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Consumption of carrageenophyte *Sarconema filiforme* by *Platynereis insolita* (Polychaeta: Phyllodocida: Nereididae)—laboratory experiments and outplanting

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Abstract Laboratory experiments and outplanting were conducted to understand the consumption of the economically important carrageenophyte *Sarconema filiforme* by the polychaete *Platynereis insolita*. When *S. filiforme* was outplanted, the harvested biomass reached its lowest value (0.56 ± 0.12 kg fresh wt m^{-2}) when the polychaete density showed its highest abundance (10 individuals per g fresh wt of alga), indicating that the algae were under a high grazing pressure by *P. insolita* on the rafts. Laboratory feeding experiments showed that the specific food consumption rate (SFR) increases with the size of the polychaete reaching seaweed consumption values that varied between 73.86 and 215.00% of animal wet body weight. These consumption values suggest that up to 71 ± 2% of biomass yield on raft can be lost due to grazing. The present study demonstrated heavy crop loss of *S. filiforme* due to grazing by *P. insolita*.

Keywords Biomass · Consume · Grazer · *Platynereis insolita* · Polychaete · *Sarconema filiforme* · Rhodophyta

Introduction

Seaweeds are known to harbour diverse assemblages of mesograzers dominated mostly by amphipods, isopods, gastropods, molluscs and polychaete worms (Colman 1940; Wieser 1952; Nagle 1968; Dean and Connell 1987). Many of these mesograzers (Brawley 1992; Buschmann et al. 1997, 2001) consume epiphytes and host as well (Bell 1991). Grazing reduces the growth rate and reproductive capability of seaweeds as has been demonstrated for *Fucus distichus* (van Alstyne 1990). The most structurally complex algae harbour diverse assemblages of invertebrates since they provide larger surface for colonization (Gee and Warwick 1994; Chemello and Milazzo 2002). Algae also provide refuge for mesograzers from physical stress (desiccation, wave impact) and protection from predators (Chemello and Milazzo 2002).

Grazing by mesograzers in a seaweed farm can lead to dramatic decreases in crop yield and concomitant monetary losses (Buschmann et al. 2001; Friedlander 2008). It also has been reported that mesograzers preferred to eat epiphytes rather than the alga or seagrass and thus enhance the growth of alga or seagrass (Foster and Hodgson 1998). While larger herbivores may be excluded from aquaculture operations by simple mechanical devices such as cages or fences, smaller herbivores that are millimetres to a few centimetres long can pass through these barriers causing significant loss to algal biomass.

Polychaetes are an important taxon in soft and hard bottom benthic communities and have an important role in transferring energy between the trophics (Cinar and Ergen 1998, 2001). Several species of polychaete attach algae to their tubes and then graze (Daly 1973; Woodin 1977). Depending on the density of polychaete, the seaweed will be either partially grazed or completely consumed (Woodin 1977). The effects of polychaetes on algal aquaculture are less understood. *Platynereis insolita* Gravior, 1901 is a tropical marine polychaete commonly found in India, Sri Lanka and Philippines (Rosito 1983).

In India, *Kappaphycus alvarezii* is being cultivated at commercial scale for producing kappa carrageenan. In 2015, about

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1490 dry tonnes of *K. alvarezii* were harvested (Mantri et al. 2017). However, iota and lambda carrageenan are not produced due to poor biomass of iota and lambda carrageenophytes in wild stock. *Sarconema filiforme* has been reported to contain hybrid of iota carrageenan and pyruvated lambda carrageenan (Chiovitti et al. 1998; Kumar et al. 2011; Ganesan et al. 2015). A small amount of biomass of less than 100 kg fresh weight was collected from wild stock along the Gulf of Mannar (Anon 2005). Therefore, cultivation of *S. filiforme* was initiated in shallow coastal region of Gulf of Mannar, southeast coast of India, with a view to augment the raw material source for carrageenan production. However, the mesograzer *P. insolita* was established on the alga even at the initial stage of cultivation. The main aim of the present study was to understand the effects of high density *P. insolita* on crop yield of *S. filiforme.* Laboratory experiments on consumption rate of alga and primary phytochemical analysis were performed to establish how far *P. insolita* consumed the alga.

