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Effect of cyanobacterial blooms on the abundance of the flounder *Platichthys flesus* (L.) in the Gulf of Finland

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Abstract. An extensive cyanobacterial bloom in the southern Gulf of Finland was observed from the end of June to the middle of July 2002 with a subsequent decaying phase of algae during 2–3 weeks after the bloom collapse. *Aphanizomenon* was the predominating genus in offshore areas, reaching in abundance the absolute maximum of the period 1997–2004. Mainly dead mass of phytoplankton driven to the coastal waters by wind affected significantly the abundance of 1-year-old flounder. Catch per unit effort of commercial size flounder decreased at several national fishing rectangles that were exposed to strongest cyanobacterial blooms according to satellite images. Strong cyanobacterial blooms were followed by a decrease in the abundance indices of the flounder spawning stock in Estonian waters of the Gulf of Finland.

Key words: cyanobacteria, flounder spawning stock, juvenile flounder.

INTRODUCTION

The abundance of *Aphanizomenon* sp. and *Nodularia spumigena* increased in the period 1974–1998 compared to the period 1887–1938 in the Baltic Sea (Finni et al., 2001). *Aphanizomenon* and *Nodularia* form annually mass populations during the summer period in the open Baltic Sea. *Nodularia spumigena* has been found responsible for the toxicity of the blooms and the toxin involved has been nodularin, a hepatotoxic cyclic pentapeptide (Anon., 1998). The cyano-

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bacterial bloom initiation always coincides with an increase of the surface water temperature over 14–16 °C (Kanoshina, 2000; Jaanus & Pellikka, 2003). The decomposition of the dead cyanobacterial mass, which can release the largest quantities of the toxic substances into the water, takes approximately 2–3 weeks after the bloom.

Phytoplankton blooms can affect different stages of fish in different ways. Laboratory experiments show that the strains of *N. spumigena* and *Microcystis aeruginosa* have a negative impact on the embryonic development and hatching regime of Baltic herring (Ojaveer et al., 2003). By clogging the fish gills and causing oxygen depletion, they can influence natural mortality of fish also without producing any toxic substances (Edler et al., 1996; Fogg, 2002).

Toxic substances can spread via the food web. A significant amount of nodularin was found in flounder liver in the Gulf of Finland, while its flesh was not found toxic (Sipiä, 2001; Karlsson et al., 2003; Kankaanpää et al., 2005).

The size, age, and seasonality determine the distribution of flounder by different depths. Smaller and younger individuals (1-year-old and younger) feed mainly in coastal areas at depths up to 2 m (Mikelsaar, 1958). Therefore their distribution overlapped with the high concentration of the cyanobacterial mass in shallow waters near the Estonian north coast in summer 2002. Dependence of young flounder on the algal blooms could be a point of interest.

The purpose of this study was to investigate the relationships between summer cyanobacterial blooms, abundance indices of young flounder, and changes in the distribution and abundance of the flounder spawning stock.

MATERIALS AND METHODS

The area covered by algal bloom in July 2002 was distinguished by using satellite images. Satellite images on 10 and 14 July, modified by A. Reinart, and on 17 July, modified by T. Kutser (Fig. 1), were considered. Two stations in the coastal area in Muuga and Tallinn bays (stations 1 and 57a) were studied for phytoplankton 2–3 times per month from June to August in 1993–2003 (Fig. 2). Additionally, data on phytoplankton from the ship route between Tallinn and Helsinki (stations wq9–wq11; Fig. 2), collected weekly in 1997–2004, were used (Jaanus & Pellikka, 2003). The abundance of cyanobacteria was analysed according to HELCOM (1988) recommendations.

For experimental catches at stations 2 and 3 (Fig. 2) monitoring gill nets with a length of 27 m and mesh sizes of 32–120 mm were used at first for the estimation of the catch per unit effort (CPUE) of younger age-groups of flounder. The age of fish was determined by otoliths. Only the catches in August and September were considered for the calculations in the case of young flounder, because the period after the bloom was relevant and the CPUE depends on season.

