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Distribution and dynamics of drifting macroalgal mats in Estonian coastal waters during 1995–2003

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Abstract. The occurrence of drifting algal mats has become a widespread phenomenon in shallow coastal waters of the Baltic Sea. In Estonian coastal waters the drifting algal mats were found on sandy-clayey bottoms in relatively shallow and sheltered bays. Except for a few localities of the Gulf of Finland, *Pilayella littoralis* or *Ectocarpus siliculosus* prevailed in the drifting algal mats. The abundance of invertebrate feeding types (herbivores or detrivores) was related to the physiological state of the macroalgae in the mat.

Key words: *Cladophora glomerata*, detrivores, drifting macroalgal mats, Estonian coastal waters, herbivores, Ihasalu Bay, Kõiguste Bay, *Pilayella littoralis*, spatial distribution.

INTRODUCTION

Within the past few decades the extensive supply of nutrients into coastal ecosystems has resulted in the luxurious growth of filamentous macroalgal species in many regions of the world. As a consequence of large macroalgal "blooms", the mass drift of algae is increasingly observed. This is due to the detachment of sessile filamentous algae at the end of their lifecycles and/or disturbances, caused by heavy wave actions or currents. The algae are either washed up on the shore or they sink down and form drifting algal mats on the sea bottom (Morand & Briand, 1996; Paerl, 1997; Valiela et al., 1997).

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The occurrence of drifting algal mats has become a widespread phenomenon also in shallow coastal waters of the Baltic Sea (Kiirikki & Blomster, 1996; Norkko & Bonsdorff, 1996a,b; Bäck et al., 1996, 2000; Vahteri et al., 2000; Lehvo & Bäck, 2001). The proliferation of annual filamentous algae and the formation of drifting algal mats has been observed in the whole Estonian coastal range (Trei, 1983, 1991; Martin et al., 2003). It is suggested that the occurrence of drifting algal mats reflects the shift in macroalgal communities from the perennial macrophytes to fast growing filamentous macroalgae, caused by increasing eutrophication of coastal waters in the Baltic Sea during the past decades (Nehring & Matthäus, 1987; Rosenberg et al., 1990; Bäck et al, 1993; Mäkinen et al, 1994; Bonsdorff et al., 1997). Naturally Baltic filamentous algae grow on different hard substrates and exhibit strong seasonality (Kiirikki, 1996; Kiirikki & Lehvo, 1997). However, after detachment and formation of loose lying algal mats, they may extend their growing area to a completely new niche, to soft bottoms. Occupying a unique habitat of higher aquatic plant and macrozoobenthos communities, the drifting algal mats represent a serious threat to the biodiversity of coastal areas (Lehvo & Bäck, 2001). The accumulation and decomposition of these algal mats can modify nutrient dynamics both in a water column and sediment (Lavery & McComb, 1991; Peckol & Rivers, 1996; Paalme et al., 2002), affect negatively the underwater light climate, result in widespread hypoxic and anoxic conditions among the algae and in the sediment, and hence destabilize the whole shallow-water ecosystem (Norkko & Bonsdorff, 1996a,b; Hansen & Kristensen, 1997).

Although the drifting macroalgal mats are a very important part of the productivity and functioning of the shallow coastal areas of the Baltic Sea, there are only a few papers dealing with various aspects of their development and occurrence (Bäck et al., 2000; Vahteri et al., 2000; Lehvo & Bäck, 2001; Paalme et al., 2002; Salovius & Bonsdorff, 2004). The aim of the study was to summarize all available records about the occurrence of the drifting macroalgal mats in Estonian coastal area in the last decade. The formation and development of drift algae were studied at two selected sites during one growing season.

