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The disappearance of stonewort populations in lobelia lakes of the Kashubian Lakeland (NW Poland)

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Abstract

The subject of this work is a comparative analysis of stonewort populations in 5 lobelia lakes of the Kashubian Lakeland based on literature data from the mid-1970s and the authors' own studies from 2006. In the 1970s 15 sites of 7 stonewort species: *Chara delicatula*, *C. fragilis*, *C. tomentosa*, *C. rudis*, *Nitella flexilis, N. opaca* and *N. mucronata* were recorded in the lakes under study. The populations of *C. delicatula* and *N. flexilis* occupied the area from 0.3 to 6 m deep and were characterized by 20% cover on average.

Thirty years later, in 2006, the presence of only 6 out of 15 stands was confirmed: 3 of *C. delicatula* and 3 of *N. flexilis*. Thus, a total of 9 stands (60%) and 5 species (71%) had disappeared completely. The majority of the preserved populations survived in a vestigial form. Population areas of *C. delicatula* reached a depth of 2 m and their cover did not exceed 5%. Populations of *N. flexilis* occupied the littoral up to a depth of 7 m and had 10% cover. The disappearance of stoneworts was probably caused by both anthropogenic factors and natural processes.

INTRODUCTION

Stoneworts (Characeae), a group of macroscopic green algae, occur predominantly in fresh and less frequently in brackish and salty waters. They are found in stagnant water bodies, as well as rivers and drainage ditches. However, they are most often recorded in lakes, both soft and hard water ones (Krause 1997).

These plants are common all over the world, but more and more frequently they have been observed to disappear from their natural environment. Results of the studies conducted by researchers, such as Królikowska (1997), Henriksen et al. (1998), Auderset Joye et al. (2002) and Kłosowski et al. (2006) confirm this fact. The most commonly identified cause of stonewort disappearance is the eutrophication of aquatic ecosystems (Roelofs 1983; Blindow 1992; Simons, Nat 1996). Mechanical stress, destruction of habitats (Torn et al. 2010 and the literature cited therein) and lake humication (Bociąg 2003; Gałka, Bociąg 2006) also result in the vanishing of these plants, albeit less frequently.

In Poland stoneworts are most often found in hard water, oligo- and mesotrophic lakes in the belt of South Baltic Lakelands, the East Baltic Lakeland and Polesie (Hutorowicz 2006). They are also fairly often recorded in the Kashubian Lakeland, where, apart from the typical hard water habitats, they also occupy soft water habitats, including lobelia lakes. *Chara delicatula* Ag. and *Nitella flexilis* (L.) Agardh (Dąmbska 1965) are species characteristic of these water bodies. In most lobelia lakes, stoneworts are sparse among the dominant isoetid and bryophyte communities. In a small group of lobelia lakes, however, stoneworts form very abundant populations coexisting with isoetids in shallow littoral zones and build virtually single-species assemblages

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or co-occur with bryophytes in deeper areas (Bociąg 2006).

The group of lobelia lakes, with vegetation made up of isoetids and stoneworts, is located in the southern part of the Kashubian Lakeland. Their stonewort flora was examined in the second half of the 1970s (Szmeja 1979, 1980). In 2006, after 30 years, the research was undertaken to determine the current condition of these stonewort populations and compare it with the one from the 1970s. The aim of this work is to analyze the observed changes in the species composition and abundance of stoneworts and to attempt to explain the causes of this phenomenon.

Materials And Methods

The studies covered the following lakes: Małe Oczko, Wielkie Oczko, Drzędno, Głęboczko and Zakrzewie (Fig. 1), the flora of which was described in the papers by Szmeja (1979, 1980). A list of stonewort species, which occurred at that time in the above-mentioned lakes, was compiled and the condition of their populations was determined based on these works and herbarium materials. In 2006 a comparative study was conducted. The phytolittoral zones of the lakes were penetrated by walking along the shores in shallow water and using the method of free diving in deeper areas with a view to locating the stonewort populations and determining the size of their ranges. Five transects were established in every lake, running perpendicular to the shoreline. In each transect, a relevé was made every 1 m of depth, with an area of 2.25 m^2, in order to assess the percentage cover of species. The nomenclature of stoneworts in this work follows Krause (1997), while that of plant communities - Matuszkiewicz (2005). The available literature, unpublished data of the Department of Plant Ecology of Gdańsk University and the authors' own data from 1995-2005 were also used to draw conclusions about changes in the populations.