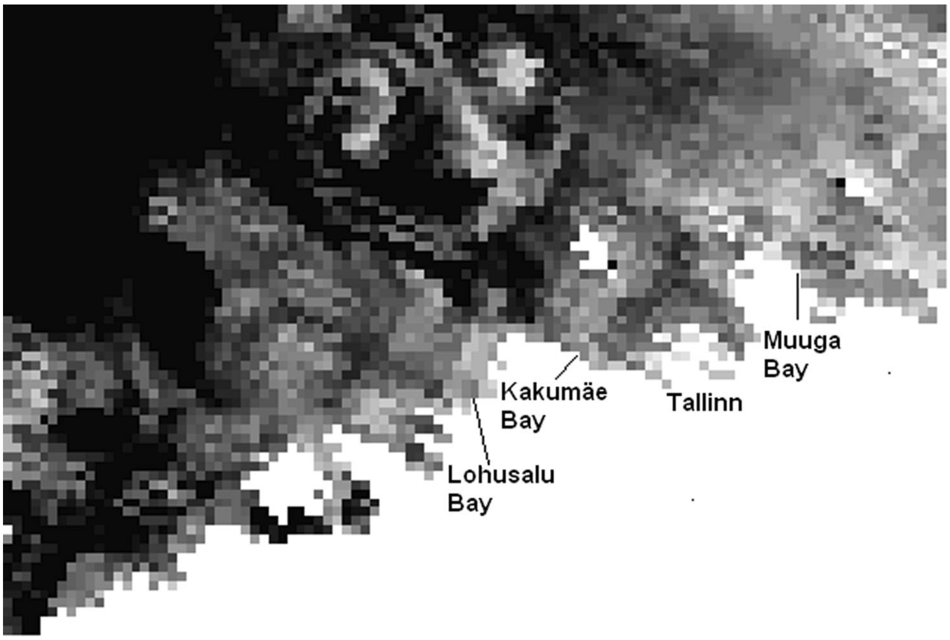

Fig. 1. Satellite image of the cyanobacterial bloom near the northern Estonian coast from the mouth of the Gulf of Finland to Muuga and Ihasalu bays on 17 July 2002 (modified by T. Kutser). The light grey colour corresponds to the cyanobacterial bloom (the darker the colour, the cleaner the water) and the white colour to land.

Experimental catches at reference station 1 in 1996–2004 were used to investigate the relative abundance of commercial size flounder. At this station gill nets with a length of 60 m and mesh size of 90–100 mm were used.

The study area of commercial fishery was situated between 25°50′ E and 24° E along the Estonian north coast, including 11 national fishing rectangles (Fig. 2). Flounder fishing takes place in the coastal area at depths up to 20 m. The fisher's log-books were used for the analysis of the abundance of commercial size flounder.

The number of nets per fishing day, summarized for different years (fishing effort) in experimental catches, is presented in Table 1. The fishing effort by fisher's log-books is shown in Table 2.

The differences in CPUE were compared using Mann–Whitney and Kolmogorov–Smirnov two-sample tests (Campbell, 1989). Regression and correlation analyses (Kiviste, 1999) were used to reveal the significance of trends in the CPUE dynamics of the commercial size flounder during the period when the beaches were closed.

Spawning stock numbers of flounder were calculated by Ad hoc Tuning of Cohort Analysis (Mohn & Cook, 1993) using the catch numbers in Estonian waters of the Gulf of Finland (Table 3). For the tuning the medians of CPUE

