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MACROALGAE MANAGEMENT IN COASTAL REGIONS IN THE ASPECT OF THE SUSTAINABLE DEVELOPMENT STRATEGY

Key words: macroalgae, organic recycling, Puck Bay

ABSTRACT. The article discusses the problem of excessive growth of one-year filamentous algae, contributing to the disturbance of ecological balance in the Puck Bay. The aim of the study is to estimate the possibility of restoring this balance through the use of macroalgae as a co-substrate for biogas and fertilizer production in the regional biological wastewater treatment plant (WWTP). Effectiveness of biogas production from aquatic plants, including free-floating filamentous algae, was examined. Tests have shown that the biogas potential of seaweed constitutes the level of 162 m³/Mg of organic dry solid substances of algae. It was estimated that using the summer intense algal growth, removing 65,000 Mg of algae, 800,000 m³ of biogas can be obtained from the area covering the inner Puck Bay. After biogas conversion, 2,320 MWh of electricity and 2,100 MWh of heat energy could be produced. Harvesting free-floating algae enables the annual removal of 100-150 Mg of phosphorus and 200-400 Mg of nitrogen from Puck Bay and, thus, reduces the level of its eutrophication. Macroalgae management at a certain stage of growth also prevents the presence of algae on beaches and contributes to the improvement of fishing conditions and boosts the tourism value of the region.

INTRODUCTION

The Baltic Sea, due to an excessive inflow of nitrogen and phosphorus (nutrients), is an area that is very much covered by eutrophication processes. Despite numerous legal regulations limiting the discharge of nutrients into the water, studies carried out for the years 2011-2016 show that 97% of the Baltic region was assessed to be below good eutrophication status[HELCOM 2018]. Eutrophication is characterized by a significant increase in primary production (reproduction of autotrophic organisms, i.e. algae, cyanobacteria). A high level of eutrophication is noted, inter alia, in shallow warm gulfwaters, where mixing processes are limited. One of the areas particularly exposed is the Puck Lagoon (inner Puck Bay from the west to Kuźnica – the Rewa line). The implementation of the sustainable development strategy in this seaside region must take into account both the aspect of environmental protection and the proper development of the economy. On the one hand, it is necessary to protect biodiversity helping to maintain the original environment and ecosystem restoration of degraded areas. On the other hand, the effect of progressing eutrophication is a decrease in attractiveness of this region, especially

in terms of recreational and tourist functions. A high concentration of filamentous algal species (green algae, brown) causes the formation of drifting seaweed mats that can be transmitted by waves and either sink to the bottom or accumulate on the shore. Floating mats are an impediment to practicing water sports which are very popular in the area of Puck Bay and fouling nets disrupt fishing. Piles of quickly decaying plant material thrown ashore reduce the tourist value of beaches located on Puck Bay. The systematic monitoring of Baltic waters [SatBaltic] allows to predict when algae will occur in large quantities, which allows for necessary remedial action to be taken before they settle on beaches. The elimination of macroalgae from Puck Bay at the stage of excessive reproduction should be carried out under the supervision of environmental protection services with particular emphasis on the protection of habitats covered by the Natura 2000 programme.

There are no studies on the development of macroalgae from Puck Bay, while between 2004-2010 attempts were made to determine an effective method of managing marine algae polluting the Tri-City beaches. The carried-out tests showed the usefulness of macroalgae for direct use as a natural fertilizer [Filipkowska et al. 2008]. A pilot research was conducted, and the effect of algae on plant growth was short-lived. It should be taken into account that, in the case of long-term fertilization of marine algae without first washing out salt from them, this algae can cause soil salinity. The phenomenon of excessive salt concentration disturbs the development of plants, limits the absorption of nutrients and water, leading to so-called physiological drought [Kłosowska 2010]. Another direction for waste management of macroalgae biomass in the area of Tri-City beaches was its use in the methane fermentation process. Despite the significant amount of biomass obtained, the use of marine algae as the basic raw material in the biogas plant proved to be unprofitable among others, due to significant hydration and seasonality of sourcing. An increase in the efficiency of biogas production was obtained only when mixed with a more energetic co-substitute (eg manure) [Kuligowski et al. 2012]. The above solutions are additionally connected with the necessity of transporting them to the biogas plant and limitations concerning the method of obtaining biomass in relation to algae that are littering beaches. Macroalgae from beaches are contaminated with sand and quickly decompose. 40% of filamentous algae washed ashore is biodegradable after one week in summer conditions, which makes it an unattractive energy source. The seagrass *Zoostera* is more resistant, with 80% of mass distribution achieved after 100 days [Kotwicki et al. 2005]. Significant impurities of sand disturb the fermentation of algae due to mechanical damage of equipment. For this reason, it is recommended that algae be obtained directly from water depth. There are a number of technological solutions enabling such collection [Timmermen, Hoving 2016].

