

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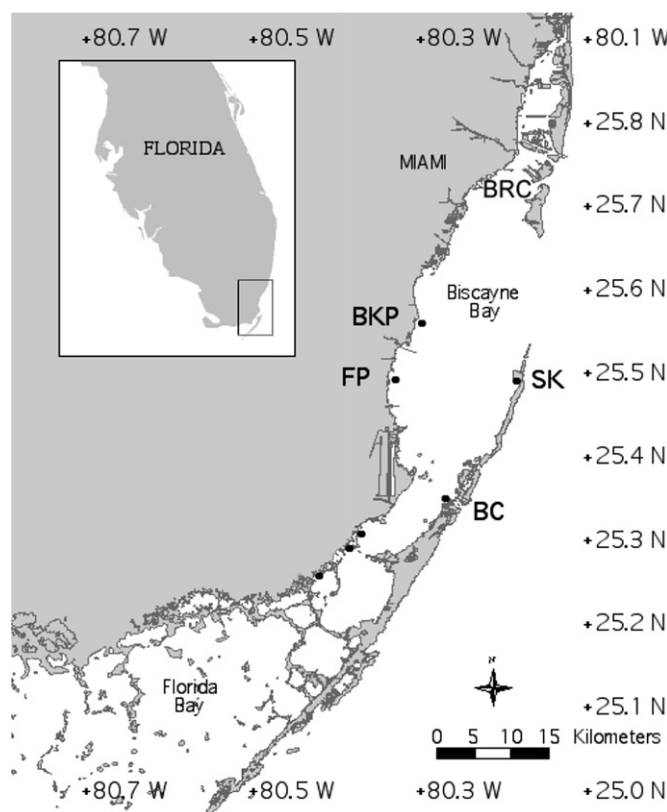


Fig. 1. Location of study sites in Biscayne Bay, Florida. Oceanic cuts are located at Sands Key (SK), Broad Creek (BC), and Bear Cut (BRC). Mainland sites are located at Black Point (BKP) and Fender Point (FP).

Holmquist, 1997). This exposure regime resulted in landscape-level accumulations or drift algae within low energy, nearshore portions of Tampa Bay.

The transport of drift algae can have implications on the colonization and dispersal of larval, juvenile and adult stages of many invertebrates and some fish species. Long distance dispersal associated with drifting algal material has been shown in many oceans, and can occur over distances of 100–1000's of kilometers (Edgar, 1987; Ingólfsson, 1995; Ólafsson et al., 2001). *Sargassum* is an important pelagic macroalga, which contains a high diversity of faunal associates that can travel extensive distances (Weis, 1968; Fine, 1970; Fletemeyer, 1978). Regional studies have shown that numerous crustaceans use drifting algae as a refuge for larval forms to move from open ocean to nearshore juvenile habitats (Forcucci et al., 1994; Holmquist, 1994; Wang et al., 2003) and vice versa for adult forms (Josselyn et al., 1983; Ingólfsson, 1995; Flindt et al., 1997; Ólafsson et al., 2001). Additionally, presence of drift algae can serve as a settlement cue and as important habitat even after settlement (Kulczycki et al., 1981; Forcucci et al., 1994; Norkko et al., 2000). Subsequently, the transport of drift algae serves an important dispersal and transport mechanism for both plants and associated fauna, however, the amount of material transported is difficult to ascertain.

The aim of this study was to investigate whether drift algae are entering and leaving Biscayne Bay, Florida through tidal inlets, and if so, what are the abundance and composition of this drift matter.

2. Methods

This study was conducted near the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS) boat dock in Bear Cut (Fig. 1). This Cut, like many others between barrier islands on the eastern side of Biscayne Bay, has a significant tidal flow from the Atlantic Ocean to the Bay. With the tidal frequency twice daily, the RSMAS docks are subjected to strong currents ($50\text{--}70\text{ cm s}^{-1}$) four times per day.

Macroalgal biomass and composition were determined from samples caught in a ($50' \times 4'$) ($15 \times 1.25\text{ m}$) seine net (Memphis Net & Twine CSS2-50) that was lashed securely to two wooden dock pilings oriented perpendicular to the current flow. The seine net was weighted with numerous additional 1.5 kg lead weights along the bottom edge, and buoyed by additional floats attached along the upper edge. This needed to be done so that the net would remain extended through the complete vertical distance of the water column, even during peak flow velocities and at high tide depths (0.5–0.6 m).