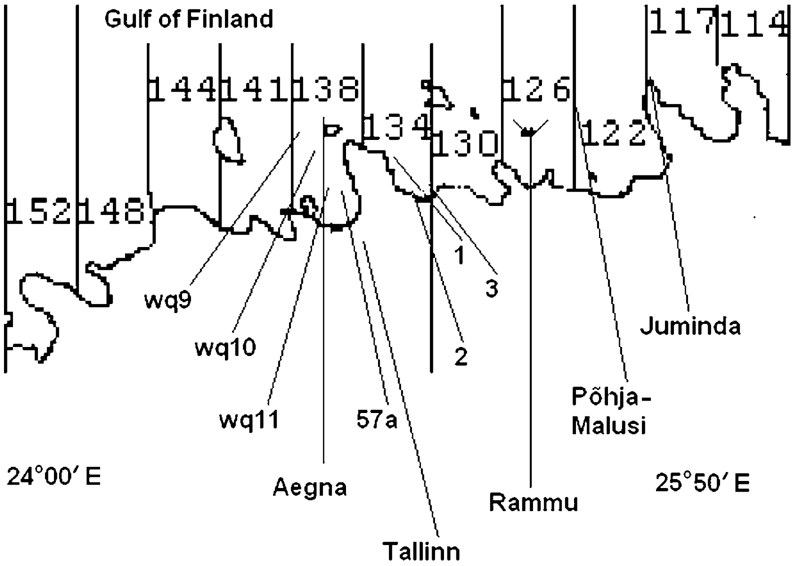

Fig. 2. Spawning areas of flounder near Muuga Bay (near the islands of Aegna, Rammu, and Malusi, and the Juminda Peninsula); Estonian national fishing rectangles 114–152 (flounder fishing takes place only in the coastal area and therefore northern borders of the rectangles are not important); monitoring stations (wq9, wq10, wq11 in Estonian waters along the ship route Tallinn–Helsinki; 57a, 1), stations of experimental catches in Muuga Bay (1–3).

Table 1. The number of experimental nets per day summarized for different years in Muuga Bay

Station	1996	1997	1998	1999	2000	2001	2002	2003	2004
1	359	535	585	862	699	625	687	513	489
2 and 3	–	–	–	70	56	99	60	62	18

– No experimental catches were made.

Table 2. Number of analysed nets per day summarized for national fishing rectangles by fisher's log-books in 2002

	Rectangle											Total
	114	118	122	126	130	134	138	141	144	148	152	
July	938	1520	1341	1012	439	609	1816	2785	361	2166	1982	14 969
August	871	1672	1467	642	240	651	2120	1757	749	2430	2200	14 799

according to experimental catches at station 1 from May to October (Fig. 3) were used. Maturity ogives 92% for age group 3, 97% for age group 4, and 100% for older flounder were observed.

Table 3. Number (thousands) of flounder caught in Estonian waters of the Gulf of Finland

Age	1996	1997	1998	1999	2000	2001	2002	2003	2004
3	426	299	529	677	451	1069	671	383	484
4	464	246	158	344	166	281	390	199	373
5	233	139	68	109	91	100	185	92	177
6	106	91	44	41	77	79	104	64	124
7	19	34	15	29	36	42	53	43	64
8+	3	13	13	9	46	34	71	91	41
Total	1251	822	827	1209	867	1605	1474	872	1263

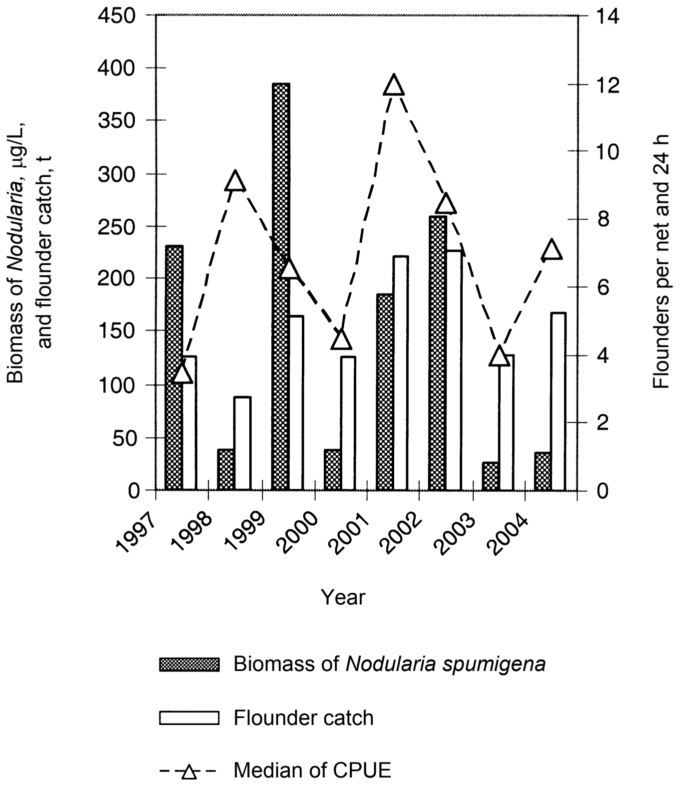

Fig. 3. Average biomass of *Nodularia spumigena* at stations wq9, wq10, and wq11 between 15 June and 31 July from 1997 to 2003; Estonian flounder catch in the Gulf of Finland; and median of the CPUE of commercial size flounder from May to October in Muuga Bay according to experimental catches at station 1.

