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Effects of grass carp introduction on macrophyte communities in a shallow lake

Joanna Krupska[1,*], Mariusz Pełechaty[1], Andrzej Pukacz[2], Przemysław Ossowski[1]

[1] *Adam Mickiewicz University, Faculty of Biology, Department of Hydrobiology, Umultowska 89, 61-614 Poznań, Poland*
[2] *Adam Mickiewicz University, Faculty of Biology, Collegium Polonicum, Kościuszki 1, 69-100 Słubice, Poland*

Key words: grass carp, *Ctenopharyngodon idella*, fish stocking, macrophytes, charophytes

Abstract

In 2002, 2005 and 2007 vegetation and physicochemical properties of pelagial water were investigated in a shallow mid-forest lake. In 2002, the highest phytocoenotic diversity was recorded; charophytes and vascular submerged macrophytes formed their own extensive communities. After stocking with grass carp (*Ctenopharyngodon idella* Val.) in 2002, reduction of water transparency, as well as changes in qualitative and quantitative composition of macrophyte communities were observed. Submerged vegetation declined during subsequent growing seasons. Charophyte meadows vanished first.

The introduction of grass carp appeared to be a potential trigger for the rapid changes observed in the vegetation.

INTRODUCTION

The presence of macrophyte communities in lakes affects the dynamics of nutrients, water quality and invertebrate-fish interactions (Jeppesen et al. 1997 and references therein).

Aquatic plants, through numerous mechanisms that control the development of phytoplankton and prevent the resuspension of sediments, support the macrophyte-dominated state in shallow lakes, despite their gradual eutrophication (e.g. Scheffer , Jeppesen 1997; Van Donk, Van de Bund 2002 and references therein).

Charophytes, among other submerged macrophytes, play a significant role in suppressing the phytoplankton, especially when they form extensive meadows (Van der Berg et al. 1998). However, in the situation where there is a shift of balance towards the turbid-water state, charophytes are the first macrophytes to disappear.

Disappearance of submerged macrophytes in shallow eutrophic lakes can lead to an alternative stable turbid state dominated by phytoplankton (Scheffer, Jeppesen 1997). The switch from a clear- into turbid-water state in shallow lakes is always associated with an increasing level of nutrients or/and removal of macrophyte vegetation. In most cases it is caused by intentional or unintentional human activity. Other mechanisms have also been suggested (e. g. Hargeby et al. 2004, 2007; Moss et al. 2004). Fish grazing is considered as a potential factor that can induce a shift from clear and turbid water, however enclosure experiments on effects of fish introduction in shallow lakes have been performed mostly with the use of zooplanktivorous fish (Stephen et al. 2004; Hietala et al. 2004; Van de Bund, Van Donk 2004). Grass carp is a long-lived generalist herbivorous species, introduced for weed control in many countries around the world (van

* Corresponding author e-mail: *jkrupska@poczta.onet.pl*

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Zon 1977; Opuszyński, Shireman 1995). In Poland grass carp has been present since 1964 (van Zon 1977). It contributes to sediment resuspension during feeding, a release of nutrients into the water with excrements and reduction of mechanisms supporting the maintenance of the vegetated clear-water state due to consuming large amounts of plant biomass (Pípalová 2006 and references therein; Dibble, Kovalenko 2009 and references therein). Further, it can result in changes of water trophy and, in shallow lakes − in switching from the clear-water state into the turbid-water state.

The study presented in this paper was performed in Lake Czyste Małe, a shallow mid-forest water body that used to be characterized by high visibility down to the lake's bottom. The lake has been explored by the authors since 2002. High species and community richness of aquatic plants, including abundant charophytes have been reported (Pełechaty, Pukacz 2004; Pukacz et al. 2004). In 2002, the lake was stocked with 120 grass carp (*Ctenopharyngodon idella* Val.) specimens. Before stocking, the fish community of Lake Czyste Małe consisted mainly of roach (*Rutilus rutilus* L.), rudd (*Scardinius erythrophtalmus* L.), common bream (*Abramis brama* L.), pike (*Esox lucius* L.) and perch (*Perca fluviatilis* L.). After the introduction of grass carp, the authors decided to carry on with field studies in 2005 and 2007. It enabled comparative analysis of vegetation and physicochemical conditions of water before and after stocking.

The paper aims at determining the influence of stocked grass carp on changes in vegetation in Lake Czyste Małe. Special attention was paid to charophytes as it is claimed that they play a significant role in the maintenance of the clear-water state, and they can also be a potential food base for grass carp. It is worth mentioning that charophyte communities are sensitive to changes of water trophy and tend to disappear first in case of an decreasing trophy level, hence they could be bioindicators of such changes.