Materials and methods

Outplanting of *Sarconema filiforme*

Sarconema filiforme outplanting was done to quantify the changes in biomass over the different seasons and also changes due to polychaete density. Outplanting of *S. filiforme* was carried out in coastal waters of Mandapam (09° 16.92′ N, 079° 11.40′ E) in the Gulf of Mannar, along the south-east coast of India. The intertidal and subtidal regions have dense seagrass meadow (*Thalassia* sp.). Adjacent to this, there is a sandy coast where pebbles and small coral stones make up the beach. *Gracilaria*, *Hypnea* and *Padina* are the dominant algae attached to these pebbles. The coast is well protected from rough sea by the chain of 20 islands located at about 8 km from the shore which makes this coast more ideal for seaweed cultivation. The intertidal region is exposed during lowest of low tides and submerged during high tides; the tidal range is 0.75 m.

Sarconema filiforme was seeded on floating rafts made of bamboos with 2 m × 2 m size. Young and healthy fragments of *S. filiforme* were collected from a single clump grown as a small patch on the natural substrata of Krusadai Island (09° 14.928′ N; 079° 13.245′ E), Gulf of Mannar Coast. Apical segments of the alga were cut (average 0.8 ± 0.25 g fresh wt) and inserted between the twists of the polypropylene rope at 5-cm intervals. Each polypropylene rope had 25 seedlings with a total fresh weight of approx. 20 g per rope (25 × 0.8 g fresh wt). A raft with 20 ropes had an initial seedling mass of 400 g fresh wt per raft which was equivalent to 100 g fresh wt m^{-2}. The lower side of the raft, below the seeded ropes, was fully covered with fish-net to prevent access by the grazing fish and minimize loss of any experimental material which might detach from the lines. The raft was anchored securely to stones (25 kg approx.). Twenty-five rafts were seeded in July 2010 and harvested at 25-day interval. At each harvest, all 25 rafts were harvested. All algae grown on the ropes were fully harvested by hand picking, and the ropes were freshly re-seeded with new seedlings from the cultivated material after every harvest. Seven harvests have been done during August 2010 to July 2011.

All attached epiphytes (*Lyngbya*, *Jania* and *Chaetomorpha*) were removed manually. Excess water was drained off by keeping the biomass on a Palmira mat (3 mm thick) over wooden stand for 5 min and fresh weights were measured. Biomass production (*Y*) from 20 ropes was expressed as mean kilogram fresh wt per square meter considering the size of the raft. Biomass production was determined using the modified formula of Doty (1986) that included the initial weight of the seedlings:

$$Y = (W_f - W_i) \Big/ m^2$$

where W_f is the final fresh weight, W_i is the initial fresh weight and m^2 is the area covered.

Density of *Platynereis insolita* on *Sarconema filiforme*

Density of *P. insolita* was quantified to understand density difference during different seasons of a year. Sample collection for *P. insolita* density study was done at every fortnight interval for 12 months from August 2010 to July 2011. At every sampling, ten rafts were randomly selected and three grazed algae were randomly selected from each raft (Total 3 × 10 = 30 samples). Individual alga collected was kept in a polythene bag filled with seawater and brought to the laboratory immediately.

In the laboratory, individual alga was thoroughly rinsed into a 100 μm sieve to dislodge all the polychaetes. The polychaetes collected on the sieve were carefully transferred into a small plastic container and preserved in 4% formalin. The cleaned alga was blotted with paper towel and then weighed. Polychaetes were identified using dissecting and stereo zoom microscope by referring standard references (Fauvel 1953; Fauchald 1977). Polychaete density was quantified and standardized to individuals per gram fresh weight of alga.

Percentage occurrence of grazed plants in harvested biomass

At every harvest, the total numbers of algae harvested from each raft were counted. Algae with short, brittle, curved fragments were considered as grazed plant. Ungrazed algae have slender, elongate with robust branches. *Sarconema filiforme* fragments showing grazing signs were separated and counted to determine the percentage of ungrazed and grazed fragments by using the formula

$$\% \text{ of Grazed plant} = N_g \Big/ N_t \times 100$$

where N_g is the number of grazed alga harvested from the raft and N_t is the total number of alga harvested from the raft.

Environmental parameters

Seawater temperature, salinity and dissolved oxygen were recorded every week at the cultivation sites. Three replicates were done for each parameter. Temperature was measured using a standard thermometer and salinity with a hand refractometer (Atago, Japan). Dissolved oxygen was estimated immediately using modified Winkler's method (Strickland and Parsons 1972). Seawater samples (in triplicate) were collected monthly, and nutrient analyses were done at the laboratory. Dissolved inorganic phosphate (PO_4-P) and nitrate (NO_3- N) were determined using a UV-visible spectrophotometer (Hitachi, model 2001, Hitachi, Japan), following the standard method (Strickland and Parsons 1972). Triplicate samples were done for each nutrient parameter.