RESULTS AND DISCUSSION

Relationship between cyanobacterial blooms and abundance of young flounder

During July 2002 the cyanobacterial species *Aphanizomenon* sp., *Nodularia spumigena*, and *Anabaena* spp. were abundant in the coastal areas of Muuga and Tallinn bays. That year the abundance of *Aphanizomenon* sp. attained the absolute maximum in the offshore areas of Estonian waters of the Gulf of Finland during 1997–2003 (Fig. 4). Its dead mass was driven by wind to the northern Estonian coastal areas during the second part of July. Clogging of the fish gills by cyanobacterial dead mass and the resulting oxygen depletion, which was amplified by relatively high water temperatures, may have been the main factor affecting the survival of young flounder.

Unfavourable conditions could be detected by an unusual behaviour of the blue mussel *Mytilus edulis*. In Muuga Bay the maximum abundance and biomass of the blue mussel were usually found at a depth of approximately 10 m in 1993–2000. During the bloom in 2002 the mussels released themselves from the hard substrate and currents carried them to deeper areas with soft bottom, unsuitable for the species. The mortality of the mussels was high (Kotta et al., 2004).

Table 4 presents the CPUE of the flounder 1998–2003 year classes at the age of 1 and 2 years. The age group 0 is very small until September and it feeds at depths of a few centimetres (Mikelsaar, 1958). Therefore its abundance could not be estimated by our experimental gillnet catches, which were done at depths of 3–15 m.

The decrease of the abundance of 1-year-old flounder in Muuga Bay after the algal bloom in summer 2002 may be a result of the increase of the natural mortality or redistribution (Table 4). Besides the 2001 year class the 2002 year class was affected. The latter was not caught from May to August 2002 in Muuga Bay. The appearance of the 2002 year class in September 2003 was a result of migration from the areas that were less affected by the bloom. There was a significant difference between medians and distributions of the CPUE of the 2001 year class and the 1998–2000 year classes of age 1–2 years at 95% confidence level.

Flounder has not been found spawning in Muuga Bay. The abundance of young flounder in the bay is probably connected with the nearest spawning areas of flounder. The most proximate spawning places are near the islands of Aegna, Rammu, and Põhja-Malusi and the Juminda Peninsula (Mikelsaar, 1957) (Fig. 2). Young flounder from these areas may migrate to Muuga Bay. According to the satellite images on 10 and 17 July 2002 the cyanobacterial bloom was stronger near Aegna and weaker off Rammu, Põhja-Malusi, and Juminda.

The cyanobacterial bloom was also strong near the southern coast of the Gulf of Finland during the first half of July 1997. During the second half of July the main mass of the cyanobacteria was moved to the northern coast of the gulf and the Estonian coastal area was less affected by the dead mass of cyanobacteria than in 2002 (Jaanus, 1997). There is no evidence that young flounder was affected.

