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SEASONALITY OF THE INVASIVE SEAWEED *GRACILARIA VERMICULOPHYLLA* ALONG THE SOUTHEASTERN COAST OF NORTH CAROLINA

D. WILSON FRESHWATER,[1] JULIE K. GREENE, and REBECCA M. HAMNER

Center for Marine Science, UNCW
5600 Marvin Moss Lane
Wilmington, NC 28409
[1]E-mail: freshwater@uncw.edu

FRANK MONTGOMERY

218 Hickory Knoll Road
Wilmington, NC 28409

Abstract: *Gracilaria vermiculophylla* is a red alga that has recently invaded the coastal waters of North Carolina. It has become abundant in the sounds and estuaries of southeastern North Carolina and is a nuisance for commercial fishing operations and industries drawing water from the lower Cape Fear River. Seasonal growth and abundance of *G. vermiculophylla* was studied along transects on an intertidal flat in Masonboro Sound, New Hanover County, using a modified Braun-Blanquet scale. Percentage of potential substrates with attached thalli was also recorded at this site. Highest Braun-Blanquet scores were found during May thru July when both water and air temperatures were warming, and were lowest during January thru April, when temperatures were coldest and the majority of thalli were observed to dieback to their bases. The percentage of potential substrates with attached thalli showed no seasonal variation and was high (>94%) throughout the year indicating that the Braun-Blanquet measured changes in cover/abundance of *G. vermiculophylla* were because of changes in the size of thalli.

Key Words: Gracilaria; *Gracilaria vermiculophylla;* invasive species; seasonality.

INTRODUCTION

Invasive species are now recognized as one of the leading threats to global biodiversity and they have a host of other ecological and economic impacts (Elton 1958; Carlton 1989). Millions of dollars are spent annually in control and eradication efforts (Pimentel et al., 2000). Unfortunately, the rate of introductions continues to increase (Ruiz et al., 1997) and once an invader becomes established it is difficult if not impossible to eradicate them, especially in the marine environment (Mills et al. 1993; Carlton et al. 1990). It is therefore essential to understand the biology and potential impacts of invasive species in their new environments.

There have been numerous reports of invasive marine algae (e.g., Rueness 1989; Maggs and Stegenga 1999; Smith et al. 2002), and some such as the recent spread of *Caulerpa taxifolia* (Vahl) C. Agardh have garnered international attention (Meinesz 1999; Jousson et al. 2000). The ecological effects of marine algal invasions can be complex (Levin et al., 2002). Some have been clearly detrimental (e.g., Ramus 1971; deVilléle

Table 1. Braun-Blanquet cover-abundance scale modified from Fourqurean et al. (2002).

Score	Description
0.0	None present
0.1	Solitary thallus base with very small cover
0.5	Multiple thallus bases with very small cover
1.0	less than 5% cover
2.0	5–25% cover
3.0	25–50% cover
4.0	50–75% cover
5.0	75% or more cover

and Verlaque 1995), but the ecological effects of many are unclear and have not been studied.

Most reports of invasive marine algae in the western Atlantic have been along the cold-temperate coasts of the United States and Canada (Villalard-Bohnsack, 2002). Only three non-indigenous species had been reported in the warm-temperate waters of North Carolina prior to 2000: *Codium fragile* subsp. *tomentosoides* (van Goor) Silva, *Polysiphonia harveyi* Bailey, and *Polysiphonia breviarticulata* (C. Agardh) Zanardini (Kapraun 1980a; Kapraun and Searles 1990; Schneider and Searles 1991; McIvor et al. 2001). A fourth species, *Gracilaria vermiculophylla* (Ohmi) Papenfuss, has recently become established in some sounds and estuaries along the North Carolina coast (Freshwater et al., 2006), and other areas in the western Atlantic (Thomsen et al., 2006), northeastern Atlantic (Rueness, 2005), and eastern Pacific (Bellorin et al., 2004). *Gracilaria vermiculophylla* was first noticed growing on the intertidal mudflats in Masonboro Sound, New Hanover County, North Carolina and has become a nuisance for commercial fishing operations in south-eastern North Carolina and the Brunswick Nuclear Power Plant, which draws water from the lower Cape Fear River.

An examination of North Carolina *G. vermiculophylla* within the Chapman and Carlton (1991, 1994) framework for invasive species indicated that it is a recent introduction to this coast, and distributional surveys suggest that it is spreading (Freshwater et al., 2006). We report on the seasonal growth and abundance of *G. vermiculophylla* at an intertidal site in Masonboro Sound, New Hanover County, North Carolina.

