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BIOMASS AND GROWTH RATE OF *POTAMOGETON PECTINATUS* L. IN LAKES OF DIFFERENT TROPHIC STATE *

ABSTRACT: The highest biomass of *P. pectinatus* (up to 250 g d.wt. $\cdot$ m^{-2}) in 10 lakes examined has been recorded in the eutrophic ones. The contribution of underground parts to total biomass is greatly differentiated. The higher the total dry weight the lower the contribution of underground parts. Laboratory experiments on the growth rate of underground and aboveground parts from tubers show that the monthly growth rate of these parts depends on the age and size of tubers.

KEY WORDS: Lakes, littoral, submerged macrophytes, dry weight of macrophytes, rhizome, tubers, eutrophication, water pollution.

1. INTRODUCTION

Potamogeton pectinatus is a cosmopolitan species found all over the world in various types of fresh and brackish waters. *P. pectinatus* is an expansive plant, well resisting pollution, which can grow quickly on vast areas of a water body also taking the place of other species (O z i m e k 1978, P o d b i e l k o w s k i and T o m a s z e w i c z 1979).

Recently V a n W i j k (1983) has observed that *P. pectinatus* may have an annual or perennial life cycle according to environmental conditions.

P. pectinatus is widely distributed on the area of Masurian Lakeland; it occurs in smaller or greater numbers in the majority of lakes. In many lakes where trophic state

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advances fast its range increases by taking place of other species especially on shallow sites, e.g., in Lake Mikołajskie (Ozimek and Kowalczewski 1984).

The aim here has been to answer the following questions: (1) Is there a relation between the quantity of biomass of *P. pectinatus* and the trophic type of lake? (2) What is the contribution of aboveground and underground parts to total plant biomass and their increment rate? (3) Is the life cycle of *P. pectinatus* in Lake Mikołajskie annual or perennial?

2. AREA AND METHODS

Intensive studies in the littoral of Lake Mikołajskie and extensive in the littoral of 9 lakes of Masurian Lakeland (Majcz Wielki, Tałtowisko, Łaśmiady, Bełdany, Tałty, Ryńskie, Śniardwy, Wobel (Miłki), Juno) were conducted in 1982 and 1983. Basic data concerning lakes examined are given in Table 1.

Table 1. Characteristics of lakes examined

Lake	Limnological type	Maximal depth (m)	Lake surface area (ha)	Percentage of lake surface overgrown by submerged macrophytes
Majcz Wielki	mesotrophic	16.4	161.5	30.7
Tałtowisko		39.5	327.0	17.9
Łaśmiady		43.7	882.0	11.0
Mikołajskie	eutrophic	27.8	460.0	6.5
Bełdany		46.0	940.6	18.0
Tałty-Ryńskie*		50.8	1831.2	7.8
Śniardwy		23.4	10970.0	27.6
Wobel	hypereutrophic	15.0	23.7	lack of data
Juno		33.0	380.7	2.4

* Further on treated as two separate lakes: Tałty and Ryńskie.

Two kinds of quantitative samples of plants were taken at the depth of 0.5 m: samples of single plants (whole rhizomes with aboveground shoots) and samples from the frame of a surface area 0.25 m^2. Both kinds were sampled from the littoral of Lake Mikołajskie on 3 sites not affected by the sewage and 2 sites polluted by municipal wastes. In other lakes samples were taken only from frames. In lakes Mikołajskie and Bełdany the wave action was quite strong on sites examined, whereas the sites on other 8 lakes were in quiet bays with small wave action. All samples were taken from the densest aggregation of *P. pectinatus*. Plants were weighed after drying at 105°C, underground and aboveground parts separately.

The growth rate of above- and underground parts was examined in 10 l-aquariums with a 20 cm layer of sediments topped with water. The experiments started in 4 aquariums in August 1983: 10 small (young) tubers were planted in 2 aquariums, whereas in the other 2 – 20 bigger (older) tubers taken from Lake Mikołajskie. The time after which the tubers germinated was recorded, monthly increments of above- and underground parts (d. wt.) were measured.

3. RESULTS

3.1. BIOMASS OF *P. PECTINATUS* IN 10 LAKES OF MASURIAN LAKELAND

In 10 lakes of Masurian Lakeland the differentiation of maximal dry weight attained by *P. pectinatus* per 1 m^2 (at the same time, August 1983) is very high – from 4.8 g in hypereutrophic Lake Wobel to 250 g in eutrophic Lake Śniardwy (Table 2). The smallest differentiation of maximal dry weight per 1 m^2 was within mesotrophic lakes, 2 – 3-fold differences, the highest dry weight in these lakes being about 100 g. In groups of eutrophic and hypereutrophic lakes, in extreme cases, maximal dry weight differed 10 times (eutrophic lakes) and about 20 times (hypereutrophic lakes).