At the end of every flood or ebb tide occurring during daylight hours, all the biomass in the cod end of the net was hand-collected into a mesh bag by snorkeling during slack tide. Algae were sorted in the laboratory to the lowest taxonomic level (usually species, but occasionally only to genus). Blotted wet weight by Division (Phaeophyta and Rhodophyta) and taxonomic composition were recorded. Samples were collected

Table 1

Ranked generic composition of drift algae coming through Bear Cut ranked across all three sampling periods. Similarity at the genus level of algae found in Bear Cut with those found over a 4 year period at two mainland sites is 50%

| Algae | Bear Cut | Mainland |
|-----------------------|----------|----------|
| <i>Acanthophora</i> | 5 | 8 |
| <i>Bostrychia</i> | 8 | |
| <i>Ceramium</i> | | 13 |
| <i>Champia</i> | 7 | |
| <i>Chondria</i> | 12 | 1 |
| <i>Cladophora</i> | 13 | 4 |
| <i>Crouania</i> | 10 | |
| <i>Dasya</i> | 4 | 10 |
| <i>Dictyota</i> | 3 | 12 |
| <i>Digenea</i> | | 5 |
| <i>Gracilaria</i> | | 9 |
| <i>Heterosiphonia</i> | 9 | |
| <i>Hypnea</i> | 6 | 11 |
| <i>Laurencia</i> | 2 | 3 |
| <i>Polysiphonia</i> | | 2 |
| <i>Sargassum</i> | 1 | 6 |
| <i>Spyridia</i> | | 7 |
| <i>Wrangelia</i> | 11 | |

over a 5–8 day period to determine inter-tidal variance, and sampling was repeated three times over the course of a year (Aug., Dec., May) to determine seasonal differences in the species composition of algae. Separate two-way ANOVAs testing season (random effect) and tide (fixed effect) were performed on the biomass data for each Division (Sokal and Rohlf, 1995). For comparison purposes, other sites along the mainland coast had also been sampled monthly to monitor abundance and composition of drift algae over a 4 year period (Biber et al., 2004; Irlandi et al., 2004; Biber and Irlandi, 2006).

3. Results

Drift algae transported through Bear Cut was comprised of *Sargassum* (a brown alga) and about 12 genera of red algae (Table 1). At the genus level, composition of the drift algae being transported through Bear Cut over the sampling period was 50% similar to the complement found at sites along the mainland shore, Fender Point and Black Point (Fig. 1), over a 4 year monitoring program. The three most common genera

observed at Bear Cut were different from those found at these two mainland sites (Table 1).

Variability in biomass among samples was high, especially of the *Sargassum* fraction, which was often present in the samples in a pulsed mode, i.e., over a few sequential days a large portion of the total biomass contained *Sargassum*. This was observed to hold true for both flood and ebb tides, possibly indicating some back and forth transport of the same aggregation on successive tides. Because the seine net sampled only a small portion (approx. 0.1%) of the total tidal volume passing through this Cut (a navigable waterway), the amount of algae removed is only a fraction of the total biomass transported by the tides (see Table 3).

Total biomass collected varied among seasons, with larger average amounts of drift algae collected in the late dry season (May) than the other two months sampled (Fig. 2). Analysis of the phaeophyte vs. rhodophyte fractions showed that mean biomass of *Sargassum* did not vary significantly either by season or by tide (flood vs. ebb) (Table 2). In contrast there was a significant increase in the biomass of red algae transported through Bear Cut in the month of May (Table 2). This corresponded with the period of peak drift algal biomass, primarily rhodophyta, at multiple study sites within the Bay (Biber, 2002; Biber et al., 2004; Biber and Irlandi, 2006), and seasonal blooms of macroalgae on the reefs outside the Bay (Lirman and Biber, 2000). There was also significantly higher biomass of red algae on incoming tides than outgoing tides (Table 2). However, this may have been confounded by higher flow rates measured at this site on incoming tides than outgoing tides, although this was not necessarily indicative of flows through Bear Cut as a whole due to variations in channel depth and profile (B. Haus & T. Jones, unpubl data).

