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Management of Aquatic Exotic Plants: The Case of *Elodea* Species.

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ABSTRACT

Elodea canadensis Michaux, coming from North America has been introduced in Europe in 1836 and soon became a widely distributed and troublesome species in Europe, after which it often became integrated in the biocoenosis. *Elodea nuttallii* (Planch.) St John was first introduced into Europe in 1939. Only female plants were observed. Apparently, *E. nuttallii* is actively spreading in many parts of Europe and seems to be replacing *E. canadensis* in many localities.

The impact of several frequencies of hand-pulling on the biomass and on the architecture of *E. nuttallii* and of *E. canadensis* was evaluated by assessment of morphological traits in stream and in a reservoir respectively. The stream is invaded by *E. nuttallii* and the reservoir by *E. canadensis*. Hand-pulling caused a temporary drastic reduction of biomass of *E. nuttallii* and of *E. canadensis*. After hand-pulling, the spread of *E. nuttallii* and of *E. canadensis* was area restricted. The development of native aquatic plants was favoured two years after the last hand-pulling. Furthermore, no significant difference was observed in the architecture of *Elodea sp.* between the reference and experimental areas. *Elodea* appeared as disturbance–tolerant species.

Keywords: non indigenous species, freshwaters, France, biological traits, hand-pulling.

INTRODUCTION

In France, biological invasion research in freshwater systems has focused on a few plants such as *Ludwigia* species (Dutartre and Oyarzabal 1993, Dutartre et al. 1997) or *Elodea* species (Thiébaut et al. 1997, Barrat-Segretain 2001, 2004, 2005, Greulich and Trémolières 2002, Barrat-Segretain et al. 2002). An indigenous of North America, *Elodea canadensis* Michaux, first recorded in the early 19th century in the British Isles (Simpson 1984, 1990), is now naturalised and widespread in Europe. *Elodea canadensis* became a persistent weed following its naturalisation, choking waterways before declining to its present, less-abundant (but still common) level (Cook and Urmi-König 1985, Thiébaut et al. 1997, Barrat-Segretain 2001). Another species from North America, *E. nuttallii* (Planch.) St John was first found in Belgium in 1939 and had spread into northern France by the end of the 1950s. For the past 30 years it has been colonising numerous ponds and streams in metropolitan France, except in the south-east. *Elodea nuttallii* is replacing *E. canadensis* at many sites (Mériaux and Gehu 1979, Thiébaut et al. 1997, Barrat-Segretain 2001). Although *E. canadensis* and *E. nuttallii* have been spreading for several years in eastern France, this species is relatively more problematic in other European countries (for example in Germany, Switzerland, Brittany, Belgium, Sweden).

In many bodies of water, it has been necessary to control overabundant aquatic plants. Large infestations of plants which cause considerable environmental impact, such as *Ludwigia* spp. or Hydrocharitaceae have the highest priority for control. There are several methods of managing aquatic plants: mechanical or manual harvests, hand-pulling, biological control, changing the aquatic environment and chemical control. The management techniques chosen must be appropriate both to the type of weed problem and to the uses and function of the body water. To our knowledge, no research on the impact of hand-pulling of *Elodea* species (*E. nuttallii and E. canadensis*) has been done.

To evaluate the impact of hand-pulling on the two *Elodea* species (*E. nuttallii, E. canadensis)*, an approach based on measurements of morphological traits was used. In this paper, we aim to determine the impact of the hand-pulling on *E. nuttallii* and on *E. canadensis* biomass, on *Elodea* population and architecture, through measurement of morphological traits.

MATERIAL AND METHODS

Study area

The study was performed in the Vosges mountains ((NE France). The landscape pattern consists of sandstone mountains. The regional climate is sub continental. Two sites were selected: a river and a reservoir. The first one, located in the Northern Vosges, is the Falkensteinbach stream. This stream is characterized by overabundance of *E. nuttallii* (mean cover percentage visually estimated between 70 and 90 % in July). The invasive species *E. nuttallii*

colonized the streams of this area since the end of 1970's (Muller 1990, Thiébaut and Muller 1999). A 100m length of stream was chosen. Two spot-checks (Reference site, experimental site E divided in two sub-units: E1 and E2) located at 45 m intervals (buffer zone) were selected (Figure 1).

The second one, located in the Donon mountains, is a reservoir used as a source of supply for the retaining water (0.5 million cubic metre water lake). It is also a leisure and nautical centre. The lake area is 39 ha. This artificial lake is characterized by overabundance of *E. canadensis* (mean cover percentage visually estimated between 70 and 90 % in July) since 2003. Two spot-checks (Reference site, experimental site E) located within the littoral zone were selected. Each area (reference, experimental) measured 20 x 20 m.