MATERIALS AND METHODS

Lake Czyste Małe (52º26.2' N, 14º51.5' E) is located in Western Poland, in the north-eastern part of the Lubuskie Lake District. Along with six other glacial lakes, it is situated in a post-glacial valley, near the town of Ośno Lubuskie. The area of the lake is 9 ha, with the average depth of 2.6 m and the maximum depth of 5.8 m (Jańczak 1996). The direct catchment area of Lake Czyste Małe is in 90% forested land, hence the lake is well isolated from external influences.

In the growing seasons (July/August) of 2002, 2005 and 2007, the qualitative and quantitative composition of the vegetation in Lake Czyste Małe was investigated with the use of the commonly applied, mid-European phytosociological method of Braun-Blanquet (1964). This method is based on phytosociological data recorded in representative patches of vegetation with the use of phytosociological relevés (records). Patches were selected randomly among the well-developed phytocoenoses, avoiding damaged and transition zones. The number of fully developed phytocoenoses decreased every year during the whole research period and this was reflected in the number of phytosociological records. In 2002, 2005 and 2007 − 85, 43 and 16 patches of different macrophyte communities were analyzed, respectively. In each studied patch, the species composition was determined, and the percentage cover of each species was estimated, with use of an anchor and free diving. The approximate size of each relevé was 16 m^2.

In each of the study periods, water temperature, oxygen concentration, conductivity and pH were measured with portable field measurement equipment (Elmetron CX-742). Visibility was measured with a Secchi disc. All field measurements and water sampling were performed at the depth of 0.5 m. Water samples for further laboratory analyses were collected with 1 dm^3 plastic bottles and preserved with chloroform. Then, the analyses of concentration of mineral forms of nutrients were performed. The concentration of $N\text{-}NH_4^+$ was determined by the colorimetric method using the Nessler reagent and that of $N\text{-}NO_3^-$ − by the salicylate method on a Spekol 11 spectrometer (Carl Zeiss Jena, Germany). The content of $P\text{-}PO_4^-$ was determined by the molybdate method using ascorbic acid as a reducer on a Spekol 11 spectrometer.

RESULTS

Physicochemical analyses performed in 2002 indicated a moderately eutrophic state of Lake Czyste Małe according to Carlson's trophy state index (1977) (Table 1). Additionally in the same year, the highest numbers of aquatic plant species and communities were recorded (Table 2), including rare communities characteristic of clear waters, such as *Charetum delicatulae* Doll 1989 and a moss community

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Table 1

Basic physicochemical properties of pelagic waters of Lake Czyste Małe in the growing seasons of 2002 – 2007.

Year	SD	pH	Cond.	T	DO	$P\text{-}PO_4^{3-}$	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$
	(m)		($\mu S\ cm^{-1}$)	(°C)	(mg dm^{-3})			
2002	4.5	8.1	252	22.3	9.3	0.08	0.03	0.10
2005	3.0	7.4	241	22.1	7.3	b.d.	0.04	0.10
2007	2.8	7.4	247	23.6	6.1	b.d.	0.21	0.01

SD = Secchi disc visibility, Cond. = Conductivity, T = Temperature, DO = Dissolved oxygen, b.d. = below level of detection

Table 2

Macrophyte communities of Lake Czyste Małe in 2002, 2005 and 2007 with the contribution of charophytes in their species composition.

Community	2002	2005	2007
Cl. *Phragmitetea australis* (Klika in Klika et Novák 1941) R. Tx. et Preising 1942			
Typhetum latifoliae Soó 1927 ex Lang 1973	+	+	ch
Typhetum angustifoliae Soó 1927 ex Pignatti 1953	ch	+	+
Caricetum acutiformis Eggler 1933	+	+	+
Cladietum marisci Allgore 1922 ex Zorbist 1935	ch	+	+
Phragmitetum communis (Gams 1927) Schmale 1939	-	-	+
Cl. *Potametea* R. Tx. et Preising 1942 ex. Oberd. 1957			
Myriophylletum verticillati Gaudet 1924	ch	ch	-
Nymphaeo albae-Nupharetum luteae Nowiński 1928	ch	ch	+
Cl. *Charetea fragilis* Fukarek 1961 ex Krausch 1964			
Nitellopsidetum obtusae (Sauer 1937) Dąmbska 1961	+	-	-
Charetum delicatulae Doll 1989	+	+	-
Charetum polyacanthae Dąmbska 1966 ex Gąbka et Pełechaty 2003	+	-	-
Charetum tomentosae Corrilion 1957	+	-	-
Nitelletum flexilis Corrilion 1957	-	+	-
Cl. *Fontinaletea antipyreticae* Hüb. 1957			
Fontinaletum antipyreticae Kaiser 1936	-	+	-
Drepanocladus sordidus (Müll. Hal.) Hedenäs community	ch	ch	+
Total	**11**	**10**	**7**