Results

Stonewort flora

In 1975, seven stonewort species occurred in the lakes under study (15 stands in total; Szmeja 1979, 1980; Szmeja, herbarium materials). *C. delicatula* and *N. flexilis* (5 stands each) were found in all the examined water bodies. In addition, *Chara fragilis* Desv., *Chara tomentosa* L., *Nitella opaca* Ag.



Fig. 1. Location of lakes: 1- Głęboczko, 2- Wielkie Oczko, 3- Małe Oczko, 4- Drzędno, 5- Zakrzewie.

(Głęboczko), *Chara rudis* A. Br. (Drzędno) and *Nitella mucronata* A. Br. (Małe Oczko; Table 1) were also recorded.

In 2006 the occurrence of only three stonewort species was observed in the lakes under study: *Chara delicatula*, *Nitella flexilis* and *Nitella tenuissima* (Desvaux) Kützing (Table 1). *C. delicatula* was found in Lakes Małe Oczko, Zakrzewie and Głęboczko. *N. flexilis* was recorded in Lakes Drzędno, Zakrzewie and Głęboczko. *Nitella tenuissima* occurred in Lake Głęboczko (Bociąg, Gbur 2008). In total 7 stonewort stands were recorded in the examined lakes (Table 1).

Thus, over a period of 30 years the following species became extinct in the lakes under study: *Chara fragilis*, *Chara tomentosa*, *Chara rudis, Nitella opaca* and *Nitella mucronata*. *C. delicatula* in Lakes Drzędno and Wielkie Oczko, and *N. flexilis* in Lakes Wielkie and Małe Oczko also vanished (Table 1). In total 9 stands (60%) and 5 species (71%) disappeared during this period.

A comparative analysis – temporal changes in populations

Symptoms of regression can be observed in the majority of the populations preserved until the present day. Most of them currently occupy a smaller area than in 1975, and a significant decrease in the

abundance has been observed in the majority of the populations.

In the mid-1970s the population of *C. delicatula* in Lake Małe Oczko occurred at a depth of 0.3-5 m with the plant cover reaching 20% (Szmeja 1979). In 2006 the population range was limited to the shallow littoral zone up to a depth of 0.1 m and the cover did not exceed 5%. The plant grew in loose patches of the association *Lobelietum dortmannae* (Ostwald 1923) R. Tx. ap. Dierss. 1972 with *Lobelia dortmanna* L., *Alisma plantago-aquatica* L., *Potamogeton natans* L., *Luronium natans* (L.) Rafin. and *Juncus bulbosus* L. (Table 2).

In Lake Głęboczko in 1975, the population of *C. delicatula* occupied an area from the shore up to a depth of 3 m. Its individuals did not form dense aggregations, but certain parts of the population had a cover of about 20% (Szmeja 1979). In 2006 the population consisted of only a few individuals growing in the northern and southern parts of the water body at a depth of 1-3 m. In the southern part of the population area, they were found in a patch of *Nitella tenuissima*. In the northern part, they accompanied sparse individuals of *Myriophyllum alterniflorum* DC. (up to 5% cover; Table 2) forming very loose patches of *Myriophyllo-Littorelletum* Jaschke 1959.

