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Ecological monitoring of marine fish farming activities by *Enteromorpha intestinalis* (Chlorophyta)

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Abstract: The biomass production of algae was markedly enhanced near a large fish farming establishment in the northern Baltic Sea, SW coast of Finland. The mean biomass values of the dominant filamentous green alga *Enteromorpha intestinalis* at sites near the fish farming establishment were 3-fold the values at the control site (160–190 g/ m^2 vs. 64 g/m^2). The nutrient discharges from the fish farms were reflected in the elemental contents of the algal tissues. The contents of phosphorus (mean values in the farming area vs. at the control site) were 0.30–0.33% (dry weight) vs. 0.25%,and the levels of N were 1.8–2.1 % vs. 1.6%. On the basis of the nutrient contents, nitrogen is the growth-limiting nutrient in these coastal waters. The results are thus in contrast with the commonly accepted view that the reduction of phosphorus discharges is the main objective in water management. In addition, the accumulation of zinc in the tissues of *Enteromorph*a appeared to be a useful indicator of fish farming activities.

Keywords: Aquaculture, Baltic Sea, Biological Monitoring, *Enteromorpha Intestinalis*, Fish Farming

1. Introduction

The production of fish for human consumption has rapidly increased throughout the world, and in the future the need for aquaculture will be even more important [1]. But unfortunately, the interests of man and the best of the nature are often in conflict. The environmental effects of aquaculture can be managed in inland fish farming, but preventing the nutrients and other harmful substances discharging from open-water establishments is difficult, if not impossible. Regardless the farm establishment types or the fish species reared, fish farms are inevitably causing negative impacts on water quality [2].

The production of rainbow trout (*Oncorhynchusmykiss* Walbaum) in floating net cages was explosively increased in the Baltic Sea in 1980's. The "net bags" are nowadays very common feature in the marine landscapes in the southwestern coast of Finland, where the number of establishments increased fourfold (to nearly 100 commercial farms consisting of several new cages each) in only six years. The annual net production of rainbow trout exceeded 10 million kilograms within a rather restricted and closed coastal and archipelago environment. And because the activities were – and still are – centralized in a few coastal areas, the fish farming caused marked detrimental degradation in the previously pristine natural state of the marine environment. On the scale of the whole Baltic Sea ecosystem, the effects of aquaculture are minor, but in the local aquatic environment the impacts are marked. The most striking cause of the fish farming boom was the eutrophication of the coastal waters [3, 4].

Only limited data are available on the environmental effects of the fish farming activities in the brackish water ecosystems in the northern Baltic Sea. Elevated levels of the major nutrients nitrogen and phosphorus have been reported from certain areas [5]. Enhanced production of littoral macroalgae was attributed to the eutrophication caused by fish farms [5]. Waste feed and fecal materials excreted by fish are the main causes of pollution of sea water and bottom deposits near the fish farming establishments [6,7,8]. The use of biological indicators provides an efficient long-term monitoring of habitat quality, and thus avoids dangers of rapid and often undirected changes in environmental conditions such as nutrient concentrations of surface waters [9]. The present paper describes a case study on the biomass production and nutrient accumulation of the dominant littoral green alga *Enteromorpha intestinalis* (L.) Link from the most intensive fish farming center of Finland.

2. Materials and Methods

2.1. Study Area

The production ecology of *Enteromorpha intestinalis*was studied at Kustavi in southwestern coast of Finland in the northern Baltic Sea (Fig. 1). The sea water in the area was classified slightly eutrophicated with no point sources of anthropogenic pollution before the rise of the new fish farming industry in the 1980's [10].

