2013

Knowledge document for risk analysis of the non-native Fanwort (Cabomba caroliniana) in the Netherlands

J. Matthews, R. Beringen, L.P.M. Lamers, B. Odé, R. Pot, G. van der Velde, J.L.C.H. van Valkenburg, L.N.H. Verbrugge & R.S.E.W. Leuven

Knowledge document for risk analysis of the non-native Fanwort (*Cabomba caroliniana*) in the Netherlands

J. Matthews, R. Beringen, L.P.M. Lamers, B. Odé, R. Pot,
G. van der Velde, J.L.C.H. van Valkenburg, L.N.H. Verbrugge,
& R.S.E.W. Leuven

30 August 2013

Radboud University Nijmegen,
Institute for Water and Wetland Research
FLORON & Roelf Pot Research and Consultancy

Commissioned by
Office for Risk Assessment and Research
(Invasive Alien Species Team)
Netherlands Food and Consumer Product Safety Authority
Ministry of Economic Affairs

Series of Reports on Environmental Science

The series of reports on Environmental Science are edited and published by the Department of Environmental Science, Institute for Water and Wetland Research, Radboud University Nijmegen, Heyendaalseweg 135, 6525 AJ Nijmegen, The Netherlands (tel. secretariat: + 31 (0)24 365 32 81).

Reports Environmental Science nr. 443

Title:	Knowledge document for risk analysis of the non-native Fanwort (*Cabomba caroliniana*) in the Netherlands
Authors:	J. Matthews, R. Beringen, L.P.M. Lamers, B. Odé, R. Pot, G. van der Velde, J.L.C.H. van Valkenburg, L.N.H. Verbrugge, & R.S.E.W. Leuven
Cover photo:	Dense vegetation of Fanwort (*Cabomba caroliniana*) at Loosdrecht, the Netherlands (Photo: R. Pot).
Project manager:	Dr. R.S.E.W. Leuven, Department of Environmental Science, Institute for Water and Wetland Research, Radboud University Nijmegen, Heyendaalseweg 135, 6525 AJ Nijmegen, the Netherlands, e-mail: r.leuven@science.ru.nl
Project number:	62001880
Client:	Netherlands Food and Consumer Product Safety Authority, P.O. Box 43006, 3540 AA Utrecht
Reference client:	NVWA, order nr. 60001296, d.d. 14th May 2013
Orders:	Secretariat of the Department of Environmental Science, Faculty of Science, Radboud University Nijmegen, Heyendaalseweg 135, 6525 AJ Nijmegen, the Netherlands, e-mail: secres@science.ru.nl, mentioning Reports Environmental Science nr. 443
Key words:	Dispersal; ecological effects; invasiveness; invasibility; non-indigenous species

Printed on environmentally friendly paper

Content

Summary

Fanwort (*Cabomba caroliniana*) is a member of a genus of plants that is endemic to South America. *C. caroliniana* has dispersed outside of its native range to a number of European countries, to the United States of America, Canada, Australia, India, China and Japan, and has been declared an invasive species in many of these countries. *C. caroliniana* was first recorded in the Netherlands in 1986 at Maasbracht harbour on the river Meuse, in the south of the country. Since then it has been recorded at a number of locations and has become invasive at Loosdrecht to the north of Utrecht and in the Oranjekanaal. To support decision making with regard to the design of measures to prevent ecological, socio-economic and public health effects, the Invasive Alien Species Team of the Netherlands Food and Consumer Product Safety Authority (Ministry of Economic Affairs) has asked that a risk analysis of *C. caroliniana* be carried out.

A literature study was performed to provide an overview of the current knowledge on the distribution and invasion biology of *C. caroliniana* and to support a risk assessment within the Dutch context. Literature data were collected on the physiological tolerances, substrate preference, colonization vectors, ecological and socio-economic impacts and potential measures for management of this species. The literature study was largely internet based, supported by the use of a university library. Academic and non-academic search engines and websites were systematically searched using the Web of Knowledge, Google Scholar and in an analysis of information available to the Dutch public, Google.nl.

C. caroliniana grows in slow flowing freshwater-bodies on soft substrates and prefers sunlight and shallow water to a maximum ten metres deep. The species may be found in ponds, ditches, small shallow lakes and slow flowing streams in the coastal vegetation of swamp forests and bogs, and inland, in areas of savannah. Research from the Netherlands indicates that low turbidity (2-6 NTU) and high dissolved CO_2 levels seem to facilitate this species. *C. caroliniana* is very well able to use bicarbonate and can photosynthesise at pHs of above 8.4 meaning it can grow in many different water types. Moreover, high nutrient levels in sediment are expected to stimulate growth. In the Netherlands, *C. caroliniana* grows in substrates with nitrogen concentrations of 0.83-21 mg/l; phosphorus concentrations of 0.079-2.585 mg/l and organic matter concentrations of 3.0-65.6 %. The plant has been shown to grow in a wide range of temperatures to levels below freezing and survives harsh winters in the Netherlands and Canada, though it’s optimal temperature range lies between 13 and 27 °C. Increases in temperature, water clarity and the legacy of high phosphate concentrations in substrate may result in increased spread and invasiveness of this species in the Netherlands in the future.

