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Harvesting of *Nodularia spumigena* in the Baltic Sea: Assessment of Potentials and Added Benefits

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ABSTRACT

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Interest to harvest wild cyanobacteria exists due to the environmental and socioeconomic risks during cyanobacteria blooms coupled with demands for nonterrestrial-based alternatives for biofuel sources. This research, therefore, sought to estimate the wild cyanobacteria harvesting potential using *Nodularia spumigena*, and using the Baltic Sea as the case study. Data from literature provided during years 2003–2009 were used to perform estimations. Additional benefits of harvesting were also assessed by estimating the nutrient removal and biogas production potentials from the harvested biomass. Results indicate that one boom unit has the potential to harvest approximately 3 to 700 kg dry weight of *N. spumigena* per hour depending on the algae concentration of the bloom. Results also suggest that nutrient removal and biogas production potentials provide substantial additional incentives to the harvesting operation during years of extensive and highly concentrated blooms. However, during nonextensive or nonconcentrated blooms such potentials are low.

ADDITIONAL INDEX WORDS: *Biomass harvesting, nutrient removal, cyanobacteria.*

INTRODUCTION

Background

Occurrences of harmful cyanobacteria blooms in the Baltic Sea have caused a variety of environmental and socioeconomic concerns. Exposure to nodularin, which is produced by *Nodularia spumigena* (Sivonen *et al*., 1989), can cause health risks and livestock mortality in coastal areas (Codd *et al*., 1999; Kononen, 1992; Pilotto *et al*., 1997). Swedish property values in areas with cyanobacteria blooms have the potential to be devalued by 50% (Hasselström, 2008). Moreover, a cyanobacteria bloom in 2005 led the county of Öland, Sweden to lose approximately US$22 million in turnover on beach tourism (Hasselström, 2008). These concerns coupled with increasing demands for nonterrestrial-based alternatives for biofuel sources (Schenk *et al*., 2008) creates interests to harvest cyanobacteria from the Baltic Sea.

Although methods to harvest cyanobacteria blooms have been previously suggested (*e.g.*, Gröndahl, 2009), there is a lack of literature on quantified approximations for: (1) the wild cyanobacteria harvesting potentials in the Baltic Sea, (2) the associated nutrient removal potentials, and (3) the associated energy production potentials. Therefore, the present study sought to provide first-hand quantified estimates for the biomass potential and the additional benefits regarding wild cyanobacteria harvesting in the Baltic Sea by examining the spatiotemporal properties of cyanobacteria blooms during the years 2003–2009.

Case Study

In this work, the Baltic Sea region was used as the study area. According to the Helsinki Commission (HELCOM, 2011), the Baltic Sea, with a total surface area of 415,266 km^2, can be divided into 10 subregions (Figure 1). The Baltic Sea has a long history of eutrophication and seasonal algal blooms (*e.g.*, Kahru, Savchuk, and Elmgren, 2007; Wasmund, Voss, and Lochte, 2001). In 2006, the total waterborne nutrient load from natural and anthropogenic sources to the Baltic Sea was an estimated 630,000 t of total nitrogen and 28,000 t of total phosphorus (*e.g.*, Pawlak, Laamanen, and Andersen, 2009). The enrichment of nutrients often leads to an increase in the abundance of primary producers, which take the form of phytoplankton blooms (including cyanobacteria) in marine environments. Numerous monitoring stations have been established by Swedish Meteorological and Hydrological Institute (SMHI) and HELCOM in the Baltic Sea. For the present study, we obtained wave height data from the Huvudskär Öst and Södra Östersjön stations and biological and hydrological data from the BY 5, BY 15, and BY 31 stations (see Figure 1). Although many other stations exist, data inaccessibility and incompatibility prevented the use of those monitoring stations in this work.

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Figure 1. Subregions of the Baltic Sea. Crosses mark observation stations from which data were used in this study (modified from HELCOM) (2011).