Chemical survey of the water

500 ml of water were collected monthly from the end of February to the end of October in 2003 and in 2005 in the Falkensteinbach stream. It was collected in July, August and October 2006 in the lake "La Plaine". Analyses were performed immediately upon returning to the laboratory (less than 24 hours after sample collection). Alkalinity was determined by titration (AFNOR 1990). Conductivity and pH were measured using a combined glass electrode and corrected for temperature (25°C). Reactive soluble phosphorus and ammonia were analysed using spectrophotometer (single reagent ascorbic acid technique for phosphorus, and indophenol's technique for ammonia, AFNOR 1990). Samples for nitrate, sulfate and chloride analyses were determined in the laboratory with ion chromatography.

Experimental protocol

Hand-pulling

Hand-pulling involves removing entire plants (leaves, stems, and roots) from the area of concern and disposing of them in an area away from the shoreline. During hand pulling, *Elodea* plants are manually removed from the bottom, with care taken to remove the entire root crown and to not create fragments. During hand pulling, we dig around and beneath the plant roots with a tool and gently lift the entire plant out of the sediment. *Elodea* plants can be readily removed from sediments. Once plants are removed, we place them into bags for transportation to the surface.

Site 1: Falkensteinbach river

The factor tested was the impact of diffrent frequencies of hand-pulling in the stream:

- one hand-pulling was practised on E1 and E2 on February 2003,
- a second hand-pulling was realised on E2 on May 2003,

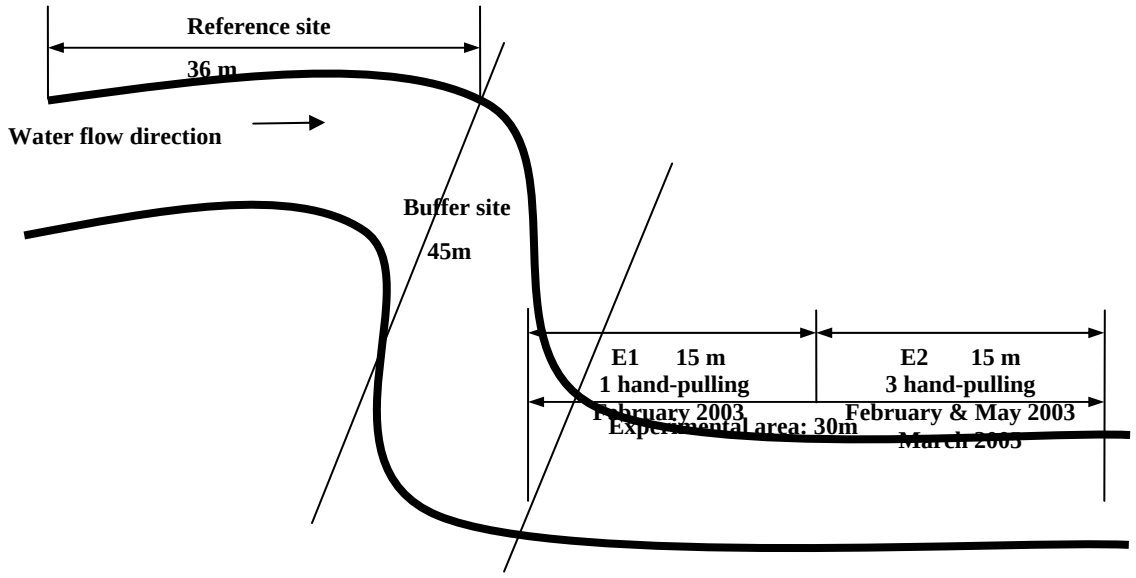


Figure 1. Description of the experimental site 1: The Falkensteinbach river.

- a third hand-pulling was realised on E2 on March 2005.

The impact of management on the architecture of plant and on the biomass was assessed each month until the end of the study.

Site 2

The lake "La Plaine", where manual methods are being used for *Elodea canadensis* eradication, typically have *Elodea canadensis* in small patches within the littoral zone. Two hand-pulling (one in July 2006, and a second one in October 2006) were tested in the litteral zone close to the beach.

Biomass production:

Ten plots (0.2 m^2 area/plot) were randomly placed each month in site 1 (reference, E1 and E2). The biomass was studied in July, in October 2006 and in June 2007 in site 2 (reference, experimental area). The vegetation was dug out manually by species. *Elodea sp.* were weighed. Three replicates of *E. nuttallii* or *E. canadensis* were dried at 65° C for three days. Results were expressed in Dry Mass/m^2. The experiments were realised from March 2003 to October 2003 in the three areas (Reference, E1, E2) and from March 2005 to July 2005 in the Falkensteinbach river (reference site 1, E2). The biomass was measured in July 2006, in October 2006 and in June 2007 in the Lake La Plaine in the reference and in the experimental areas.

