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Seasonality pattern of biomass accumulation in a drifting *Furcellaria lumbricalis* community in the waters of the West Estonian Archipelago, Baltic Sea

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Abstract

A free-floating, loose form of *Furcellaria lumbricalis* (Huds.) Lamour is rare in the Baltic Sea area. Kassari Bay, situated in the West Estonian Archipelago Sea area contains the largest known community of this kind. Here the free-floating mixed *Furcellaria lumbricalis-Coccotylus truncatus* (Paela) M. J. Wynne et J. N. Heine community inhabits sandy bottom, covering up to 120 km^2. Commercial exploitation of the community started in 1966 and has led to regular monitoring surveys for the quantification of the commercial resource. The aim of the present study was to determine the potential growth rates of the two community-forming species as well as to test different environmental factors affecting their growth. Results showed that the highest growth rates were measured in shallower depths (4 m) for both species. The seasonal growth pattern was also very similar for both species, showing the highest growth rates during the beginning of summer. Incubation of both species in another sea area with apparently similar basic environmental conditions (the northern part of the Gulf of Riga, Kõiguste Bay) resulted in significantly lower growth rates during the whole incubation period.

Introduction

In the Baltic Sea, at least two ecologically distinct forms of the red algal species *Furcellaria lumbricalis* are found. The attached form of this species is very common on the hard bottoms of the lower part of the phytobenthic zone of the Baltic Sea (Nielsen et al., 1995). Loose-lying *F. lumbricalis* is, on the contrary, very unique. Only three localities have been described as having large communities of this form in the Baltic Sea. One of these (Puck Bay) has already lost the population due to eutrophication and pollution problems (Martin et al., 1996; Kruk-Dowgiallo & Ciszewski, 1994). Austin (1959) described a similar agglomeration of loose *Furcellaria* in the central Kattegat area. The sea area of the West Estonian Archipelago hosts the largest known community of this kind, where a mixed community of loose-lying *Furcellaria lumbricalis* and *Coccotylus truncatus* covers up to 120 km^2 of sea bottom with more than 140 000 tons of wet biomass in Kassari Bay. The community was described for the first time by Kireeva (1961, 1964). The mean biomass of this community varied between 500 and 1000 g of wet weight m^{-2} and occasionally reached a maximum of 2.1 kg wet weight m^{-2} (Trei, 1975, 1976; Martin et al., 1996). The community was found on sandy substrates at depths between 5 and 9 m, where it formed a 0.15 to 0.3 m thick carpet on the seafloor. The proportion of the two dominant species differed slightly depending on locality but usually 60–70% of the biomass was *F. lumbricalis,* while *C. truncatus* accounted for 30–35%, on average. The proportion of other species was usually low, less than 5% (Trei, 1975, 1976; Martin et al., 1996).

The loose red algal community has been used as raw material for agar production since 1966 and annual yields have been estimated to be near 1000 t wet weight. The status of the community has been

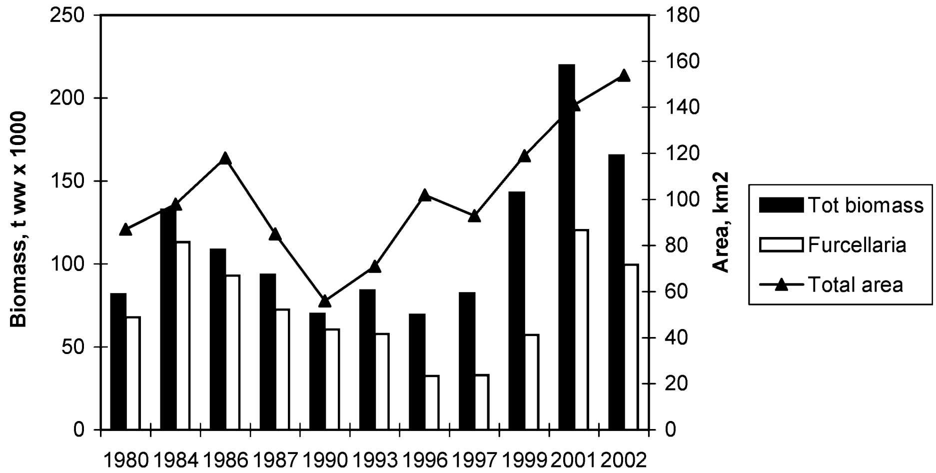

Figure 1. Dynamics of different characteristics of loose red algae community in Kassari Bay according to the results of commercial resource monitoring studies. Parameters shown are total biomass of the community, biomass of the species *Furcellaria lumbricalis* in the community and total area of the community.

monitored regularly and a decline in the loose *Furcellaria lumbricalis – Coccotylus truncatus* community was recorded in the Kassari Bay of the Väinameri area during 1996–97. Since then, both the total area of the community and total biomass have been steadily increasing (Figure 1). The decline in the loose red algal community was due to the extensive overgrowing of filamentous brown algae, which fixed the algal carpet and caused oxygen deficiency in the near-bottom layer (Martin & Kukk, 1997a,b, 1998, 1999).

