Temporal and Spatial Patterns of the Alga *Cladophora conchopheria* on the Shell of the Intertidal Gastropod *Turbo coronatus coreensis*

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Abstract Shells of the intertidal gastropod *Turbo coronatus coreensis* at Tanabe Bay, central Japan, were fouled predominantly by the green alga *Cladophora conchopheria*, the latter being more abundant on these snails higher up the shoreline. The abundance of *C. conchopheria* on the shells of large snails (shell length > 10 mm) showed no significant seasonal changes, although the alga was recorded on small snails (shell length < 10 mm) from June to October and December but not in February or April. *C. conchopheria* was less abundant on *T. coronatus coreensis* shells inhabited by hermit crabs than on the shells of living snails. Increments of *C. conchopheria* coverage were not correlated with shell growth of individual snails. Under laboratory conditions, the coverage of *C. conchopheria* on snail shells decreased, and the rate of such not differing among early dead snails, later dead snails and shells inhabited by hermit crabs. The survival rates of *T. coronatus coreensis* in the laboratory was similar between snails fouled heavily or not at all by *C. conchopheria*.

Key words: *Cladophora, Turbo*, epibiont, plant-animal relationship, intertidal rocky shore

Introduction

The turbinid gastropod *Turbo coronatus coreensis* (Recluz) is an intertidal rocky shore inhabitant, its distribution, food, growth and reproduction having recently been described by Yukihira *et al.* (1995a, 1995b, 1995c). The shells of *T. coronatus coreensis* are commonly inhabited by the alga *Cladophora conchopheria* Sakai (Cladophorales, Chlorophyceae). The life history of the latter has been reported by Wang and Sakai (1986), and perforation of the rhizoid into the snail shell described by Matsuyama and Aruga (1993) and Matsuyama *et al.* (1999). In addition, the distribution of *C. conchopheria* has been studied qualitatively by Matsuyama *et al.* (1999), who reported *C. conchopheria* as occurring on all living snails of *T. coronatus coreensis* found in the intertidal zone. Matsuyama *et al.* (1999) also observed *C. conchopheria* on both living and dead snails for 6 months under rearing conditions, but these observations also lacked quantitative data.

This paper describes the natural distribution of *C. conchopheria* quantitatively in terms of tidal levels, snail size and season, and examines temporal changes in algal coverage of living and dead snails, and shells inhabited by hermit crabs in the laboratory.

Materials and Methods

Field survey

Periodic sampling of *Turbo coronatus coreensis* and hermit crabs (*Pagurus filholi* and *P. dubius*) inhabiting shells of *T. coronatus coreensis* was carried out on an intertidal rocky shore of two sites (Sts. A & B) (Fig. 1) in Tanabe Bay, central Japan (33° 41'N, 135° 22'E) from June 1996 to April 1997. Station A was a wave-exposed rocky platform, whereas St. B was more protected. Samples were collected during daytime low spring tides at two monthly intervals, about 200 snails being randomly collected from low, mid and high tide levels of St. A, and from low and high tide levels of St. B. At the same time, about 100 hermit crabs inhabiting shells of *T. coronatus coreensis* were also collected throughout the intertidal areas. The shell length of each snail collected was

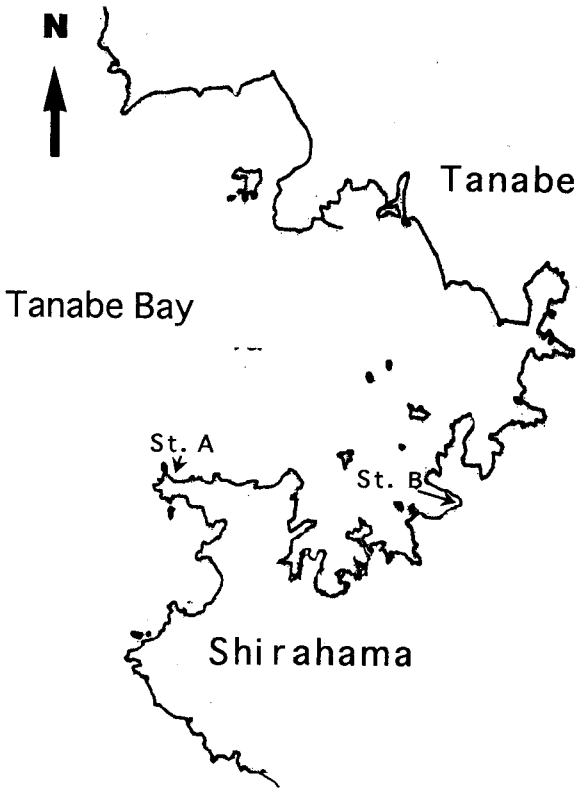

Fig. 1. Location of sampling stations (Sts. A and B) in Tanabe Bay, central Japan.