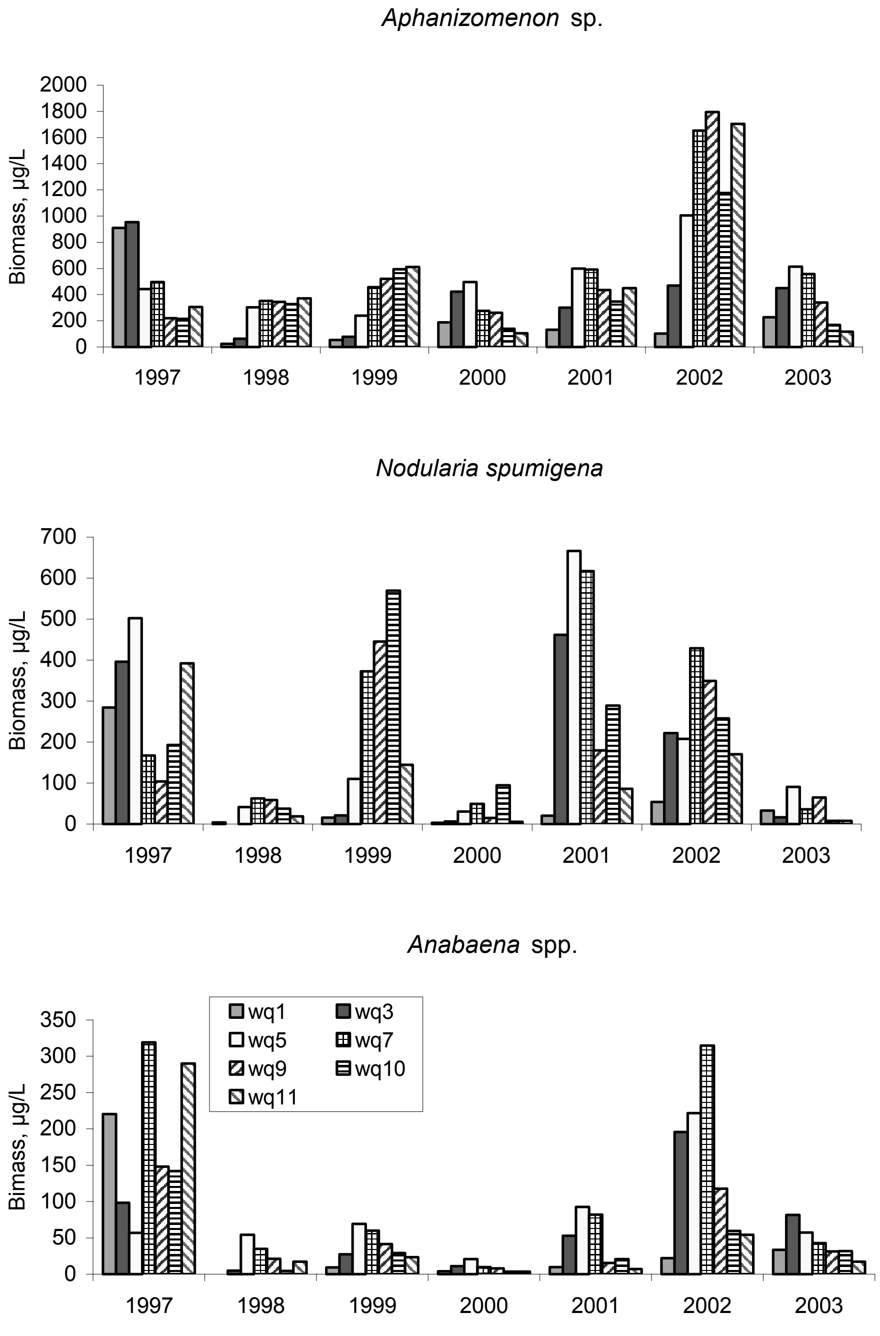

Fig. 4. Averaged (15 June to 31 July) biomass of *Aphanizomenon* sp., *Nodularia spumigena*, and *Anabaena* spp. according to weekly observations along the ship route Helsinki–Tallinn (stations wq1–wq11). The stations wq9–wq11 are situated near the Estonian coast.

Table 4. CPUE (number of individuals per net and night) of the 1998–2003 year classes of 1 and 2 years of age in Muuga Bay. Different catches are separated by semicolon, – no fishing

Fishing year	Year class	Age	April–July	August	September
1999	1998	1	0.07	8.3	2.4; 1.8
2000		2	2.2	–	22.7; 1.1
2000	1999	1	–	–	0.5; 1.1
2001		2	–	14.5	5.8
2001	2000	1	0.2; 0; 0	1.0	2.4
2002		2	2.4; 1.4; 2.4	1.9	4.0; 15.3
2002	2001	1	–	0	0; 0
2003		2	–	0	0.39
2003	2002	1	0	0	1.39
2004	2002	2	0.56; 2.3	–	–
2004	2003	1	0.1; 0.3	–	–

Relationship between cyanobacterial blooms and the abundance of flounder spawning stock

According to the data of the Estonian Central Laboratory of Microbiology of the Health Protection Inspectorate the absolute summer maximum of phytoplankton biomass in the coastal sea was registered in North Estonia during the second half of July 2002. Analyses were made near Tallinn at the beaches of Pirita, Kakumäe, and Stroomi. Between 16 and 30 July 2002 the water quality was regarded as unsuitable for bathing because of the cyanobacterial bloom (Anon., 2003b; N. Sossulina, pers. comm.). Data on the developing bloom at stations 57a and 1 in Tallinn and Muuga bays are presented in Table 5. Distribution of the dead cyanobacterial mass can be seen in the satellite image.

