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Growth and nutrient uptake by two species of *Elodea* in experimental conditions and their role in nutrient accumulation in a macrophyte-dominated lake

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Abstract

The capacity of *Elodea nuttallii* (Planch.) St. John and *Elodea canadensis* Michx. to remove nitrogen from water was evaluated in laboratory experiment. The growth rate of plants and their effect on the nitrogen level of hypertrophic Lake Zwemlust (the Netherlands) as well as on lake water enriched with nitrogen were investigated. The plants grew best in water enriched with up to 2 mg NH_4-N l^{-1} and 2 mg NH_4-N l^{-1} plus 2 mg NO_3-N l^{-1}. During a 14 day experiment, plants absorbed from 75% to 90% of nitrogen. Higher nitrogen concentration than 4 mg l^{-1} had a negative effect on growth of both species. *Elodea nuttallii* and *E. canadensis* prefer NO_4^+ over NO_3^- when both ions were present in water in equal concentrations.

Introduction

Submerged macrophytes grow between the shoreline and open waters and they can intercept or modify material flows from land to the pelagial. Most of them are rooted and constitute a living link between sediments and the overlaying water. They build an ecotone – horizontaly between land and open water and verticaly between sediments and overlaying water. Submerged macrophytes can play a central role in nutrient cycling, especially in small, shallow lakes. They often accumulate large quantities of inorganic elements (Boyd, 1968; Boyd, 1971; Hutchinson, 1975) and can thus have major effects on phosphorus and nitrogen cycling if their biomass is high (Carpenter & Lodge, 1986; Reddy *et al.*, 1987). Submerged macrophytes, despite of their well developed root systems, absorb some mineral elements directly from the water, especially those with a large foliage surface area (Agami & Waisel, 1986).

In small, shallow lakes dominated by submerged macrophytes, deficiences of some nutrients may occur (Boyd, 1971). This occurred in Zwemlust, a small (1.7 ha) lake in the Netherlands, after steps were taken to restore the lake by biomanipulation in 1987 (Van Donk *et al.*, 1989). Before and during the biomanipulation, aquatic plants were absent. After biomanipulation they rapidly developed and occupied 70% of the lake bottom in summer 1988 and almost 100% in summer 1989 (Ozimek *et al.*, 1990). *Elodea* *nuttallii* (Planch.) St. John was the dominant species.

In summer 1988, when plants were abundant, nitrate and ammonia nitrogen concentrations declined to near detection level. Phosphorus concentration was high (about 1 mg PO_4-P l^{-1}) and stable (Van Donk *et al.*, 1989).

The goal of our research was to quantify the effect of *E. nuttallii* and *E. canadensis* Michx. on phosphorus and nitrogen concentrations in Lake Zwemlust, and to evaluate the ability of these plants to remove nitrogen and phosphorus from nutrient-rich waters. *Elodea nuttallii* and *E. canadensis* are common species not only in small, shallow lakes but they can also be dominant in the littoral of big lakes (Kuni, 1982; Ozimek, 1983). Their role in nitrogen and phosphorus cycling was studied in laboratory experiments.

Material and methods

Elodea nuttallii and *E. canadensis* were collected in September 1988 from Lake Zwemlust. The plants were washed under running tap water, taking care not to damage their tissues. The apical, portion (*ca* 20 cm) of mother shoots were cut off and acclimatized for 3 days in the laboratory (19 °C; 16:8 dark:light; 30 W m^{-2} PAR) before the experiments. Several samples of each species were weighed, dried (105 °C for 24 h) and reweighed, to measure fresh and dry weight, respectively.