+ - community without charophytes;
ch - community occurred, with charophytes;
– - absent community

composed of *Drepanocladus sordidus* (Müll. Hal.) Hedenäs. In total, 10 communities belonging to 3 classes were determined, as well as one community with no syntaxonomic affinity. Four stonewort species, including *Chara polyacantha* A. Br. − rare in Poland, developed their own extensive communities (the class of *Charetea fragilis*, Table 3). Charophytes contributed to nearly all macrophyte communities, irrespective of the depth of occurrence. Communities of vascular plants were also well developed and characterized by a high number of species.

Table 3

Charophyte communities distinguished in Lake Czyste Małe in 2002 and 2005 and their species structure.

Community	CD				CP		NO		NF		CT	
Date	2002		2005		2002		2002		2005		2002	
No. of relevés	4		1		4		3		1		1	
	n.o.	c.c.	n.o.	c.c.	n.o.	c.c.	n.o.	c.c.	n.o.	c.c.	n.o.	c.c.
Ch Cl. *Charetea fragilis*												
Chara delicatula Ag.	4^{4-5}	8125	1^4	6250	2^{+-2}	255	1^1	500	.	.	1^1	500
Chara polyacantha A. Br.	1^1	500	.	.	4^5	8750	.	.	1^+	10	.	.
Nitellopsis obtusa (Desvaux) Groves	.	.	.	.	1^+	10	3^5	8750	.	.	1^+	10
Nitella flexilis (L.) Ag.	.	.	1^+	10	.	.	1^+	10	1^5	8750	.	.
Chara tomentosa L.	.	.	.	.	.	.	.	.	.	.	1^4	6250
Accompanying species												
Myriophyllum verticillatum L.	2^{2-3}	2125	1^3	3750	.	.	1^r	<1	.	.	1^1	50
Myriophyllum spicatum L.	.	.	.	.	3^{1-2}	917	.	.	.	.	.	.
Drepanocladus sordidus (Müll. Hal.) Hedenäs	.	.	1^+	10	.	.	2^{+-1}	255	.	.	.	.
Nymphaea alba L.	.	.	.	.	.	.	.	.	.	.	1^3	3750
Typha angustifolia L.	.	.	.	.	1^3	3750	.	.	.	.	.	.
Ceratophyllum demersum L.	.	.	.	.	.	.	1^r	<1	.	.	.	.

n.o. – number of occurrences , c.c. – coefficient of cover.
The cover-abundance scale (superscript of n.o.): + : mean cover 0,1%, 1: 5%, 2: 17,5%, 3: 37,5%, 4: 62,5%, 5: 87,5%.
CD - *Charetum delicatulae* (no occurrence in 2007), CP - *Charetum polyacanthae* (no occurrence in 2005 and 2007), NO - *Nitellopsidetum obtusae* (no occurrence in 2005 and 2007), NF - *Nitelletum flexilis* (no occurrence in 2002 and 2007), CT - *Charetum tomentosae* (no occurrence in 2005 and 2007).

In April 2002, the administrator of the lake - Polish Angling Association, stocked the lake with 120 individuals of grass carp, each about 1 -1.5 kg in weight (Polish Angling Association, personal communication), in order to reduce the aquatic plant biomass. In the summer season of that year, the abundant submerged vegetation was still diverse and extensively developed. In the following years, however, a decrease of water transparency (Table 1), as well as changes in qualitative and quantitative composition of particular communities were observed (Table 3 and 4). The most significant changes affected the charophyte vegetation. Already in 2005, despite the appearance of the charophyte association *Nitelletum flexilis* Corillion − new in the lake, three out of four previously recorded charophyte communities completely disappeared. Furthermore, no more *Chara tomentosa* L. individuals were found in the lake, while *C. polyacantha* occurred sparsely among other communities. By contrast to previous years, it did not form separate extensive phytocoenoses. Still, the phytocoenoses of *Myriophylletum verticillati* Gaudet 1924 dominated among submerged vegetation, overgrowing almost the whole water column in the littoral. However, it

Table 4

Aquatic communities of Lake Czyste Małe constantly observed in 2002, 2005 and 2007 and their species structure.