measured to the nearest 0.1 mm (being the greatest distance between the apex and far rim of the aperture). In addition, coverage (%) of three common epibionts (*Cladophora conchopheria*, crustose coralline algae and tubiculous polychaetes) was visually evaluated for each and recorded in the appropriate category, viz 0, 0–10, 10–50, 50–100%.

To record any temporal changes in *C. conchopheria* coverage on individual snail shells, marking and recapture of snails were conducted monthly from May 1997 to May 1998 in the high tide area of St. A. In each month, about 40 snails of 14–22 mm shell length with 130–280 mm^2 coverage of *C. conchopheria*, were collected for individual marking. For each snail collected, shell length and coverage of *C. conchopheria* were measured, the latter (area in mm^2) being obtained from a tracing of the outline of *C. conchopheria* on a transparent plastic sheet over the snail. The snails were then individually marked by painting different colors on the shell and released to their original sites. During each sampling session, snails that had been marked during previous sampling were also sought, over an approximately 6 hour period. Shell length and coverage of *C. conchopheria* were also recorded for recaptured snails.

Laboratory observations

Temporal changes in *Cladophora conchopheria* coverage on individual shells of *Turbo coronatus coreensis* were described by rearing the snails and shell-inhabiting hermit crabs (*Pagurus filholi*) in the laboratory. Snails and crab-inhabited shells (shell length: 15–20 mm) that were covered heavily by *C. conchopheria* (coverage: 110–220 mm^2) were used for the observations. Shell length and extent of *C. conchopheria* coverage on individual shells were measured and the shell

individually color marked. The marked snails and hermit crabs were reared in test tanks for about 3 months, air and sea water temperatures being measured daily. Every 30 days, snail and hermit crab mortality, and coverage of *C. conchopheria* were recorded. The observations included 2 series (Series I and II).

Series I: Rearing period was from May to August, 1997. The test tank (0.6 m x 0.4 m x 0.1 m high) was left in full sunlight, being kept full of running sea water (shells not exposed to air). Twenty-six snails and 13 hermit crabs were used.

Series II: Rearing period from September to December 1997. The test tank (0.5 m x 0.5 m x 0.4 m high) was kept indoors (70-400 lux during daytime) and provided with a tidal simulater that allowed the samples to alternate between exposure to air and submergence in artificial sea water (32 psu). The sea water was circulated by the tidal simulater, with an air stream provided at the floor of the tank. Forty snails with *C. conchopheria*, 40 snails without *C. conchopheria*, and 35 hermit crabs were used.

Results

Zonation pattern of epibionts

Three common epibionts (*Cladophora conchopheria*, crustose coralline algae and tubiculous polychaetes) on the shells of *Turbo coronatus coreensis* greater than 10 mm in shell length, showed zonation patterns at both stations (Fig. 2). *C. conchopheria* was more abundant on snails at high tide level, whereas crustose coralline algae were more abundant at low tide level. Polychaetes were more abundant at low tide level at St. B, but there was no obvious zonation pattern in the abundance of polychaetes at St. A.

Seasonal pattern of epibionts at two stations

The frequency of snails with different coverages of the three dominant epibionts (*C. conchopheria*, crustose coralline algae and tubiculous polychaetes) showed no significant seasonal changes, except that *C. conchopheria* on smaller snails (shell length < 10 mm) occurred from June to October and December but not in February or April (Fig. 3).

The coverage of *C. conchopheria* was similar on large snails (shell length > 10 mm) at both stations, but was greater on small snails at St. A than at St. B. Crustose coralline algae were more abundant on both large and small snails at St. A. In contrast, tubiculous polychaetes were more