MATERIALS AND METHODS

Since 1995 quantitative data on the spatial distribution of macroalgal communities have been regularly collected in Estonian coastal waters. During sampling the diver recorded the presence and spatial coverage of different macroalgal communities including the drift algal mats. Most of the studies were performed in late July and August. However, as the drift algae were not specially surveyed no quantitative frame samples from the mat were taken. In order to collect more quantitative information on the algal mats the development of the drifting algal mats was followed at two selected sites in the Gulf of Finland and the Gulf of Riga during the ice-free season in 2002/2003. In addition to plant species the biomass of associated invertebrates was estimated in the samples of the two selected sites. The samples of drifting macroalgal mats were collected by SCUBA diving. A frame sampler (400 cm^2) was used both for plant and animal species. Dry weights were obtained after drying the plant material for 2 weeks and animals for 48 h at 60 °C.

The physiological state of the algal material during different developmental stages of the drifting algal mat was estimated in the two selected sites. For this purpose the net photosynthetic and dark respiration rates were measured using the oxygen method (Paalme et al., 2002).

RESULTS

The drifting macroalgal mats were observed at 18 localities throughout the Estonian coastline (Fig. 1). The drift algae were mainly found on sandy-clayey bottoms. The depth ranged from 0.5 to 12 m, with the optimum values below 2–3 m (Table 1). *Pilayella littoralis* or *Ectocarpus siliculosus* were the prevailing macroalgal species that formed the algal mats. Monotypic mats that consisted mainly of *Cladophora glomerata* were observed only at two locations (Table 1).

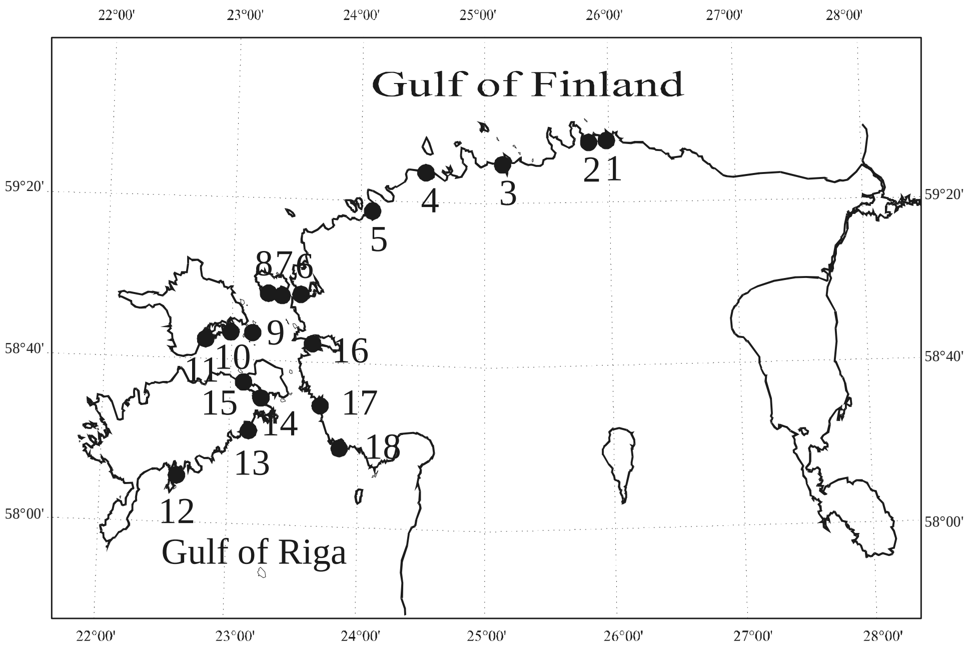


Fig. 1. Study area. Filled circles indicate the sites where drifting macroalgal mats were observed. Numbers refer to the locations listed in Table 1.

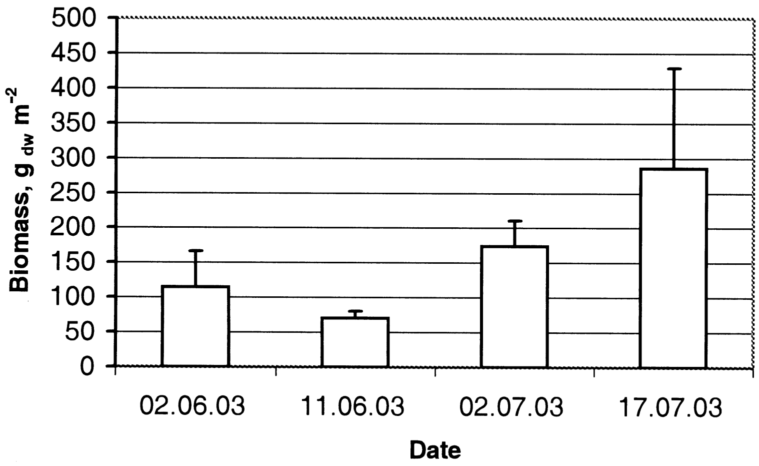
Table 1. Locations where drifting macroalgal mats were observed together with depth range, dominant algal species, and prevailing bottom type

