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Factors controlling the occurrence of *Furcellaria lumbricalis* (Huds.) Lamour. and *Phyllophora truncata* (Pallas) Zinova in the upper littoral of the Archipelago of SW Finland

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Abstract

The influence of eutrophication on the occurrence of the red algae *Furcellaria lumbricalis* and *Phyllophora truncata* was studied in the sea area of Turku. Due to increased sediment load and planktonic production, light penetration in the water has decreased in the northern parts of the study area. Furthermore, the quality of the sea bottom has changed. Plots of 1 m^2 (N = 100) in the upper littoral zone (0.5–6 m) were studied by SCUBA diving, in order to investigate the factors controlling the occurrence of the red algae. Two transects were situated in the eutrophicated area, and two in the reference area. In the plots, the percentage cover of each plant species and of *Mytilus edulis* was documented, and the Secchi disc visibility and depth was measured.

The numerical data were analyzed by correlation analysis and stepwise multiple regression analysis (BMDP2R). In the eutrophicated area, abiotic factors (percentage cover of plain bottom and bottom quality) explained 81.28 % of the variation of red algae cover. In the reference area, the biotic factors (total number of species and *Mytilus* cover in %) were the most important factors, explaining 66.4 % of red algae cover.

Introduction

The influence of eutrophication on the occurence of the red algal species *Furcellaria lumbricalis* (Huds.) Lamour. (the nomenclature follows CHRISTENSEN et al. 1985) and *Phyllophora truncata* (Pallas) Zinova was studied in the SW Archipelago of Finland.

Due to increased sediment load and planktonic production, light penetration in the water has decreased in the northern parts of the study area. Furthermore, the bottom quality has changed. The response of vegetation to these changes has been documented in earlier studies: all the vegetation belts now occur in shallower water than before, and the species composition has changed (RÖNNBERG 1981, MÄKINEN et al. 1984, RÖNNBERG et al. 1985).

In this pilot study, we have documented the upward shift of the red algae *Furcellaria lumbricalis* and *Phyllophora truncata* due to eutrophication and furthermore, we analysed the factors controlling their occurrence in the upper littoral of the SW Archipelago of Finland.

Study area

The area studied is located near the town of Turku in the SW Archipelago of Finland (Fig. 1). The salinity in the area varies from 5.7 to 7 $^0/_{00}$ S (KOLJONEN and TULKKI 1981).

In 1983, phytoplankton primary production was 43–105 g C m^{-2} a^{-1} in the northern part of the sea area (referred later as the study area), and 42 g C m^{-2} a^{-1} in the southern part (reference area) (JUMPPANEN and KOLEHMAINEN 1984). The Secchi disc visibility in the southern part was 2.3 – 3.5 m (mean annual turbidity < 1.5 FTU; JUMPPANEN and

KOLEHMAINEN 1984), decreasing towards the town of Turku (FTU – value > 1.5). According to our measurements, the minimum Secchi disc visibility was < 1 m in the study area.

The western part of Airisto Sound (see Fig. 1) is 40–100 m deep, whereas the eastern and northern parts are shallower (HEINO 1979). The proportion of rocky shores in the