In 1975, the population area of *C. delicatula* in Lake Zakrzewie reached a depth of 2 m. This stonewort's individuals were generally scattered and the cover was up to 20% only here and there (Szmeja 1979). In 1996 *C. delicatula* occurred in almost entire phytolittoral zone of the lake, from 1 to 11 m, forming a very dense carpet with high biomass in the zone between 4 and 8 m (Dep. of Plant Ecology, Gdańsk Univ., unpublished observations). However, 5 years later (in 2001) the population area reached a depth of only 6 m, and the individuals grew in loose patches with low biomass (Bociąg, unpublished observations). In 2003 the condition of the population was similar (op. cit.). By 2006 the population became almost completely extinct, as only a few individuals were found in the eastern and southern parts of the water body in patches of *Lobelietum dortmannae*. In the eastern part, they grew in shallow water among dense aggregations of *Lobelia dortmanna* (Table 2). In the southern part, in turn, they were widely scattered at a depth of 2 m among sparse individuals of *Isoëtes lacustris* L. (5% cover; Table 2).

The populations of *Nitella flexilis,* as *C. delicatula,* which survived until 2006, were generally less numerous and occupied much smaller area than 30 years earlier.

In the 1970s the population of *N. flexilis* in Lake Głęboczko covered an area up to a depth of 6 m. In the northern part of the water body, its individuals formed vast single-species aggregations, and the cover was as much as 80% (Szmeja 1979). In 2006 the population comprised only a few individuals growing at a depth of 2-3 m. They occurred among loose aggregations of *Myriophyllum alterniflorum* (5% cover, Table 2) in *Myriophyllo-Littorelletum*.

In 1975 the population area of *N. flexilis* in Lake Drzędno reached a depth of 2.5 m. The population was made up of scattered individuals in the northern and eastern parts of the water body, and the cover was 20% (Szmeja 1979). In 2006 only a few individuals were found at a depth of 0.5 m. Smooth stonewort individuals grew only in the southern part of the lake and were widely scattered. This stonewort occurred in the patches of *Lobelietum dortmannae* among *Lobelia dortmanna* aggregations (10-15% cover; Table 2). In addition, it was accompanied by *Potamogeton natans*, *Myriophyllum alterniflorum* and *Luronium natans*.

Table 1

Stonewort stands in lobelia lakes of the Kashubian Lakeland.

Species / Lake	*Chara delicatula*	*Chara fragilis*	*Chara tomentosa*	*Chara rudis*	*Nitella flexilis*	*Nitella tenuissima*	*Nitella mucronata*	*Nitella opaca*
Wielkie Oczko	+				+			
Małe Oczko	^				+		+	
Głęboczko	^	+	+		^	*		+
Zakrzewie	^				^			
Drzędno	+			+	^			

Explanations:
^ recorded in the 1970s, confirmed in 2006;
+ recorded in the 1970s, not confirmed in 2006;
* not recorded in the 1970s, found in 2006.

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Table 2

Stoneworts in the patches of underwater vegetation in the lobelia lakes.

No. of phytopsociological relevés	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
No. of transect	1	2	1	2	2	2	3	1	2	1	1	1	1	1	1	2	2	2	3	4	4
Depth (m)	0.5	0.5	2	1	2	3	1	0.1	0.1	2	3	4	5	6	7	1	2	7	2	2	3
Lake	D	D	G	G	G	G	G	MO	MO	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z
Part of lake	S	S	S	N	N	N	SW	NE	NW	SE	SE	SE	SE	SE	SE	E	E	E	N	S	S
Ch. Charetea																					
Chara delicatula			**<5**		**<5**	**<5**		**5**	**<5**							**<5**				**<5**	
Nitella flexilis	**5**	**5**		**<5**						**<5**	**10**	**<5**	**<5**	**5**	**5**		**<5**	**<5**	**<5**		**5**
Nitella tenuissima			**80**				**<5**														
Ch. Lobelietum dortmannae																					
Lobelia dortmanna	15	10						20	15	<5						80	<5				
Ch. Myriophyllo-Littorelletum																					
Myriophyllum alterniflorum		<5	5	5	5	<5	5			<5	5	<5				5	5		75		
Ch. Littorelletea uniflorae																					
Isoëtes lacustris										<5						<5	<5			5	
Luronium natans		<5						5													
Juncus bulbosus									<5												
Ch. Potametea																					
Potamogeton natans	<5						5	<5													
Potamogeton crispus																			<5		
Myriophyllum spicatum																			15		
Elodea canadensis												<5									
Ceratophyllum demersum																			<5		
Ch. Phragmitetea																					
Phragmites australis									<5												
Alisma plantago-aquatica								<5	<5												