Table 5. Biomass (µg/L) of live cyanobacteria in Tallinn and Muuga bays in summer 2002

Station	Date	Cyanophyta	*Anabaena* spp.	*Aphanizomenon* sp.	*Nodularia spumigena*
57a	13 June	15	0	5	0
57a	26 June	1712	76	1356	0
57a	09 July	1889	180	1600	98
57a	24 July	547	16	286	227
57a	21 Aug	169	0	3	164
1	07 July	1071	15	601	427
1	17 July	437	43	374	0
1	28 July	1694	67	785	835
1	13 Aug	6	0	4	0
1	28 Aug	1199	65	268	136

The decrease of the CPUE (catch per net haul, kg) of the commercial size flounder at three national fishing rectangles (134, 144, and 148) according to fisher's log-books during the second half of July 2002 was statistically significant at $p < 0.05$ (Fig. 5). According to the satellite images, in July 2002 (Fig. 1) the bloom was strongest in Lohusalu (rectangle 148), Muuga (rectangle 134), Ihasalu (rectangle 130), and Kakumäe bays (rectangles 144 and 141). The CPUE of flounder was restored in rectangles 134 and 148 in August after the disappearance of the algal mass. In rectangle 144 the CPUE did not increase after the bloom. The CPUE depends on the effort. In rectangle 144 the effort doubled in August, but in rectangles 134 and 148 the effort did not change significantly. The relationship between CPUE and effort suggests that the latter could not be the main reason of the decrease of the CPUE in the second part of July 2002. Restoration of the CPUE after the bloom leads to the conclusion that the bloom affected mainly the distribution of larger flounder. In Estonian waters of the Gulf of Finland exploitation of the flounder stock was regulated by minimum mesh size of gill-nets (100 mm) and minimum commercial total length of the fish (21 cm in 2002). This makes the fisher's data of different fishing rectangles comparable as only spawning stock was considered.

The significance level of the negative trend of the CPUE (number of commercial size flounders per 24 hours and a net) of experimental catches at station 1 (rectangle 134) during the second part of July 2002 was 0.051 (almost significant).

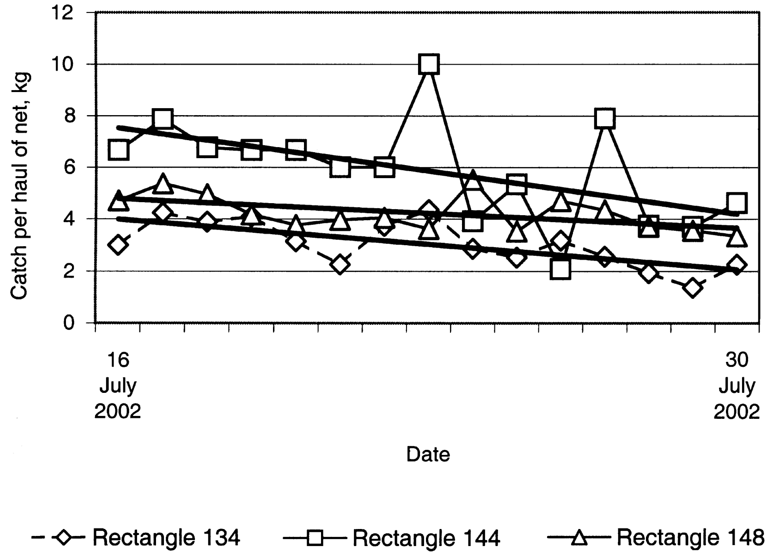

Fig. 5. Negative trend ($p < 0.05$) in catches per haul of net according to fisher's log-books at three national fishing rectangles.