Impact of the management on the morphology of Elodea species

Thirty plants were collected each month in site 1 (reference, E1 and E2) from March to October 2003 and from March 2005 to July 2005. They were removed in July and October 2006 in site 2 (reference, experimental area). Apical shoots of 3cm length, corresponding to the optimal growth area, was cut off. Lateral shoots included the initial lateral which developed from the nodes on the apical original shoot and the others lateral which was a development either from the same nodes, or from the nodes on the lateral shoots (Kunii 1981). Nine morphological traits were measured of each plant by a ruler (see for example *E. nuttallii*: Figure 2):

- trait 1: main shoot length
- 2: lateral shoot length (initial +secondary shoots)
- 3: number of lateral shoots (initial shoot)
- 4: length of total shoot (main + lateral)
- 5: bulk. It corresponded to the ratio between dried biomass of the plant and length of total shoot.
- 6: length of ten internodes after the cut of three cm apex.
- 7: length of a leaf located at the sixth whorl
- 8: width of a leaf located at the sixth whorl
- 9: surface of a leaf located at the sixth whorl. One leaf on this sixth whorl is cut, fixed on a paper with sailor tape. Surface was calculated by using logician Scion image V. 1.63.

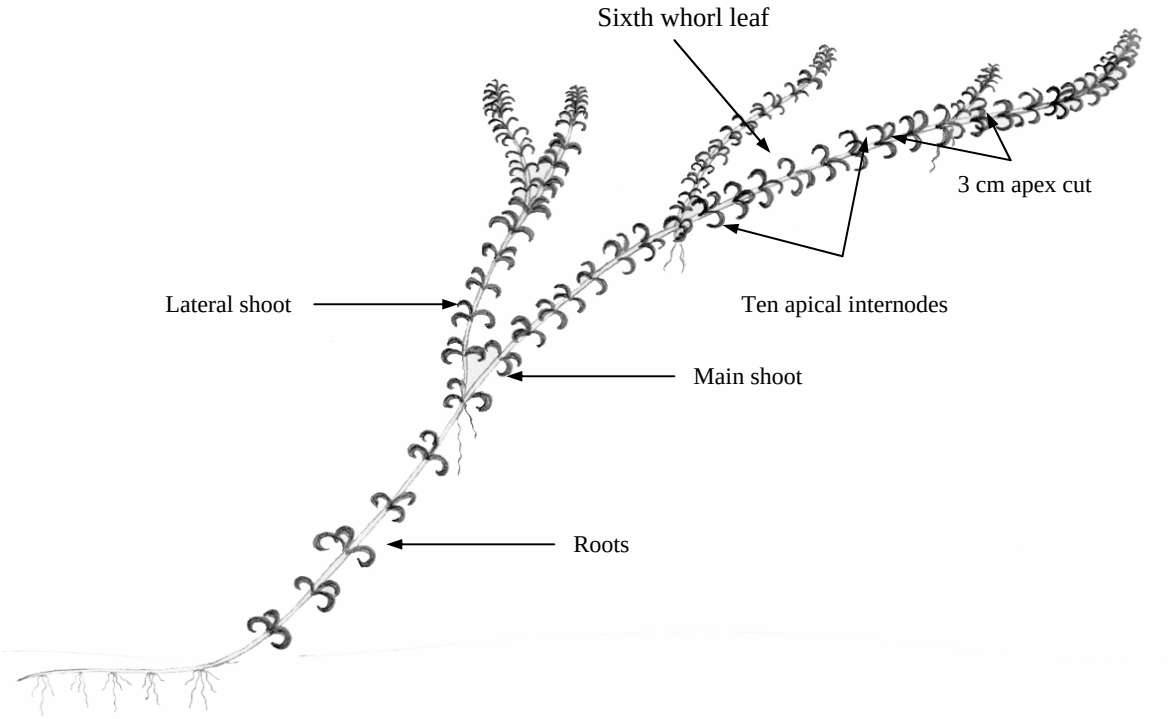


Figure 2. Diagram illustrating *E. nuttallii* and its morphological traits.

Statistical analysis

After the verification of the normal distribution of the values and homogeneity of variance, one way ANOVAs were used to test the management and the temporal effect. For each significant difference of $P < 0.05$, a HDS Tuckey's posthoc test was performed.