The species chosen for the study was *N. spumigena*, which can produce large intracellular concentrations of the toxic nodularin (Codd *et al*., 1999; Lehtimäki *et al*., 1997; Sivonen *et al*., 1989). Exposure to nodularin has the potential to cause livestock mortality (Codd *et al*., 1999; Sivonen *et al*., 1989) and may impose potentially serious health risks (Codd *et al*., 1999; Pilotto *et al*., 1997). Blooms of *N. spumigena* have been observed in the Baltic Sea in the past and are stimulated by availability of iron and molybdenum (Stal, Staal, and Villbrandt, 1999; Stolte *et al*., 2006), a suitable N : P ratio in the water (Håkanson, Bryhn, and Hytteborn, 2007), and suitable irradiance (Staal *et al*., 2002). *Nodularia spumigena* are competitive toward other species because of their physiological abilities, *e.g*., nitrogen fixation (Bergman *et al*., 1997; Ferber *et al*., 2004) and tolerance of high radiation intensities including ultraviolet radiation (Mohlin and Wulff, 2009). Suitable temperature, weather conditions, vertical stratification of the Baltic Sea (Kanoshina, Lips, and Leppänen, 2003), and the loss of buoyancy regulation (Graham, Graham, and Wilcox, 2008) also contributes to bloom developments.

However, one of the most important factors that leads to bloom formations of N_2-fixing cyanobacteria in the Baltic Sea, *e.g*., *N. spumigena*, is the low concentration of dissolved inorganic nitrogen (DIN) at the end of the spring phytoplankton bloom, which favours N_2-fixing cyanobacteria (Larsson *et al*., 2001; Walve and Larsson, 2007, 2010). As summer progresses into July, August, and early September, the competition for dissolved inorganic phosphorus (DIP) increases, which eventually causes the collapse of the N_2-fixing cyanobacteria blooms in the Baltic Sea at the end of the summer (Walve and Larsson, 2010). This is partially reflected by the elemental composition of *N. spumigena*, which has been found to vary widely (Czerny, Ramos, and Riebesell, 2009; Karlson, Nascimento, and Elmgren, 2008; Larsson *et al*., 2001; Lignell *et al*., 2003; Mohlin and Wulff, 2009; Panosso and Graneli, 2000; Walve and Larsson, 2007, 2010) with C : N : P ratios that differ from the Redfield ratio, 106 : 16 : 1 (Karlson, Nascimento, and Elmgren, 2008; Mohlin and Wulff, 2009; Panosso and Graneli, 2000). Larsson *et al*. (2001) suggest that the C : N : P ratio for *N. spumigena* is highly sensitive to the concentrations of DIN and DIP, with high nitrogen and phosphorus contents in the spring drastically decreasing toward July and August, as also observed by Lignell *et al*.(2003) and Walve and Larsson (2007, 2010).

METHODS

Extent of *N. spumigena* Blooms

The extent of blooms was explored in two respects. The first considered the number of days of intensive blooms during a season for each of the regions in Figure 1. This represents the number of days during which boom units could be operated, thus limiting the total harvest. The second considered the largest area covered by an intensive bloom on a single day. Previously, the use of satellite images has been proposed as a means of performing observations of the sporadic nature of cyanobacteria blooms (*e.g*., Kahru, Horstmann, and Rud, 1994; Kahru, Savchuk and Elmgren, 2007). Therefore, satellite images provided by SMHI were used to determine the areas and the annual periods in which intensive blooms of cyanobacteria occurred during the years 2003–2009. In this study, blooms evident from satellite imagery between June and September were assumed to be cyanobacteria blooms. This assumption follows observations in the literature (*e.g*., Wasmund and Uhlig, 2003; Wasmund, Voss, and Lochte, 2001) showing that the Baltic Sea is regularly subjected to three major blooms of photosynthetic microorganisms per year, where the summer bloom (spanning from approximately June to September) is dominated by cyanobacteria (Gröndahl, 2009; Håkanson, Bryhn, and Hytteborn, 2007; Larsson *et al*., 2001; Lignell *et al*., 2003; Walve and Larsson, 2007; Wasmund and Uhlig, 2003). The sizes of the cyanobacteria blooms are determined by measuring the spatial size of blooms as witnessed from the satellite images using geographical information system tools.