No.	Location	Depth range, m	Dominant species	Bottom type
1	Käsmu Bay *	2–3	*C. glomerata*	Sand
2	Eru Bay *	4–8	*C. glomerata*	Sand
3	Ihasalu Bay **	2–3	*P. littoralis*	Sand
4	Kakumäe Bay **	1.5–3	*P. littoralis*	Sand
5	Pakri Bay *	1–2	*P. littoralis* and/or *C. glomerata*	Sand
6	Haapsalu Bay ***	0.5–2	*P. littorali or E. siliculosus*	Sand, clay
7	Sviby Bay ***	0.5–1.5	*P. littoralis or E. siliculosus*	Sand, clay
8	Hullo Bay ***	0.5–2	*P. littoralis or E. siliculosus*	Sand, clay
9	Heinlaid **	1–4	*P. littoralis or E. siliculosus* and/or *C. glomerata*	Sand, clay
10	Õunaku Bay **	1–2	*P. littoralis or E. siliculosus*	Sand, clay
11	Jausa Bay **	1–2	*P. littoralis or E. siliculosus*	Sand, clay
12	Kuressaare Bay *	1–2	*P. littoralis or E. siliculosus*	Sand, clay
13	Kõiguste Bay ***	0.5–1, 3–5, 8–12	*P. littoralis or E. siliculosus*	Sand, clay
14	Väike väin *	1.5–2	*P. littoralis or E. siliculosus*	Sand
15	Väike väin *	1.5–3	*P. littoralis or E. siliculosus*	Sand
16	Matsalu Bay ***	2–3	*P. littoralis or E. siliculosus*	Sand, clay
17	Paatsalu Bay **	0.5–2	*P. littoralis or E. siliculosus*	Sand
18	Tõstamaa Bay **	0.5–1	*P. littoralis or E. siliculosus*	Sand

* Macroalgal mats were found during a single observation.
** Macroalgal mats were found occasionally.
*** Macroalgal mats were found during every observation.

In Ihasalu Bay (3 in Fig. 1) drift algae were first observed in early June at 1.5 to 2 m depth. The patches were small and elongated and their shape followed the patterns of sand waves. The size of the patches was less than 0.5 m^2 and the thickness about 5 cm. Ten days later the size of the patches had increased approximately up to 20–30 m^2. The thickness of the mat varied between 5 (in June) and 9 (in July) cm. The average biomass of the algae was in the range 70 to 280 g dw m^{-2} (Fig. 2a). Drift algae covered less than 10% of the total bottom area of the bay. The dominant macroalgal species was *P. littoralis*. In June up to 97–99% of the total biomass consisted of *P. littoralis*, but in July the proportion of *C. glomerata* had increased on average to 15% (Fig. 2b). The biomass of other species (the phanerogams *Ruppia* sp. and *Zostera marina*, the green alga *Enteromorpha intestinalis*, the red algae *Ceramium tenuicorne* and *Polysiphonia fucoides*) was less than 1% of the total biomass of the mat.