To remove this potentially confounding effect, the volume of water filtered through the seine net during flood and ebb tides was calculated. The results indicated that during ebb tides a little over two-thirds the volume of water passed through the seine net compared to flood tides (with a total volume filtered of about $2 \times 10^5 \text{ m}^3$). Extrapolating this to the rest of Bear Cut, an estimate of total algal biomass entering and leaving through this Cut (one of four) into the Bay shows greater total biomass entering and leaving the Bay in May than Aug. or Dec., and more biomass of red algae than *Sargassum* moving through the Cut in all

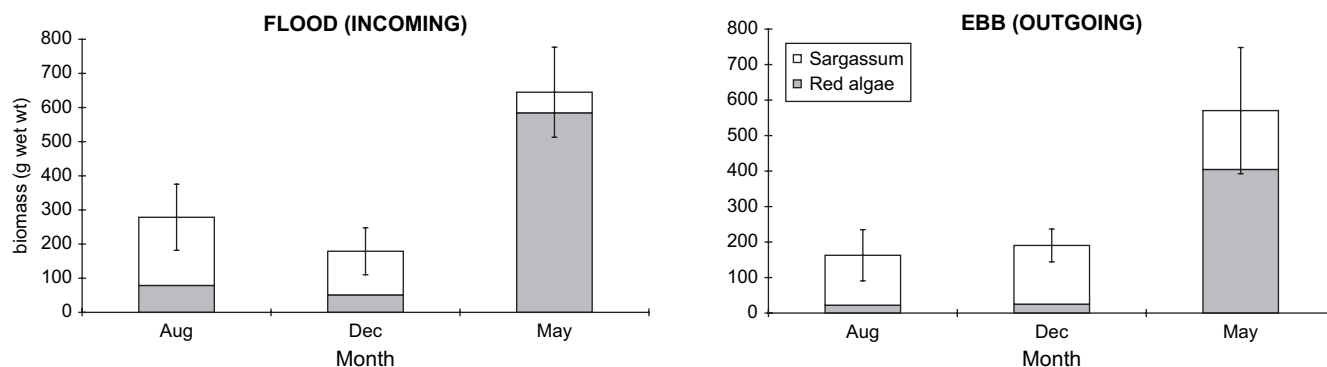


Fig. 2. Mean (\pm SD) biomass (spun wet wt) of drift algae transported by tidal currents through Bear Cut and collected from the seine-net cod end. Samples were collected over a 5–8 day period three times over the course of one year (Aug., Dec., May).

Table 2

Two-way ANOVAs of algal biomass by month (random factor) and tide (fixed factor), presented in Fig. 2. Significant effects are highlighted in bold font, and Tukey's post-hoc comparisons of significant results

| Source | df | SS | MS | F | P |
|--------------------------------|----|--------|---------|---------|--------------------|
| <i>Rhodophyta</i> ^a | | | | | |
| Month (M) | 2 | 74.932 | 37.4659 | 27.0261 | < 0.0001 |
| Tide (T) | 1 | 16.042 | 16.0482 | 11.5764 | 0.0016 |
| M × T | 2 | 1.3773 | 0.6889 | 0.4969 | 0.6122 |
| Error | 39 | 54.065 | 1.3863 | | |
| <i>Sargassum</i> ^b | | | | | |
| Month | 2 | 0.119 | 0.0593 | 0.0240 | 0.9763 |
| Tide | 1 | 0.665 | 0.6645 | 0.2694 | 0.6071 |
| M × T | 2 | 2.141 | 1.0705 | 0.4341 | 0.6514 |
| Error | 34 | 83.854 | 0.5946 | | |

^a Rhodophyte data were ln-transformed for normality (Shapiro Wilk's $W = 0.9668$, $P < 0.3331$) and homoscedasticity (Bartlett's $F = 1.4048$, $P < 0.2189$), with $r^2 = 0.6286$ for the ANOVA, $n = 5-11$.

^b *Sargassum* data were ln-transformed for normality (Shapiro Wilk's $W = 0.9485$, $P < 0.0955$) and homoscedasticity (Bartlett's $F = 0.9195$, $P < 0.4669$), with $r^2 = 0.0342$ for the ANOVA, $n = 4-10$.

months sampled (Table 3). From these data an estimate for total algal biomass moving through all the inlets (Bear Cut, Safety Valve, Caesar Creek, and Broad Creek), based on volumetric estimates from the circulation model of Wang et al. (2003), into Biscayne Bay yields about 200 kg *Sargassum* plus 100 kg red algae = 300 kg (Aug., Dec.), or 50 kg *Sargassum* plus 500 kg red algae = 550 kg (May) moving into/out of the Bay per tide (i.e., twice a day); about a half to one ton of biomass per day. Given the dimensions of Biscayne Bay (65 × 15 km), this corresponds to a biomass of 0.05–0.1 g m⁻², which is substantially less than has been reported from beach-cast wrack accumulations (Ochieng and Erfteimeijer, 1999; Orr et al., 2005).