Although cloud coverage may be expected and obscure the determinations of bloom occurrences from satellite imagery, evidences from satellite images provided by SMHI (2011) indicate that blooms disperse temporarily during major cloud coverage and reform once the weather become stable. Furthermore, Kanoshina, Lipps, and Leppänen (2003) suggest that warm and calm weather is mandatory for cyanobacteria bloom development. This suggests that bloom events are well represented by satellite imagery. However, since satellite images do not portray spatial cyanobacteria concentration variations, an interval of *N. spumigena* concentration extremes during intensive blooms was estimated to reflect the potential *N. spumigena* concentrations throughout the intensive blooms' area. This yields extreme estimation values, framing a representative mean of the whole area and bloom event. More accurate estimations would require statistically based methods, for which compatible data are not available.

Biomass Concentration during an Intensive Bloom

The cyanobacteria concentration during an intensive bloom in the Baltic Sea was determined by observing available data

Table 1. *Number of days with intensive blooms in different basins of the Baltic Sea over the period 2003–2009 (data compiled from SMHI, 2011).*

	2003	2004	2005	2006	2007	2008	2009
Bothnian Bay							
Bothnian Sea				2	2	6	2
Åland & Archipelago Sea							
Gulf of Finland			1		10		
Northern Baltic proper	18		17		4	9	
Gulf of Riga	2			4	7		
Gotland Basin	23	6	21	16	2	12	2
Southern Baltic proper	12	7	14	16		7	
Gulf of Gdansk	6	2	4	1			

Blank cell means that the blooms were either not indicated as intensive or not detected on the satellite images.

from cyanobacteria sampling from the selected monitoring stations. Blooms that result in major surface accumulations are monitored and classified as “Kraftig” (“intensive” in English) by SMHI (SMHI, 2011) through using satellite imagery (Kahru, Horstmann, and Rud, 1994; Kahru, Savchuk, and Elmgren, 2007) coupled with manual determinations (Jörgen Öberg, pers. comm.) of the bloom’s intensiveness. In the present study, we included only intensive-labeled blooms, despite the fact that considerable concentrations of *N. spumigena* may have been present at other occasions, thereby keeping our estimates conservative.

Cyanobacteria concentrations in the Baltic Sea are monitored by SMHI using a 10-m tube, from which a sample is taken to determine species-specific phytoplankton concentrations (Helena Höglander, *personal communication*). However, Hajdu, Höglander, and Larsson (2007) report that various species of cyanobacteria are concentrated toward the sea surface during an intensive bloom. In some cases, *N. spumigena* are highly concentrated from the surface to around 1-m depth, whereas in other cases their abundance spans from the surface to around 5-m depth. This means that water sampled with a 10-m tube reflects a more concentrated solution of cyanobacteria from the top of the water column mixed with a more dilute solution at depth. To estimate the concentration in the top 1 m, which was accessed with the boom harvesting equipment, the values obtained were multiplied by a factor of 2 and 10 to reflect low and high estimates of surface accumulation during intensive blooms, assuming cyanobacteria to be concentrated in the top 5 m and 1 m, respectively. From the low and high estimates of cyanobacteria surface accumulation, the minimum and maximum concentrations were determined and used to represent the concentration extremes during intensive blooms.

To convert biomass concentration from ng C L^{-1} (as reported from the monitoring stations) to μg dry weight (dwt) biomass L^{-1} (C^{dw}), we used data on the elemental composition of *N. spumigena*. The elemental composition of *N. spumigena* has been found to vary as previously discussed. In this study, the average summer C : N : P (280 : 58 : 1) of *N. spumigena* collected in Landsort Deep provided by Walve and Larsson (2010) was used, where on average the C, N, and P constitute approximately 43%, 8%, and 0.6% of *N. spumigena* dry weight, respectively. Hence the quantification of *N. spumigena* biomass concentration is obtained by:

$$C^{dw}_{Nodularia} = \frac{(C^{Carbon}_{Nodularia}/z^{\%\ dwt}_{carbon}) \times 100}{1000} \quad (1)$$

where $C^{dw}_{Nodularia}$ is the *N. spumigena* dry weight biomass concentration in μg dwt L^{-1}, $C^{Carbon}_{Nodularia}$ is the *N. spumigena* biomass concentration in ng C L^{-1}, and $z^{\%\ dwt}_{carbon}$ represents the carbon percentage of dry weight of *N. spumigena*, which was taken as 43%, as discussed above.