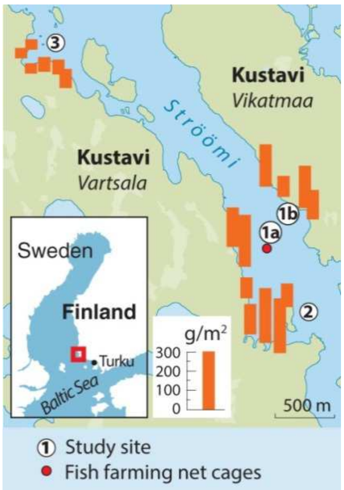

Fig 1. *Location of the study area and the values for the biomass of the littoral green alga Enteromorpha intestinalis at varying distances from the fish farming establishment.*

Nowadays the study area hosts the most intensive fish farming activities in Finland. At the peak, the annual production totalledmillions of tons of rainbow trout. With the drastic expanse of the fish farming, the quality of the coastal waters declined rapidly and detrimentally. The official water quality monitoring by national authorities showed that the concentrations of phosphorus in the surface waters increased markedly(from the background level of 10 $\mu g/m^3$ to 15–27 $\mu g/m^3$ near the fish farms) during the period of the fish farming expansion [11].At present, anthropogenic emissions and discharges burden the northern Baltic Sea so much that the condition of surface waters is locally classified as moderate to bad [3]. The fish farming activities are threating the health of the marine ecosystem here, both through eutrophication and species diversity impoverishment.

2.2. Vegetation Sampling and Analyses

Samples of the filamentous green alga*Enteromorpha intestinalis*(Fig. 2) were collected at three sites near a large-scale (annual production of 100–200 tons) fish farming establishment, and at a control area outside the visible environmental effects of the establishment (Fig. 1). Six randomly placed samples were taken at each of the four littoral sections. Sampling of the algal biomass was restricted to rocky shores, where the attachment and existence of filamentous algae was optimal. Biomass samples were collected by using a circular frame (area 225 cm^2). In the laboratory, the dry weight of the samples was determined after oven-drying at 105°C for 48 h.

For the nitrogen, phosphorus, and zinc analyses, 200 mg (dry weight) samples of homogenized algal tissues were wet digested by the hydrogen peroxide-sulphuric acid reagents [12]. The contents of N were determined by the semi-micro Kjeldahl digestion and titration with 0.01 N sulphuric acid. The levels of P were measured colorimetrically by the ammonium-molybdate method [12], while the determinations of zinc were made by conventional methods of flame atomic absorption spectrophotometry in air-acetylene flame [12]. All the values are expressed on the dry weight basis.

2.3. Statistical Analyses and Terminology

The parametric (mean ± standard error of the mean and standard deviation of the mean, one-way analysis of variance; ANOVA), and non-parametric (Kruskal–Wallis one-way analysis of variance) statistical analyses of the numerical data were performed by using the Analyse-it for Microsoft Excel (version 2.12) program package [13]. The terminology follows the latest edition of the *Oxford Dictionary of Plant Sciences*[14].

3. Results

3.1. Biomass of Filamentous Algae

The values of the peak biomass of the filamentous green alga*Enteromorpha intestinalis* at the study sites are given in Fig. 1 and in detail in Table 1. The concentrations of the major nutrients nitrogen and phosphorus and of the trace element zinc accumulated in the algal tissues are given in Table 2.

Fig 2*. Masses of Enteromorpha intestinalisattached to littoral rocks near the fish farming net cages in the SW coast of Finland.*

Fig 3. *Typical floating net-cage fish farm in the northern Baltic Sea, off the SW coast of Finland.*

The enhancement of the algal production is clearly revealed by the biomass values. Thus, the lowest individual biomass values near the fish farming establishment (min. 106.6 g/m^2 dry wt.) exceed the highest values determined at the nearby control are (max. 78.8 g/m^2 dry weight). In the mean biomass values, the sites near the fish farming cages were three times higher than the levels at the control site (Table 1). The highest biomass values (max. 294.4 g/m^2) determined for *E. intestinalis* near the fish farm were exceptionally high for this species. In the Kruskal-Wallis one way analysis of variance, the biomass values at the three sampling sites varied statistically significantly ($H = 11.79$, $P < 0.01$).