Among the solutions concerning the management of troublesome macroalgae biomass in the coastal region, the possibility of existing sewage management facilities has not been taken into account. WWTP 'Swarzewo' is equipped with fermentation chambers, where selected organic waste can be processed directly at Puck Bay. The advantage of this biogas plant is the year-round availability of raw material in the form of initial sludge and excess sludge from the biological part of WWTP. Seasonally occurring macroalgae (and other vegetation overgrowing water reservoirs) can be used as a complementary substrate for fermentation chambers. Processing algae in the 'Swarzewo' treatment plant also allows for the comprehensive management of waste, because the digested sludge is composted

together with plant structural material (straw, branches, leaves). Algae salinity does not affect the compost negatively because chlorides leach in the fermentation chamber. The compost obtained has a fertilizer certificate, thus the management of macroalgae in a biogas plant at WWTP 'Swarzewo' would, to a large extent, meet the requirements of a circular economy.

The aim of the study is to estimate the possibility of restoring ecological balance in Puck Bay through the use of marine filamentous macroalgae as a co-substrate for biogas and fertilizer production in the regional biological wastewater treatment plant.

MATERIAL AND METHODS

Methane fermentation was carried out in a model batch reactor with a capacity of 50 dm³, filled with sludge from the fermentation chamber of the Wastewater Treatment Plant 'Swarzewo'. Total dry solids (TS) of sludge was 2.66%. During the study, the temperature was maintained at $36 \pm 1^\circ\text{C}$ and the pH was 7.3 ± 0.2 .

To measure biogas potential, 0.5 kg samples of shredded aquatic plants were added to the chamber (mechanically macerated with fermentation sludge). Each fermentation cycle was carried out until the end of the biogas production process (6-7 days). In order to confirm the reproducibility of results and ensure proper fermentation conditions, after each cycle, fermentation of primary sludge from the treatment plant was carried out. The average value of methane in the obtained biogas is 64%, which is comparable with parameters obtained in technical conditions in fermentation chambers of WWTP 'Swarzewo'. The energy value of biogas with these parameters is 6,5 kWh/m³, which allows to obtain (considering the efficiency of devices) 2.9 kWh of electricity and 3,6 kWh of heat energy from 1m³ of biogas.

Research was carried out on plants harvested from the water column of Puck Lagoon in the time period from June to September 2018. Samples collected from marine waters of Puck Lagoon (Rzucewo) contained typical water-vegetation of the region – a mixture of algae: brown algae (*Ectocarpus*, *Pilayella*) and green algae (*Enteromorpha* sp. *Cladophora*) and a *Zostera seagrass* [Kotwicki et al. 2005, Filipkowska et al. 2009]. The second group was freshwater-vegetation collected from pre-treatment ponds of WWTP 'Swarzewo' (*Cladophora algae*, *Myriophyllum spicatum* sp. *Myxophyllum* sp. and *Lemna minor duckweed*). In addition, biomass collected from beaches (Swarzewo), constituting waste with significant odour nuisance, which consisted of decaying algae and seagrass, was subjected to research. The samples of plants were collected in the months in which considerable reproduction occurred.

RESULTS

The basic raw material used to produce biogas in WWTP fermentation chambers is primary sludge. The biogas potential of primary sludge is not high (400 m³/Mg VS), thus, in practice, the co-fermentation of sludge with high-energy organic waste is often used. Fermented substrates can significantly differ in content of volatile solids (VS), which constitute the proper source of obtained biogas. For this reason, in order to compare the biogas

Table 1. Biogas potential of plant biomass harvested from sea and pond water

Plant biomass	Month (in 2018)	d.m. [%]	VS [% d.m.]	Biogas potential [m ³ /Mg]	Biogas potential [m ³ /Mg VS]
Freshwater algae	June	4.4	81.8	12.5	347
Water milfoils and duckweed	August	7.2	64.5	11.3	243
Green and Brown algae	August	15.3	48.7	12	162
Algae biomass from the beach	June	6.2	56.3	3	86
Seagrass	September	19.7	38.0	4.8	65

Source: own research

potential of different substrates, its value is expressed as the volume of biogas obtained (m³) per VS unit. The experimentally determined dry mass (d.m.) volatile solids (VS) and biogas potential of plant biomass harvested from this water column are summarized in table 1.