Potential for Field Harvesting of Wild *N. spumigena*

To estimate the potential for field harvesting of *N. spumigena*, the method of harvesting proposed by Gröndahl (2009) for cyanobacteria was used as an example. The method involves using one or two boats to tow a 50-m-long oil boom. The boom is modified to accommodate a polyester fabric, which successfully captures *N. spumigena* but is only effective to a maximum depth of 1 m (Gröndahl, 2009). However, this depth limitation does not prevent the capture of *N. spumigena*, since previous sampling studies (e.g., Hajdu, Höglander, and Larsson, 2007) suggest that wild *N. spumigena* are usually concentrated near the surface. The effectiveness of an oil boom decreases at significant wave heights beyond 1 m (USEPA, 1999). However, examination of data from the Huvudskär Öst and Södra Östersjön stations (SMHI, 2011) showed that significant wave heights were never more than 1 m during any of the intensive blooms in 2002–2009. Thus, wave height would not limit the efficiency of *N. spumigena* harvesting.

Pilot tests performed by Gröndahl (2009) showed successful removal of cyanobacteria from the water column at speeds of up to 3.7 km h^{-1} (2 knots). A coverage rate of 0.1 km^2 h^{-1} is achievable at a speed of 3.7 km h^{-1} with a 50-m oil boom, corresponding to a treated volume of 100 million L h^{-1} and boom unit. The biomass harvesting efficiency is here assumed to be 100% due to lack of field test results. The uncertainty of the efficiency is low when compared with the uncertainty of the biomass concentration during intensive blooms and will not greatly affect our results. The harvesting capacity of wild *N. spumigena* biomass per hour and boom unit is obtained by:

$$M_{wild\ harvest} = C^{dw}_{Nodularia} \times W_{processed} \times t \times 10^{-9} \quad (2)$$

where $M_{wild\ harvest}$ is the wild biomass harvesting capacity or the total yield of one boom unit in kg dwt per oil boom unit, t is the harvesting time in hours, $W_{processed}$ is the processed water in L h^{-1}, and $C^{dw}_{Nodularia}$ is the *N. spumigena* dry weight biomass concentration in μg dwt L^{-1}.

Estimate of Nutrient Removal and Energy Production Potential as Additional Benefits

The nutrient removal potential was estimated to correspond to the intracellular nitrogen and phosphorus contents, obtained from Walve and Larsson (2010), of the harvested biomass. We also estimated the energy production potential of *N. spumigena* biomass if used for biogas production. Rui *et al*. (2007) showed that blue-green algae consist of approximately 94% volatile solids (VS) and that a 2 : 2 : 1 mixture of blue-green algae, pig manure, and water can achieve a gas production of 366 mL (g VS)$^{-1}$, whereas the biogas production from microalgae has been reported to range from 287 to 587 mL (g VS)$^{-1}$ (Mussgnug *et al*., 2010). Thus, the potential biogas yield $B_{wild\ harvest}$ (mL) was roughly estimated as:

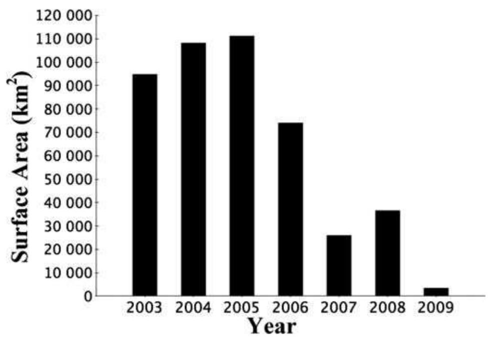

Figure 2. Surface areas (km^2) of the largest intensive cyanobacteria blooms in the Baltic Sea during 2003–2009, calculated using data and tools provided by SMHI (2011) and HELCOM (2011).

$$B_{\text{wild harvest}} = G \times \text{VS}_{\%} \times M_{\text{wild harvest}} \times 1000 \quad (3)$$

where $\text{VS}_{\%}$ is the percentage of VS in cyanobacteria and G is the biogas production (mL [g VS]$^{-1}$). Here, G was assumed to be 366 mL (g VS)$^{-1}$ and VS 94%, following the experimental results of Rui *et al*. (2007).