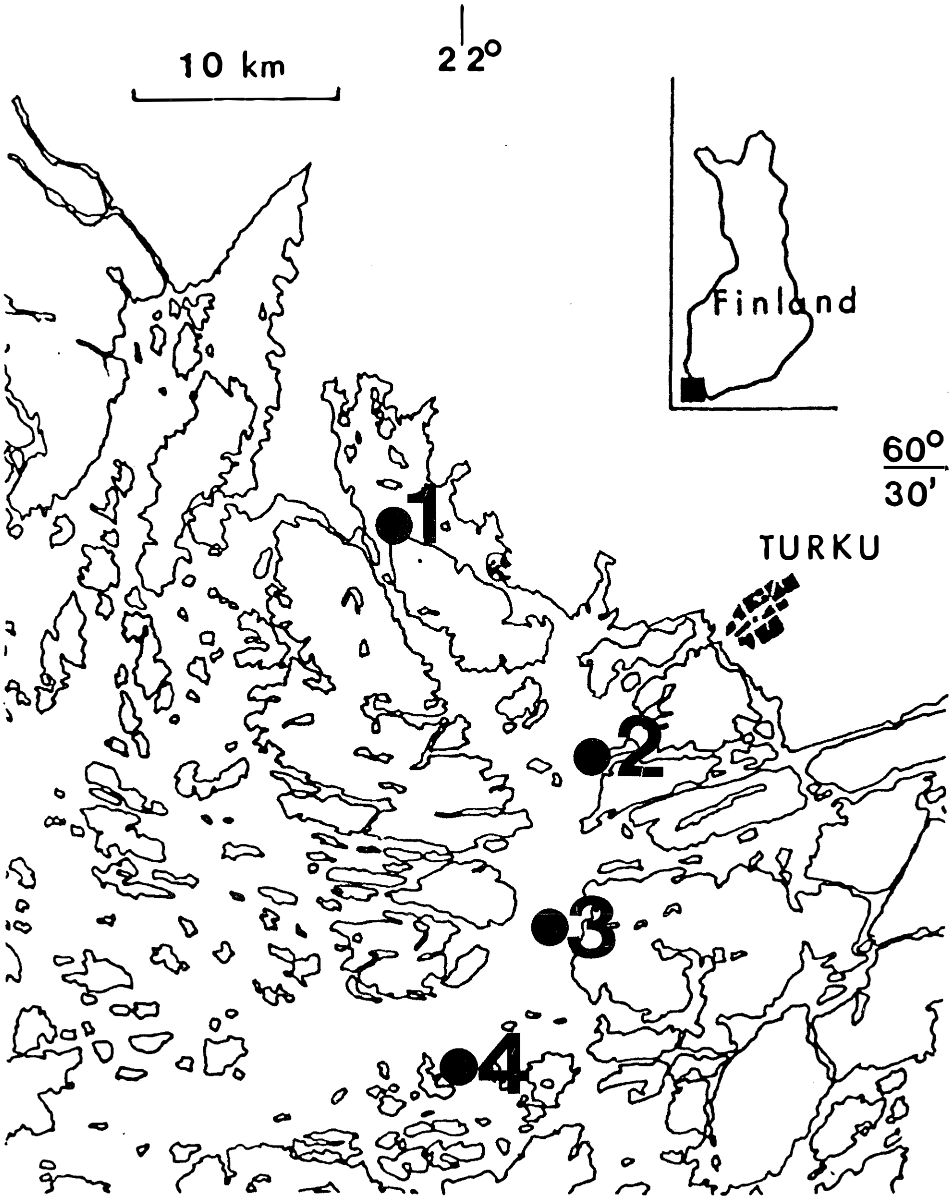

Figure 1
The study area

investigated sea area is 51 %, stony shores about 32 %, sandy 13 % and clay 4 % of all shore types (PYÖKÄRI 1978). Due to eutrophication and heavy ferry traffic in the sea area, the proportion of the shore types is possibly different nowadays.

The littoral macrophyte communities of the sea area have been described by RAVANKO (1972), PEUSSA and RAVANKO (1975), RÖNNBERG (1981) and MÄKINEN et al. (1984).

Material and methods

Samples of 1 m^2 (n = 100) in the depth zone from 0.5 to 6.0 m were studied by SCUBA diving in summer 1985. Two transects (station 1 and 2, Fig. 1) were situated in the eutrophicated area and two (station 3 and 4) in the reference area.

Percentage cover of each plant species and of *Mytilus edulis* was estimated (minimum value over 5 %) and the bottom quality was documented for each sampling square (rock = 1:, gravel/sand = 2, sand = 3, sand/mud = 4, mud = 5). The species having a percentage cover under 5 % were included in the number of the species present on the square. The depth of the water column over the squares was measured.

The data were analysed by stepwise multiple regression analysis (BMDP2R; DIXON and JENNRICH 1985). The occurrence of the red algae species *Furcellaria lumbricalis* and *Phyllophora truncata* was examined by the variables listed in Table 1. Because the two species usually grow together in the same area, their percentage cover was combined.

In the study area, as well as in the reference area, the cover percentage of red algae was correlated with bottom quality, percentage cover of *Mytilus edulis* and the total number of species found in the square.

Results

Furcellaria lumbricalis and *Phyllophora truncata* were found in 20 samples of the study area (n = 49), and in 15 samples of the reference area (n = 51). The percentage cover of the red algae in the depth zone examined was higher in the eutrophicated study area (mean = 28.9 %, range 0–100.0 %, see Table 1) than in the reference area (mean = 1.8 %, range 0–10.0 %).

The two areas were also different in the total number of species found in the squares. In the reference area, on average 5.1 species (range 2–8) were recorded, whereas in the study area the number was remarkably smaller (mean = 2.8; range 0–6). *Cladophora* sp., *Potamogeton pectinatus* and *P. perfoliatus* were the species having a higher percentage cover in the study area than in the reference area. *Ceramium tenuicorne* and *Tolypella* sp. were more common in the reference area.