Lake Zakrzewie, contrary to the water bodies discussed above, appears to have had a much more abundant population of *N. flexilis* than 30 years earlier. In 1975 its range reached 2.5 m of depth, its predominantly scattered individuals grew only in the eastern and western lake parts, and the cover was up to 20% only in some places (Szmeja 1979). In 2006 the population area of *N. flexilis* encompassed virtually the whole phytolittoral zone up to a depth of 7 m. The individuals were widely scattered. Only in the south-eastern part of the water body they formed small aggregations representing a loose, initial form of *Nitelletum flexilis* (Table 2, transect 1). In this part of the population area, at a depth of 2-5 m, *N. flexilis* had 5-10% cover, while other species occurred only sporadically. In the remaining parts of the area, the cover did not exceed 5%. In shallow water *Nitella flexilis* accompanied aggregations of *Lobelia dortmanna* in patches of *Lobelietum dortmannae*, whereas in the deeper parts of the area, it coexisted with scattered *Myriophyllum alterniflorum* forming the community of *Myriophyllo-Littorelletum* (Table 2). The observed population development might be connected with new habitats left by the regressing population of *Chara delicatula*.

The population of *N. tenuissima*, which had not been recorded earlier in Lake Głęboczko, was located in the south-eastern and south-western parts of the water body. In the former part, individuals grew between 1 and 2.5 m of depth forming a fairly dense patch with 80% cover. What is more, a few individuals were found at a depth of 1 m in the latter

lake part in patches of *Myriophyllo-Littorelletum*. They accompanied scattered *Myriophyllum alterniflorum* and *Potamogeton natans* (Table 2).

To sum up, in 1975 the populations of *C. delicatula* and *N. flexilis* in the lobelia lakes were characterized by large population areas and considerable abundance. The stoneworts not only formed their own aggregations but were also scattered among other plants.

In 2006 the stonewort populations in the studied lobelia lakes were not numerous and most often occupied a small area in the shallow littoral zones. The stoneworts were generally scattered and did not form aggregations. Most frequently they occurred in the patches of the *Lobelietum dortmannae* association. In Lakes Głęboczko and Zakrzewie the stoneworts were also found in *Myriophyllo-Littorelletum*, which had a form of loose aggregations of *Myriophyllum alterniflorum*. In a part of the littoral zone of Lake Zakrzewie, the stoneworts also formed their own community from the *Charetea – Nitelletum flexilis* class, which comprised very small and scattered aggregations of *Nitella flexilis* (Table 2).

DISCUSSION

Two groups of factors, namely natural phenomena and the human impact can be taken into account as possible causes of stoneworts extinction in the studied lobelia lakes. As the examined water bodies and their catchment areas have been exploited in various ways for a long time, the observed changes may result from the processes occurring in the vegetation under the influence of anthropopressure.

Much of the existing literature underlines the negative effect of increasing water trophism on stoneworts (Ozimek, Kowalczewski 1984; Blindow 1992; Królikowska 1997; Sand-Jensen et al. 2000, Auderset Joye et al. 2002). The available hydrochemical data from the 1990s, however, indicate no increase in the concentration of phosphates in the lake water over the studied period (Szmeja et al. 1993, Gbur 2008). It appears that in this case, the extinction was not caused by eutrophication.

