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THE IMPACT OF CRUSTACEAN HERBIVORES ON CULTURED SEA-WEED POPULATIONS

M.E. NICOTRI

Woods Hole Oceanographic Institution, Woods Hole, Mass. 02543 (U.S.A.)

Present address: Department of Biology, University of Washington, Seattle, Wash. 98195 (U.S.A.)

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ABSTRACT

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The impact of two herbivorous crustaceans on seaweeds raised in an aquaculture system has been estimated from laboratory determined grazing rates and estimated crustacean densities in the system. Grazing losses are generally very small in comparison to algal productivity but may be significant when crustacean populations are abundant and algal productivity is low.

INTRODUCTION

A tertiary sewage treatment—marine aquaculture system has been developed (Ryther et al., 1972; Ryther, 1975) in which secondary sewage effluent is used as a nutrient source on which to grow phytoplankton. These algae remove nutrients from the water and, in turn, are themselves used as a food source for several species of shellfish. The final stage of nutrient removal consists of suspended seaweed cultures which assimilate nutrients not taken up initially by the phytoplankton as well as those reintroduced by shellfish excretion. The objective of this whole procedure is to reduce levels of nutrients in final effluent waters and, at the same time, to produce commercially valuable crops.

Several species of algae have been used in the final "polishing" step (Ryther et al., 1975) but current research has focussed on two potentially commercial species of red algae, *Gracilaria foliifera* and *Neoagardhiella baileyi*, which yield agar and carrageenan respectively.

Several species of crustacean herbivores have become abundant in these seaweed cultures. The isopod *Idotea baltica* and the tube dwelling amphipod *Ampithoe valida* are the most important of these grazers and potentially could be affecting algal productivity. Two other amphipod species are abundant, *Hyale plumosus*, which occurs almost entirely on *Enteromorpha* growing attached to the side walls, and *Jassa falcata*, which is a suspension feeder eating mainly copepods abundant in the algal cultures. Neither of these species has much influence on the macroalgae of interest here.

The present study was undertaken to investigate the impact of herbivores, such as *Idotea* and *Ampithoe*, on cultured seaweed populations.

METHODS

The seaweeds were grown in two cement raceways, 1.2 × 12.2 × 1.5 m deep, and kept in suspension by circulation driven by an air line set along the bottom. Over most of the study period, both *Gracilaria* and *Neoagardhiella* were kept in half of each raceway, and separated by a plastic mesh barrier which allowed animals to move freely from one algal species to the other. Over the winter months one of the raceways (number 4) was heated to about 20°C, and the other raceway (number 2) was kept at 15°C. During extremely cold periods temperatures dropped below this, but remained above 11°C.

Grazer densities and size distributions were sampled periodically by taking six portions of the seaweed (each sample weighing approximately 30—60 g wet weight) from each culture. These were treated with 3% formalin and hand sorted to separate the animals from the algae. Animals were counted and total body length of each was measured to the nearest millimeter. Amphipods were stretched against a ruler to straighten them, resulting in some small error.

Growth rates were estimated from individually laboratory-reared animals fed on *Gracilaria* at 20°C. Rates for *Idotea* fed *Neoagardhiella* were also obtained. Body length was measured weekly by immobilizing animals on a dissecting microscope stage with a piece of transparent plastic. Amphipods were carefully straightened against a rigid edge. Measurements were made with an ocular micrometer calibrated to the nearest 0.1 mm. Repeated measurements showed accuracy to be within 0.2 mm. Molting frequency proved difficult to estimate as several molts per week occur for both *Idotea* and *Ampithoe*.

Grazing rates were obtained from laboratory experiments carried out at 12°C. Six species of algae were offered to isopods and amphipods: *Gracilaria foliifera, Neoagardhiella baileyi, Hypnea musciformis, Chondrus crispus, Fucus vesiculosus*, and *Corallina officinalis*. The former three are economically valuable species obtained from the mass outdoor cultures already described, and the latter three are very abundant, readily encountered algae collected from natural field populations. Three grams (wet weight) of each of the above species were placed in each of 12 containers. Four isopods (7—12 mm) were added to each of four of these containers, and four amphipods (7—9 mm) were added to each of four others. The remaining four containers of alga were left without grazers to serve as controls. These were all left in a well-lit water table for 1 week. At the end of this time the herbivores were removed and the algae reweighed. Corrections were made for weight changes in the controls and for animal deaths during the experiment to arrive at the amount of each alga consumed per individual grazer per week. From calculations based on these rates, the density of grazers, and algal standing crop and productivity (DeBoer et al., 1976), the impact of *Idotea* and *Ampithoe* on seaweed cultures was estimated.