Table 1. *Biomass (g/m^{2,} dry weight) of the littoral green alga Enteromorpha intestinalis near a floating fish farming establishment in the Baltic Sea, SW coast of Finland.*

Study locations	Mean ±S.E.	Range
Control (Site 3)	64.0 ± 3.9^a	46.6 – 78.8
Adjacent to the farm		
Exposed shores (Sites 1a and 1b)	192.3 ± 22.7^b	106.6 – 269.8
Sheltered shore (Site 2)	157.0 ± 26.1^b	113.3 – 294.4

N = 6 stands in each successional stage. Statistical analysis: In the analysis of variance (ANOVA), different letters in the vertical columns indicate highly significant difference (P < 0.01).

3.2. Nutrient and Zinc Contents of Algal Tissues

The levels of N and P in the algal thalli were rather uniform both at the study sites near the fish farm (the coefficient of variation of 9.1 % for N and 13.2 % for P) and at the control sites (CV = 7.5 % for N and 14.6 % for P). The levels of zinc in the algal thalli were markedly elevated near the fish farming establishment (Table 1), and typical for coastal waters in the more remote control site.

Table 2. *The concentrations of nitrogen, phosphorus, and zinc in the thalli of Enteromorpha intestinalis at varying distances from the large-scale fish farming establishment at Kustavi, SW Finland.*

Study locations	N (% dry wt)	P (% dry wt)	Zn (μg/g dry wt)
Site 1a	1.81 ± 0.11^a	0.30 ± 0.02	33.6 ± 2.6^a
1b	1.99 ± 0.13^a	0.30 ± 0.05	37.6 ± 2.1^a
Site 2	2.13 ± 0.09^a	0.33 ± 0.06	42.6 ± 3.9^a
Site 3	1.63 ± 0.20^b	0.25 ± 0.03	19.8 ± 2.6^b

Site 1 a & b = exposed, open rocky shores near the floating fish farming cages
Site 2 = sheltered bay with rocky shore near the floating fish farming cages
Site 3 = sheltered bay in the control area, outside the influences from the fish farm

Comparison of the elemental levels between the two sampling locations showed marked differences: As revealed by the analysis of variance (ANOVA), the levels of nitrogen and zinc were significantly (P< 0.01) higher near the fish farming establishment than at the control area.

4. Discussion

Production of the littoral alga *Enteromorpha intestinalis*showed clear enhancement in the vicinity of the fish farming establishment (Fig. 1, Fig. 3). This trend was consistent with the previous reports on the production ecology of the filamentous green alga *Cladophoraglomerata*, the biomass of which were markedly elevated in areas with the most intensive fish farming activities in the coastal waters of Baltic Sea in the SW Finland [5, 6]. In the same geographical conditions on the SW coast of Finland, the biomass values of *Cladophoraglomerata* were higher than those for *Enteromorpha* in the present study. The higher biomass values for *Cladophora* can be attributed with different seasonal life cycles of the two species. *Cladophora* is the dominant filamentous algal species in the littoral rocky shores through May to August, whereas the period of *Enteromorpha*’s dominance is markedly shorter lasting only four to six weeks. In addition, a remarkable proportion (60 % on the average) of the biomass recorded for *Cladophoraglomerata* is composed of epiphytes [15], whereas Enteromorpha intestinalis is free of diatomaceous epiphytes.

The present results are consistent with the observations in SWÅland, northern Baltic Sea, where the growth and production, and the contents of chlorophyll a of the filamentous green alga *Cladophora* were enhanced near fish farming establishments [16].

The accumulation of nutrient elements in algal thalli mirrors the state of the ambient waters [5]. The capacity of nutrient enrichment is high in littoral green algae, thus emphasizing their applicability in biomonitoring of coastal eutrophication [5, 17]. The elevated levels of nitrogen and phosphorus in the algal tissues at the sites near the fish farm clearly indicate the high nutrient loading discharged from the floating net ponds [7].

The contents of N in the algal thalli equaled (site #2) or were below the critical concentration of 2.1 % dry weight [18]. The concept of critical concentration refers to the level of essential nutrients in the plant tissues, below which optimal growth would be nutrient-limited [19]. The levels of P equaled the critical concentration of 0.3% [18,19].