METHODS

Four randomly spaced 15 m transects running perpendicular to the shoreline were established within the intertidal zone at one site in Masonboro Sound, New Hanover County. Points were marked every 1.5 m along these transects and five points chosen randomly on each transect, for the placement of 0.25 m^2 quadrats. Estimates of percent cover using a modified Braun-Blanquet score scale (Table 1), and the number of substrates with attached *G. vermiculophylla* thalli were recorded in each quadrat. The percent of possible substrates with attached thalli was assessed at this site by counting the number of potential substrates (worm tubes, shells, etc.) and number of substrates with attached thalli in 20 randomly placed 0.25 m^2 quadrats in the intertidal zone. Observations were made approximately every two weeks during daytime low tides from May 2003 through August 2004. Less frequent observations were made during periods when the tidal range did not expose the study site. The North Carolina Estuarine Reserve program provided Year 2003 water temperature data at a site within 0.5 km of the observed transects. Statistical analyses were performed using SigmaStat version 3.1 software (Systat Software, Inc., Point Richmond, CA, USA).

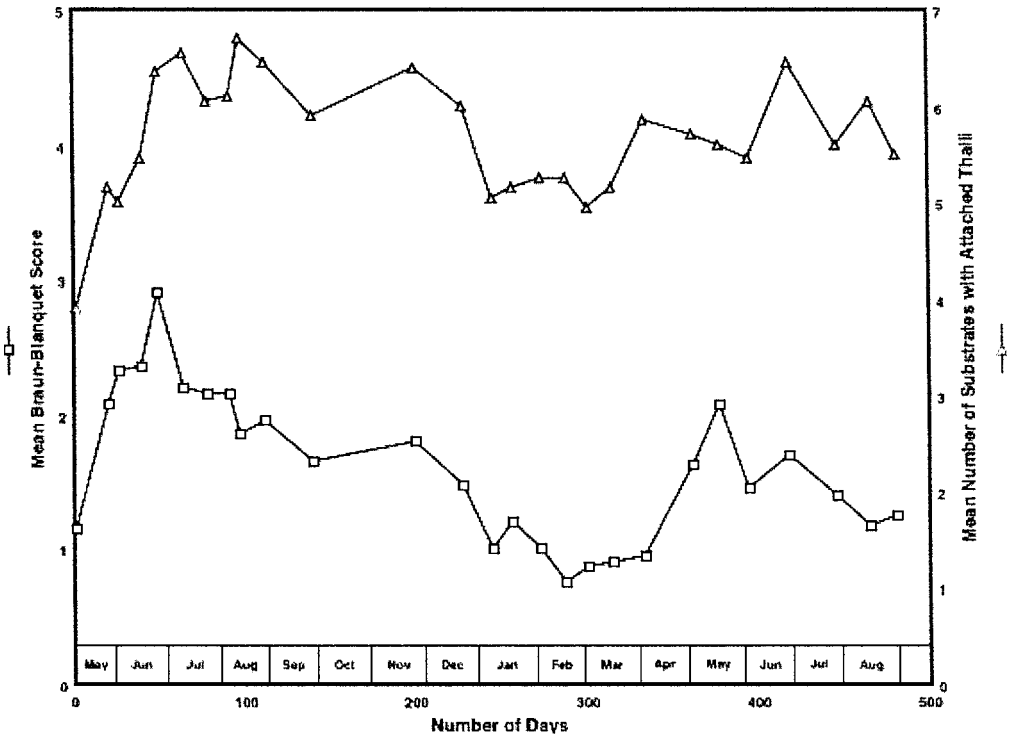

FIG. 1. *Gracilaria vermiculophylla* variations in mean Braun-Blanquet scores and mean number of substrates with attached thalli over a 481-day period at a study site in Masonboro Sound, New Hanover Co., North Carolina.

RESULTS

The mean Braun-Blanquet scores ranged from 0.755 to 2.9 over the entire survey period (Fig. 1). A Kruskal-Wallis analysis of variance indicated a significant difference in scores among some of the observation dates ($p < 0.001$). A Mann-Whitney test found that Braun-Blanquet scores during periods when water temperatures were below 15°C (December–April) were significantly different from scores during periods when water temperatures were above 15°C (May–November). The 0.755 to 2.9 range in score values indicated a large change in the cover/abundance of thalli (Table 1).

A Spearman Rank Order Correlation test indicated a significant correlation between Braun-Blanquet scores and the number of substrates with attached thalli ($p < 0.001$). Despite this correlation, a Mann-Whitney test found that there was no significant difference ($p > 0.05$) in the number of substrates with attached thalli when water temperatures were below 15°C versus when they are above 15°C. The range in mean number of substrates with attached thalli of 3.9 to 6.7 was relatively small in contrast to the changes in cover/abundance indicated by Braun-Blanquet scores, and demonstrated that the differences in Braun-Blanquet scores were more a reflection of the change in size of thalli rather than the number of substrates with attached thalli or number of thalli. A further indication of this was our observation of substrates with multiple small (<2 cm), un-branched thallus bases attached to them in quadrats with the lowest Braun-Blanquet scores.

Table 2. Mean number of potential substrates (Mean Pot. Sub.) and mean number of potential substrates with attached invasive *Gracilaria* plants (Mean Sub. w/Plants) found in 20 randomly placed intertidal 0.25 m^2 quadrats at the Masonboro Sound study site.