RESULTS

The mean number of isopods per 100 g (wet weight) of algae and the same information for *Amphithoe* is shown in Table I. The numbers for *Idotea* are underrepresentative of true densities for two reasons. First, *Idotea* is a highly mobile animal, and some individuals undoubtedly avoid the sampling net although the majority tend to cling to the seaweed and so are sampled. Secondly, there is a portion of the population that clings to the side walls and to algae such as *Ulva* or *Ceramium* attached there. Sampling has shown that densities on attached *Ceramium* may be as much as two and a half times those on the suspended seaweed (258 on *Ceramium* versus 101 on *Gracilaria*). Distribution is patchy, however, and sampling animals on the side walls is very difficult. This portion of the population remains unrepresented in the following analysis.

Such problems for *Ampithoe* are unimportant since it is rather sedentary. Animals build tubes and rarely leave them (Skutch, 1926), and few avoid the sampling net. Although amphipods are abundant in *Ulva* on side walls due to their sedentary habits, this portion of the population has very little effect on the tumbling cultures.

There was a tendency for isopod densities to decrease in winter, even in the 20°C raceway. If a two-way analysis of variance is performed on densities in December (comparing raceways and algal species), it is found that densities were significantly greater on *Gracilaria* than on *Neoagardhiella* ($F_{1,20} = 6.40$, $P < 0.025$), and greater in raceway number 2 (15°C) than in number 4 (20°C) ($F_{1,20} = 4.35$, $P = 0.05$). The cause of the difference between raceways is obscure and probably unrelated to heating regimes, since it was evident in October before heat differences between raceways came into effect.

Ampithoe densities showed a strong tendency to decrease over the period of study, but the reason for this is again unknown. In December, densities were significantly greater on *Gracilaria* ($F_{1,20} = 53.76$, $P < 0.001$), although no difference between algae was evident in October ($F_{1,20} = 3.15$, $P = 0.08$). No temperature effects were seen and densities in raceways numbers 2 and 4 were of similar magnitude ($F_{1,20} = 0.88$, $P > 0.75$).

Size distributions of *Idotea* (Fig.1), as well as the presence of brood females, reveal that reproduction is continuous throughout the year, although the percentage of very small animals present was lower in December. Size distributions were very similar on *Gracilaria* and *Neoagardhiella.*

Reproductive potential for *Idotea* is great since growth and development are fast, and brood sizes relatively large. The life cycle is similar to that described for other species of the same genus (Naylor, 1955 a and b). Reproduc-

TABLE I

Densities of *Idotea baltica* and *Ampithoe valida* (mean number per 100 g wet weight of algae ± 1 standard deviation; $N = 6$)

Algal substrate	*Idotea baltica*				*Ampithoe valida*			
	September	October	December	July	September	October	December	July
Raceway number 2 (15°C)								
Gracilaria	81.5 ± 28.2	100.6 ± 34.9	39.5 ± 20.3	135.7 ± 48.3	42.9 ± 34.7	108.6 ± 20.5	49.5 ± 22.4	6.7 ± 2.3
Neoagardhiella	—	30.4 ± 17.3	15.3 ± 3.8	73.3 ± 47.2	—	171.3 ± 15.0	0.5 ± 1.6	28.1 ± 26.1
Raceway number 4 (20°C)								
Gracilaria	—	20.5 ± 34.1	11.1 ± 3.8	61.2 ± 7.5	—	83.8 ± 43.6	47.9 ± 11.2	9.8 ± 3.2
Neoagardhiella	23.1 ± 8.7	25.3 ± 7.8	15.8 ± 5.7	—	304.0 ± 93.8	62.2 ± 24.7	9.2 ± 5.5	—