The growth rate of *E. nuttallii* and *E. canadensis* was studied under different concentrations of nitrogen (Table 1). For each nitrogen concentration, three one-litre aquaria were used. Five shoots each of *E. nuttallii* and *E. canadensis* were separately cultivated in an aquarium for 14 days. Initial shoots were without lateral shoots and roots. The variables measured at the beginning and the end of experiments were: length of shoots, fresh weight of each shoots and roots (*E. nuttallii*: experiments I–IV; *E. canadensis*: IA–IVA), total fresh weight of plants in each aquarium, concentrations of NH_4-N, NO_3-N, PO_4-P in water (*E. nuttallii*: experiments I–VII; *E. canadensis*: experiments IA–VIIA; Table 1). The average relative growth rate ($\overline{R}$) was calculated using the following equation (Hunt, 1978):

Table 1. Nitrogen concentration for the growth rate experiment with *Elodea nuttallii* and *E. canadensis* from Lake Zwemlust. Each experiments had three replicates.

Nitrogen concentration mg l^{-1}	Experiment number	
	E. nuttallii	*E. canadensis*
Water from Lake Zwemlust	I	I A
Water + 2 mg NO_3-N	II	II A
Water + 2 mg NH_4-N	III	III A
Water + 2 mg NO_3-N + 2 mg NH_4-N	IV	IV A
Water + 5 mg NO_3-N	V	V A
Water + 5 mg NH_4-N	VI	VI A
Water + 5 mg NO_3-N + 5 mg NH_4-N	VII	VII A

$$\overline{R} = \frac{\ln W_2 - \ln W_1}{T_2 - T_1}$$

where R is the average weight-specific growth rate (g d.w. g^{-1} d.w. day^{-1}), and W_1 and W_2 are plant weights at time T_1 and time T_2, respectively, in days.

Preferential uptake of NH_4-N or NO_3-N by plants was measured in the laboratory. One-litre aquaria containing filtered water (Whatman GF/F) from Lake Zwemlust enriched with 2 mg NH_4-N l^{-1} and 2 mg NO_3-N l^{-1}, or with 5 mm NH_4-N l^{-1} and 5 mg NO_3-N l^{-1} were used. Five shoots of *E. nuttallii* or 5 shoots of *E. canadensis* were cultivated. The control aquaria were without plants. The concentration of NH_4-N, NO_3-N were measured after 4, 8, 16, 32 and 64 hours. Three replicates were used for each exposure time.

PO_4-P was determined according to Murphy & Riley (1962), NO_3-N according to Stainton *et al.* (1974), and NH_4-N following Verdouv *et al.* (1977), using a Cerco automated analyzer.

Results

Growth and dry weight yield

Initial dry weight did not significantly differ. Length and dry weight of individual shoots of

Table 2. Growth of individual shoot of *Elodea nuttallii* under different nitrogen treatments during 14-day laboratory experiments. Means ($n = 15$) with 95% confidence limits in parentheses.

Experiment no. (see table 1)	Length (cm)		Dry weigh (mg)		Specific growth (mg d.w. mg^{-1} d.w. day^{-1})	% share of roots in final d.w.
	Initial	Final	Initial	Final		
I	21.2 (0.8)	29.4 (2.0)	60 (4)	74 (8)	0.015	12.7
II	24.0 (1.3)	38.4 (3.6)	76 (10)	128 (16)	0.037	4.3
III	21.8 (0.6)	45.4 (5.4)	80 (14)	176 (26)	0.056	4.4
IV	22.2 (0.4)	47.8 (4.8)	76 (8)	172 (20)	0.058	3.4

E. nuttallii under different nitrogen treatments differed (Table 2). NO_4-N enrichment in the bioassays had a greater effect on plant growth than NO_3-N. The plants grew best in water enriched with 2 mg NH_4-N and with 2 mg NH_4-N plus 2 mg NO_3-N l^{-1}. Similar results were obtained for *E. canadensis* (Table 3). Final dry weight of plants in experiments I and III; I and IV and IA and IIA; IA and IVA significantly differed (Mann–Whitney U-test, $P < 0.01$).

The plants cultivated in non-enriched nitrogen water had the highest share of roots in their total biomass (Tables 2 and 3).