4. Discussion

The abundance of drifting algae is governed by the availability of biomass imported from its source(s) and physical forces such as wind, currents, and wave action (Norkko et al., 2000). Drift algae can originate as macroalgae growing on hard-bottom and coral-reef substrates, or alternatively as epiphytes growing on seagrass blades (Phillips, 1960; Hamm and Humm, 1976; Josselyn, 1977). Some species that commonly comprise the drift in Biscayne Bay (e.g., *Laurencia* spp.) are not usually epiphytes on seagrass blades (Phillips, 1960; Hamm and Humm, 1976; Williams-Cowper, 1978; Biber, 2002). Some macroalgae found within Biscayne Bay do represent species carried in by water currents (e.g., *Sargassum* spp.); however, most species of rhodophytes (e.g., *Chondria* spp., *Cladophora* spp. *Polysiphonia* spp.) found at the mainland study sites within the Bay were not abundant elsewhere and probably originated as seagrass epiphytes (Biber, in press).

Hydrodynamic setting is a critical feature in determining drift algal transport (Bell and Hall, 1997). Increasing flow

Table 3

Biomass of drift algae calculated coming through Bear Cut into Biscayne Bay, based on volume flows from the model of Wang et al. (2003). Two major components of the drift, *Sargassum* and red algae are expressed as total biomass (kg) and standardized biomass (mg m⁻³). Biomass of the floating *Sargassum* was calculated on only the upper 0.5 m volume of the water column, while for red algae the entire depth was considered

| Month | Flood | | | | Ebb | | | |
|-------|------------------|--------------------|-----------|--------------------|------------------|--------------------|-----------|--------------------|
| | <i>Sargassum</i> | | Red algae | | <i>Sargassum</i> | | Red algae | |
| | kg | mg m ⁻³ | kg | mg m ⁻³ | kg | mg m ⁻³ | kg | mg m ⁻³ |
| Aug. | 26.3 | 1.0 | 131.5 | 0.5 | 14.0 | 0.8 | 35.2 | 0.2 |
| Dec. | 21.5 | 0.8 | 131.5 | 0.5 | 14.0 | 0.8 | 35.2 | 0.2 |
| May | 6.6 | 0.25 | 789.0 | 3.0 | 19.4 | 1.1 | 352.0 | 2.0 |

velocities reduce the persistence time of drift algae within a seagrass bed. In Bear Cut, drift clumps entangled in sparse seagrass beds with short canopies were often removed from the bed within less than 24 h by currents, whereas clumps occurring in dense seagrass did not readily move, with residence times of up to four days (Biber, in press). In a similar study in Florida Bay, only 15% of clumps were moved in seagrass beds with low flow-velocities, whereas 95% of clumps were transported over bare substrate under moderate to strong flows (Holmquist, 1994). Export of clumps that were not initially entangled in the seagrass was greater, with 85% moving more than 100 m, and in some cases up to 500 m in 24 h (Holmquist, 1994). Tidal currents could dislodge and transport enmeshed algal clumps from seagrass beds a distance of at least 50 m over 20 days (Holmquist, 1994).

Flow-vector outputs from a hydrodynamic circulation model of Biscayne Bay (Wang et al., 2003) indicate high flow regions occur at the oceanic cuts along the eastern margin of Biscayne Bay adjacent to the Atlantic Ocean. Tidal flows with vectors of magnitudes up to 100 cm s⁻¹ or greater are predicted by this model at the Bear Cut, the Safety Valve, Caesar Creek, and Broad Creek inlets (J. Wang, pers. comm.). In contrast, mean flow velocities along the eastern side of the Bay are only between 15 and 30 cm s⁻¹ (Wang et al., 2003). The flow velocities predicted by the model were dependent on the magnitude of tidal exchange with higher tidal volumes during spring tides, and wind driven water circulation patterns within the Bay (Wang et al., 2003).