The fact that the lakes have been used as fisheries also has a damaging impact on the stonewort populations (Zdanowski et al. 1999; Krzywosz 1997; Hutorowicz, Dziedzic 2008). Fish from the family Cyprinidae, such as grass carp (*Ctenopharyngodon idella* Val.) and common carp (*Ciprinus carpio* L.) have been bred in all the lakes but Drzędno (oral information from the lakes' leaseholders). The fish forage the bottom by stirring the substrate, which causes the increased phosphorus resuspension from the sediment to the water. This in turn causes the development of plankton algae, the decreased water transparency, transformation and even extinction of plant communities in the lake (Breukelaar et al. 1994; Krzywosz 1997, Hutorowicz, Dziedzic 2008). The studies on grass carp populations in Masurian lakes have shown that plants from the genera *Potamogeton* and *Chara* are the first to disappear under their pressure (Krzywosz 1997). Thus, inconsiderate exploitation of the lakes for fishing purposes might be one of the most important factors responsible for the extinction of stoneworts.

The exploitation of lakes as reservoirs for wood soaking also has a negative effect on the populations of stoneworts and other aquatic plants. Lake Wielkie Oczko was exploited in this way in the second half of the 1980s. Observations from that time show a dramatic fall in the abundance of many plant species, including *Lobelia dortmanna*, *Luronium natans* and stoneworts (Szmeja, personal communication).

Lakes included in the drainage systems of peatlands and swamp forests receive unnaturally large quantities of acid organic matter (e.g. the colored fraction of humic substances) and mineral compounds from the drained areas. This leads to a number of unwelcome changes defined as humication (Szmeja 2000), which adversely affect stonewort populations (Bociąg 2000, 2006; Szmeja 2000; Gałka, Bociąg 2006). The effects of this process can be observed in two of the studied lakes (Małe and Wielkie Oczko) connected to the drainage system of the neighboring peatlands. A comparison of contemporary hydrochemical studies in these lakes with data from the 1990s shows an increase in the concentration of humic substances in the water and a decrease in its transparency (Szmeja et al. 1993, Gbur 2008). Thus, the anthropogenic process of lake humication may cause the disappearance of stonewort populations in these lakes.

It appears that the extinction of stoneworts in the lakes under study, undoubtedly accelerated by anthropopressure as it is, follows the natural direction of vegetation succession. All the analysed water bodies are located in the vicinity of pine forests (*Peucedano-Pinetum* W. Mat.), raised bogs and poor fens, which favors the process of their natural acidification (Górniak 1996, Szmeja 1997, Wetzel 2001). The water is acidified with organic acids constantly migrating from the catchment (Takai,

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Kamura 1966), including the colorless fraction of humic substances, which may precipitate for example with calcium carbonate (Lampert, Sommer 1996). This leads to a reduction in electrolytic conductivity, and calcium and carbonate content in the water. Chemical processes of precipitation result in quick deposition of sediments. Creating conditions favorable mainly to acidophilic bryophytes, the acidic sediment deposit limits the occurrence of many neutrophilic and alkaliphilic plants (Szmeja 1992, Arts 2002 and the literature cited therein). Stoneworts, which prefer environments richer in calcium ions and higher pH, gradually disappear during this process, and their habitats are occupied by bryophytes and isoetids. Such a direction of vegetation succession in water bodies has been observed in paleoecological and paleolimnological studies on lakes in the Tuchola Forest (Hjelmroos-Ericsson 1981, Bogaczewicz-Adamczak 1990, Milecka et al. 2002, Milecka 2005). A noticeable reduction in electrolytic conductivity and calcium concentration in the water has been observed for over ten years in two of the studied lakes (Zakrzewie, Małe Oczko), which confirms that the studied lakes evolve in this direction (Szmeja et al. 1993, Gbur 2008, unpublished data of the Dep. of Plant Ecology from 1995- 2000).

All in all, the results of the conducted studies are clearly indicative of stonewort extinction in the examined lobelia lakes. This phenomenon is probably of anthropogenic origin and results from the human exploitation of the water bodies, for example for fishing purposes, and their humication. Nevertheless, it is in line with the natural direction of succession in this group of lakes.

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