RESULTS

Chemical characteristics of the water

The water of the two studied sites was neutral, with low mineral content (Table 1). The site 1 was characterized by a high nitrogen concentration (NNH_4^+ = 109 ± 40µg/l) and a moderate concentration of phosphate (PPO_4^{3-} = 37 ± 10 µg/l), whereas the site 2 was defined by a moderate nutrient level (Table 1).

Biomass production

There was a significant difference in the biomass produced among one, two and three hand-pulling in site 1. No stands of *E. nuttallii* were found after July in site E2 in 2003 (Figure 3a). Only some individuals were present in the end of 2003. However at the beginning of 2005, *E. nuttallii* have again colonized the experimental area. A higher biomass was measured in the reference site 1 in 2005 than in 2003. The hand-pulling had also a significant impact on the production of biomass of *E. canadensis* (Figure 3b).

Table 1. Water chemical composition. Mean annual values.

		La Plaine			Faklensteinbach		
pH		7.67	±	0.5	6.95	±	0.12
conductivity	µScm^{-1}	92	±	6.7	71	±	6
alkalinity	µeq L^{-1}	520	±	7	291	±	29
phosphate	µgPL^{-1}	30	±	10	37	±	10
ammonia	µgNL^{-1}	40	±	10	109	±	40
nitrate	mgNL^{-1}	0.66	±	0.05	0.55	±	0.10
sulphate	mg L^{-1}	6.50	±	0.26	9.37	±	0.75
chloride	mg L^{-1}	5.73	±	0.78	5.7	±	0.21

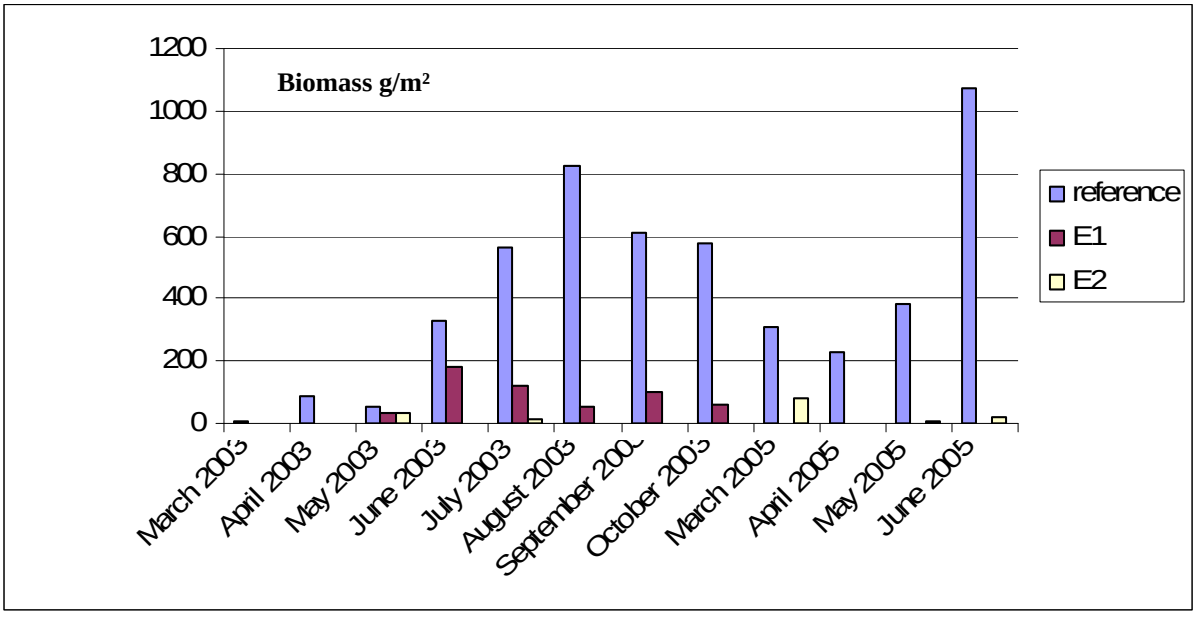


Figure 3. Evolution of the biomass of *Elodea* species in reference site and in hand pulling areas.