Laboratory experiments

Consumption rate of alga

To confirm the grazing of *S. filiforme* by *P. insolita*, food consumption experiments were performed on two size class of *P. insolita* in the laboratory. Animals of the larger size class were an average of 5.20 ± 0.16 cm in length, and those of the smaller class were 3.13 ± 0.07 cm in length. *Sarconema filiforme* collected from raft culture were blotted dry, weighed and placed in with one individual of *P. insolita* in 650 mL plastic container with 500 mL seawater. After 24 h, the alga was taken out from the container, blotted dry and reweighed to determine the loss of biomass due to grazing. Control flask without *P. insolita* containing one pre-weighed specimen was weighed daily and maintained under the same experimental conditions, allowing biomass changes due to growth (Peterson and Renaud 1989). Six containers were used for each size classes and three containers for control (Total 6 + 6 + 3 = 15). The experiment was conducted for 4 days by keeping it at 28 °C with 12:12 LD condition. The experiment was repeated four times and the mean calculated.

The consumed biomass (C_g) was calculated using the equation $C_g = [(H_0 \times C_f/C_0) - H_f]$ suggested by Cronin and Hay (1996) where H_0 and H_f correspond to the initial and final wet masses, respectively, and C_0 and C_f are the initial and final masses of the control.

Daily food consumption rate (C_g) was then standardized for body weight and expressed as a daily specific consumption rate (per cent of animal wet body weight) using the formula of Britz (1995) $C_{\%\ b.wt.} = C_g/W \times 100$, where $C_{\%\ b.wt.}$ is the animal food consumption (as per cent of body weight), C_g the biomass consumed, and W the animal weight (g).

Loss of biomass of Sarconema filiforme on rafts by grazing

Based on the laboratory experiments on consumption of alga by *P. insolita*, loss of biomass on rafts was calculated using the following formula

$$C_g \times D_p \times B_d \times 100 \Big/ B_d$$

where C_g = average biomass consumed per day, D_p = density of *P. insolita* and B_d = biomass produced in rafts per day.

Phytochemical analysis

Primary phytochemical contents of *S. filiforme* were analysed to quantify the levels of phytochemical contents in the alga. Ten healthy plants were randomly selected from different rafts. They were shade dried and primary phytochemical analyses viz. phenolic content, alkaloids, flavonoids, tannin and dissolved carbohydrate content of dried alga were carried out as described by Trease and Evans (1989), Sofowora (1993) and Harborne (1973). Total phenolic content was estimated by adding 5 mL of Folin-Ciocalteu reagent and 5 mL of 7.5% solution of Na_2CO_3 to 1 mL of seaweed extract. The absorbance was measured at 765 nm. Gallic acid was used as control. The presence of alkaloids was determined by adding HCl and Mayer's reagent to 100 mg of seaweed powder, and absence of white precipitate indicated the absence of alkaloids (Sofowora 1993). The presence of flavonoids was determined by adding ethanol, concentrated HCl and magnesium turnings to 100 mg seaweed powder. No formation of red colour indicated absence of flavonoids. The test for tannins was carried out by dissolving 0.1 g of the dried powdered seaweed extract in 0.5 mL of Folin-Ciocalteu phenol reagent and 1 mL of 35% Na_2CO_3 solution reagents. The absorbance was measured at 760 nm after incubated for 30 min at room temperature. Tannic acid was used as control. One hundred milligram of seaweed powder was dissolved in distilled water and filtered. The dissolved carbohydrate was estimated by adding 5 mL of equal volumes of Fehling's solution A and B to seaweed filtrates, and formation of orange colour precipitate confirmed the presence of dissolved carbohydrate (Sofowora 1993).

Statistical analyses

Analysis of variance (ANOVA) was used to determine significant differences in average values of biomass of *S. filiforme*, *P. insolita* density, percentage of grazed and ungrazed plants during different seasons. ANOVA was performed to test the difference in food consumed by polychaete, food consumption rate during the 4-day laboratory experiments. Two-way ANOVA was used to analyse the difference in food consumed by two size groups and also the seasonal changes in percentage occurrence of healthy and affected plants. Tukey's HSD test was used to separate means whenever the F values were significant in ANOVA. Student's t test was used to analyse the difference in specific consumption rate between two size groups. Influence of *P. insolita* density and ecological parameters on seasonality of biomass of *S. filiforme* was analysed by multiple regression analysis. All data were subjected to testing for normality and homoscedasticity before carrying out statistical analysis. The statistical analyses were performed by using the software SYSTAT version 7.