RESULTS AND DISCUSSION

Extent of Cyanobacteria Blooms

Table 1 shows the number of days with intensive blooms in the Baltic Sea, as monitored by SMHI through satellite imagery. The values shown take no account of whether the blooms were continuous or singular. Several limitations to wild cyanobacteria harvesting are suggested by Table 1. The first of these is the location, with intensive blooms of cyanobacteria occurring in the Gotland Basin every year but more erratically in other basins of the Baltic Sea. The second limitation to wild cyanobacteria harvesting is the duration of the blooms, with the number of days varying between 0 and 23 for different basins and years.

Although annual occurrences of cyanobacteria blooms are very likely in the Gotland Basin (Table 1), these blooms are sporadic in terms of size (Figure 2), location, and duration. For example, one continuous intensive bloom with large sea-surface coverage in 2005 lasted for approximately 15 days, whereas an intensive bloom with small sea-surface coverage in 2009 lasted only 3 days (Table 1 and Figure 2). However, the large difference between 2003 and 2009 coupled with the decreasing trend of Figure 2 does not reflect declining blooms over time. Similar trends have been previously observed between 1982 and 1986 and 1989 and 1993 (Kahru, Horstmann, and Rud, 1994; Kahru, Savchuk, and Elmgren, 2007). Moreover, satellite images between 2007 and 2009 indicate long-term unstable weather conditions throughout the summers, which is detrimental to cyanobacteria bloom development (Kanoshina, Lips, and Leppänen, 2003). Furthermore, satellite images for 2010 onward suggest that major summer blooms still exist. The 2010 and 2011 data sets were, however, not included in this study because of a change in the bloom characterization by SMHI (2011), providing data that were incompatible with the 2003 to 2009 data.

Table 2. *Dry weight concentrations of* Nodularia spumigena *in intensive blooms at different SMHI monitoring stations in the Baltic Sea (see Figure 1).*

Date	Monitoring Station	10-m Tube Field Data (μg dwt L^{-1})[a]	Surface Accumulation Corrected Values (μg dwt L^{-1})[b]	
			Low Surface Accumulation[b]	High Surface Accumulation[b]
31 July 2003	BY 15	32.4[c]	65	320
14 July 2005	BY 15	123.9[c]	250	1200
12 July 2006	BY 5	733.3	1500	7300[d]
30 July 2008	BY 31	13.4	27[d]	130
31 July 2008	BY 15	77.8	160	780

[a] Data from SMHI (2011).
[b] Concentrations of *N. spumigena spumigena* harvested with the modified boom were multiplied by a factor of 2 or 10 to represent the depth distribution in the top 5 m and 1 m, respectively.
[c] Calculated from reported number of individuals per litre by SMHI (2011) using average carbon content of 1.428 ng C per individual from data for 2006–2008.
[d] Estimated minimum and maximum cyanobacteria concentration extremes during intensive blooms.

Figure 2 shows the largest area covered by blooms on a single day in each year during the years 2003–2009. The maximum size of intensive cyanobacteria blooms varied from one year to the next as portrayed in Figure 2. The largest intensive bloom covered as much as 34% of the Baltic Sea surface and the lowest as little as 1% (Figure 2). On the basis of the concentrations provided in Table 2, the results for 2006 in Figure 2 correspond to 520,000 t dwt *N. spumigena*. The retrieval of this biomass corresponds to 42,000 t of nitrogen removal potential or 40–50% of the Swedish anthropogenic nitrogen discharge as given by SEPA (2009), suggesting that such removal would potentially affect the nitrogen balance of the Baltic Sea. Such retrieval of biomass also has the potential to produce biogas with a market value of US$80,000, assuming a biogas price of US$0.07 (kWh)$^{-1}$, on the basis of Davidsson and Turesson (2010).