Experimental catches at station 1 in Muuga Bay in 1996, 1998, 2000, 2001, and 2003, when the cyanobacterial bloom in Estonian waters was weaker than in 1999 (Fig. 4), did not show a statistically significant negative trend in the CPUE of flounder in the second half of July. In 1999, when the cyanobacterial bloom was stronger than the average of the period 1997–2003 (HELCOM, 2003; Jaanus & Pellikka, 2003), a negative trend was found. In 1997 the number of experimental catches in July was not sufficient for precise analysis.

The average biomass of *Nodularia* exceeding 200 µg/L between 15 June and 31 July, which was observed in 1997, 1999, and 2002 at stations wq9–wq11, was followed by a smaller flounder catch a year later in the Gulf of Finland (Fig. 3). The decrease of the CPUE of commercial size flounder at station 1 in 2000 and 2003 coincided with the decrease of total catch compared to the previous year (Fig. 3), which indicates a decrease of the flounder spawning stock. Also in September and October 1997, 1999, and 2002 smaller CPUE values by experimental catches were recorded at station 1 than in 1998, 2000, 2001, 2003, and 2004 (significance <0.001, Mann–Whitney test). The estimated spawning stock numbers decreased in 2000 and 2003 (Fig. 6). Experimental catches in Muuga Bay did not reveal any statistically significant decrease in the CPUE values in 1998 compared to the previous year, but in 2000 and 2003 it was found. The differences of the medians and in the distributions of CPUE values between 1999 and 2000 (medians 4.5 and 3.5, respectively) as well as between 2002 and 2003 (medians 8.5 and 4.0, respectively) were statistically significant (significance <0.01).

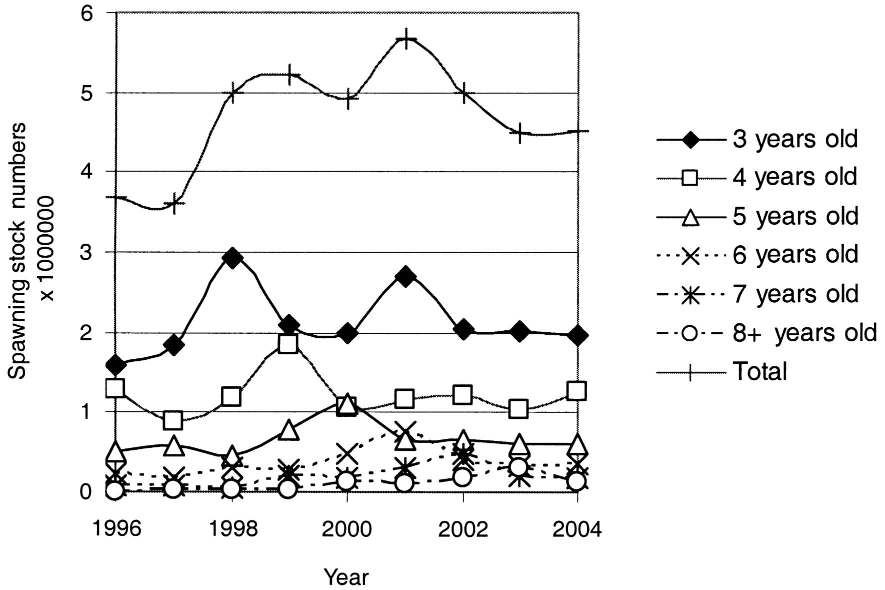

Fig. 6. Flounder spawning stock numbers in Estonian waters of the Gulf of Finland, estimated by Ad hoc Tuning of Cohort Analysis.

The changes of spawning stock abundance of flounder may be related to toxic *Nodularia spumigena.* Significant amounts of nodularins were found in flounder liver at the northwestern coast of the Gulf of Finland in 2000 and 2002, but no relationship between the liver histology and toxin content was found (Karlsson et al., 2003; Kankaanpää et al., 2005). In 2000 the abundance of *N. spumigena* was low (Fig. 4). In 2002 the cyanobacterial bloom kept mostly offshore from the northwestern coast of the gulf and was stronger near the southern coast (Perttila, 2003).