Results

Environmental parameters

Seawater temperature (31.5 ± 1.0 °C) was high in May 2011 and low (24.5 ± 2.0 °C) in January 2011. Salinity peaked (39.0 ± 2.0 ‰) in September 2010 and lowest (27.0 ± 0.5 ‰) during December 2010 and January 2011. The maximum dissolved oxygen (8.1 ± 1.9 mL L^{-1}) was recorded in July 2011 and the minimum (1.6 ± 0.5 mL L^{-1}) during August 2010, April and May 2011. The inorganic phosphate content ranged from a minimum of 0.06 ± 0.02 μg L^{-1} (March 2011) to a maximum of 4.1 ± 1.6 μg L^{-1} (August 2010). Nitrate varied from 0.05 ± 0.02 μg L^{-1} (March 2011) to 6.10 ± 2.0 μg L^{-1} (November 2010) (Table 1).

Outplanting of *Sarconema filiforme*

The biomass production of *S. filiforme* ranged from 0.56 ± 0.07 to 1.97 ± 1.07 kg fresh wt m^{-2}. Lowest biomass production value (0.56 ± 0.07 kg fresh wt m^{-2}) was observed in July 2011 (Fig. 1), while highest biomass production was observed (1.97 ± 1.07 kg fresh wt m^{-2}) during December 2010–January 2011. ANOVA showed significant difference in biomass production during different months ($F = 134.320$; $df = 6, 168$; $P < 0.001$). Multiple regression analysis showed density of *P. insolita*, salinity and seawater temperature influencing biomass production of *S. filiforme* (Table 2).

Density of *Platynereis insolita* on *Sarconema filiforme*

Platynereis insolita was established on *S. filiforme* within 10 days of seeding. It secreted a slime tube by which it bundled the fragments and nestled between them and grazed out the fronds. The grazed alga became short, curved, brittle and with less weight.

Platynereis insolita density ranged from 2 ± 1 to 10 ± 3 individuals g^{-1} fresh wt of alga. *P. insolita* density differed significantly during different culture months ($F = 318.108$; $df = 6, 203$; $P < 0.001$) with highest density (10 ± 3 individuals g^{-1} fresh wt of alga) in July 2011 (Fig. 2). During this period, lowest biomass of *S. filiforme* was observed. Lowest *P. insolita* density (2 ± 1 individuals per g fresh wt of alga) was recorded during December 2010–January 2011 (Fig. 2) when biomass peaked.

Percentage of grazed *Sarconema filiforme* in the harvested biomass

The percentage of grazed and ungrazed *S. filiforme* is shown in Fig. 3. It ranged from 4.5 ± 4 to 85.2 ± 14%. The highest percentage of grazed alga (85.2 ± 14%) was observed in July 2011 and lowest percentage (4.5 ± 4%) during February–March 2011. The values showed significant difference ($F = 178{,}984.857$; df = 6, 14; $P < 0.001$) during different months. Maximum percentage of ungrazed algae was observed during February–March 2011 (95.5 ± 4%) and the minimum (14.8 ± 7%) in July 2011. The values differed significantly during different months ($F = 179{,}774.714$; $df = 6, 14$; $P < 0.001$). Two-way ANOVA showed no significant difference between healthy and affected plants ($F = 0.026$; $df = 6, 1$; $P > 0.876$) and no significant difference in monthly variation between healthy and affected plants ($F = 0.00013$; $df = 6, 1$; $P > 1.0$). Percentage of grazed plants showed negative correlation with biomass yield ($r = -0.712$; $P < 0.001$). Biomass production was lesser when numbers of grazed plants were higher. Salinity ($r = 0.614$; $P < 0.001$) and phosphate contents of seawater ($r = 0.609$; $P < 0.01$) positively correlated with percentage of grazed alga.