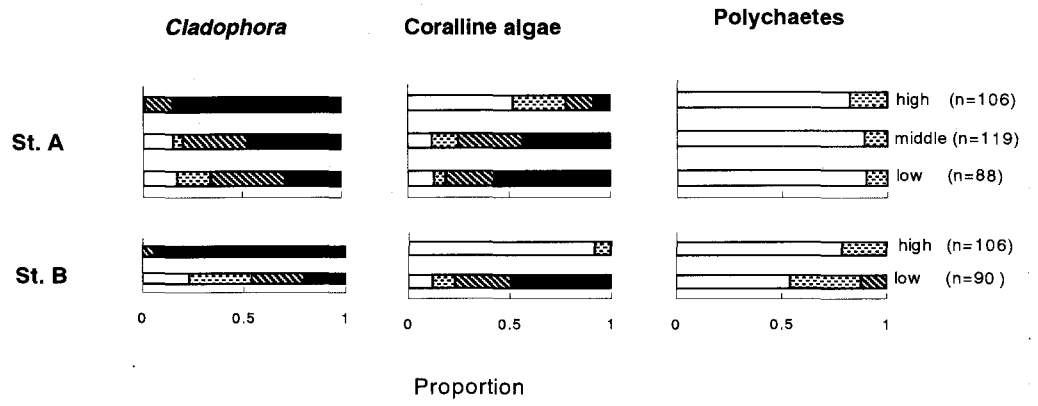

Fig. 2. Distributions of three common epibionts on shells of snails larger than 10 mm in shell length in relation to intertidal height at Sts. A and B, recorded in October. Coverage of epibionts ranked as > 50 % (solid column), > 10 < 50 % (hatched), > 0 < 10% (stippled) and 0% (open).

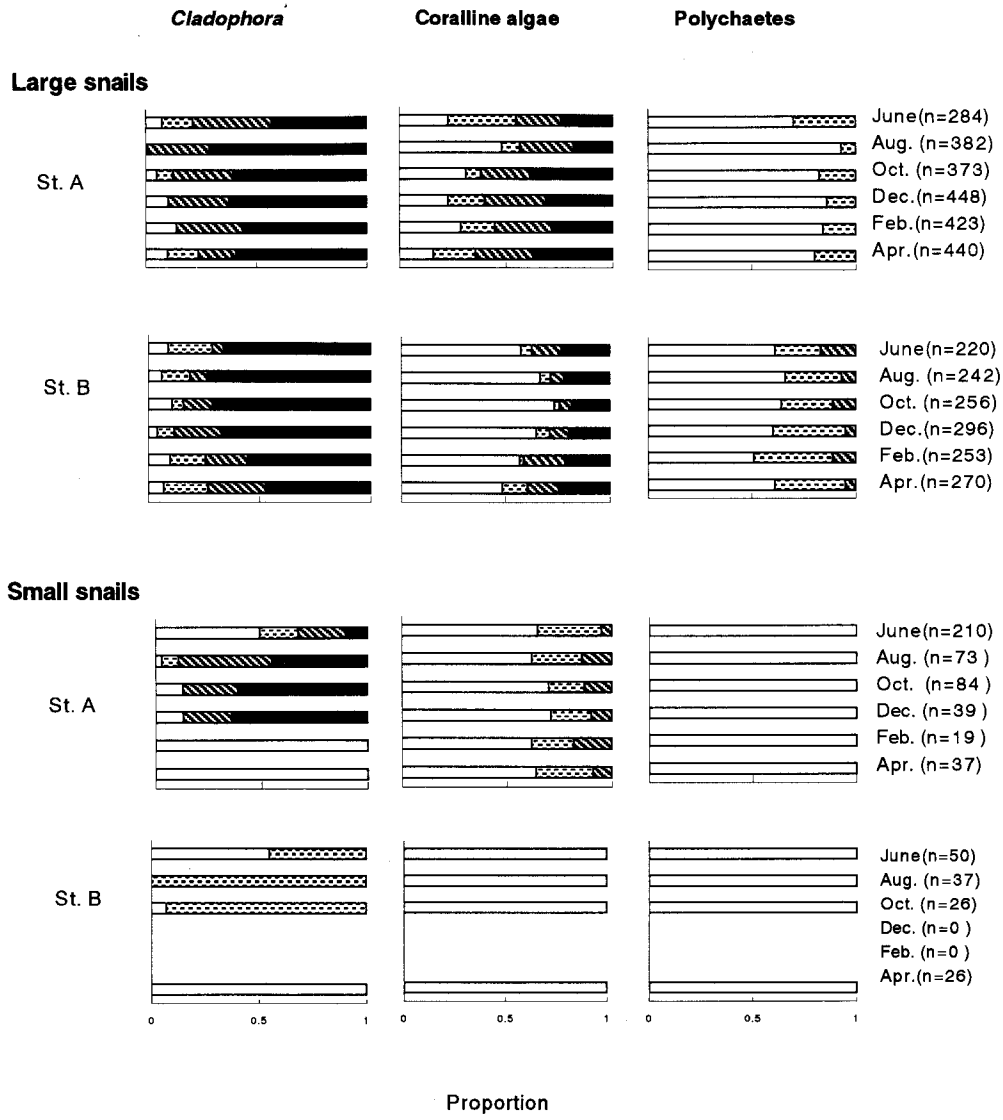

Fig. 3. Distributions of three common epibionts on small (shell length $\leq$ 10 mm) and large (> 10 mm) snails in each survey month at Sts. A and B. Coverage of epibionts ranked as in Fig. 2.