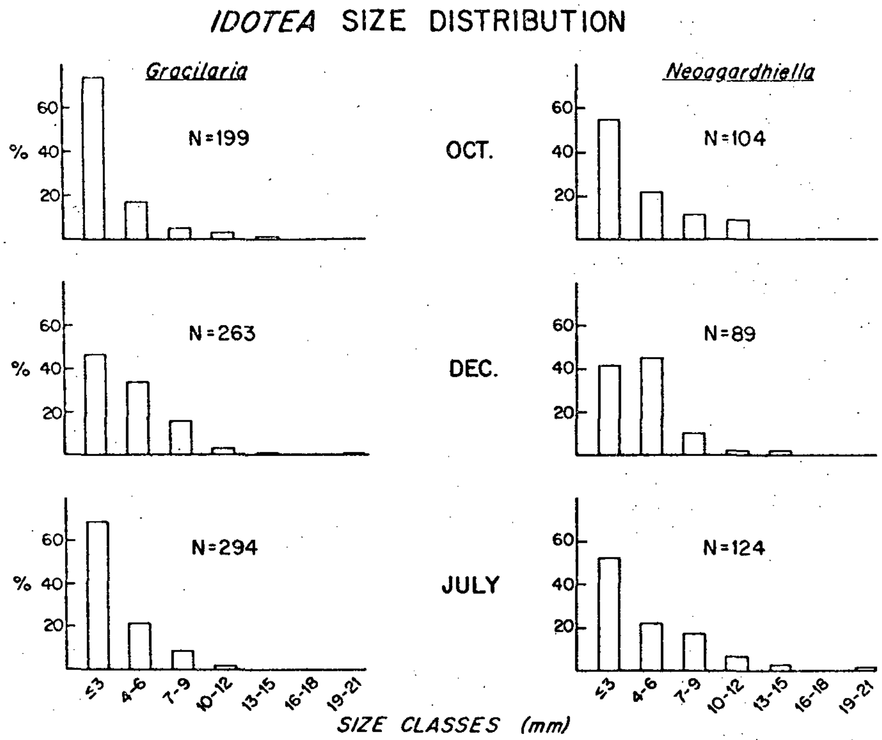

Fig.1. Size distribution for *Idotea.*

tion begins at a size of 7—9 mm. A maximum size of 23 mm for females and 30 mm for males has been observed. Eggs are incubated in a thoracic pouch and brood size increases rapidly with female size. A large female may produce more than 200 young. Development is direct and eggs are incubated for about 2 weeks, after which 2-mm juveniles are released. Females reproduce more than once but the actual number of broods per female is unknown. Growth is rapid, averaging 1 mm/week on *Gracilaria* and 0.33 mm/week on *Neoagardhiella.* At this rate, it takes 5—15 weeks to reach sexual maturity. Total life span is unknown but is probably less than 1 year, as seen by comparing observed maximum sizes with sizes at 1 year predicted from growth information.

Ampithoe life cycles are similar. Sample size distributions for September are shown in Fig.2. Juveniles dominate the population and distributions on *Gracilaria* and *Neoagardhiella* are very similar. Due to the scarcity of animals in December and July, seasonal patterns are difficult to see. However, it is clear that reproduction is continuous. A maximum size of 12 mm was observed for both males and females. Brood sizes are smaller and more variable than for *Idotea*, and development takes about 2.5 weeks. Growth is rapid, averaging about 1 mm/week on *Gracilaria*. Reproduction begins at 6 mm, and there may be several broods per female (Bousfield, 1973).

Grazing rates for similar sized isopods and amphipods are variable and not

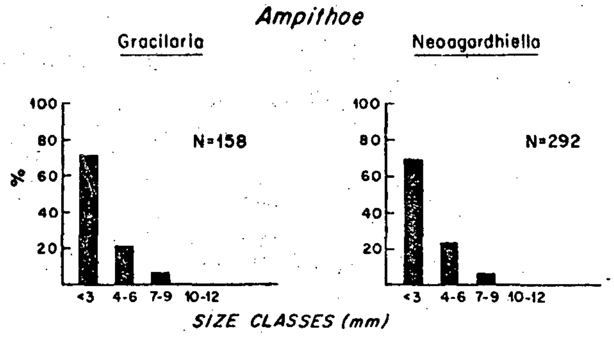

Fig.2. Size distributions for *Ampithoe* in September. Distributions at other times of year are similar.

significantly different on any alga except *Fucus*, which *Ampithoe* ignores (Table II). The rates for *Idotea* on the six species of algae are not significantly different from each other ($F_{5,16} = 2.24, P > 0.10$), but *Ampithoe* does graze *Hypnea* significantly faster than any of the other algae ($F_{5,16} = 6.31, P < 0.005$). The *Hypnea* used here was relatively unhealthy, however, and rates on robust *Hypnea* have not been determined.

TABLE II

Laboratory determined grazing rates (mean of four samples ± 1 standard deviation)

Algal species	Amount eaten by *Idotea* (g wet weight/isopod/week)	Amount eaten by *Ampithoe* (g wet weight/amphipod/week)
Gracilaria	0.03 ± 0.03	0.03 ± 0.02
Neoagardhiella	0.01 ± 0.03	0.02 ± 0.01
Hypnea	0.09 ± 0.03	0.09 ± 0.03
Chondrus	0.01 ± 0.02	0.03 ± 0.03
Fucus	0.05 ± 0.02	0.00 ± 0.04
Corallina	0.07 ± 0.07	0.03 ± 0.02