The aim of this study was (1) to experimentally compare the growth rates of loose-lying form of *F. lumbricalis* with the accompanying species *C. truncatus,* (2) to compare the growth rates of these species in different ecological conditions (two different experimental sites, three different incubation depths) and (3) to follow seasonal changes in production.

Material and methods

Study area

Väinameri (inner sea of West-Estonian Archipelago) is formed by a system of straits connecting the waters of the Gulf of Riga to the Baltic Proper and the entrance to the Gulf of Finland (Figure 2). The total surface area of the system is 2243 km^2 (Suursaar et al., 1998). The mean depth of the whole system is less than 10 m. Kassari Bay, in the western part of the area, is connected to the Baltic Proper through the narrow Soela Strait and separated from the eastern part by a grid of islets. Hydrologically, this area behaves differently from the other parts of the Väinameri as it is more influenced by the saline waters of the Baltic Proper (Suursaar et al., 1998). The impact of the riverine inflow on the system is very small; the amount of fresh water entering the system reaches only 1 km^3 yr (Astok et al., 1999). The sea-floor is mainly of soft sediments, including fine mud and sand fractions. Harder substrata such as gravel or boulders can be found only in the most shallow and wave exposed areas. Due to the shallowness and the substrate being dominated by fine sediment fractions on the bottom, the water transparency is often very poor. After storms the Secchi depth may decrease to 0.5 m, while in the case of prolonged calm weather conditions the photic zone reaches the bottom in about 90% of this area.

The Gulf of Riga has a surface area of 16 330 km^2 with a water volume of 424 km^3, which makes up 3.9% of the total area of the Baltic Sea and 2.1% of its volume (Berzinsh, 1995). The volume of the annual freshwater input to the system is estimated to about 31 km^3 (Yurkovskis et al., 1993). An important feature of the basin is the lack of permanent stratification which enables intensive water exchange processes between the deep and surface layers. The nutrient regime of the Gulf of Riga basin differs greatly from that of the other parts of the Baltic, having several time higher nutrient concentrations compared to adjacent basins (Astok et al., 1999, Yurkovskis et al., 1993).