The relative growth rate of both *Elodea* species was from 2 to 4 times higher in the N-enriched water than in the controls, and that of *E. nuttallii* was higher than that of *E. canadensis* in all experiments (Tables 2 and 3). This was true for the total biomass increments for both species (Figs 1 and 2). Higher nitrogen concentrations than 4 mg l^{-1} had negative effects on dry weight yield

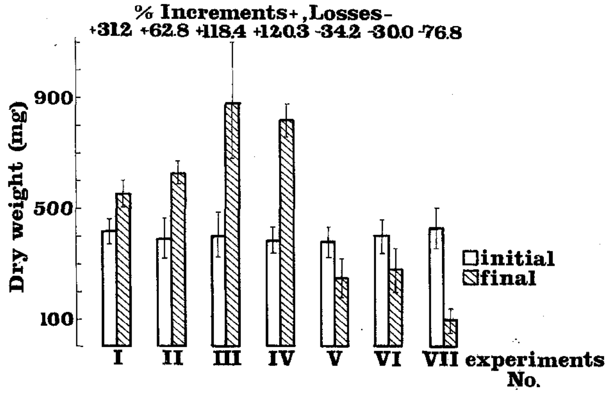

Fig. 1. Changes of dry weight of *Elodea nuttallii* under different nitrogen treatments (for codes see Table 1).

in both species. Plants grew and new lateral shoots were observed, but old shoots started to die. Increment was lower than loss, so the final dry weight was lower than the initial dry weight. At 10 mg n l^{-1}, loss of dry weight was ca 77% for *E. nuttallii* (Fig. 1) and *ca* 52% for *E. canadensis* (Fig. 2).

Table 3. Growth of individual shoot of *Elodea canadensis* under different nitrogen treatments during 14-day laboratory experiments. Means ($n = 15$) with 95% confidence limits in parentheses.

Experiment no. (see table 1)	Length (cm)		Dry weigh (mg)		Specific growth (mg d.w. mg^{-1} d.w. day^{-1})	% share of roots in final d.w.
	Initial	Final	Initial	Final		
I A	20.8 (2.5)	30.2 (2.0)	97 (21.0)	111 (19)	0.010	14.9
II A	17.8 (1.8)	34.6 (5.6)	93 (14.0)	116 (17)	0.016	6.5
III A	17.8 (1.5)	40.8 (3.4)	88 (11.0)	156 (28)	0.041	6.4
IV A	18.1 (2.4)	39.6 (4.4)	85 (11.8)	146 (28)	0.039	5.3

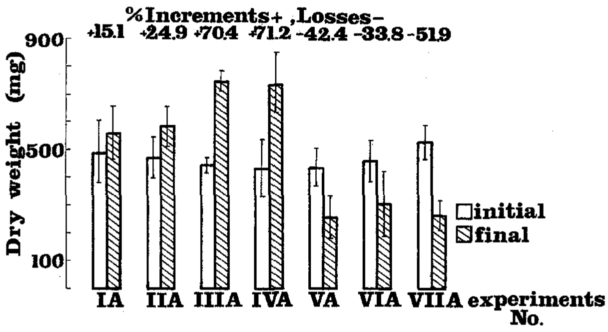

Fig. 2. Changes of dry weight of *Elodea canadensis* under different nitrogen treatments (for codes see Table 1).

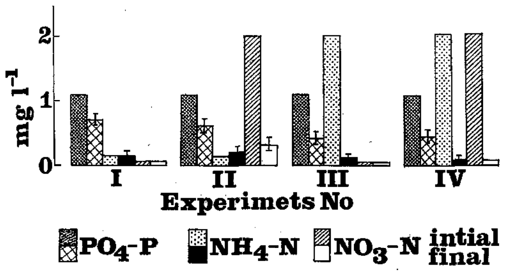

Fig. 3. Changes in the concentrations of NH_4-N, NO_3-N and PO_4-P in the medium after 14 days of cultivation of *Elodea nuttallii* (codes as in Table 1).