In lakes Mikołajskie and Ryńskie the biomass was analysed on polluted and unpolluted sites. In both lakes the biomass was higher on polluted sites (Table 2).

Table 2. Biomass of *P. pectinatus* in 10 lakes of Masurian Lakeland
M – mesotrophy, E – eutrophy, H – hypereutrophy, A – polluted sites, B – unpolluted sites

Limnological type	Lakes		Dry weight of above- and underground parts · m^{-2}	Percentage of underground parts in total d. wt.	Number of tubers
M	Majcz Wielki		32.8	41.4	148
	Tałtowisko		53.3	6.1	44
	Łaśmiady		95.6	12.1	192
E	Mikołajskie	A	43.6	17.4	48
		B	26.4	27.7	24
	Bełdany		27.6	36.2	24
	Tałty		110.4	14.5	36
	Ryńskie	A	167.0	3.0	24
		B	148.0	6.5	52
	Śniardwy		274.8	12.6	100
H	Wobel		4.8	25.0	8
	Juno		112.3	7.4	8

Striking is the rather low dry weight of *P. pectinatus* per m^2 in lakes Bełdany and Mikołajskie.

The higher the total dry weight the lower the contribution of underground parts. And so, in lakes Tałtowisko, Łaśmiady, Tałty, Ryńskie, Śniardwy and Juno, where the dry weight exceeded 50 g · m^{-2}, the contribution of underground parts did not exceed

15% (6.1 – 14.5%). In other lakes at rather low total biomass, less than 50 g·m^{-2}, the contribution of underground parts was higher and ranged between 17.4 and 41.4%.

The number of tubers on rhizomes in lakes examined is greatly differentiated and is not proportional to the biomass of rhizomes.

3.2. CHARACTERISTICS OF *P. PECTINATUS* IN LAKE MIKOŁAJSKIE

The densest aggregations of *P. pectinatus* (about 100 shoots per m^2) in Lake Mikołajskie were recorded in shallow parts of the littoral to the depth of 0.7 m. The range of occurrence deep into the lake does not exceed 2.5 m. *P. pectinatus* grows usually in monospecific aggregations, although it forms sometimes phytocoenoses where other species also occur, e.g., other species of pondweeds *Potamogeton perfoliatus* L., *P. lucens* L., *P. crispus* L., and *P. compressus* L.

The first aboveground shoots of *P. pectinatus* appear at the beginning or in the middle of May (depending on the temperature of water) and disappear at the end of October on unpolluted sites, or already in August on polluted sites, whereas in September new shoots grow. O z i m e k (1978) has mentioned earlier the disturbed phenological cycle of *P. pectinatus* in polluted environments.

On polluted sites grows *P. pectinatus* v. *scoparius* with strongly branched aboveground shoots.

Rhizomes of *P. pectinatus* penetrate the bottom to the depth of 0.5 – 3 cm, occurring most frequently at the depth of 1.5 cm. Roots reach the depth of 12 cm.

The dry weight of single plants was analysed on two types of sites during the vegetation season as well as the contribution of underground parts (Fig. 1).

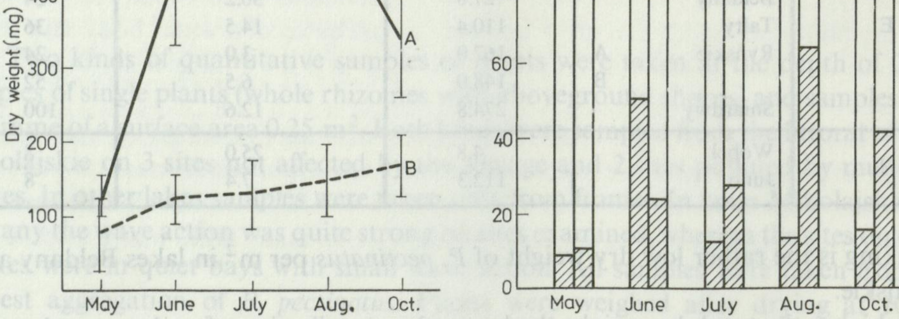

Fig. 1. Mean dry weight ± standard deviations of single *P. pectinatus* plants and percentage of above- and underground parts in the littoral of Lake Mikołajskie

A – polluted sites, B – unpolluted sites, 1 – aboveground parts, 2 – underground parts

The highest increment of biomass of *P. pectinatus* on polluted and unpolluted sites was between May and June. The contribution of undeground parts to total biomass was the lowest in May, the underground parts consisting at the time mainly of tubers, the rhizomes having maximal length of 0.5 – 1 cm. On unpolluted sites mean biomass of plants was lower, whereas the contribution of underground parts was higher (with the exception of June).