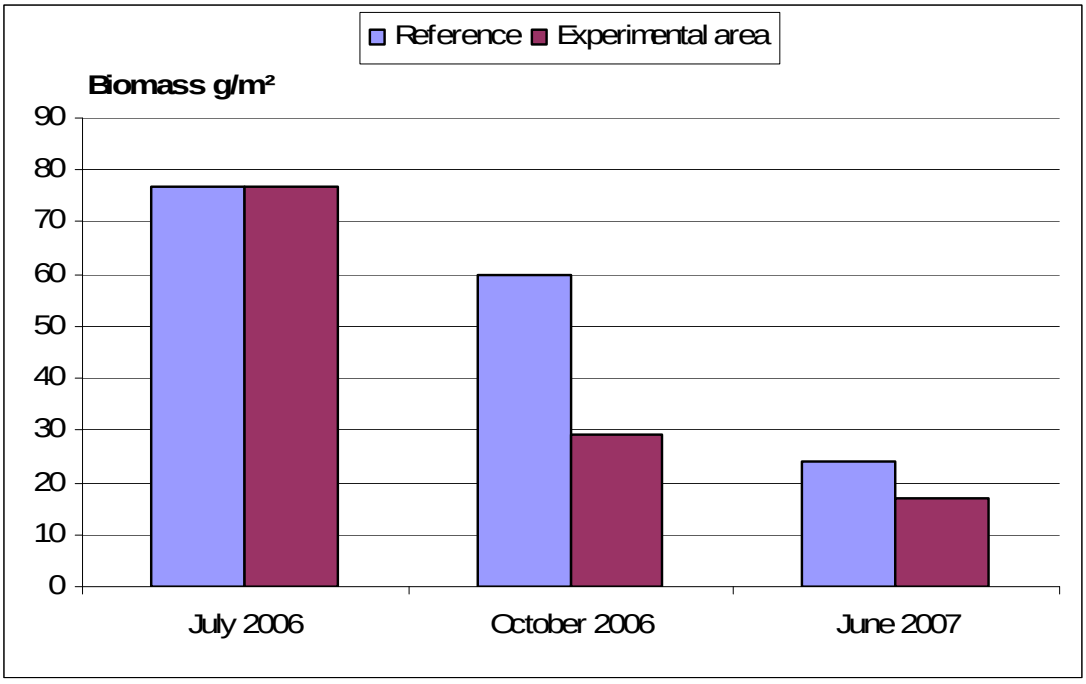


Figure 3a. Biomass of *E. nuttallii* in the Fakensteinbach river;

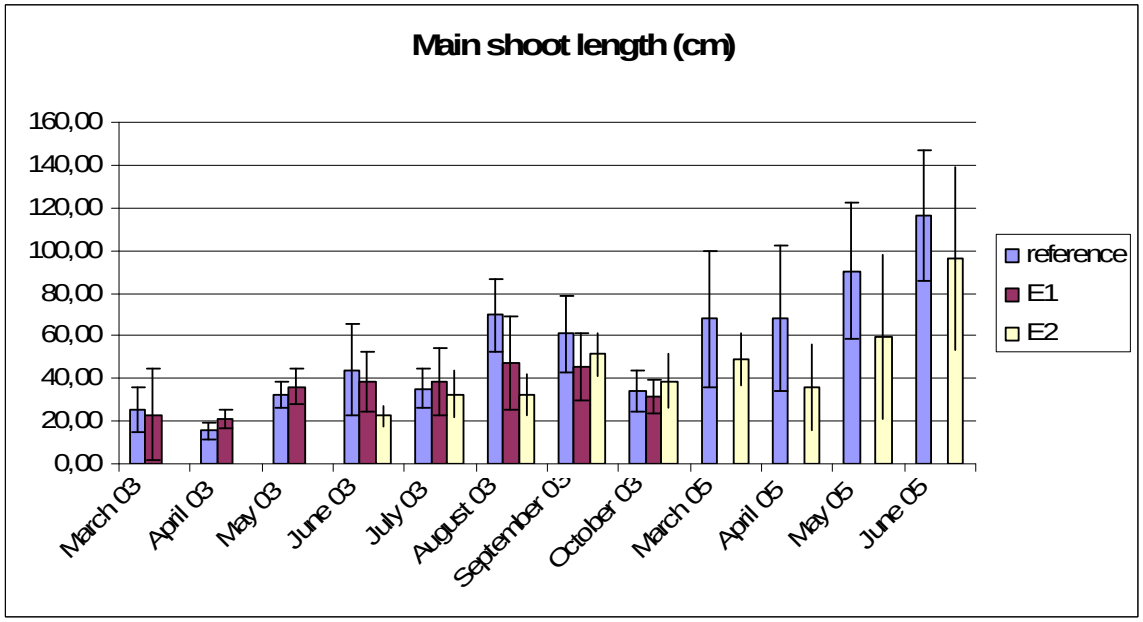


Figure 3b. Biomass of *E. canadensis* in the Lake La Plaine.