(a)



(b)

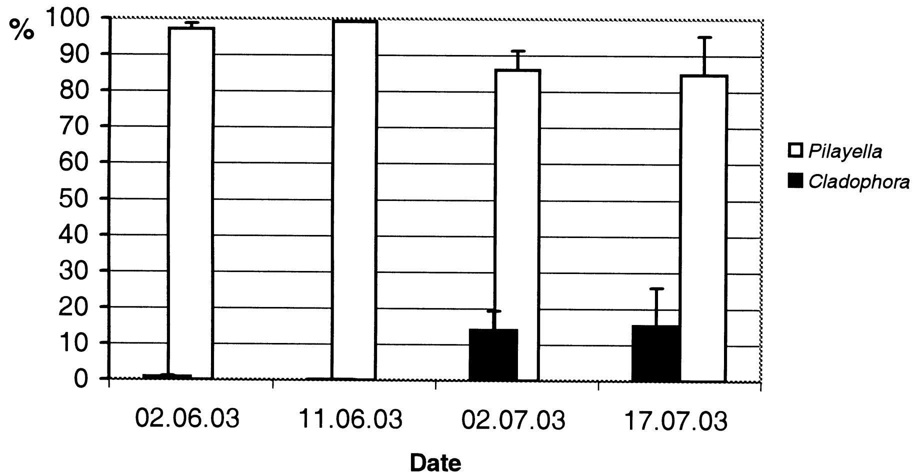


Fig. 2. Total biomass of the drifting macroalgal mat (a) and the percentage of *Pilayella littoralis* and *Cladophora glomerata* in the total biomass of the mat (b) (± SE, *n* = 3).

Patchy occurrence of the algal mats was observed until their disappearance in the middle of July, when large amounts of decaying algal mass were deposited on the shore. From August to early October high amounts of loose *P. littoralis* (ca 25%) and *C. glomerata* (ca 75%) occurred in the water column down to 3 m depth, but no formation of new algal mats was observed.

We found 9 zoobenthos taxa inside the macroalgal mat: *Corixa* sp., *Lymnea* sp., *Bithynia tentaculata*, *Hediste diversicolor*, *Gammarus* sp., *Cerastoderma glaucum*, Hironomidae, *Theodoxus fluviatilis*, and *Physa fontinalis*. Herbivores were the most important feeding type in terms of abundance and biomass. Nevertheless, the biomass of invertebrates was low and usually did not exceed 25 g dw m^{-2}.

In June the drifting mats were productive, i.e. the net photosynthetic rates of *P. littoralis* measured were relatively high, up to 10 mgO_2 $g_{dry\ weight}$ h^{-1}. In July the net photosynthetic rates of the mat decreased about 10 times, and the oxygen consumption rates (dark respiration) of the dominant species in algal mats increased.

In Kõiguste Bay drift algae were first observed in late May. About 25% of the total bottom area of the bay was covered by drift algae. The mat consisted mainly of *P. littoralis*, and the prevailing invertebrate species were the herbivores *Hydrobia ulvae* and *Theodoxus fluviatilis*. As the thickness of the mat rarely exceeded 1 cm (<20 g dw m^{-2}) the biomass of invertebrates did not exceed 20 g dw m^{-2}. In July the average biomass of the drifting macroalgal mat was 330 ± 154 g dw m^{-2}. The mat was thickest and uniform at 4–5 m depth. The mat was not productive (i.e. photosynthetically not active). The prevailing species was *P. littoralis.* The thickness of the mat varied between 1 and 5 cm. The most common animal species inside the mat was *Macoma balthica*. Consequently, detrivores were the dominant feeding group with average abundance of 1306 ind m^{-2} and average biomass of 76 g dw m^{-2}. *Hydrobia ulvae* was the prevailing herbivore species inside the algal mat (Table 2). In early August the mat was almost decomposed and inhabited only by Chironomidae. Similarly to Ihasalu Bay the drift algae were partly productive in early summer and only decomposition took place in July–August.

Table 2. List of animal species found inside the drifting macroalgal mat in Kõiguste Bay in 2002

Polychaeta	*Hediste diversicolor* (Müller)
	Marenzelleria viridis (Verrill)
Nemertina	*Prostoma obscurum* Schultze
Crustacea	*Saduria entomon* (L.)
	Idotea baltica (Pallas)
	Jaera albifrons Leach
	Corophium volutator (Pallas)
	Gammarus oceanicus Segestråle
	Gammarus salinus Spooner
	Gammarus juv.
Insecta	Chironomidae
Mollusca	*Theodoxus fluviatilis* (L.)
	Lymnaea sp.
	Hydrobia ulvae (Pennant)
	Hydrobia ventrosa (Montagu)
	Mytilus edulis L.
	Cerastoderma glaucum (Bruguire)
	Macoma balthica (L.)
	Mya arenaria L.