abundant on large snails at St. B. No tubiculous polychaetes were found on small snails at either station.

Distribution of epibionts on hermit crab shells

Hermit crab species inhabiting *T. coronatus coreensis* shells included *Pagurus filholi* and *P. dubius*. The three common epibionts (*C. conchopheria*, crustose coralline algae and tubiculous polychaetes) on hermit crab shells were less abundant than those on snail shells (Figs. 3 and 4), there being no obvious seasonal changes in abundance of these epibionts (Fig. 4).

Temporal changes in algal coverage in the field

Monthly changes in shell length and *C. conchopheria* coverage on marked snails revealed some

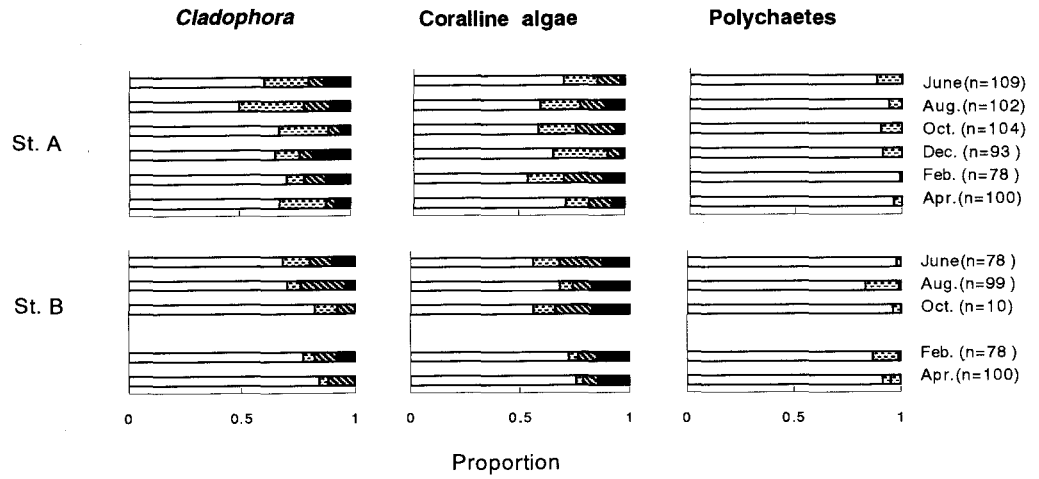

Fig. 4. Distributions of three common epibionts on hermit crab shells in each survey month at Sts. A and B. Coverage of epibionts ranked as in Fig. 2.

seasonal differences (Table 1). Incremental changes in shell length occurred from March to November, but not from November to March. Increments of *C. conchopheria* coverage per month showed higher mean values from May to September, but were not significantly correlated with increasing shell length in any single month.

Temporal changes in algal coverage in the laboratory

Series I (Table 2): Coverage of *C. conchopheria* decreased on all the snail shells, including those of snails that died in June and July ($n=13$), those of snails that died in July and August ($n=11$) and those inhabited by hermit crabs ($n=13$). Among the three groups, initial shell lengths and initial coverage of *C. conchopheria* were not significantly different. The survival rate of *C. conchopheria* did not differ significantly among the three groups in any of the three periods (May-June, May-July and May-August). Sea water temperatures during the rearing period ranged from 22.1 to 27.5°C.

Series II (Table 3): Coverage of *C. conchopheria* decreased on all the snail shells, including those of snails that died in September and October ($n=4$), those of snails that died in October and November ($n=14$), those of snails that died in November and December ($n=20$), and those inhabited by hermit crabs ($n=35$). Among the four groups, initial shell lengths and initial coverage of *C. conchopheria* were not significantly different. Survival rate of *C. conchopheria* did not differ significantly in any of the three periods (September-October, September-November and September-December). The surviving periods of the snails did not differ significantly between those with *C. conchopheria*-fouled (mean$\pm$SD$=53.7\pm18.8$ days, range$=15$-85 days) and unfouled shells (mean$\pm$SD$=54.0\pm18.8$ days, range$=15$-85 days) (Mann-Whitney's U-test, $p=0.98$). Air and sea water temperatures during the rearing period ranged from 16.2 to 24.5°C, and from 15 to 23.7°C, respectively.