The obtained results confirm the low value of biogas potential of the studied plants. Only algae obtained from freshwater reservoirs have potential similar to that of the value obtained from primary sludge from WWTP. It can also be noted that the biogas potential of marine algae removed from water depth (green and brown algae) is two-fold lower in the case of acquiring biomass lying on the beach, associated with rapid decomposition. The lowest biogas potential is shown by sea grass, due to its lowest share of fermentable compounds (38% d.m.) and the content of lignocellulose compounds that are difficult to access for methanogenic bacteria. Research also showed that feeding the chamber with macroalgae did not negatively affect the condition of the sludge.

It is also necessary to estimate how large macroalgal waste resources are and whether it would be profitable to treat them in the fermentation process. According to data from 2010, in Sopot, 200 Mg of algae were collected from beaches seasonally, and it was determined that another 700 Mg could be taken from water depth [Kuligowski et al. 2012]. In relation to Puck Bay, the potential of biomass from macroalgae, which could hypothetically be converted into biogas, can be estimated on the basis of data concerning the volume of primary organic matter production. The average annual value of this production in the Puck Bay are is 190 mg C m²/day [Kotwicki et al. 2005]. In winter, due to low temperatures and limited metabolism, primary production is small (about 20 mg C m²/day), while in the summer (May-August) this value increases even a hundredfold (1,900 mg C m²/day, data from June 2018). Therefore, biomass acquisition from water should be limited to a short, 2-3-month summer period when it is profitable. The maps in figure 1a-d illustrate the changes in organic carbon production that took place in the Puck Lagoon in the summer months of 2018.

The most intense growth of organic matter in the Puck Lagoon region was observed in June 2018 (figure 1b). In July, sea currents moved organic matter towards the open waters of the Gulf of Gdansk and Tri-City beaches (figure 1c). The one-year filamentous macroalgae, belonging to the brown and green algae, are characterized by very fast growth and a short

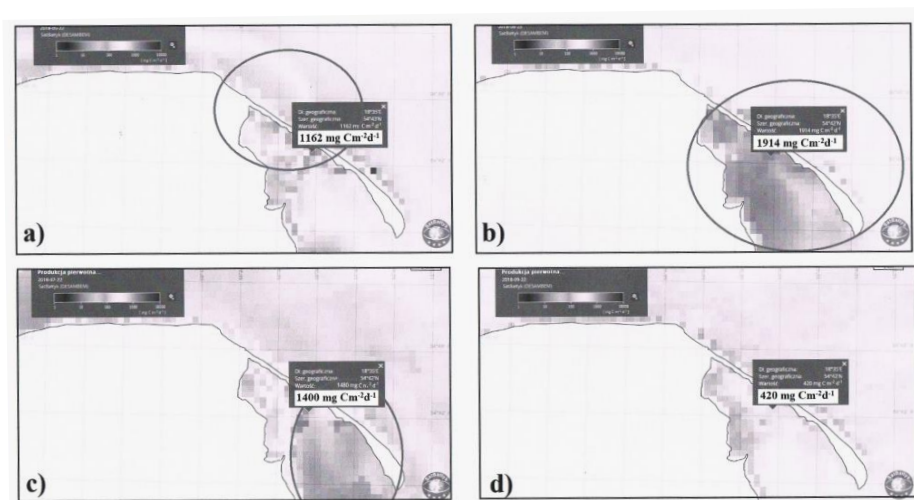


Figure 1. Primary production of organic matter [mg C m²/day] in the Puck Lagoon in 2018 year: a) May, b) June, c) July, d) August

Source: [<http://satbaltyk.iopan.gda.pl>]

life cycle. They efficiently use the presence of nutrients and, in optimal conditions, dominate over perennial species, overgrow them and inhibit their growth by limiting access to light. It is estimated that, in shallow coastal bay waters, floating algae constitute approx. 30-40% of primary production [Kruk-Dowgiałło 1996]. During intensive growth, algae consume biogens for building cells (nitrogen 2-4% d.m., phosphorus 1-1.5% d.m.), thus significantly reducing their content in the aquatic environment [Pedersen, Borum 1997]. In the post-vegetative period, the algae break down and biogens return to the environment. In order to return to balanced oligotrophic conditions, phosphorus would be deficient and would be the element limiting primary production. Annual phosphorus inflowing (about 20 Mg/year) and phosphorus released from deposits (the load of phosphorus migrating from sediments estimated at 100 Mg/year [Bolałek 1992]) should be removed from Puck Bay.