Laboratory experiments

Food consumption rate of alga

Mean daily food consumed by smaller size group (3.13 ± 0.07 cm) of *P. insolita* ranged from 0.032 ± 0.015 to 0.055 ± 0.035 g fresh wt (Table 3). Significant difference was seen in food consumed during 4 days ($F = 112.335$; $df = 3,20$; $P < 0.007$). Food consumed by larger size group (5.20 ± 0.16 cm) ranged from 0.065 ± 0.032 to 0.19 ± 0.083 g fresh wt and significantly differed during 4 days ($F = 108.606$; $df = 3,20$; $P < 0.001$). Two-way ANOVA showed significant difference in food consumption between two size groups ($F = 9.937$; $df = 3,1$; $P < 0.05$) and no significant difference in trend in food consumption between the size groups during 4 days ($F = 1.412$; $df = 3,1$; $P > 0.391$).

Mean daily specific consumption rate for smaller size group of polychaete (3.13 ± 0.07 cm) ranged between 48.48 ± 10.12 and 83.00 ± 19.015% of animal wet body

Table 1 Monthly variation in various physical and chemical parameters recorded in farm site during the study period (mean ± SD, *n* = 3)

Physical and chemical parameters					
Months	Salinity (‰)	Dissolved oxygen (mL L^{-1})	Temperature (°C)	Phosphate (µg L^{-1})	Nitrate (µg L^{-1})
August 2010	36 ± 0.5	1.6 ± 0.5	28.0 ± 0.5	4.1 ± 1.6	0.3 ± 0.09
	37 ± 1.0	2.2 ± 0.4	28.5 ± 0.5		
	37 ± 1.2	2.5 ± 1.2	29.0 ± 1.0		
	35 ± 0.8	2.5 ± 1.3	28.0 ± .0.7		
September 2010	35 ± 1.0	2.8 ± 1.5	27.5 ± 0.6	0.5 ± 0.1	0.3 ± 0.07
	39 ± 2.0	2.8 ± 1.7	27.0 ± 1.0		
	35 ± 1.5	2.8 ± 1.4	28.0 ± 2.0		
	36 ± 1.0	2.8 ± 1.2	29.0 ± 1.0		
October 2010	36 ± 0.8	3.3 ± 2.0	28.5 ± 2.0	1.6 ± 0.4	1 ± 0.9
	35 ± 2.0	2.8 ± 2.0	27.5 ± 1.5		
	35 ± 1.0	3.9 ± 1.1	27.0 ± 2.0		
	36 ± 0.9	3.9 ± 0.9	27.5 ± 1.5		
November 2010	38 ± 2.0	3.9 ± 0.8	29.0 ± 1.0	1.2 ± 0.5	6.1 ± 2.0
	35 ± 2.0	3.3 ± 0.3	28.5 ± 2.0		
	35 ± 0.9	3.9 ± 0.7	27.5 ± 2.0		
	35 ± 0.8	3.3 ± 0.6	28.0 ± 1.5		
December 2010	35 ± 0.9	3.9 ± 0.8	28.5 ± 1.5	1.3 ± 0.5	3.8 ± 1.7
	34 ± 1.0	4.4 ± 1.3	27.5 ± 2.0		
	27 ± 0.5	3.3 ± 31.0	25.5 ± 2.5		
	33 ± 0.6	3.9 ± 1.5	27.5 ± 2.0		
January 2011	275 ± 0.5	5.05 ± 2.0	26.0 ± 1.5	0.15 ± 0.1	2.92 ± 1.0
	28 ± 1.0	3.3 ± 1.5	25.0 ± 1.3		
	29 ± 2.0	2.8 ± 1.2	25.5 ± 2.0		
	29 ± 1.5	2.8 ± 2.2	24.5 ± 2.0		
February 2011	29 ± 2.0	3.3 ± 1.5	25.0 ± 2.0	0.07 ± 0.02	1.83 ± 1.0
	30 ± 1.0	2.2 ± 1.0	26.5 ± 1.5		
	32 ± 2.0	2.2 ± 0.9	29.5 ± 0.5		
March 2011	31 ± 1.0	2.2 ± 0.5	27.0 ± 0.7	0.06 ± 0.02	0.05 ± 0.02
	31 ± 1.0	2.2 ± 0.7	27.5 ± 1.2		
	32 ± 2.0	3.3 ± 1.0	28.5 ± 1.5		
	32 ± 2.0	2.2 ± 0.9	29.5 ± 0.5		
April 2011	35 ± 1.5	1.6 ± 1.5	29.0 ± 1.0	0.7 ± 0.1	0.5 ± 0.1
	34 ± 1.5	2.8 ± 1.0	28.5 ± 1.0		
	33 ± 2.0	3.3 ± 1.5	30.5 ± 1.5		
	32 ± 2.0	2.2 ± 1.2	29.5 ± 1.2		
May 2011	36 ± 3.0	2.2 ± 1.2	31.5 ± 1.5	3.2 ± 1.2	1.9 ± 0.9
	35 ± 2.5	1.6 ± 1.5	31.5 ± 1.0		
	36 ± 2.0	2.5 ± 1.4	30.5 ± 1.9		
	34 ± 1.0	2.8 ± 1.6	28.0 ± 0.8		
June 2011	37 ± 2.0	5.6 ± 2.2	29.5 ± 1.5	3.2 ± 1.5	1.2 ± 0.6
	35 ± 1.0	4.4 ± 2.0	28.5 ± 0.5		
	36 ± 2.0	2.2 ± 1.2	29.0 ± 1.0		
	36 ± 2.0	2.2 ± 1.5	31.0 ± 1.0		
July 2011	36 ± 1.0	2.8 ± 1.9	29.5 ± 0.9	4.0 ± 1	0.3 ± 0.08
	35 ± 1.5	8.1 ± 1.9	28.5 ± 1.5		