DISCUSSION

In Estonian coastal waters drifting macroalgal mats occurred as a rule on sandy-clayey bottoms. Normally filamentous algae do not grow on soft substrates. Hence, the mats represent a serious threat to phanerogams, *Chara* spp., and various animal species characteristic of soft sediments. The negative effects of drift algae include shading, increase in organic matter as a result of their degradation, and the development of anoxic conditions under the mats (Bonsdorff et al., 1997; Bäck et al., 2000; Vahteri et al., 2000; Lehvo & Bäck, 2001).

Drifting macroalgal mats were found in rather small, shallow and sheltered bays (e.g. the Väinameri region in the Gulf of Riga). The mats were not found at open shores (e.g. at the western coasts of Saaremaa and Hiiumaa islands including Küdema Bay in the NW coast of Saarema Island).

Except for a few locations in the Gulf of Finland the prevailing species in drifting algal mats was *P. littoralis* or *E. siliculosus.* The next important species was *C. glomerata*. This pattern reflects the natural occurrence and dominance of species in the area. A similar species composition of drifting algal mats has been described in the Archipelago Sea area, SW Finland (Vahteri et al., 2000; Salovius & Bonsdorff, 2004) and in the northern coast of the Gulf of Finland (Lehvo & Bäck, 2001).

Depending on the succession of dominant algal species as well as on meteorological conditions, drifting algal mats may occur during quite a short period or persist more than a year. The decomposition rate of a drifting algal mat depends on its species composition. The decomposition rate of *P. littoralis* is higher than of *C. glomerata*, especially in summer at high water temperatures (Paalme et al., 2002; Salovius & Bonsdorff, 2004).

Most of drifting algal mats in the Estonian coastal zone were observed at very shallow depths and are thus strongly affected by wave action (storms). Occasionally mats are washed up to the shore before their complete decomposition (Golubkov et al., 2003). At greater depths with the more stable hydrodynamic conditions the drift algae persist longer and may even overwinter like in Kõiguste Bay in 2003.

Vahteri et al. (2000) described and classified drifting algal mass according to the thickness of the mat and occurrence of anoxia (smell of hydrogen sulphide, black coloured sediment). According to their classification the algal mats in the Estonian coastal area may be ranked as “algal cover”, i.e. free floating productive algal mass or “mat” with visible oxygen deficiency in the lower layers. The “mattress”, i.e. totally anoxic algal mass, was observed only at depths below 5 m in Kõiguste Bay.

The share of invertebrate feeding groups in macroalgal mats is probably dependent on the physiological state of the mat. In Ihasalu and Kõiguste bays in the case of productive “algal cover” the prevailing functional group inside the mat was herbivores, whereas detrivores were the most abundant functional group in the partly decomposed “algal mat”.

This study is a first attempt to summarize the data on the drift algae and associated invertebrates in the Estonian coastal sea. As the phenomenon has great ecological and socio-economic importance more detailed studies on the dynamics and environmental forcing of freefloating algal accumulations involving both field surveys and experimental manipulations are needed.

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Vabalt hõljuvate makrovetikamattide levik ja dünaamika Eesti rannikumeres (1995–2003)

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Vabalt hõljuvate makrovetikamattide esinemine on laialt levinud ja üha kasvavat tähtsust omav nähtus Läänemere rannikuvetes. Eesti rannikumeres esinevad vabalt hõljuvad vetikamatid suhteliselt madalates ja varjulistes lahtedes ning valdavalt liiva-savipõhjadel. Vetikamatte moodustavad tavaliselt *Pilayella littoralis/ Ectocarpus siliculosus*. Herbivooride ja detrivooride arvukus vetikamattides sõltub matis domineerivate vetikaliikide füsioloogilisest seisundist.