Impact of management on the architecture of Elodea species and on the biodiversity

No significant difference was observed in the architecture of *E. nuttallii* (Figure 4a) or *E. canadensis* (Figure 4b) between the plants collected in reference and in experimental areas. At the beginning of the study, the biodiversity was low in the river Falkensteinbach. *E. nuttallii* was the dominant species. The decrease of *E. nuttallii* stands allow the development of native aquatic plants such as *Ranunculus peltatus* or *Callitriche platycarpa* two years after the end of the management in 2007.

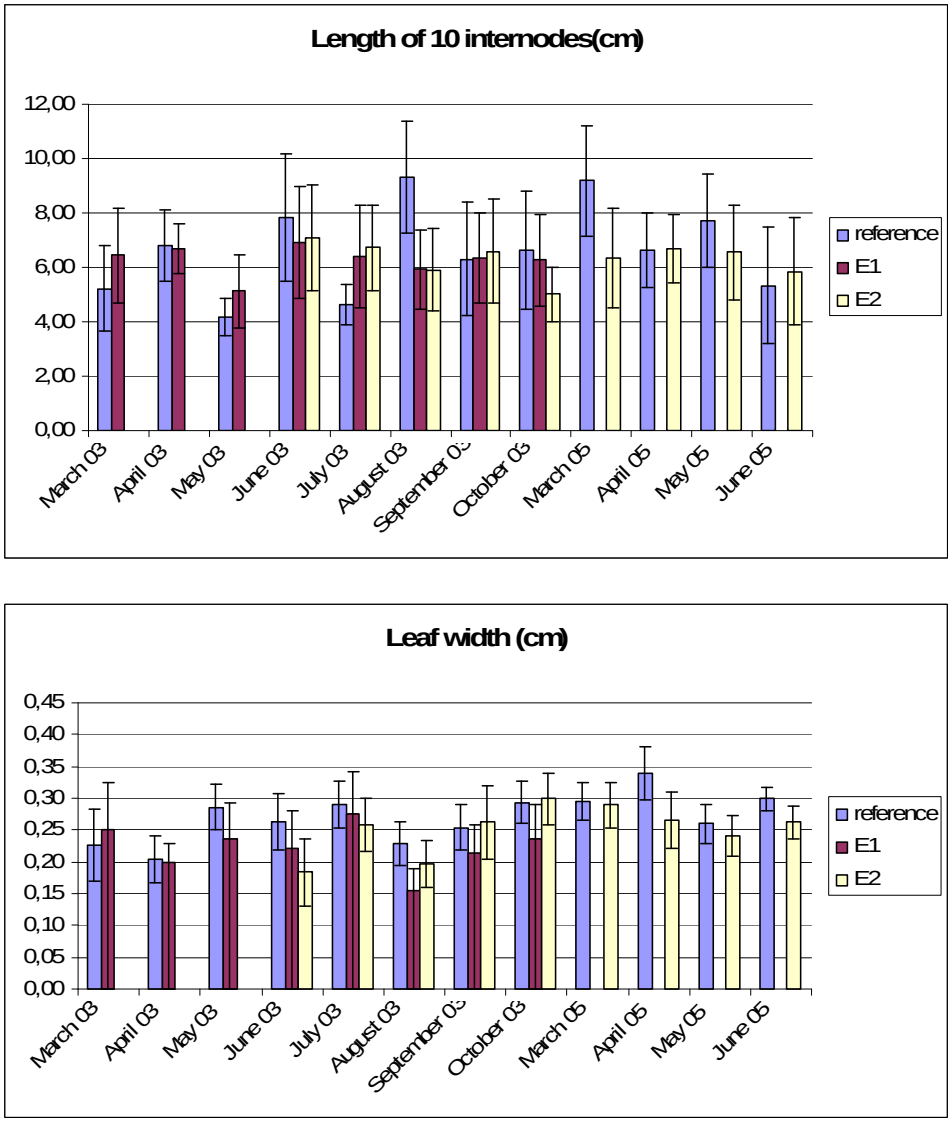
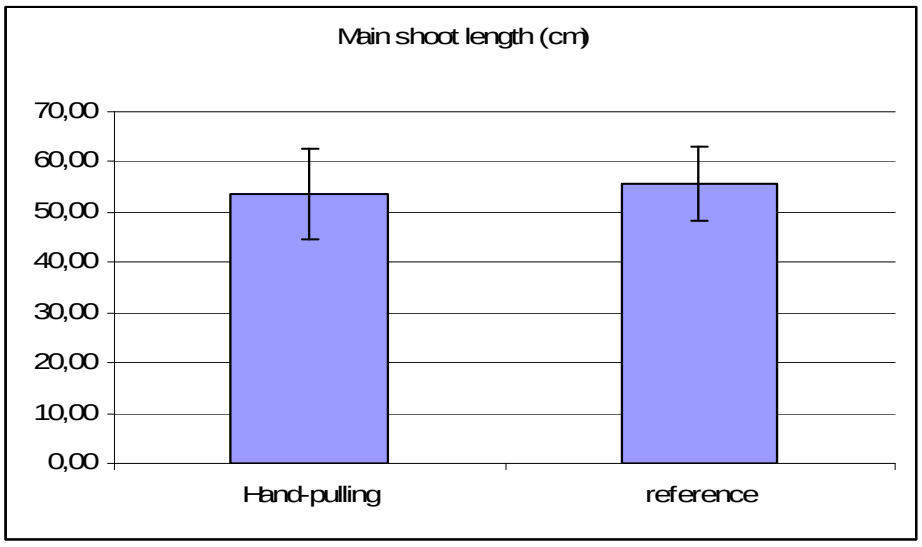
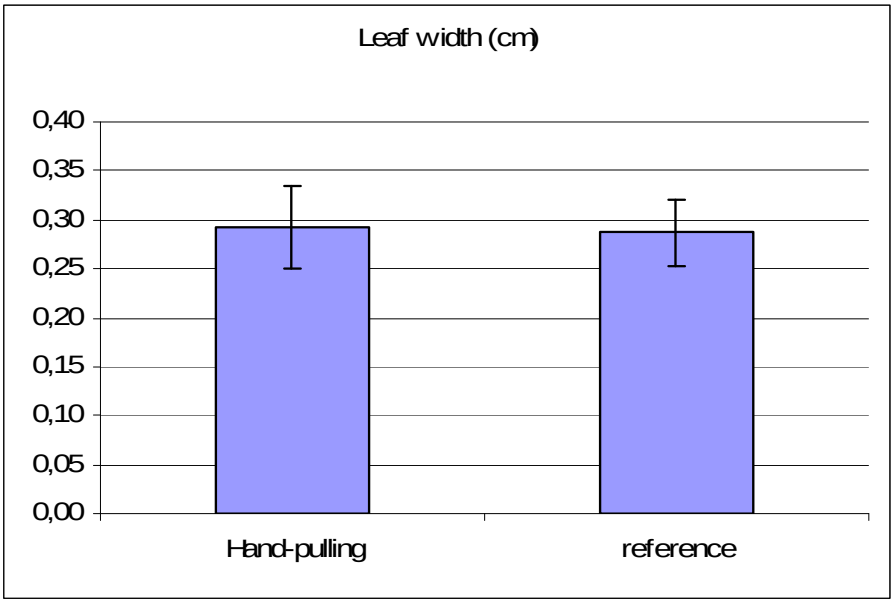