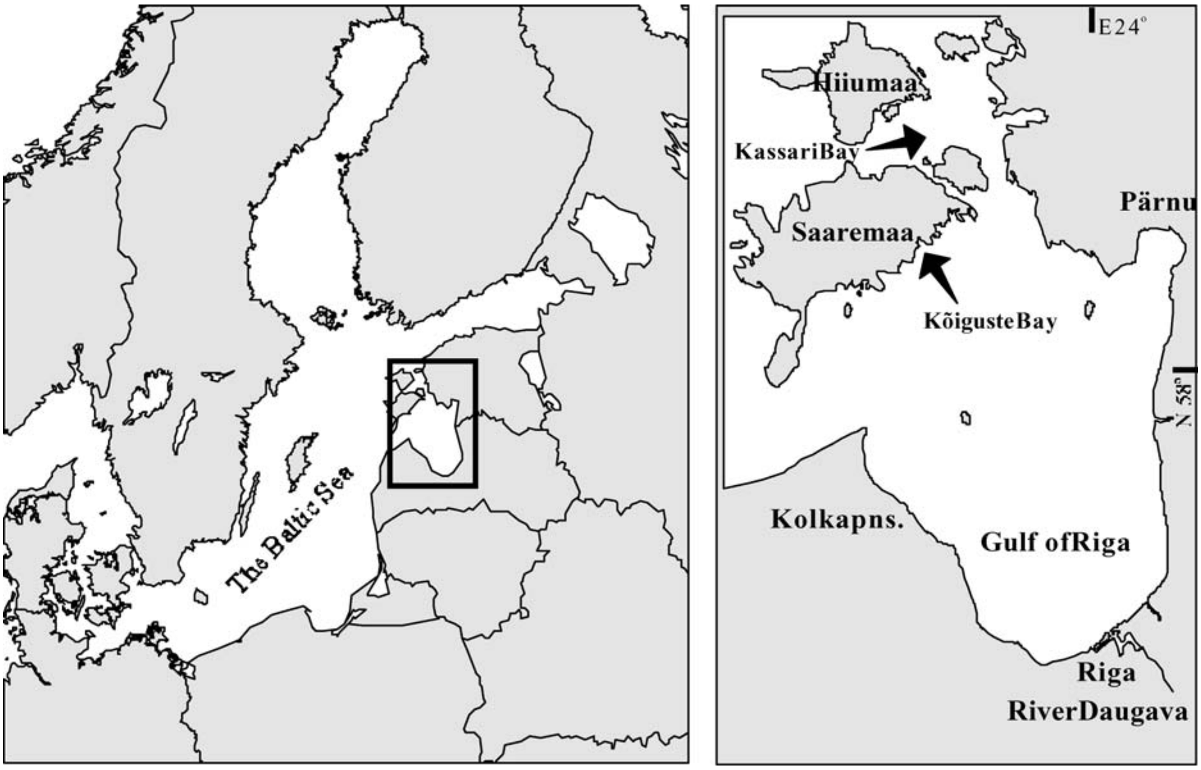

Figure 2. Study area. Location of two experimental sites are shown by arrows.

Field experiments

Field experiments for estimating the growth rate of loose-lying *F. lumbricalis* and the accompanying species *C. truncatus* were carried out in the period 20 April 2002–21 October 2002 in Kassari Bay (West-Estonian Archipelago Sea) and Kõiguste Bay (northern part of the Gulf of Riga) (Figure 2). *In situ* incubations of algal material were performed in special nylon mesh bags (with plastic frame inside; diameter 5.5 cm, height 20 cm) of 1 mm mesh size. Mesh bags with freshly collected algae (about 2–5 g wet weight per bag) which were free of macroepiphytes were incubated at depths of 4, 6 and 8 meters (Figure 3). Once a month 5 replicates from each depth of each species were collected for determination of growth rate. The changes in algal biomasses are presented as a percentage of the initial value (mean ± SE). Relative daily growth rates (DGR) were calculated for six experimental periods: 20 April–22 May (I); 22 May–19 June (II); 19 June–20 July (III); 20 July–22 August (IV); 22 August–16 September (V) and 16 September–21 October (VI), using the equation:

$$DRG(\%) = [(lnW_1 - \ln W_o)/n - 1]100$$

where n is the number of days of the incubation period, W_1 and W_o are the final and the initial weight of the algal material. Water temperature at incubation depths was measured as single measurements at the moment of sampling. Water transparency was estimated by Secchi disc.

Results

Environmental parameters

Water transparency was low during the entire observation period, generally not exceeding 2 m (Table 1). The water temperature at incubation depths varied between 0.5 and 22.8°C, measured between April and October 2002 (Figure 4). There were no major differences in the measured parameters for the two experimental sites.

Growth rates

The highest growth rates during the investigation period, in both experimental localities, for the loose-lying

Table 1. Water transparency values (as Secchi depth) in two experimental sites

	Water transparency (m)	
Date of measurement	Kassari	Kõiguste
20 April	2	1.5
23 May	1.9	2.1
20 June	2.3	2.3
21 July	1.8	1.8
23 Aug.	1.8	1.7
17 Sept.	3.5	3.3
22 Oct.	1	0.7

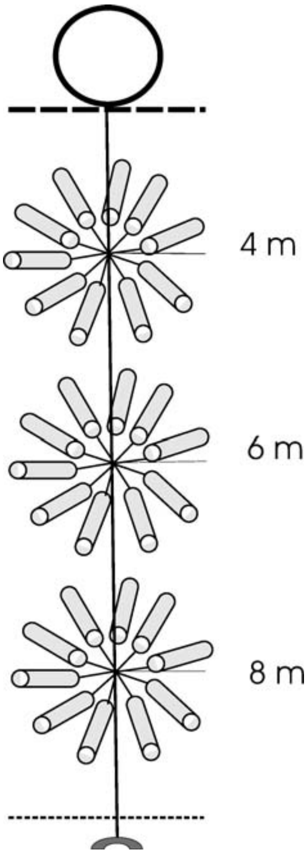

Figure 3. Illustration of experimental setup.

form of *Furcellaria lumbricalis* as well for *Coccotylus truncatus* were obtained at the incubation depth of 4 m, resulting in an increase in initial biomasses (on dry weight bases) of 268% and 238% respectively at the end of the incubation period. At the depths of 6 and 8 m the biomass increment was significantly lower (Figures 5 and 6).