In the study area, the most important factors controlling the occurrence of the red algae were abiotic ones. The proportion of plain bottom and the quality of the bottom explained 81.3 % of the variation in the percentage cover of red algae. By contrast, in the reference area the biotic factors (*Mytilus edulis* and total number of plant species; R2 (%) = 66.4) seem to control the occurrence of red algae. The detailed results of multiple regression analysis are shown in Table 2.

Correlation between the bottom quality and the percentage cover of red algae in the study area was positive and highly significant ($r = .7128$; $P < 0.001$; Fig. 2). In the reference area, the correlation was also positive but less significant ($r = .2367$; $P < 0.1$).

No correlation was found between percentage cover of the red algae and of *Mytilus edulis* in the study area ($r = .1323$; NS), but in the reference area the correlation was highly

Table 1

Variables used in multiple regression analysis and correlation analysis. (S.D. = standard deviation)

Variable	mean	S.D.	range
1) %cover of red algae			
study area	28.0	40.7	0.0 – 95.0
reference area	1.8	3.5	0.0 – 10.0
2) Depth (m)			
study area	2.8	1.7	0.5 – 6.5
reference area	2.9	1.3	0.1 – 5.2
3) Quality of bottom			
study area	2.7	1.2	1 – 5
reference area	2.5	1.1	1 – 4
4) Total number of species found in the square			
study area	2.8	1.5	0 – 6
reference area	5.1	1.7	2 – 8
5) %cover of plain bottom			
study area	19.8	28.8	0 –100
reference area	31.3	26.4	0 – 90
6) %cover of *Fucus*			
study area	0.7	3.4	0 – 20
reference area	0.1	0.7	0 – 5
7) %cover of *Cladophora*			
study area	25.0	37.2	0 –100
reference area	11.6	22.0	0 – 70
8) %cover of *Enteromorpha*			
study area	0.6	2.2	0 – 10
reference area	0.4	0.8	0 – 5
9) %cover of *Ceramium*			
study area	0.3	1.5	0 – 10
reference area	15.6	16.7	0 – 60
10) %cover of *Pilayella*			
study area	2.2	7.5	0 – 40
reference area	9.3	10.4	0 – 40
11) %cover of *Potamogeton pectinatus*			
study area	11.0	19.0	0 – 65
reference area	5.1	14.3	0 – 60
12) %cover of *Potamogeton perfoliatus*			
study area	4.6	20.7	0 –100
reference area	1.7	5.5	0 – 30
13) %cover of *Tolypella*			
study area	0.0	0.0	0
reference area	0.8	2.5	0 – 15
14) %cover of *Mytilus edulis*			
study area	7.1	16.2	0 – 80
reference area	23.2	37.4	0 –100

significant ($r = .7824$; $P < 0.001$). The total number of species found in the squares had no correlation with the percentage cover of the red algae in the study area ($r = .0690$; NS), but in the reference area the correlation was significant ($r = .7465$; $P < 0.001$).