Elodea nuttallii and *E. canadensis* seemed to play a significant part in nitrogen cycling. During the 14 days of these experiments, plants absorbed about 50% of the phosphorus and from 75% to 90% of the nitrogen offered (Figs 3 and 4). Depending on nitrogen concentrations in water, *E. nuttallii* can utilize 0–9 mg N g^{-1} d.w. and *E. canadensis* 0–6.5 mg g^{-1} d.w. Their respective phosphorus demands are 1.3–1.6 mg P g^{-1} d.w. and 1.0–1.6 mg P g^{-1} d.w.

Preferential uptake of inorganic nitrogen

Both species of Elodea prefer NH_{+4} to NO_3^+ if both ions are present in water at the same concentrations (Figs 5–8). In water enriched with 2 mg NH_4-N and 2 mg NO_3-N a 50% reduction of initial NH_4^+ concentration was noted after 8 h and 90% after 32 h. The plants started to absorb NO_3-N after 16 h and this absorption increased

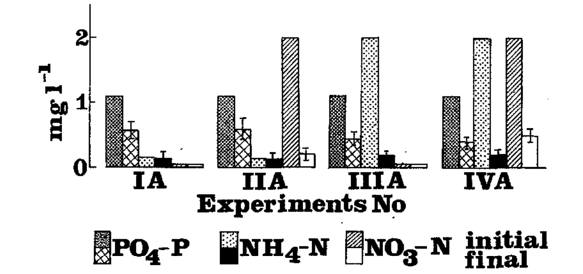

Fig. 4. Changes in the concentrations of NH_4-N, NO_3-N and PO_4-P in the medium after 14 days of cultivation of *Elodea canadensis* (codes as in Table 1).

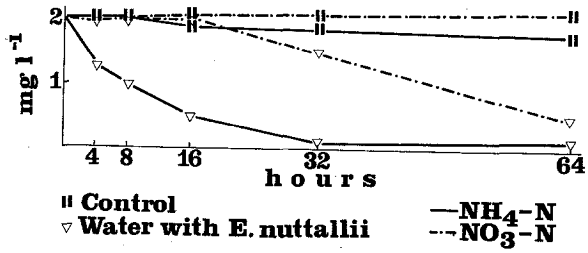

Fig. 5. Effect of *Elodea nuttallii* on changes of nitrogen concentrations in water enriched up to 2 mg NH_4-N l^{-1} and 2 mg NO_3-N l^{-1}.

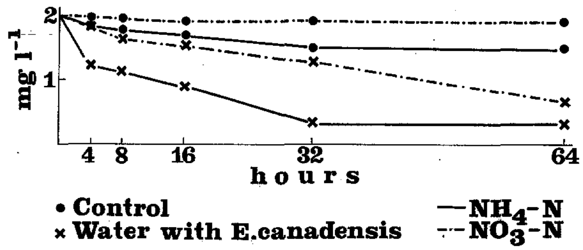

Fig. 6. Effect of *Elodea canadensis* on changes of nitrogen concentrations in water enriched up to 2 mg NH_4-N l^{-1} and 2 mg NO_3-N l^{-1}.

after 32 h when NH_4-IV levels dropped below detection level. After 64 h 75% of the added NO_3-N was taken up by the plants (Figs 5 and 6).

In experiments in which *E. nuttallii* and *E. canadensis* were cultivated in water with addition of 5 mg NH_4-N plus 5 mg NO_3-N at the beginning, the plants absorbed only NH_4-N, but after 16 h the plants started to die and leach nitrogen (Figs 7 and 8).