A significant seasonal variation in the relative daily growth rates (DRG) at all incubation depths was found (Table 2 and 3). At 4 m depth no great differences in DRG values (varied between 1.1–1.6%) were obtained for *Furcellaria* during the first 4 months of incubation, while at the depths of 6 and 8 m, DRG values (up to 2.5%) increased from the beginning of the investigation period until the end of July, followed by a rapid decrease in growth rates in August-September. The most pronounced increase in DRG of *Coccotylus* was recorded in June–July at all incubation depths (1.7–1.9%).

In July–August a large increase in biomass was obtained only at 4 m depth for both species. The lowest DRG values (in some cases even decrease of biomass) for all species were obtained in August-September resulting in a large decline of the biomass.

A comparison of biomass increase at the two separate experimental locations showed significantly lower growth of biomass for both species in Kõiguste Bay (Figures 5 and 6). The general pattern of biomass increase was similar at the different locations. *Coccotylus truncatus* showed some decrease of biomass in Kõiguste Bay by the end of the experiment due to prevailing decomposition processses (Figures 5 and 6). In our study, both incubation period and incubation depth significantly affected the growth rates of looselying form of *Furcellaria* as well *Coccotylus truncatus* (2-way-ANOVA; $p < 0.001$). At a depth of 4 m the gain of biomass, in both the species studied, was significantly higher compared to 6 m and 8 m, indicating the more favourable growing conditions at shallower depths.

Discussion

In natural conditions, most of the loose *Furcellaria-Coccotylus* community is found at depths of 6–9 m in Kassari Bay (Martin et al., 1996). In our experiment the highest growth was observed much shallower than that. This contradiction can be explained by several other limiting environmental factors such as wave action, biological interactions, keeping most of the loose algae community in deeper water. Most of the added biomass (compared to the initial condition) was gained during the first half of the observation period and the pattern was similar in both studied species and experimental sites. This indicates that most of the net annual production of the natural algal communities is achieved during the spring and beginning of summer. According to

Table 2. Summary of two-way ANOVAs for *Furcellaria lumbricalis* growth parameters measured in Kassari (a) and Kõiguste (b) Bays over 6 experimental periods at the depths of 4, 6 and 8 m

			Biomass increment per experimental period			DGR	
Source of variation	*df*		*F*	*P*		*F*	*P*
Experimental	5	a)	430.30	<0.001	a)	203.54	<0.001
Period		b)	93.90	<0.001	b)	13.03	<0.001
Incubation depth	2	a)	258.46	<0.001	a)	860.39	<0.001
		b)	45.15	<0.001	b)	46.24	<0.001
Experimental	10	a)	27.59	<0.001	a)	26.59	<0.001
Period × incubation depth		b)	3.39	0.001	b)	2.93	0.004

Table 3. Summary of two-way ANOVAs for *Coccotylus truncatus* growth parameters measured in Kassari (a) and Kõiguste (b) Bays over 6 experimental periods at the depths of 4, 6 and 8 m

			Biomass increment per experimental period			DGR	
Source of variation	*df*		*F*	*P*		*F*	*P*
Experimental	5	a)	147.72	<0.001	a)	79.19	<0.001
Period		b)	26.75	<0.001	b)	7.37	0.001
Incubation depth	2	a)	119.04	<0.001	a)	467.04	<0.001
Experimental	10	b)	49.69	<0.001	b)	88.70	<0.001
Period × incubation depth		a)	9.21	<0.001	a)	12.91	<0.001
		b)	2.12	0.033	b)	1.38	0.206

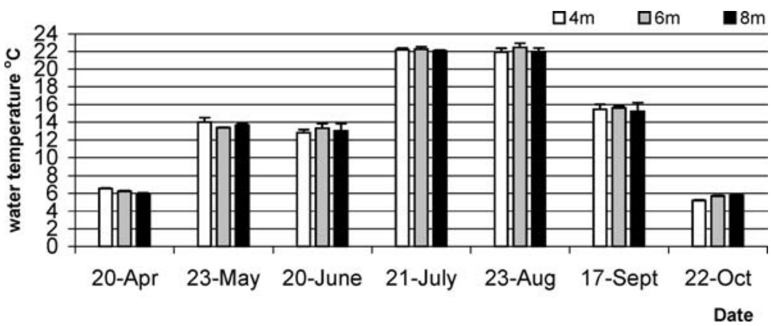

Figure 4. Water temperature measured in Kassari Bay at incubation depths.

literature data this is also true for many other macroalgal species (Kiirikki, 1996).