Biomass Concentration during Intensive Blooms

Cyanobacteria concentrations recorded during intensive blooms identified during the years 2003–2009 are shown in Table 2. The concentration of *N. spumigena* was found to be lowest at the BY 31 station and highest at BY 5. After correction for (uncertain) depth distribution of *N. spumigena* and temporal and spatial variation in data, the minimum and maximum *N. spumigena* concentrations ($C^{\text{dw}}_{Nodularia}$) were estimated to be approximately 25 μg dwt L^{-1} and 7000 μg dwt L^{-1} for intensive blooms. These concentration extremes bracket the cyanobacteria concentrations in blooms previously observed by Kanoshina, Lips, and Leppänen (2003) from 1997 to 1999, for which the average *N. spumigena* correspond to approximately 80 μg dwt L^{-1} and 1200 μg dwt L^{-1}, on the basis of the 40% dry intracellular content following Bratbak and Dundas (1984).

Although the extensive concentration extremes are likely to bracket natural variations in concentrations, they negatively affect the precision of the potential biomass harvest estimates. Increased accessibility to data from monitoring stations during

Table 3. *Hourly nutrient removal and energy production potential of wild* Nodularia spumigena *harvesting with one oil boom.*[a]

	Minimum	Maximum
N. spumigena harvest capacity (kg dwt)	2.7	730
Intracellular nitrogen (kg N)	0.21	59
Intracellular phosphorus (kg P)	0.02	4.4
Biogas production potential (L)	920	250,000

[a] One hour corresponds to 3.7 km of harvest (Gröndahl, 2009).

intensive blooms may potentially provide a better understanding of concentration variability or a narrower range for concentration extremes estimates.

Annual Harvesting Potential per Unit Boom

The results reported in Table 1 indicated that the Gotland Basin has the most extensive and regular blooms. Using the hourly harvesting capacity of one oil boom (Table 3) in conjunction with maximum number of days of harvesting (Table 1) for Gotland Basin, Table 4 shows the annual harvesting potential, as an example. Harvesting of cyanobacteria to avoid environmental and socioeconomic risks of blooms may, however, also be located at other sites. The calculated annual harvesting potential follows the assumption of 12 hours of harvesting per day. Table 4 suggests that harvesting of wild cyanobacteria in the Gotland Basin with one unit alone would potentially have yielded 0.06–200 t of biomass annually. The corresponding estimated annual nitrogen removal potential is 0.005–16 t, which is equivalent to the annual local emissions to the hydrosphere via organic waste handling from 2 to 5000 people. Moreover, this harvesting of wild cyanobacteria in the Gotland Basin would also have potentially yielded 0.0007–2.3 t of phosphorus. Such harvesting of phosphorus from the Baltic Sea is interesting in view of the increasing global scarcity of phosphorus (Hultman *et al.*, 2001; Neset and Cordell, 2012; Schipanski and Bennett, 2012). Although the retrieval of biomass will not directly reduce availability of nutrients in eutrophic coastal areas, it may positively affect the nutrient balance of the Baltic Sea as a whole.

In terms of energy potentials, Table 4 shows mixed results. The maximum energy production estimates are nearly twice the energy required to perform wild cyanobacteria harvests. However, the minimum estimates suggest that energy provided by biogas production is much lower than the energy required for wild cyanobacteria harvest. Although a positive outlook exists for energy potentials of wild cyanobacteria harvests (Tables 3 and 4), in some cases anaerobic digestion in microalgae cultivation systems has led to a negative energy balance of microalgae-to-biofuel systems (*e.g.*, Razon and Tan, 2011). Thus, a more thorough investigation on large-scale cyanobacteria harvests and energy production is needed to reveal if the energy benefits from highly concentrated blooms are potential incentives for cyanobacteria harvesting.

CONCLUSIONS

This study investigated the energy production and nutrient removal potentials as additional benefits of harvesting wild cyanobacteria for alleviation of economic and health risks, aspects of which have not been previously addressed in the scientific literature. The accuracy of the estimates was limited by the availability of concentration data for surface-accumulated biomass in the literature and knowledge of the spatiotemporal variations of concentrations. Nevertheless, the results indicate that potential exists for harvesting wild cyanobacteria using oil booms, with the Gotland Basin observed to be the location with the largest and most regular blooms in the Baltic Sea. During years of extensive cyanobacteria blooms, the harvesting of wild cyanobacteria has the potential to remove considerable quantities of nutrients. However, during years of nonextensive cyanobacteria blooms, the potential to remove nutrients remains minimal. Results also suggest that potential energy incentives may exist when cyanobacteria concentrations are high, but further investigations on energy and economic issues of biogas production from cyanobacteria are required. Furthermore, environmental, social, and economic consequences of cyanobacteria harvests need to be addressed in future studies.