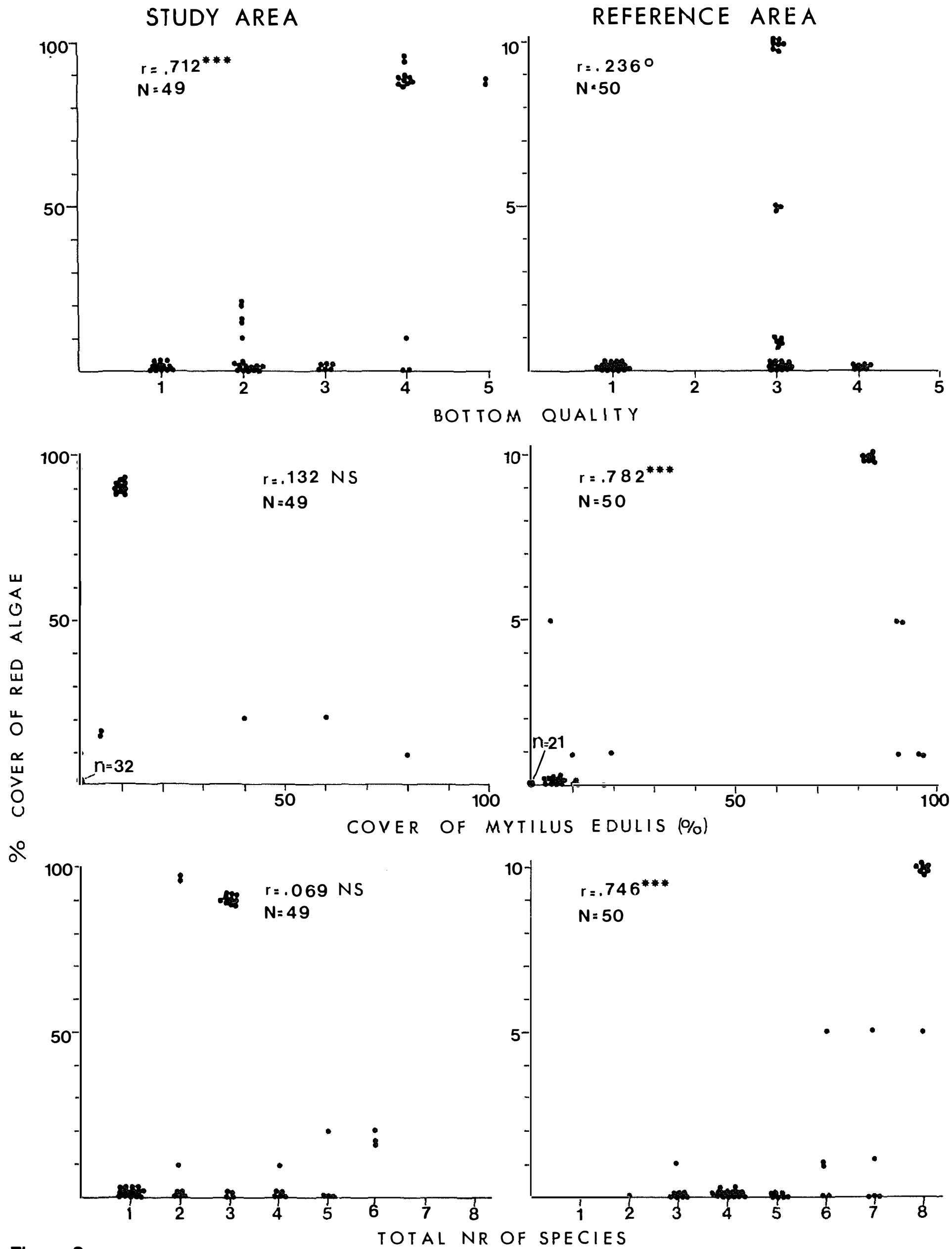

Figure 2

Results of the correlation analysis

*** = $p < 0.001$, ** = $p < 0.01$

Discussion

According to this pilot study, red algae also exist in great quantities in the eutrophicated area, but in shallower water than in the reference area.

Eutrophication causes changes in the quality of the bottom, as well as in the composition of the vegetation. In the study area, the bottom was more often muddy, and less plain bottom was found than in the reference area. Also, more species of vascular plants were found, and the frequency of the annual filamentous green algae like *Cladophora* was higher.

This kind of changes in the vegetation has been documented in the investigated area in earlier studies (RÖNNBERG 1981, MÄKINEN 1984, RÖNNBERG et al. 1985) and elsewhere on the coast of Finland (KANGAS et al. 1982).

In the study area, *Mytilus edulis* was found less frequently than in the reference area of the corresponding depth zone. In conditions not affected by eutrophication, the zones of red algae and *Mytilus* overlap. In the course of eutrophication and increasing water turbidity, apparently the decrease of light causes the upward shift of the red algae. *Mytilus*, in turn, persists at the original depth. Hence, the zones are separated and no correlation can be found between the percentage covers of the two.

In the reference area, the bottom quality was not an important factor controlling the occurrence of red algae, as it was in the study area (see Table 2). So the quality of the bottom seems not to be a primary controlling factor, but an indication of eutrophication (higher primary production and water turbidity cause changes in the bottom quality). Also, decreased light penetration into the water is due to eutrophication. Possibly, decreased light penetration causes the upward shift of red algae, especially where competing species are absent in the upper zone.

Table 2

Results of stepwise regression analysis

*** = $p < 0.001$, ** = $p < 0.01$

Study area

	R^2 (%)	coefficient	F to remove
Plain bottom	81.28***	−0.72561	42.28
Bottom quality	69.29***	21.54938	23.67
Depth	57.16 (NS)	3.75004	1.42
Variables not in equation (see the reference area)			F to enter
Total number of species			0.16
Percentage cover of *Mytilus*			0.00

Reference area

	R^2 (%)	coefficient	F to remove
Total number of species	66.40***	0.72339	7.30
Percentage cover of *Mytilus*	61.21**	0.04829	14.99
Variables not in equation (see study area)			F to enter
Depth			0.15
Bottom quality			1.47
Plain bottom			0.25

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