Seasonal variation in the amount of drift algae associated with seagrass substrates was found by Riegl et al. (2005) in the Indian River Lagoon. Spatial and temporal variation in macroalgal biomass occurred with large accumulations in the cooler months recorded in the shallow water seagrass sites, subsequently in the summer much of this biomass was washed to deeper channels and was either exported or broken down (Riegl et al., 2005). Shallow seagrass substrates cover most of the mainland coast of Biscayne Bay, with very few adjacent deep channels. The lack of channels to transport drift algae out of the grass beds, may be a reason why biomass in these sites did not decline in the summer (Biber, 2002), instead water-column mixing by early winter cold fronts caused most of the removal of drift algae biomass in these sites (Josselyn, 1977).

The spatial distribution of drift algae depends on the interplay of local and landscape scale effects. At the small spatial scale (meters) within a site, water motion and current flow may not always be directly related to the accumulation of drift algae. At Broad Creek (BC), a site of rapid current flow, I often observed clumps of algae drifting across the site and PVC poles, which marked monitoring transects, regularly snagged large mats of algae. Accumulation of drift algae occurs at high-energy locales only if currents are locally reduced enough to allow deposition (like the lee of a bank, or depression where current flow is reduced), or if obstructions entangle passing clumps of algae (such as PVC posts or more commonly, sponges, soft corals, or clumps of the rhizophytic alga, *Halimeda opuntia*). The question of whether the drift algae are settling out at the low-flow velocities present along the mainland coastline after net transport across the Bay from tidal currents is still a matter requiring further study.