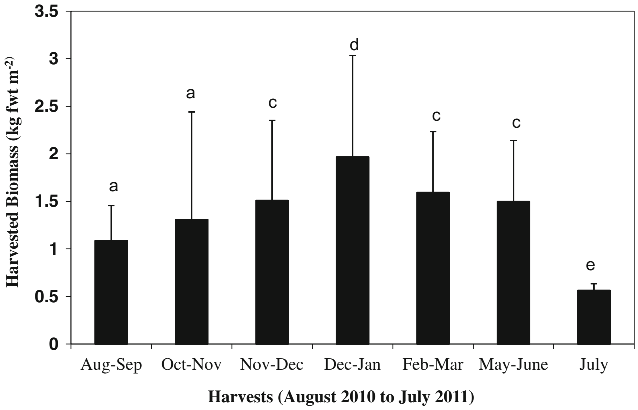

Fig. 1 Biomass of *S. filiforme* in raft method of outplanitng. *Error bars* are standard deviation. *Different small letters* denote significant difference at $P < 0.05$ **(**$n = 25$**)**

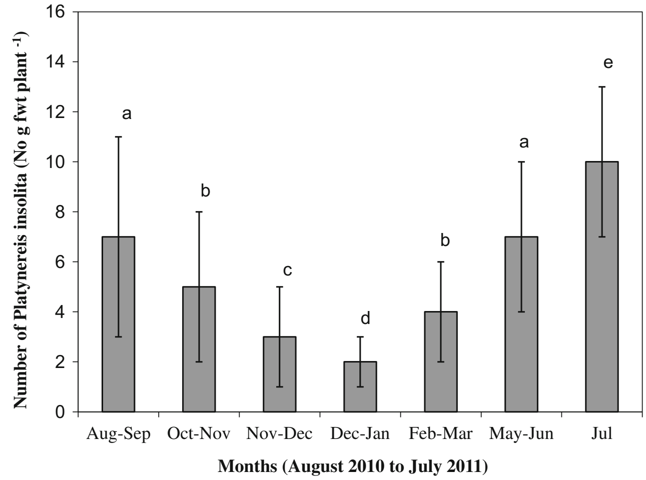

Fig. 2 Population of *P. insolita* on *S. filiforme* in outplanting rafts. *Error bars* are standard deviation. *Different small letters* denote significant difference at $P < 0.05$ ($n = 30$)

weight) and consumption rate significantly differed during 4 days ($F = 18{,}004.031$; $df = 3{,}20$; $P < 0.001$). Specific consumption rate for larger size group (5.20 ± 0.16 cm) ranged from 73.86 ± 12.34 to 215 ± 23.42% of animal wet body weight) and showed significant difference ($F = 1837.123$; $df = 3{,}20$; $P < 0.001$) (Table 3). *t* test showed significant difference in specific consumption rate between two groups ($P < 0.002$).

Loss of biomass of Sarconema filiforme on rafts by grazing

Maximum weight loss of *S. filiforme* (71 ± 2%) was observed in July 2011 and minimum weight loss (14.2 ± 5%) during Dec 2010–Jan 2011 (Table 4). It significantly differed ($F = 385.600$; $df = 6168$; $P < 0.001$) during different harvest periods. Weight loss of the alga showed a strong negative correlation to total biomass yield ($r = 0.901$; $P < 0.001$) and strong positive correlation ($r = 0.852$; $P < 0.01$) to *P. insolita* density.