The germination time of underground tubers and the growth rate of above- and underground parts show that young tubers germinated as new plants very quickly, almost without a resting period, usually 10 days after planting. Older tubers had a longer resting period, germinating usually after 30 days (50% of planted ones) and 58 days (25% of planted ones). About 5% of planted tubers germinated after 110 days (biomass increments were not measured). Monthly growth rate of plants germinating after 10 days was many times lower than that of plants germinating after 30 and 58 days. The increment rate of underground parts was faster than of aboveground ones for tubers germinating after 10 days, for those germinating after 30 days the increment rate was equal, whereas after 58 days the aboveground parts grew slightly faster (Table 3).

Table 3. Growth rate of above- and underground parts (in mg per month) from tubers of *P. pectinatus* depending on germination time
A – small (young) tubers, B – big (old) tubers

Time of germination from tubers (days)		Increments of aboveground parts		Increments of underground parts	
		mean	range	mean	range
A	10	0.09	0.08 – 0.11	0.24	0.20 – 0.29
B	30	30.5	22.0 – 123.0	30.6	16.0 – 50.0
	58	21.2	30.0 – 120.0	29.2	10.6 – 52.0

3. DISCUSSION

The literature statements that *P. pectinatus* grows most abundantly in fertile waters (O z i m e k 1978, P o d b i e l k o w s k i and T o m a s z e w i c z 1979) have been confirmed here. In eutrophic lakes examined biomass of *P. pectinatus* is usually higher than in mesotrophic lakes. A deviation from this tendency is the low maximal biomass in two eutrophic lakes Bełdany and Mikołajskie and in hypereutrophic Lake Wobel. In the case of the two first lakes this may be caused by the choice of sites which otherwise than sites on other eutrophic lakes are exposed to considerable waves. The considerable number of broken *P. pectinatus* shoots in these places may indicate that the real maximal biomass with consideration to losses caused by waves would be much higher.

Lake Wobel (Miłki) is a lake strongly polluted with organic wastes (mainly from the dairy). The vegetation in the lake is scarce and in poor condition (O z i m e k 1978). *P. pectinatus* is still one of the very few species there, but grows rather poorly (T. Ozimek – unpublished data). Low biomass of *P. pectinatus* in Lake Wobel allows to assume that the pollution level of this lake exceeds the resistance of *P. pectinatus* – a species well enduring even strong pollution (O z i m e k 1978). This is also confirmed by data of L a c h a v a n n e (in press) for the polluted hypereutrophic lakes in Switzerland.

The contribution of underground parts to total biomass of *P. pectinatus* is greatly differentiated. In eutrophic lakes, especially on polluted sites, mainly *P. pectinatus* v. *scoparius* grows, its production being mainly the green aboveground shoots.

The contribution of underground parts to total biomass of *P. pectinatus* is lower and more differentiated than in two other species of pondweeds *P. perfoliatus* and *P. lucens* (O z i m e k et al. 1976). Rhizomes of *P. pectinatus* penetrate the bottom at a similar depth as *P. perfoliatus* but not so deeply as *P. lucens* (O z i m e k et al. 1976).

The greatest increments of *P. pectinatus* biomass are at the begining of vegetation season, in summer the biomass increment is small. Apart from physiological mechanisms, conditioning faster increment rate of young plants and the limits of plant growth under the given environmental conditions, the slight increase of plant biomass during the summer may be affected by filamentous algae growing abundantly at the time in the majority of eutrophic lakes. They inhibit the growth of *P. pectinatus* by shading and "crushing" it (plants lie at the bottom under the algae).

The analysis of biomass increments from tubers formed on rhizomes shows that the bigger and older are the tubers the greater the increments of under and aboveground parts. It seems to be due to greater stores and thus more food for the germinating plant supplied for a longer time.

Plenty of tubers grow on rhizomes during the whole vegetation season, which can germinate after different resting periods. Thus *P. pectinatus* may survive unfavourable conditions, e.g., mass growth of filamentous algae, and as soon as they disappear new shoots begin to grow immediately (also in autumn).