Figure 4a : Impact on the hand-pulling on the architecture of *E. nuttallii*. Example of 3 traits. : trait 1: main shoot length; trait 6: length of ten internodes; trait 8: width of a leaf located of the sixth whorl.





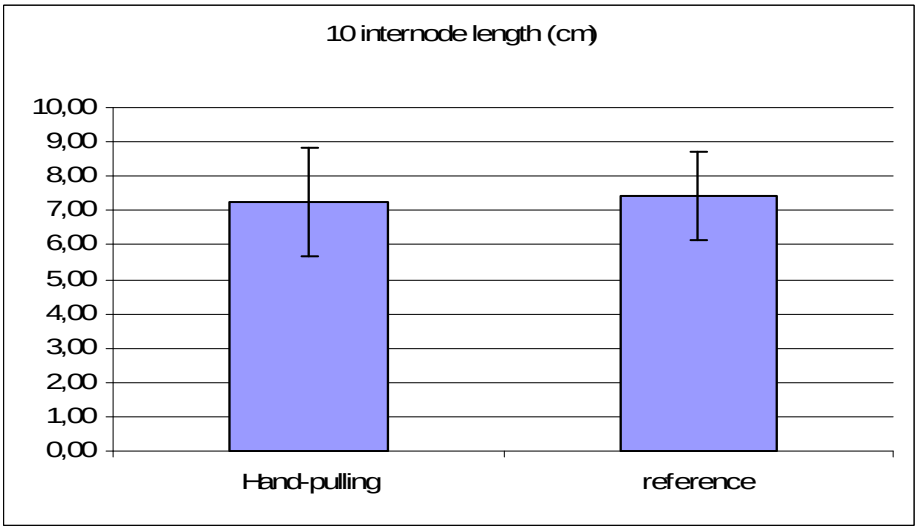


Figure 4b. Impact on the hand-pulling on the architecture of *E. canadensis*. trait 1: main shoot length; trait 6: length of ten internodes; trait 8: width of a leaf located of the sixth whorl.