The abundance of flounder spawning stock depends on several factors. Among hydrological factors salinity and oxygen conditions are important. The salinity in deeper layers in the Gulf of Finland is positively connected to flounder spawning stock abundance (Drevs, 1999, 2000). Between Tallinn and Helsinki (HELCOM station F3) salinity at a depth of 60 m and deeper was rather high in 2001, and in 2003–2004 it was the highest in the period 1998–2004 (A. Põllumäe, unpubl. data). Therefore the changes in salinity could not cause the drop of commercial flounder abundance after the cyanobacterial bloom in 2003. In the same period and station, at a depth of 76 m, oxygen deficiency (0.4 mg/L) was observed once, on 25 July 2003 (S. Stjopin, pers. comm.). As during summer the major aggregations of flounder are distributed down to a depth of 40 m (Mikelsaar, 1958), short oxygen depletion in deeper layers cannot influence the abundance of flounder.

Cyanobacterial blooms coincide with higher water temperatures. At depths of 9–11 m (the main flounder fishing depth by gillnets in summer) a positive correlation was found between water temperature at the fishing depth and CPUE in the temperature range 11–19 °C, but it was not statistically significant at 95% confidence level. In the fishing depth by gillnets the temperature did not exceed 19.5 °C. In the temperature range 6–11 °C the correlation was very weak. Therefore the decrease of the CPUE of flounder in summer 2002 cannot be explained by higher water temperature.

In 2003 a decrease of the biomass of *Macoma baltica*, the main food of larger flounder, was observed at depths of approximately 6 m in Muuga Bay and an increase occurred at depths of approximately 16 m in comparison with 2002 (Kotta et al., 2004; Anon., 2003a; Kotta & Kotta, 2003). Such difference may change the CPUE of flounder in gillnets put in shallow waters, but not stock abundance.

Algae, especially entangled Cladophora, decrease the catchability by gillnets as these become more visible for fish. In the case of cyanobacterial masses, the size of the particles is small and the cyanobacterial dead mass is located in the surface layers, so that the visibility of nets situated near the bottom does not change significantly.

CONCLUSIONS

Summer cyanobacterial blooms may decrease the abundance of young flounder. The blooms change the distribution of the older flounder. They leave the areas with an unfavourable algal situation. Stronger cyanobacterial blooms are followed by decreased commercial flounder abundance indices in Estonian waters of the Gulf of Finland. There is a possibility that accumulation of cyanobacterial toxins may affect the flounder spawning stock.

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Sinivetikaõitsengute mõjust lesta *Platichthys flesus* (L.) arvukusele Soome lahes

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Tugev sinivetikaõitseng 2002. a suvel tõi kaasa 2001. a lestapõlvkonna arvukuse vähenemise Soome lahe katsepüükides. 2002. a suvel registreeriti sinivetika *Aphanizomenon* sp. biomassi absoluutne maksimum vahemikus 1997–2004. Viimase surnud mass kandus Põhja-Eesti rannikule juuli teisel poolel, millega kaasnes aastaks 1-aastase lesta kadumine Muuga lahe katsepüükidest. Lesta kudekarja arvukuse vähenemine 2002. a juuli teisel poolel Muuga, Kakumäe ja Lohusalu lahes oli ajutine ja seostus lesta ümberpaiknemisega. Toksilise sinivetika *Nodularia spumigena* biomassile üle 200 µg/L 15. juuni ja 31. juuli vahel, mis registreeriti 1997., 1999. ja 2002. a, järgnes lesta kudekarja suhteliselt madalam saagikus (CPUE) septembris–oktoobris ja Eesti lestasaagi vähenemine aasta hiljem Soome lahes. Võrreldes eelmise aastaga, vähenes CPUE Muuga lahe katsepüükides 2000. ja 2003. a. Seega võib öelda, et neil aastatel vähenes ka lesta kudekarja arvukus. Kuna 2000. ja 2002. a leiti Soome edelaranniku lähedalt lesta maksast suhteliselt suuri nodulariini koguseid ka väiksema *Nodularia* arvukuse korral kui Eesti vetest 1999. ja 2002. a, võib oletada, et see mõjutas lesta kudekarja tervislikku seisundit.