P. pectinatus in Lake Mikołajskie winters only in the form of tubers (indicated by biomass measurements and observation made early in spring and late in autumn); the annual life cycle of this species is thus realized. A similar life cycle has been observed for *P. pectinatus* in Lake Velure in Holland (V a n W i j k 1983).

5. SUMMARY

The biomass of *Potamogeton pectinatus* has been analysed in 10 lakes of different trophic state (mesotrophic, eutrophic and hypereutrophic) (Tables 1, 2). The highest biomass – up to 250 g d. wt. $\cdot$ m^{-2} is attained by this species in eutrophic lakes. This is confirmed by literature data about abundant growth of *P. pectinatus* in fertile waters. The contribution of underground parts to total biomass of *P. pectinatus* is greatly differentiated. The higher the total dry weight the lower the contribution of underground parts.

Dry weight of single plants and contribution of underground parts during the vegetation seasons on unpolluted and polluted sites in Lake Mikołajskie were analysed (Fig. 1). The highest biomass increment is

recorded on both sites at the beginning of the vegetation season. On polluted sites mainly *P. pectinatus* v. *scoparius* grows, the production of which are mainly the green aboveground shoots.

Tubers grow on rhizomes of *P. pectinatus* during the whole vegetation season and can germinate after different resting periods. Increments of above- and underground parts are bigger when the tubers are older (greater stores) (Table 3).

In Lake Mikołajskie *P. pectinatus* winters only in the form of tubers (as indicated by biomass measurements early in spring and late in autumn) thus fulfilling the annual life cycle of this species.

6. POLISH SUMMARY

Analizowano biomasę *Potamogeton pectinatus* w 10 jeziorach o różnej trofii (mezotroficznych, eutroficznych i hypereutroficznych) (tab. 1, 2). Najwyższą biomasę dochodzącą do 250 g suchej masy $\cdot m^{-2}$ gatunek ten osiąga w jeziorach eutroficznych. Potwierdza to notowane w literaturze stwierdzenia o obfitym rozwoju *P. pectinatus* w żyznych wodach. Udział części podziemnych w całkowitej biomasie *P. pectinatus* jest bardzo zróżnicowany. Stwierdzono, że im wyższa całkowita sucha masa, tym niższy jest w niej udział części podziemnych.

Analizowano suchą masę pojedynczych roślin i udział części podziemnych w ciągu sezonu wegetacyjnego na stanowiskach niezanieczyszczonych i zanieczyszczonych w Jeziorze Mikołajskim (rys. 1). Najwyższy przyrost biomasy następuje na początku sezonu wegetacyjnego na obu typach stanowisk. Na stanowiskach zanieczyszczonych rośnie głównie *P. pectinatus* v. *scoparius*, którego produkcja realizuje się głównie w zielonej nadziemnej masie pędów.

Bulwy na kłączach *P. pectinatus* tworzą się przez cały sezon wegetacyjny i mogą kiełkować po różnym okresie spoczynku. Przyrosty części nad- i podziemnych z bulw są tym większe, im starsze są bulwy (o większej zawartości materiałów zapasowych) (tab. 3).

W Jeziorze Mikołajskim *P. pectinatus* zimuje tylko w postaci bulw (wskazują na to pomiary biomasy i obserwacje terenowe wczesną wiosną i późną jesienią), realizuje się więc jednoroczny cykl życiowy tego gatunku.

7. REFERENCES

1. Lachavanne J. B. (in press) – The influence of accelerated eutrophication on the macrophytes of Swiss Lake: abundance and distribution – Verh. int. Verein. Limnol.
2. Ozimek T. 1978 – Effect of municipal sewage on the submerged macrophytes of a lake littoral – Ekol. pol. 26: 3–39.
3. Ozimek T., Kowalczewski A. 1984 – Long-term changes of the submerged macrophytes in eutrophic Lake Mikołajskie (North Poland) – Aquat. Bot. 19: 1–11.
4. Ozimek T., Prejs A., Prejs K. 1976 – Biomass and distribution of underground parts of *Potamogeton perfoliatus* L. and *P. lucens* L. in Mikołajskie Lake, Poland – Aquat. Bot. 2: 309–316.
5. Podbielkowski Z., Tomaszewicz H. 1979 – Zarys hydrobotaniki [An outline of hydrobotany] – Państwowe Wydawnictwo Naukowe, Warszawa, 531 pp.
6. Van Wijk R. J. 1983 – Life-cycles and reproductive strategies of *Potamogeton pectinatus* L. in the Netherlands and the Camargue (France) – Proc. Int. Symp. Aquat. Macrophytes, Nijmegen, 18–23 September, 1983, 317–321.