Community	NA - NL						DS					
Date	2002		2005		2007		2002		2005		2007	
No. of relevés	12		5		2		4		2		1	
	n.o.	c.c.	n.o.	c.c.	n.o.	c.c.	n.o.	c.c.	n.o.	c.c.	n.o.	c.c.
Nymphaeid community and ChCl. Potametea												
Nymphaea alba L.	12^{3-5}	7090	5^{3-4}	5750	2^{4}	6250	.	.	.	.	.	.
Myriophyllum verticillatum L.	9^{1-5}	3754	5^{+-5}	2852	.	.	4^{r-4}	2253	1^{2}	750	.	.
Ceratophyllum demersum L.	.	.	.	.	.	.	2^{1-2}	500	1^{r}	<1	.	.
Potamogeton compressus L.	.	.	1^{r}	<1	.	.	.	.	.	.	.	.
Utricularia vulgaris L.	.	.	1^{r}	<1	.	.	.	.	.	.	.	.
Moss community												
Drepanocladus sordidus (Müll. Hal.) Hedenäs	.	.	.	.	.	.	4^{5}	8750	2^{5}	8750	1^{5}	8750
Fontinalis antipyretica L.	1^{1}	500	1^{+}	2	.	.	.	.	1^{1}	125	.	.
charophytes												
Chara delicatula Ag.	9^{1-4}	1641	2^{r-1}	50	.	.	.	.	.	.	.	.
Chara polyacantha A. Br.	5^{r-3}	1068	1^{+}	2	.	.	.	.	.	.	.	.
Nitellopsis obtusa (Desvaux) Groves	2^{r-2}	500	1^{r}	<1	.	.	2^{1-2}	500	1^{r}	<1	.	.
Nitella flexilis (L.) Ag.	2^{r}	<1	3^{r-2}	350	.	.	.	.	.	.	.	.
Chara tomentosa L.	1^{r}	<1	.	.	.	.	.	.	.	.	.	.
vascular plants												
Typha angustifolia L.	5^{1-2}	1250	.	.	1^{r}	<1	.	.	.	.	.	.

n.o. – number of occurrences, c.c. – coefficient of cover.
NA-NL - *Nymphaeo albae-Nupharetum luteae*, DS - community with *Drepanocladus sordidus*

vanished in 2007, together with charophyte communities – remnants from 2005. Among the charophytes, only clusters and individuals of *Chara delicatula* Ag. were found at a few shallow sites within the rushes (Table 2). The moss community of *D. sordidus* remained in the deepest parts of the littoral as the only submerged community.

Apart from changes in the composition of communities, a general decline in the number of species was observed in the macrophyte vegetation. Patches of *Nymphaeo albae-Nupharetum luteae* Nowiński 1928, although present in the lake throughout the study period, decreased in the area in the subsequent years. In the final year of the research, the effects of the grass carp feeding on them were particularly noticeable (e.g. leaf blades of *Nuphar* and *Nymphaea* detached from petioles just below the water surface and parts of petioles were observed in different lake areas, including the rushes). The visibility recorded in 2007 was reduced by almost half compared to the visibility of the lake at the beginning of the study (Table 1).

The rush vegetation of Lake Czyste Małe was the least changed. Only in the year 2007, the presence of phytocoenoses of *Phragmitetum communis* (Gams 1927) Schmale 1939, an association new to the lake was recorded (Table 2).

DISCUSSION

Within just a few years, the submerged vegetation in Lake Czyste Małe had almost completely disappeared. Charophyte meadows vanished first.

Such a model of shifts in the macrophyte vegetation often occurs in shallow water bodies during the transformation from a clear-water into a turbid-water state (Scheffer et al. 1993). It is likely that Lake Czyste Małe is in transition between two alternative states, and the existing macrophyte communities delay the changes to a certain extent.

Charophyte communities are particularly sensitive to the increasing trophy state, therefore they serve as phytoindicators of the low trophy and proceeding eutrophication (e.g. Hutchinson 1975; Krause 1981; 1997; Blindow 1992; Pełechaty, Pukacz 2008). Based on the measurements of physicochemical indicators, it may be concluded that in the years 2002 – 2007 there were no drastic changes in the trophy state of the waters of Lake Czyste Małe. In the light of the above statement, along with the forested catchment area, which is favorable for the lake stability, one may conclude that the introduction of grass carp in 2002 was the direct cause of the present character of the vegetation.