Discussion

Although *Cladophora conchopheria* has been reported as living on the shells of living *Turbo coronatus coreensis*, the rhizoid perforating the periostracum of the shell (Matsuyama and Aruga, 1993), the occurrence of *C. conchopheria* in terms of *T. coronatus coreensis* shell size and season

Table 1. Monthly increases in shell length and increments of *C. conchopheria* coverage of marked snails from May 1997 to May 1998; relationship between shell growth and coverage increments given by Spearman's rank correlation.

Period	Number of marked snails	Shell length (mm)				Coverage of *C. conchopheria* (mm²)				Spearman's rank correlation
		Initial		Increase per 30 days		Initial		Increment per 30 days		
		Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	
May-June 1997	9	18.3±1.8	14.0−20.7	0.1±0.1	0−0.2	186.5±28.5	150−210	12.7±16.9	−1.4−57.5	$p=0.22$
June-Jul.	7	16.8±1.7	14.2−19.0	0.1±0.1	0−0.2	159.0±20.6	154−208	20.7±17.7	−13.0−43.0	$p=0.10$
Jul.-Aug.	5	18.6±2.4	14.5−21.5	0.1±0.1	0−0.3	183.1±26.5	131−203	19.9±12.9	2.8−43.2	$p=0.65$
Aug.-Sep.	5	17.2±1.7	14.5−21.5	0.2±0.1	0.1−0.2	150.3±38.4	160−259	17.0± 3.6	13.0−23.0	$p=0.23$
Sep.-Oct.	7	17.4±1.5	14.2−20.4	0.1±0.1	0−0.2	190.3±40.7	140−274	3.5± 5.3	−3.1−14.6	$p=0.60$
Oct.-Nov.	8	17.2±2.3	14.3−20.4	0±0.1	0−0.2	180.3±38.8	141−280	3.6±16.8	−16.0−35.0	$p=0.94$
Nov.-Dec.	7	17.5±1.6	15.4−20.4	0	0	188.8±36.9	145−270	5.4± 4.1	0−11.0	$p=0.21$
Dec.-Jan.	10	16.7±0.7	15.9−17.9	0	0	174.3±22.1	145−207	6.0±12.4	−19.7−22.6	$p=0.16$
Jan.-Feb. 1998	11	17.2±0.9	15.7−19.0	0	0	168.8±19.7	147−219	−0.6±17.8	−30.9−27.3	$p=0.11$
Feb.-Mar.	14	17.3±0.9	15.9−19.0	0	0	170.1±25.4	137−216	−2.0±16.7	−22.2−22.2	$p=0.08$
Mar.-Apr.	12	17.2±1.2	14.8−19.1	0.1±0.1	0−0.2	168.8±15.9	144−200	3.2±12.7	−18.9−22.5	$p=0.51$
Apr.-May.	7	17.8±0.8	15.1−19.1	0.1±0.1	0−0.2	172.3±21.9	140−200	−7.7±20.7	−30.0−31.0	$p=0.12$

Table 2. Results of laboratory observations, Series I. Initial shell length, initial coverage of *C. conchopheria* and survival rates of *C. conchopheria* shown for three groups of snail shells (a, b & c), with comparisons among the groups by ANOVA.
a: snails that died during June-July, b: snails that died during July-August, c: hermit crabs.

	Initial shell length (mm)		Initial coverage of *C. conchopheria* (mm^2)		Survival rate of *C. conchopheria* (%)					
					May-June		May-July		May-August	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
a ($n=13$)	17.1±1.3	14.7−19.0	157±15	132−176	54.6±16.9	21.2−78.1	15.9±17.3	0−49.6	6.1±11.2	0−30.1
b ($n=11$)	17.7±1.1	15.7−19.5	158±12	137−172	53.8± 9.4	34.8−63.1	25.7±16.6	0−43.9	12.3±11.1	0−33.6
c ($n=13$)	16.7±0.8	15.9−18.3	151±16	129−169	50.9±17.0	23.7−85.3	19.2±14.7	0−40.0	7.2± 8.9	0−24.0
ANOVA	$p=0.41$		$p=0.56$		$p=0.17$		$p=0.20$		$p=0.42$	

Table 3. Results of laboratory observations, Series II. Initial shell length, initial coverage of *C. conchopheria* and survival rates of *C. conchopheria* shown for four groups of snail shells (a, b, c & d), with comparisons among the groups by ANOVA.
a: snails that died during September-October, b: snails that died during October-November, c: snails that died during November-December, d: hermit crabs.