The Puck Lagoon covers an area of 103 km². Assuming that the summer harvest period of floating filamentous algae lasts 50 days and about 500 mg C m²/day is eliminated (accounting for approx. 30% of primary production), it would be possible to obtain 5,000 Mg VS of algae (about 65,000 Mg of hydrated biomass, 1300 Mg/day). This means the removal of 100-150 Mg of phosphorus and 200-400 Mg of nitrogen annually from Puck Lagoon waters, significantly reducing the eutrophication level of its waters. From such a quantity of organic matter, it is hypothetically possible to obtain 800,000 m³ of biogas (500,000 m³ methane), constituting 2,320 MWh of electric energy worth about PLN 740,000 and 2,100 MWh of heat energy (which is consumed in technological processes) in WWTP 'Swarzewo'. The estimated amount of biogas is comparable to eight-months of biogas production in WWTP 'Swarzewo' (1,200,000 m³/year). The cost of a full processing cycle of 1Mg of biomass of algae in WWTP, including costs of the phosphorus precipitating coagulant (PLN 3.37), organic carbon to remove nitrogen from post-fermentation effluents (PLN 3.6), polymer for drainage of post-fermentation sludge

(PLN 8.27), straw for composting (PLN 23.3), mechanical composting (PLN 1.8), amounts to PLN 40.34. Partial reimbursement can be obtained from the sale of compost (PLN 9.0) and biogas production (PLN 11.4). It would be possible to reduce the costs of compost production by changing the structural material from straw to branches. Despite this, the processing of algae biomass in the 'Swarzewo' biogas plant would require external co-financing. Real possibilities of processing algae as a co-substrate in WWTP 'Swarzewo' are much smaller (about 15 Mg/day – 30% of the fermentation charge), thus other regional units should be included for the disposal of algae (eg. WWTP 'Dębogórze'). The disadvantages of the project include the seasonality of dynamic growth of algae mass and the need to develop technological solutions, both harvesting and transport to the treatment plant.

SUMMARY

Conducted analysis shows that the systematic removal of undesirable algae and its fermentation in the biogas plant of the regional municipal WWTP leads to an improvement of the ecological status of Puck Bay and can be a source of significant amounts of renewable energy. Due to well-developed monitoring, it is possible to determine the months in which intensive reproduction of algae in Puck Bay takes place, but there is a strong need to develop a strategy for harvesting filamentous algae and transporting them to a biogas plant. Removal of eutrophic phosphorus resources in the Puck Lagoon would require harvesting 30-40% of primary production in summer months. Then, the reduction of nutrients would achieve 100-150 Mg of phosphorus and 200-400 Mg of nitrogen per year. Such a project is difficult to implement due to technical reasons, however, in order to effectively counteract eutrophication, the regional waste management plan needs to develop a methodology for annual removal of at least 25% of calculated algae biomass in order to eliminate both: the phosphorus accumulated in the Bay and the inflowing phosphorus.

A similar problem with overgrowing algae occurs in many anthropogenically modified regions. The calculations presented for Puck Bay can be applied to other ecologically threatened water areas (both marine and freshwater ponds), the eutrophication of which often results from agricultural activity. The estimation of primary production and seasonal harvesting of undesirable vegetation from the water column may constitute a seasonal source of waste for agricultural biogas plants. An additional benefit could be obtained from the production of energy and compost during the fermentation of algae waste.

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ZAGOSPODAROWANIE MAKROGLONÓW W REGIONACH NADMORSKICH W ASPEKCIE STRATEGII ZRÓWNOWAŻONEGO ROZWOJU

Słowa kluczowe: makroglony, recykling organiczny, Zatoka Pucka

ABSTRKAT

Przedstawiono problem nadmiernego przyrostu nitkowatych jednorocznych glonów, przyczyniającego się do zakłócenia równowagi ekologicznej w Zatoce Puckiej. Celem artykułu jest oszacowanie możliwości przywrócenia tej równowagi przez wykorzystanie makroglonów jako kosubstratu do produkcji biogazu w biogazowni regionalnej oczyszczalni ścieków. Zbadano efektywność produkcji biogazu z roślin wodnych, w tym z wolnopływających nitkowatych glonów morskich. Przeprowadzone badania wykazały, że potencjał biogazowy glonów morskich kształtuje się na poziomie 162 m³/Mg suchej masy organicznej alg. Oszacowano, że wykorzystując letni intensywny wzrost glonów z obszaru obejmującego Zalew Pucki, usuwając 65 000 Mg alg, można pozyskać 800 000 m³ biogazu, a po jego konwersji 2320 MWh energii elektrycznej oraz 2100 MWh energii cieplnej. Odławianie wolnopływających alg umożliwia usunięcie z wód Zatoki Puckiej 100-150 Mg fosforu i 200-400 Mg azotu rocznie, a tym samym redukcję poziomu jej eutroficzności. Zagospodarowanie makroglonów na etapie ich wzrostu przyczynia się również do poprawy warunków rybołówstwa i wzrostu walorów turystycznych regionu.

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