Date	Mean Pot. Sub.	Mean Sub.w/Plants	%
11 July 03	3.9	3.9	100
13 Aug 03	2.8	2.65	94.6
28 Aug 03	4.3	4.15	96.5
25 Sep 03	4.2	4.2	100
24 Nov 03	3.4	3.4	100
22 Dec 03	2.8	2.75	98.2
08 Jan 04	3.35	3.25	97.0
20 Jan 04	3.65	3.65	100
05 Feb 04	3.2	3.2	100
20 Feb 04	3.6	3.55	98.6
04 Mar 04	4.5	4.5	100
18 Mar 04	5.85	5.75	98.6
04 May 04	2.5	2.4	96.0
19 May 04	3.95	3.95	100
05 Jun 04	2.45	2.45	100
29 Jun 04	3.05	3.05	100
27 Jul 04	3.8	3.75	98.68
16 Aug 04	4.5	4.4	97.78
31 Aug 04	4.5	4.5	100

The highest Braun-Blanquet scores were recorded during the period from May thru July when both water and air temperatures were warming. Braun-Blanquet scores declined during the warmest part of the year (late July–August) but changed little from September to December when the scores declined again. The lowest Braun-Blanquet scores were recorded in February, and they remained low until the increase in May occurred. Extrapolating the 2003 water temperature data over the complete survey period, Braun-Blanquet values increased as water temperatures rose from 15°C to 27°C and declined most sharply when water temperatures dropped below 15°C. During the May thru July period there were many highly branched thalli throughout the study site. Many of the large thalli broke loose from substrates and/or died back so that there was a mix of large and small thalli present during the heat of the summer. During the winter time period from January to March all thalli were small and in some quadrats only the bases of thalli were found attached to substrates. The percentage of possible substrates with attached thalli in quadrats randomly placed in the intertidal zone was never less than 94% and varied little with season (Table 2). The size of the attached thalli in the randomly placed quadrats varied considerably, as was observed along the monitored transects.

DISCUSSION

Optimum temperatures for growth found in *G. vermiculophylla* culture studies ranged from 15–25°C (Yokoya et al. 1999; Rueness 2005). Water temperatures at our study site ranged from 15°C to 27°C during the period of increasing and maximum cover/abundance of *G. vermiculophylla*, demonstrating a close correlation with the optimum growth temperatures found in culture experiments. Southeastern North Carolina is part of the western Atlantic warm temperate biogeographic zone (Stephenson and Stephenson

1952; Kapraun 1980b). The inshore marine algal flora of this region is characterized by a seasonal variation in composition between warm-water and cold-water species (e.g., Kapraun 1977, 1978; Kapraun and Zechman 1982). *Gracilaria vermiculophylla* seems to be occupying a seasonal niche previously unoccupied on North Carolina tidal flats. Marine algal species of the orders Ulvales (Chlorophyta) and Ectocarpales (Phaeophyta) are often found attached to hard substrates and worm tubes on tidal flats in southeastern North Carolina sounds during the cold-water spring season. Presence of marine algae on these tidal flats has traditionally been greatly reduced during the warm-water summer and fall seasons. *Gracilaria vermiculophylla* has been found attached to substrates on these flats throughout the year, and is often abundant during the warm-water periods when the occurrence of marine algae is usually reduced.

Marine algal species such as *Porphyra* "disappear" during parts of the year as a result of heteromorphic life histories that include microscopic stages (e.g., Kapraun and Luster, 1980). Species with isomorphic life histories may "disappear" by existing as undeveloped germlings or dieing back to thallus bases or holdfasts (e.g., Richardson 1979; Edwards and Kapraun 1973). *Gracilaria vermiculophylla* falls into the second group as the majority of thalli died back to their bases during the times of coldest water temperatures. Dieback of thalli also occurs to a lesser extent during the heat of summer, and thalli of various sizes are then found attached to available substrates on the tidal flats. Large amounts of unattached *G. vermiculophylla* may be found drifting throughout the sounds and washed up as wrack during this time.

Red algae, and especially large taxa such as *Gracilaria*, are known important primary producers (Kain and Norton, 1990). *Gracilaria vermiculophylla* thalli found in North Carolina may be highly branched and grow to 2+ meters in length (Freshwater et al., 2006), and they may be attached to nearly all available substrates in the areas where they are present. The total biomass of *G. vermiculophylla* in the sounds of southeastern North Carolina has not been estimated, but based on the observed size of thalli and number of substrates with thalli during the late spring and summer, it is extensive. The seasonal turnover of this extensive biomass suggests that *G. vermiculophylla* may be affecting the energy and nutrient cycles in the sound ecosystems. This species has also changed the physical dynamics of the area's tidal flats by increasing the amount of structure present in these ecosystems during some periods of the year. The current distribution and probable continued spread of *G. vermiculophylla* in southeastern North Carolina suggest that it is well established in the area (Freshwater et al., 2006). Additional study is required to establish what effects this new resident will have on the regions ecosystems.

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