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References

- Bell, S.S., Hall, M.O., 1997. Drift macroalgal abundance in seagrass beds: investigating large-scale associations with physical and biotic attributes. *Marine Ecology Progress Series* 147, 277–283.
- Biber, P.D., 2002. The Effects of Environmental Stressors on the Dynamics of Three Functional Groups of Algae in *Thalassia testudinum* Habitats of Biscayne Bay, Florida: A Modeling Approach. Ph.D. dissertation. University of Miami, Coral Gables, FL, 350 pp.
- Biber, P.D., 2007. Transport and persistence of drifting macroalgae (Rhodophyta) are strongly influenced by flow velocity and substratum complexity in tropical seagrass habitats, *Marine Ecology Progress Series*, in press.
- Biber, P.D., Irlandi, E.A., 2006. Temporal and spatial dynamics of macroalgal communities along an anthropogenic salinity gradient in Biscayne Bay (Florida, USA). *Aquatic Botany* 85, 65–77.
- Biber, P.D., Harwell, M.A., Cropper Jr., W.C., 2004. Modeling the dynamics of three functional groups of macroalgae in tropical seagrass habitats. *Ecological Modelling* 175, 25–54.
- Dawes, C.J., Moon, R.E., Davis, M.A., 1978. The photosynthetic and respiratory rates and tolerances of benthic algae from a mangrove and salt marsh estuary: a comparative study. *Estuarine and Coastal Marine Science* 6, 175–185.
- Edgar, G.J., 1987. Dispersal of faunal and floral propagules associated with drifting *Macrocystis pyrifera* plants. *Marine Biology* 95, 599–610.
- Fine, M.L., 1970. Faunal variation on pelagic *Sargassum*. *Marine Biology* 7, 112–122.
- Fletemeyer, J.R., 1978. Underwater tracking evidence of neonate loggerhead sea turtles seeking shelter in drifting *Sargassum*. *Copeia* 1, 148–149.
- Flindt, M., Salomonsen, J., Carrer, M., Bocci, M., Kamp-Nielsen, L., 1997. Loss, growth and transport dynamics of *Chaetomorpha aerea* and *Ulva rigida* in the Lagoon of Venice during an early summer field campaign. *Ecological Modelling* 102, 133–141.
- Forcucci, D., Butler, I.M., Hunt, J., 1994. Population dynamics of juvenile Caribbean spiny lobster, *Panulirus argus*, in Florida Bay, Florida. *Bulletin of Marine Science* 54, 805–818.
- Hamm, D., Humm, H.J., 1976. Benthic algae of the Anclote Estuary 2. Bottom dwelling species. *Florida Scientist* 39, 209–229.
- Holmquist, J.G., 1994. Benthic macroalgae as a dispersal mechanism for fauna: influence of a marine tumbleweed. *Journal of Experimental Marine Biology and Ecology* 180, 235–251.
- Holmquist, J.G., 1997. Disturbance and gap formation in a marine benthic mosaic: influence of shifting macroalgal patches on seagrass structure and mobile invertebrates. *Marine Ecology Progress Series* 151, 121–130.
- Ingólfsson, A., 1995. Floating clumps of seaweed around Iceland: natural microcosms and a means of dispersal for shore fauna. *Marine Biology* 122, 13–21.
- Irlandi, E.A., Orlando, B.A., Biber, P.D., 2004. Drift algae-epiphyte-seagrass interactions in a subtropical *Thalassia testudinum* meadow. *Marine Ecology Progress Series* 279, 81–91.
- Josselyn, M.N., 1977. Seasonal changes in the distribution and growth of *Laurencia poitei* in a subtropical lagoon. *Aquatic Botany* 3, 217–229.
- Josselyn, M.J., Cailliet, G.M., Niesen, T.M., Cowen, R., Hurley, A.C., Connor, J., Hawes, S., 1983. Composition, export and faunal utilization of drift vegetation in the Salt River submarine canyon. *Estuarine, Coastal and Shelf Science* 17, 447–465.
- Kulczycki, G.R., Virnstein, R.W., Nelson, W.G., 1981. The relationship between fish abundance and algal biomass in a seagrass-drift algae community. *Estuarine, Coastal and Shelf Science* 12, 341–347.
- Lirman, D., Biber, P., 2000. Seasonal dynamics of macroalgal communities of the northern Florida Reef tract. *Botanica Marina* 43, 305–314.
- Lobban, C.S., Harrison, P.J., 1994. *Seaweed Ecology and Physiology*. Cambridge University Press, Cambridge, 366 p.
- Norkko, J., Bonsdorff, E., Norkko, A., 2000. Drifting algal mats as an alternative habitat for benthic invertebrates: species specific responses to a transient resource. *Journal of Experimental Marine Biology and Ecology* 248, 79–104.
- Norton, T.A., Mathieson, A.C., 1983. The biology of unattached seaweeds. *Progress in Phycological Research* 2, 333–386.
- Ochieng, C.A., Erfteimeijer, P.L.A., 1999. Accumulation of seagrass beach cast along the Kenyan coast: a quantitative assessment. *Aquatic Botany* 65, 221–238.
- Ólafsson, E., Ingólfsson, A., Steinarsdóttir, M.B., 2001. Harpacticoid copepod communities of floating seaweed: controlling factors and implications for dispersal. *Hydrobiologia* 453–454, 189–200.
- Orr, M., Zimmer, M., Jelinski, D.E., Mewes, M., 2005. Wrack deposition on different beach types: spatial and temporal variation in the pattern of subsidy. *Ecology* 86, 1496–1507.
- Phillips, R.C., 1960. Ecology and distribution of marine algae found in Tampa Bay, Boca Ciega Bay and at Tarpon Springs, Florida. *Quarterly Journal of the Florida Academy of Science* 23, 222–260.
- Riegl, B.M., Moyer, R.P., Morris, L.J., Virnstein, R.W., Purkis, S.J., 2005. Distribution and seasonal biomass of drift macroalgae in the Indian River Lagoon (Florida, USA) estimated with acoustic seafloor classification (QTCView, Echoplus). *Journal of Experimental Marine Biology and Ecology* 326, 89–104.
- Sokal, R.R., Rohlf, F.J., 1995. *Biometry*, third ed. W.H. Freeman and Co., New York, 887 pp.
- Virnstein, R.W., Carbonara, P.A., 1985. Seasonal abundance and distribution of drift algae and seagrasses in the mid-Indian River lagoon, Florida. *Aquatic Botany* 23, 67–82.
- Wang, J.D., Luo, J., Ault, J.S., 2003. Flows, salinity and some implications on larval transport in South Biscayne Bay, Florida. *Bulletin of Marine Science* 72, 695–723.
- Weis, J.S., 1968. Fauna associated with pelagic *Sargassum* in the Gulf Stream. *American Midland Naturalist* 80, 554–558.
- Williams-Cowper, S., 1978. The drift algae community of seagrass beds in Redfish Bay, Texas. *Contributions in Marine Science* 21, 125–132.