The ratio between the concentrations of the major nutrients in the algal tissues showed a uniform pattern ranging from 6.4 to 6.7. The low N/P -ratios recorded further emphasize the surplus of phosphorus in relation to nitrogen in the vicinity of the fish farming establishment [5, 17]. The tissue analyses thus indicate that nitrogen is the growth-limiting nutrient in these coastal waters. The high biomass values and cover of the algal turfs on the rocky shores near the fish farming cages express the strength of the fertilization effects caused by nutrients from the waste feed and fish faeces.*Enteromorpha*macroalgae are shown to respond rapidly to enhancements in nitrogen availability in marine waters [20].The applicability of tissue analyses of *Enteromorpha intestinalis* in monitoring of nutrient enrichment in coastal waters was proved also in experimental field studies [21].

The enrichment of zinc in the algal tissues near the fish farm results from direct and especially indirect effects via resuspension of the bottom deposits beneath the establishment. Zinc is typically enriched at the bottom sediments beneath large fish farms [22], and through resuspension of the deposits the elements are spread throughout the surroundings of the cages. It was shown previously that the levels of zinc are markedly elevated beneath the floating fish ponds. After remobilization, the discharged metals are efficiently trapped by the littoral algae [23].

The difference between the distribution patterns of the three elements analyzed can be explained by the varying routes of the elements. Phosphorus and zinc are deposited in the sediments, being available to the primary produces in the littoral rocky shores only after remobilization. In contrast, nitrogen is discharged directly into the ambient water in soluble forms [8], thus being effectively spread in the surface waters and is readily available to primary producers.

The massive production and accumulation of algal biomass is troublesome for fisheries, as well as for recreational usage of the shores [11]. This has led to powerful public pressure to put limits for the expanding industry. For more than a decade since the rapid rise of the commercial fish farming in the northern Baltic Sea the authorities were unable to provide solid evidence of the detrimental impacts of the aquaculture in the pristine coastal waters and archipelagoes. But the biological studies – like the present case study – gave strong support for the previously observed chemical chances. The debate of the risks and inconveniences of the fish farming came evident, when the rocky shores were overgrown with green algal mats. And soon after the realization of those consequences, the decisions made by authorities and courts were strengthened and the amounts of annual production allowed in the floating net ponds were markedly lowered [4].

In the European Union, the maintenance of adequate quality (“good status”) of aquatic environments requires – in addition to traditional chemical analyses – systematic monitoring of biological and multipurpose use suitability of waters [24]. Today the aquaculture has succeeded in developing the quality of fish feeds, as well as the feeding mechanisms. Due to the improvements made by the industry – partly demanded by the authorities, partly by voluntary introduction of technological improvements – the production of rainbow trout is nowadays on sustainable grounds, and now the aquaculture causes only negligible annoyance for the environment and people [4].

The environmental effects of loadings from the fish farming establishment in the present study area clearly enhance the primary production of algae in these coastal waters. Fish farms can, however, have also strictly opposite influences. Large establishments in the Mediterranean Sea can cause decrease or total disappearance of seagrass meadows near the fish farms [25]. Such examples emphasize the necessity of detailed background evaluation of the location for future establishments. The knowledge about the detrimental environmental effects of net cage fish farming enables the evaluation and modeling of best practices in marine fish farming. The openness and water exchange are the key characteristics for the most successful fish farming, even in industrial scale [26,27,28].

5. Conclusions

Biological monitoring and assessment of environmental effects of fish farming proved superior to traditionally appliedphysico-chemical follow-up measurements. The biomass production and nutrient ecology of littoral filamentous alga *Enteromorpha intestinalis* showed indisputable – and detrimental – changes in the quality of coastal waters near the industrial-scale fish farming establishments in the SW coast of Finland. The biological measurements are nowadays widely used by the water management authorities, as well as court decision in determining the acceptable levels of commercial rainbow trout rearing in the coastal waters of the northern Baltic Sea.

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