DISCUSSION

It is possible to use the type of information discussed above to estimate the macroscopic algal losses to grazers. Only very approximate answers can be obtained, since grazing rates are difficult to quantify and will be affected by a number of variables not considered here; for example, temperature, the physiological states of both the grazer and the alga, and reproductive status. Given the density of algae (data from De Boer et al., 1976), densities of grazers given in Table I can be converted to an areal basis. Since most of the animals will be smaller than the 7—12-mm individuals used to obtain grazing rates, and hence will eat less, the calculated density must be reduced. An approximate correction factor of 0.5 has been used to produce a corrected density. This figure was arrived at by calculating the total biomass of each sample (assuming biomass as a cubic function of length) and dividing this by the biomass of the 7—9-mm size class, to get an approximate density if all biomass were concentrated in 7—12-mm sized animals. When this density is multiplied by the grazing rates, given in Table II, a rough estimate of the amount of algal biomass consumed per week per square meter is obtained. The results of such calculations are shown in Table III for both *Idotea* and *Ampithoe*. It is evident that very little of the standing crop is being consumed by grazers. Isopods have slightly more of an effect on *Gracilaria*, and amphipods on *Neoagardhiella*

This degree of grazing could be significant if it were concentrated on the growing tips of the plants. Observations of grazing damage does not support this hypothesis, however, since damage is generalized throughout the plant.

What impact does this amount of grazing have on productivity? Algal dry weight is approximately 12% of wet weight (DeBoer et al., 1976); in Table IV the amounts of algae eaten by *Idotea* and *Ampithoe* have been converted to a dry weight per square meter per day basis and compared with observed productivity values (data from DeBoer et al., 1976). These figures show that isopod grazing generally causes only a very small reduction in productivity of *Neoagardhiella*, but that it may be significant, especially on *Gracilaria*, during times of low algal productivity. *Ampithoe* may have a significant impact on *Neoagardhiella* and *Gracilaria* during times when amphipods are abundant, but such densities are uncommon.

These calculations have several implications. First, moderate grazer densities in actively growing summer cultures pose very little problem to the aquaculturist. A potential problem may arise if crustacean densities stay high when cultures are growing slowly, as in winter at temperate latitudes. Secondly, grazers may have different impacts on various algal species in culture. The easiest way to avoid the grazer problem is to use a grazer resistant algal species like *Neoagardhiella*.

Control measures are difficult for small, highly mobile animals. Hand picking of algae is tedious, inefficient and time consuming. Specific arthropod poisons, such as Sevin, are a possibility but are expensive and should be avoided in a polyculture system attempting to produce a clean effluent. Fish predators could possibly be included in the system, although large *Idotea* are not favored by fish. *Ampithoe*, although readily eaten when found, is tube-dwelling and generally unavailable. Control measures presently employed consist of the removal of large isopods encountered during algal sorting and periodic drainage and cleaning of raceway walls. These appear to be keeping grazer populations within acceptable limits.

TABLE III

Impact of *Idotea* and *Ampithoe* grazing on algal standing crops

Crustacean and alga	Month sampled	Density of seaweed (g wet weight/m²)*	Corrected density of crustacean (number/m²)	Grazing rate (g wet weight eaten/grazed/week)	Amount of algae eaten (g wet weight/m²/week)	Standing crop eaten (%)
Idotea						
Neoagardhiella	September	3 100	358	0.01	3.6	0.1
	October	2 600	395		4.0	0.2
	December	3 100**	237		2.4	0.1
	July	3 100**	1 136		11.4	0.4
Gracilaria	September	2 600	1 060	0.03	3.18	1.2
	October	1 700	855		25.7	1.5
	December	2 800**	553		16.6	0.6
	July	2 800**	1 900		57.0	2.0
Ampithoe						
Neoagardhiella	September	3 100	4 712	0.02	94.2	3.0
	October	2 600	2 227		44.5	1.7
	December	3 100**	14		0.3	0
	July	3 100**	436		8.7	0.3
Gracilaria	September	2 600	558	0.03	16.7	0.6
	October	1 700	923		27.7	1.6
	December	2 800**	693		20.8	0.7
	July	2 800**	94		2.8	0.1

*Data from DeBoer et al. (1976).
**Biomass estimated.

TABLE IV

Impact of *Idotea* and *Ampithoe* grazing on algal productivity

Alga	Month sampled	*Idotea*			*Ampithoe*		
		Observed productivity (g dry weight/ m^2/day)*	Amount of algae eaten (g dry weight/ m^2/day)	Percentage of total productivity eaten	Observed productivity (g dry weight/ m^2/day)*	Amount of algae eaten (g dry weight/ m^2/day)	Percentage of total productivity eaten
Neoagardhiella	September	14.2	0.1	0.7	14.2	1.6	10.1
	October	5.9	0.1	1.7	5.9	0.8	11.9
	December	5.7**	0.04	0.7	5.7**	0.01	0.2
	July	19.4**	0.2	1.0	19.4**	0.2	1.0
Gracilaria	September	20.9	0.5	2.3	20.9	0.3	1.4
	October	0.8	0.4	33.3	0.8	0.5	38.5
	December	21.5**	0.3	1.4	21.5**	0.4	1.8
	July	6.1**	1.0	14.1	6.1**	0.04	0.7

*Data from DeBoer et al. (1976).
**Estimated.

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