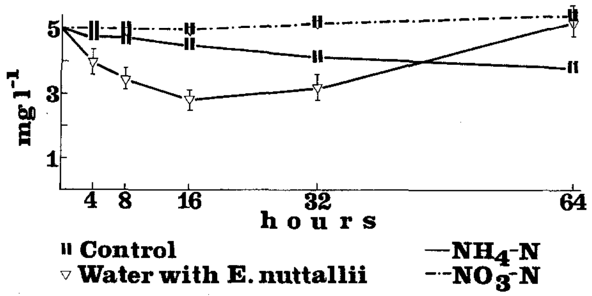

Fig. 7. Effect of *Elodea nuttallii* on changes of nitrogen concentrations in water enriched up to 5 mg NH_4-N l^{-1} and 5 mg NO_3-N l^{-1}.

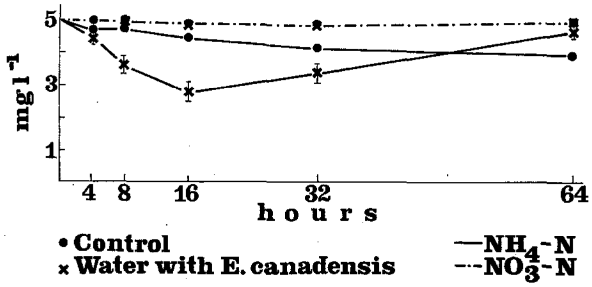

Fig. 8. Effect of *Elodea canadensis* on changes of nitrogen concentrations in water enriched up to 5 mg NH_4-N l^{-1} and 5 mg NO_3-N l^{-1}.

Discussion

Elodea nuttallii and *E. canadensis* occurred in small amounts in Lake Zwemlust in 1987, the year the lake was biomanipulated (van Donk *et al.*, 1989). The conditions for plant growth were favourable; Secchi-depth extended to the bottom, phosphorus concentration was about 1 mg PO_4-P l^{-1} and nitrogen concentration about 2 mg l^{-1}, which was found optimal for both species in the bioassay experiments. Both *Elodea* spp. exhibited similar patterns of growth and nutrient uptake. Thus, what caused the dominance of *E. nuttallii* in 1988 and 1989, when *E. canadensis* occupied only about 3% of the lake bottom and thus had a much lower biomass than *E. nuttallii* (*Ozimek et al.*, 1990). Kuni (1982) showed that *E. nuttallii* can grow slightly even in winter if the mean water temperature is higher than 4 °C. The critical temperature for vegetative growth of this species lies between 8.2 and 12.0 °C (Kuni, 1982), *E. canadensis* needs higher temperatures for active growth. Therefore, *E. nuttallii* starts growing earlier than *E. canadensis*, and its growth rate is higher. In Lake Zwemlust, *E. nuttallii* started growing actively in April 1988. At this time phytoplankton was effectively controlled by zooplankton (Gulati, 1989; Van Donk *et al.*, 1989), and therefore macrophyte competition for nutrients with phytoplankton was not important.

Elodea nuttallii can absorb and accumulate large quantities of nitrogen as shown in our laboratory experiments. This species was mainly responsible for the decrease of nitrogen concentration in Lake Zwemlust to below detection level.

Different forms of nitrogen, both organic and inorganic, can be utilized by aquatic plants: NH_4-N and NO_3-N being the preferable ones (Forsberg, 1975). *Elodea nuttallii* and *E. canadensis* can use both these ions but prefer NH_4-N. Similar results were reported for other species (Toetz, 1974; Reddy *et al.*, 1987).

In the summer of 1988 and 1989 *E. nuttallii* and *E. canadensis* in Lake Zwemlust had long roots, growing from the tops of its shoots (Ozimek, unpubl.). In laboratory experiments this phenomenon was observed in plants cultivated using low nitrogen concentrations. Curtis & Clark (1975) and our experimental results show that the root to shoot ratio may be a good indicator of a lack of nitrogen in the environment.

Conclusion

1. *Elodea nuttallii* and *E. canadensis* have the potential to remove nitrogen from hypertrophic waters.
2. Both species can grow in water in which the nitrogen concentration does not exceed 4 mg l^{-1}.
3. *Elodea canadensis* can be more profitably used in removing nitrogen from water, because it is widely distributed in the world.

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