Phytochemical content of Sarconema filiforme

Sarconema filiforme has a phenolic content of 0.28 ± 0.03 mg g^{-1} dry wt and tannin content of 0.07 ± 0.01.2 mg g^{-1} dry wt. Average dissolved carbohydrate content was 2.8 ± 0.09%. Alkaloids and flavonoids were absent in *S. filiforme* (Table 5).

Table 2 Multiple regression analysis for biomass of *S. filiforme* ($R^2 = 0.846$)

	Estimate	Standard error	*t* value	*P* value
Density	−0.038	0.041	−2.037	0.050*
Salinity	−0.032	0.013	−2.411	0.030*
Dissolved oxygen	0.026	0.021	1.240	0.235
Temperature	0.058	0.019	2.978	0.009*
Phosphate	0.014	0.040	0.364	0.721
Nitrate	−0.027	0.019	−1.414	0.179

*Significant

Discussion

Both positive and negative effects were reported on grazing of algae by herbivores. Grazing by some species of crustaceans can reduce macroalgal biomass (Duffy 1990; Geertz-Hansen et al. 1993; Sfriso and Pavoni 1994). Other invertebrate species feed preferentially on epiphytes on the macroalgae and as a result have a positive effect on macroalgal growth (Brawley and Adey 1981; Dudley 1992). Density of grazers can be an important proxy for the grazing pressure (Poore 2005). Poore et al. (2009) observed no grazing in algal beds when meso grazers with <40 mm size and density ranged from 1 to 12 g^{-1}.

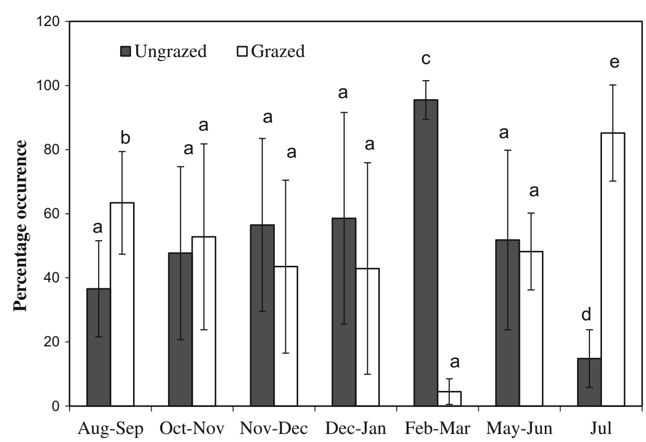

Fig. 3 Percentage of healthy and grazed *S. filiforme* in harvested plants. *Different small letters* denote significant difference at $P < 0.05$

Table 3 Daily food consumed (FC) (mean ± SD, $n = 6$) and specific food consumption. Rate (SFR) (mean ± SD, $n = 6$) for two different size classes of *P. insolita* fed *S. filiforme*

Size class (cm)	Days							
	1		2		3		4	
	FC (g fresh wt)	SFR (%)	FC (g fresh wt)	SFR (%)	FC (g fresh wt)	SFR (%)	FC (g fresh wt)	SFR (%)
3.13 ± 0.07	0.032 ± 0.015	48.48 ± 10.12	0.047 ± 0.031	71.21 ± 9.34	0.040 ± 0.025	60.60 ± 12.40	0.055 ± 0.035	83.00 ± 19.01
5.20 ± 0.16	0.065 ± 0.032	73.86 ± 12.34	0.097 ± 0.045	110 ± 17.24	0.190 ± 0.083	215 ± 23.42	0.180 ± 0.115	204 ± 17.89

Brawley and Fei (1987) found heavy grazing in *Gracilaria astiatica* when meso grazers with 50–75 mm size and density about 20 to 68 g^{-1}. In our study, even lower number of *P. insolita* about 2–10 g^{-1} grazed the alga heavily. About 71% weight loss was observed. This appears to be in higher range.

P. insolita population was found during all months on *S. filiforme* with higher density during June and July. The higher density of *P. insolita* exerts more grazing pressure on *S. filiforme* that resulted in lowest biomass production in July. This shows that biomass production of *S. filiforme* was heavily affected by *P. insolita* density. However, the grazing effect was minimum when *S. filiforme* growth was high, particularly during December, January and February.