According to Pípalová (2006), for the vegetation control purpose, lakes should be stocked with lower weights of grass carp than ponds. For lakes, 12 kg ha^{-1} is considered as low and 37 kg ha^{-1} as high stocking densities. With 180 kg of the maximum fish stock and the area of 9 ha, Lake Czyste Małe can be considered as moderately stocked (20 kg ha^{-1}). According to different authors, grass carp consume from 15% to nearly twofold of their own weight a day (Fischer 1968; Fischer, Lyakhnovich 1973; Cure 1970). It depends mainly on the age of fish (Fischer 1968), temperature of the water (Fischer, Lyakhnovich 1973; Opuszyński and Shireman 1995) and on the species of a plant consumed (Fischer, Lyakhnovich 1973). Charophytes are definitely placed among numerous plants that have been found in the alimentary tracts of adult grass carp (Fischer 1968; Opuszyński 1969, and the summary by Fischer, Lyakhnovich 1973). However, it must be emphasized that different authors disagree whether charophytes are preferred, tolerated or avoided food for this fish species. Pine and Anderson (1991) put these algae among plants least preferred by grass carp, this being explained by strong odor of charophytes. In contrast, Cassani and Caton (2006) found that *Chara* sp. was readily consumed in large quantities. Krzywosz et al.

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(1980) described transformation of vegetation in Lake Dgał Wielki, which had been stocked with grass carp every year for over a decade since 1966. Between 1974 and 1978, grass carp reduced the biomass of lake vegetation about 70 times, including the complete elimination of the extensive *Chara* meadows – a dominant element of vegetation before and a long time after stocking. It is unclear whether charophytes in Lake Dgał Wielki were preferred by grass carp or were readily consumed because of their great biomass. As Cure (1970) suggested, grass carp's diet depends chiefly on the availability and only slightly on food preference.

It has been agreed upon that grass carp prefers soft-tissue and soft structure species (Jähnichen 1967; Fischer 1968; Pine, Anderson 1991; Catarino et al. 1997, Opuszyński and Shireman 1995). More fibrous and rigid structure plants, and plants with toxic or other compounds (e.g. cellulose, silica, and iron content), which make them more difficult to use as food, are disliked by the fish (Jähnichen 1967, Fischer 1968, Bonar et al. 1990, Van der Zwerde 1990). While charophytes, especially *Chara* spp., lack fibrous tissue, they often precipitate calcium carbonate encrustation on their surface, which can constitute even up to 60% of the plant dry weight (Hutchinson 1975). The encrustation is hard and sharp, therefore it could make charophytes unpalatable for fish. On the other hand, Bonar et al. (1990) reported that calcium as a compound of plant food was positively correlated with the consumption rates of grass carp.

It is difficult to conclude whether the elimination of charophyte communities in Lake Czyste Małe was the direct result of grazing by grass carp or indirect consequence of stocking, like a release of nutrient-rich excrements or disturbing the sediments (Pípalová 2006), as the charophytes are sensitive to an increasing trophy level and decreasing water transparency (e.g. Hutchinson 1975; Krause 1981; 1997; Blindow 1992; Pełechaty, Pukacz 2008). Even so, charophytes in Lake Czyste Małe were forced to withdraw to shallow sites among rush vegetation. According to literature data, charophytes living in shallow eutrophicated lakes are usually replaced by higher plants, especially due to the strong shading factor (Blindow 1992, van den Berg et al. 1999). However, in the investigated situation, the rush community has a refuge function towards the charophytes. The factor of shading by vascular macrophytes plays a less significant role here, considering the structure of the community in which the charophytes were found. This is due to the fact that phytocoenoses of *Typhetum latifoliae* Soó 1927 ex Lang 1973 are characterized by naturally small species cover (usually 3 in the Braun-Blanquet scale, which means between 25 and 50% cover). In addition, small depth and surroundings of hard plants, avoided by grass carp (Fischer 1968), hinder the grazing on charophytes in their new habitat.

Due to the diminished light conditions, which may occur in patches of other macrophytes, charophytes with large thalli are eliminated first (Blindow 1992). Thus, it is also noteworthy that the species that survived in rushes was *C. delicatula*, whose thalli reach small sizes and small axis diameters (Dąmbska 1964; Krause 1997; Pełechaty, Pukacz 2008). The withdrawal of individuals of these species to shallow rush vegetation sites was also described with reference to another reservoir located in the same area as Lake Czyste Małe (Pełechaty 2006).

The decline of charophyte meadows and extensive patches of submerged vegetation (*Myriophylletum verticillati*), which play a crucial role in maintaining a clear-water state in shallow lakes, may soon cause the transformation of Lake Czyste Małe into a stable turbid-water state. The charophytes that survived in the shallow rush communities have no influence on delaying these changes. The extermination of aquatic macrophytes in Lake Czyste Małe may not be a direct result of grass carp stocking. However, it is highly probable that active grazing by grass carp and the accompanying mechanisms (e. g. disturbance of the sediment, and deposition of high nutrient fecal matter) had largely contributed to such drastic changes in the vegetation of this water body.

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