Table 4. *Annual potential of wild cyanobacteria harvesting per unit oil boom for the Gotland Basin and additional benefits.*[a]

	2003		2004		2005		2006		2007		2008		2009	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Nodularia spumigena sp. (t dwt)[b]	1.4	380	0.4	100	1.3	350	0.98	270	0.12	33	0.73	200	0.12	33
Intracellular P (kg P)	4.4	1200	1.2	320	4	1100	3	840	0.39	110	2.3	630	0.39	110
Intracellular N (kg N)	59	16000	15	4000	54	15000	41	11000	5.1	1400	31	8500	5.1	1400
N emissions per person equivalent[bc]	19	5200	5	1400	17	4800	13	3600	2	450	10	2700	2	450
Biogas potential (GJ)[cd]	0.61	170	0.16	44	0.56	150	0.42	120	0.05	15	0.32	87	0.05	15
Potential diesel required for harvest (GJ)[de]	100	100	27	27	92	92	70	70	9	9	53	53	9	9

[a] Min and Max represent results using different assumptions on cyanobacteria surface accumulation, and spatiotemporal variation in field observations reported in the literature.

[b] Twelve hours of harvesting per day (coupled to Table 1).

[bc] Nitrogen removal potential in ratio of the nitrogen discharge to the hydrosphere via organic waste handling per person (3.1 kg N per capita and year as given by Neset, Bader, and Scheidegger [2006]).

[cd] Energy produced from the potential biogas yield can be estimated as $E_{\mathrm{biogas}} = E_{\mathrm{methane}} \times X^{\%}_{\mathrm{methane}} \times B_{\mathrm{harvest}} \times 10^{-3}$ where E_{biogas} is the potential energy produced from the potential biogas yield(MJ), E_{methane} is the energy obtained from combusting methane (MJ L^{-1}), and $X^{\%}_{\mathrm{methane}}$ is the percentage of methane content of the biogas produced. Here E_{methane} is considered to be 0.004 MJ L^{-1} (Houdkova *et al.*, 2008) and $X^{\%}_{\mathrm{methane}}$ is considered to be 60% (Rui *et al.*, 2007).

[e] The energy required to harvest wild cyanobacteria can be estimated as $E_{\mathrm{harverst}} = \mathrm{t} \times \mathrm{F} \times \mathrm{D} \times E_{\mathrm{diesel}}$ where E_{harvest} is the energy required to harvest wild cyanobacteria (MJ), F is the fuel consumption (L h^{-1}), D is the fuel density (kg L^{-1}), and E_{diesel} is calorific value of diesel (MJ kg^{-1}). On the basis of the assumption that Yanmar 4BY2-150 engine would be used, F is 10 L h^{-1}, D is 0.85 kg L^{-1} (Heywood, 1988), and E_{diesel} is 43.1 MJ kg^{-1} (Stephenson *et al.*, 2010).

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☐ ABSTRAKT ☐

Intresset för skörd av cyanobakterieblomningar beror på de miljö- och socio-ekonomiska risker som blomningarna medför. Ytterligare en bidragande orsak till detta intresse är efterfrågan efter icke markbaserade biobränslealternativ. Denna studie ämnar därför att undersöka potentialen med skörd av vilt förekommande cyanobakterieblomningar med arten *Nodularia spumigena* och Östersjön som fallstudie. Litteraturdata från åren 2003–2009 användes för att kvantifiera blomningarna. Ytterligare fördelar med skörden utvärderades också genom en uppskattning av näringsreduktionens och biogasproduktions potentialen av den skördade biomassan. Resultat indikerar att en skördeenhet har potentialen att skörda uppskattningsvis 3 till 700 kg ts *Nodularia spumigena* per timme beroende på algblomningens koncentration. Resultaten indikerar dessutom att näringsreduktionsförmågan och biogasproduktions-potentialen tillhandahåller ytterligare substantiella incitament för skörd under år med omfattande och koncentrerade blomningar. Dessa ytterligare incitament är dock inte betydande under de år då blomningarna inte är omfattande och koncentrerade.