Polychaete density negatively affected biomass and salinity negatively affected biomass, whereas temperature positively affected biomass indicating that polychaete density, salinity and temperature are three important factors influencing *S. filiforme* biomass.

As polychaetes are mobile invertebrates, they can separate the use of seaweed as habitat and food (Buschmann 1990). Therefore, the polychaete density can increase depending upon the installation of the *S. filiforme* rafts just by recruitment on the algae or by migration of the adults from nearby areas. As polychaete abundance starts to increase due to the maintenance of the seaweed farm being constantly in place, the polychaetes start to increase the consumption of the seaweed and habitat as also demonstrated with crustacean mesograzers (Brawley and Adey 1981; Brawley and Fei 1987). A management strategy to control the polychaetes could be to avoid having seaweed during the period of high recruitment or migration of the polychaetes. However, this will require experimental testing in the future. During 4 days of experiment, we observed that *P. insolita* fed on *S. filiforme* slowly during first 2 days and ate more during days 3 and 4. Many herbivores are nocturnal (Brawley and Adey 1981; Brawley and Fei 1987; Buschmann 1990; Brawley 1992). In the present study, the feeding experiment was conducted with a 12:12 light/dark cycle at ambient temperature close to the condition exists in nature. We closely monitored the movement of polychaetes and observed that *P. insolita* was lethargic during day hours and grazed very little while being active during night hours consuming more *S. filiforme*.

P. insolita consumed between 0.032 and 0.19 g of its fresh weight per day. The daily food consumed in laboratory condition by single polychaetes was extrapolated to field condition with density of polychaete and days of culture. Maximum weight loss of 71% was observed in cultivation during July when the density of *P. insolita* reached maximum. Consumption rates of herbivorous marine invertebrates have been shown to decrease with increasing body size (Buxton and Field 1983; Emmerson and McGwynne 1992). This was not found with *P. insolita.* Both size classes of polychaete ate *S. filiforme*, and the larger polychaetes consumed more *S. filiforme* than the smaller. The larger polychaetes consumed almost double the amount than the smaller size class. This may be mainly because of higher metabolic rate in the larger size animals, as metabolic rate varies with the size of meso grazers (Branch 1981; Peck et al. 1987).

Table 4 Percentage weight loss of *S. filiforme* on rafts

Culture months	Percentage weight loss
August–September 2010	49.7 ± 3.5
October–November 2010	35.5 ± 1.6
November–December 2010	21.3 ± 0.9
December–January 2010, 2011	14.2 ± 5.0
February–March 2011	28.4 ± 1.2
May–June 2011	49.7 ± 4.8
July 2011	71.0 ± 2.0

Mean ± SD, $n = 25$

Table 5 Phytochemical content of *S. filiforme*

Phytochemicals	Concentration (mg g dry wt^{-1})
Phenol	0.28 ± 0.03
Tannin	0.07 ± 0.012
Dissolved carbohydrate (%)	2.80 ± 0.09
Alkaloids	–
Flavonoids	–

Mean ± SD, $n = 3$

– not detected

Preference for an alga depends on the ability to digest the alga (Montgomery and Gerking 1980). Alpha-linked polysaccharides, such as starch, are more susceptible to amylases than beta-linked polymers like cellulose and its derivatives (Percival and McDowell 1967). *Sarconema filiforme* contained hybrid iota and lambda carrageenan with more alpha-linked and beta-linked galactans (Ganesan et al. 2015).

Many seaweeds can deter a variety of common marine herbivores using a diverse array of secondary metabolites (Paul et al. 2001) which are qualitatively or quantitatively variable. Rhodophyceae generally having a high quantity and diversity of secondary metabolites (Manley and Chapman 1978; Pedersen 1978). We estimated phenolic content, tannin, alkaloids, flavonoids and dissolved carbohydrate in *S. filiforme*. However, their concentrations were found to be very low.

In conclusion, the present study has demonstrated heavy crop loss of *S. filiforme* due to grazing by *P. insolita*. The polychaete consumed *S. filiforme* on rafts. This was confirmed by laboratory experiments. Food consumption rate correlated to the size of the animal; larger size polychaetes consumed more algae than the smaller size individuals. Higher specific consumption rates indicated the preference for *S. filiforme* by *P. insolita* possibly because *S. filiforme* contains lower levels of phenolic and tannin.

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