Biomass dynamics of loose-lying *Furcellaria* and *Coccotylus,* during the entire experimental period, followed a similar seasonal pattern at all incubation depths and both experimental sites, reaching the highest biomass in August. Loose-lying *F. lumbricalis* and *C. truncatus* together form a unique mixed community in Kassari Bay and thus are most probably adapted to similar environmental conditions, which was reflected in their similar growth in the experiment.

In the second half of the investigation period, the observed slight decline in biomass of both species was probably due to the onset of decomposition processes in the algal material. The latter would have been favoured by relatively high water temperature: as a rule decomposition processes depend on temperature (Carpenter & Adams, 1979; Birch et al., 1983). Besides high water temperature, losses of algal biomass could also be attributed to low photosynthetic activity of the algae caused by low water transparency due to increased pelagic productivity during this warm period. It was

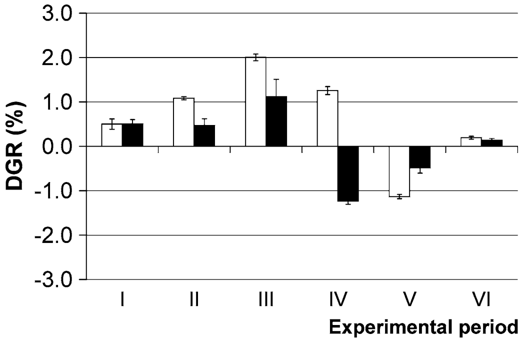

Figure 5. Relative daily growth rates (DGR) ± standard error (n = 5) of *Furcellaria lumbricalis* calculated for six experimental periods: 20 Apr.–22 May (I); 22 May–19 Jun. (II); 19 Jun.–20 Jul. (III); 20 Jul.–22 Aug. (IV); 22 Aug.–16 Sept. (V) and 16 Sept.–21 Oct. (VI) in Kassari Bay (white bars) and Kõiguste Bay (black bars) at the depths of 4 m (A), 6 m (B) and 8 m (C).

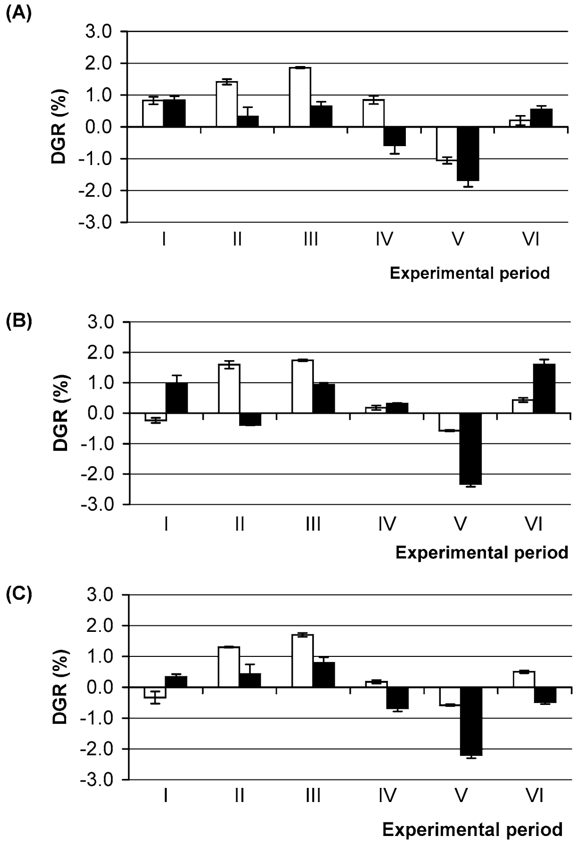

Figure 6. Relative daily growth rates (DGR) ± standard error (n = 5) of *Coccotylus truncatus* calculated for six experimental periods: 20 Apr.–22 May (I); 22 May–19 Jun. (II); 19 Jun.–20 Jul. (III); 20 Jul.–22 Aug. (IV); 22 Aug.–16 Sept. (V) and 16 Sept.—21 Oct. (VI) in Kassari Bay (white bars) and Kõiguste Bay (black bars) at the depths of 4 m (A), 6 m (B) and 8 m (C).

remarkable that the high water temperature values had similar effects on both the algal species studied.

The relatively low increases in biomass that were obtained at the Kõiguste experimental site, for both tested species, cannot be explained in terms of environmental variables measured during the experiment, because both transparency and water temperature values stayed similar at both sites. However, there may have been differences in nutrients in the two areas. It is stated that the waters of northern part of Gulf of Riga have higher nutrient concentrations compared to other parts of the Baltic Sea and also lower water transparency in general (HELCOM, 2002). In our case the exact mechanism remained unclear but the difference between two experimental sites was obvious.

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