	Initial shell length (mm)		Initial coverage of *C. conchopheria* (mm^2)		Survival rate of *C. conchopheria* (%)					
					September-October		September-November		September-December	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
a ($n=4$)	17.1±0.7	16.1−18.0	189±26	163−227	96.0± 2.9	92.0−100	91.2± 5.1	84.0−97.0	88.7± 5.7	79.8−95.0
b ($n=14$)	16.7±1.0	15.9−18.7	177±24	145−210	88.7± 8.2	71.3−100	65.4±10.4	42.9−77.6	56.7±12.6	37.0−73.7
c ($n=20$)	15.8±0.8	15.9−17.2	154±22	127−189	81.4± 9.2	65.3− 98.3	71.1±11.0	52.9−85.6	56.1±13.7	37.0−73.4
d ($n=35$)	17.8±1.0	16.0−19.3	154±18	124−186	74.0±13.3	51.9−95.2	66.7± 9.6	45.0−76.1	52.8±11.6	29.1−69.7
ANOVA	$p=0.40$		$p=0.61$		$p=0.07$		$p=0.29$		$p=0.06$	

has not been described. Although *C. conchopheria* did not occur on small snails (< 10 mm in shell length) in February or April, from June to December it was found on both small and large snails (> 10 mm in shell length) (Fig. 3). This finding suggests that settlement of *C. conchopher*ia on small snails occurs in warm season but not in cold season.

The data also clarified seasonal changes in *C. conchopheria*, incremental increases in coverage of the shells occurring in the warm months (May–September), concurrent with shell growth. However, no relationship was found between increments of *C. conchopheria* coverage and increments of shell length of individual snails. Accordingly, increasing *C. conchopheria* coverage on the snail shell is not directly related to shell growth.

The laboratory observations indicated that the decrease in *C. conchopheria* was similar among early dead snails, later dead snails and hermit crabs. Similarly, Matsuyama *et al.* (1999) reported that *C. conchopheria* continued to live for 6 months under rearing conditions not only on the shells of living snails but also on the shells of dead snails. These findings suggest that the occurrence of *C. conchopheria* depends upon the availability of shells of *T. coronatus coreensis*, irrespective of whether or not the snails are alive.

Not all of the *T. coronatus coreensis* shells bore *C. conchopheria*, including individuals at both St. A and St. B (Fig. 3). Other locations were also found, where *C. conchopheria* was absent from the shells of abundant *T. coronatus coreensis*. Matsuyama *et al.* (1999) also reported *C. conchopheria* as being absent from *T. coronatus coreensis* shells in some parts of Japan. Moreover, the present laboratory observations showed that the survival pattern between snails with and without *C. conchopheria* did not differ, indicating that *C. conchopheria* is not a necessary factor for *T. coronatus coreensis* growth and survival.

Epibionts have the potential to substantially increase drag on their hosts , with a correponding reduction in shell growth (Wahl, 1996). Different epibiotic communities increase drag to different degrees, algae being expected to have a lesser effect than rigid and rougher epibionts (Wahl, 1996). Macroepibionts, such as crustose coralline algae, polychaetes, oysters and barnacles, if attached to the shell of *T. coronatus coreensis*, may be much more detrimental than *C. conchopheria* in terms of increased drag. The zonation pattern of common epibionts on the snail shells indicated that crustose coralline algae on the snail shell was less abundant at higher levels (where snails were heavily fouled by *C. conchopheria*) than at lower levels (where *C. conchopheria* was less common). The presence of *C. conchopheria* on snail shells may restrict colonization by other epibionts, that are potentially more detrimental to the snails. Furthermore, fouling by *C. conchopheria* on the snail shell may reduce predation pressure on the snail, as has been demonstrated for epibionts on mussels (Laudien and Wahl, 1999). However, no predators of *T. coronatus coreensis* were apparent during the present study. Growth and survival of *T. coronatus coreensis* need to be compared among those with *C. conchopheria*, those with other epibionts and those lacking macroepibionts.

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