DISCUSSION

Impact of hand-pulling on the E. nuttallii and on E. canadensis

No significant difference was established for morphological traits of *E. nuttallii /E. canadensis* between plants collected in the experimental and in the reference areas. Hand-pulling have no impact on the architecture of *Elodea* species. Our results didn't corroborate the conclusions of Abernethy et al. (1996) that showed a 44% reduction for length response after two cuts. *Elodea* species appeared as a disturbance-tolerant species. The responses of *Elodea* species to the stress (hand-pulling) was eliminated very quickly, less than one month. The plants grow fast and reach the water surface only few weeks after hand-pulling.

In our study, the maximum of biomass of *E. nuttallii* was obtained in June 2005. The three treatments induced a drastic reduction of *E. nuttallii* in the stream, less than 2% in the end of the study. The biomass response of *E. canadensis* was more marked in our area (reduction of 63% after one treatment) than in the study of Abernethy et al. (1996), which measure biomass reductions of 41 % after one cut.

Management options

After several hand-pulling the spread of *E. nuttallii* and of *E. canadensis* is area restricted. This method is efficient. However, due to expense and the time intensive nature of manual methods, sites suitable for hand pulling are limited to lakes or ponds only lightly infested with invasive species. This method may also be applicable in waterbodies where no herbicide use can be tolerated such as in a lake used as a municipal drinking water supply and running waters.

E. canadensis appeared to be less susceptible to cutting-based weed control measures than *Myriophyllum spicatum*, a native species (Abernethy et al. 1996). Sabbatini and Murphy (1996) using a multivariate approach, showed that *E. canadensis* has a strong tolerance of management based on disturbance, such as cutting. Cutting, especially mechanical control, could induce a reduction of the biomass of indigenous plants and allow *Elodea* to spread to new areas because this management break up the plant. Stem fragmentation is the main dispersal mode for *Elodea* sp. Both *Elodea* species showed similar resistance to currents, while fragment regeneration and colonisation were only slightly higher in *E. nuttallii* than in *E. canadensis* (Barrat-Segretain et al. 2002). Management such as hand-pulling or harvests favor the downstream plant propagation. However harvests can be quite useful in areas where the weed is already established, or when the species will disperse into areas unfavourable to its survival (Bowmer et al. 1995).

The growth of *E. canadensis* is affected by low light intensity, contrary to *E. nuttallii* (Barrat-Segretain 2004). *E. nuttallii* and *E. canadensis* have wide amplitude in nutrient levels (Robach et al. 1995, Rolland et al. 1999, Thiébaut and Muller 2003, Thiébaut 2005). Changes in management practices especially those that have the potential to directly impact the river will be important to help manage exotic macrophytes. This includes practices such as maintaining and enhancing the condition of riparian vegetation and, stormwater and nutrient management. Reduction of nutrients entering the river is important in the fight against exotic macrophytes species, as these species grow best in high nutrient waters.

The biological control of aquatic macrophytes has received considerable interest all over the world. Although *Elodea* species are often preferred food for waterfowl or crayfish (Lodge 1991), they are avoided by many insect herbivores (Newman 1991). However, a slightly higher palatability was established for *E. nuttallii* than for *E. canadensis* by *Limnea stagnalis* (Barrat-Segretain et al. 2002). *E. nuttallii* is avoided by herbivorous larvae of *Acentria ephemerella* (Erhard et al. 2007). No herbivore damage of apical meristems was observed for *E. canadensis* because *Acentria ephemerella* larvae also avoid feeding on this species removed leaves below the apical tips (Gross et al. 2001). In the lake La Plaine, the spread of *E. canadensis* may be also explained by the abundance of this aquatic lepidopteran in dense mats of *Elodea*.

An other solution was to do nothing and to "wait and see". A noticeable decline of *E. canadensis* in European freshwaters (Simpson 1990) and of *E. nuttallii* indeed was also reported after the peak of the outburst in Japan's lake (Nagasaka et al. 2002). *E. nuttallii* populations exhibited a genetic uniformity that made them vulnerable to attack by fungi or pathogens.

Further work is needed to improve our knowledge to estimate the ecological risk of management on biodiversity and on ecosystem function. The risk of adverse side-effects for users of the water and for the ecosystem health must always be taken into account. Stronger enforcement of existing laws, coupled with an intensive public education campaign, is needed to prevent further non indigenous species introduction.

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