Movement of aquatic plants across borders can be attributed to the trade in aquatic plants. Despite attempts by Dutch nature organisations to educate the public regarding the invasive potential of *C. caroliniana*, the plant constitutes more than 30% of all aquatic plants imported to the Netherlands for use in aquaria and garden ponds. The plant is sold freely at garden centres and over the internet. It is often mistakenly

imported and sold under the name *Cabomba aquatica* and hobbyists may also confuse these two species. *Cabomba aquatica* is visually similar to *C. caroliniana* and displays similarly attractive bright green divided leaves and flowers.

Global introductions of *C. caroliniana* in several Asian, Pacific and European countries have been attributed to the discarding or deliberate planting of aquarium plants in natural waterways. A small proportion of hobbyists also report the disposal of water plants into local watercourses in the Netherlands. The sale of *C. caroliniana* through the plant trade associated with the dumping of unwanted plants to the freshwater network may be an important path of introduction for this species. In the Netherlands, *C. caroliniana* reproduces vegetatively through fragmentation. Therefore, secondary dispersal of this species will rely on the presence of dispersal vectors that transport fragments to new locations. The most important vectors of secondary dispersal, apart from water current, are related to human activity e.g. boats, anglers, weed harvesters. Waterfowl may also carry plant fragments.

Since 1986, *C. caroliniana* has been recorded in 65 kilometre squares in the Netherlands. After 2006 there was a rapid increase in records. Every year the species was recorded in several new kilometre squares where it was not seen before. In 2011 it was recorded in 30 new kilometre squares, mostly in the Oranjekanaal region. In that year, however, this canal was intensively surveyed. In the year 2012 there were only four new kilometre square recordings. In 2013, *C. caroliniana* has been recorded in four new kilometre squares, an urban water-body in Tilburg and Breda (the first records in the province of North Brabant), the Musselkanaal and Breukeleveen. *C. caroliniana* has been recorded in Natura 2000 areas in the Netherlands. The plant has been recorded in the Vechtplassen area and in the Gelderse Poort (Rijnstrangen) and may appear in EU habitat type H3150 (Natural eutrophic lakes with Magnopotamion or Hydrocharition type vegetation). However, During an intensive survey in 2013, *C. caroliniana* could not be found at the location in the Gelderse Poort where it was discovered in 2012. To date there are no signs of *C. caroliniana* becoming invasive in this area.

At Loosdrecht, the Netherlands, *C. caroliniana* has become invasive and is said to have 'smothered' native aquatic plant species. Despite this, in most instances there was no other macrophyte growth in areas where *C. caroliniana* became established. However, at Lake Tienhoven, the Netherlands, *C. caroliniana* has been observed to outcompete other macrophytes, except floating leaved species and helophytes (Van den Berg *et al.,* unpublished results). A study in the Netherlands suggested that *C. caroliniana* requires a 'window of opportunity' where the original vegetation has disappeared or is strongly reduced giving it the space to establish. Once established, rapid growth of dense vegetation and a reduction in light levels will result in *C. caroliniana* outcompeting other submerged aquatic plants. The Netherlands has been matched climatically with Ottawa (Canada), which lies in close proximity to Kasshabog Lake where *C. caroliniana* has established and grows extensively. At Kasshabog Lake, statistically significant differences between *C. caroliniana* beds and native macrophyte beds include: reduced light penetration in *C. caroliniana* beds, considerably lower abundance and uneven distribution of native macrophytes in *C. caroliniana* beds, more epiphytic algae and similar taxonomic composition but higher abundance of macroinvertebrates in *C. caroliniana* beds. Socio-economic impacts are related to the loss of recreational amenity and visual appeal that results from dense macrophyte growth in recreational waters, costs relating to management interventions and the smell associated with mass vegetation die offs. Moreover, an increase in the abundance of chironomids (non-biting midges) has been significantly related to *C. caroliniana* stands compared with native macrophyte stands in Ontario (Canada). No evidence of transmission of diseases or genetic effects due to hybridisation were found during the literature study. However, a local increase in the distribution of *C. caroliniana* may result in an increase in the abundance of trematode carrying aquatic snails that cause swimmers itch.

In the Dutch code of conduct for aquatic plants (2010), *C. caroliniana* has been declared a list 2 species. This means that it should only be sold when accompanied with a warning about its invasiveness. This should help stop the release of plants into open water by hobbyists who are unaware of the plants invasive nature or how to properly dispose of it. *C. caroliniana* is often imported under the name *Cabomba aquatica*. The correct identification of *C. caroliniana* and other plant species imported to the Netherlands should be prioritised in order to avoid confusion with species that are not listed in the Dutch code of conduct for aquatic plants.

Limiting management intervention appears to be the best method to prevent the spread of *C. caroliniana* in the Netherlands. The population at Loosdrecht became invasive following cutting and collection of fragments using an inefficient harvesting machine. The *C. caroliniana* population at Maasbracht was unmanaged and did not spread. However, the growing conditions for *C. caroliniana* were less favourable at this location. If control is required to safeguard water functions, then the prime focus should be on the prevention of fragment spread. Mowing baskets or harvesting boats can be used, but only when efficient removal of the plants is guaranteed. Retaining nets can be used to minimise the spread of fragments by isolating the area being cut. The removal of the whole plant, including the root system should be made a priority. Complete eradication is difficult. Small populations may be eradicated by covering a treatment area with opaque material such as geo-textile. The lack of light will kill *C. caroliniana* along with all other aquatic plants and many animal species. The application of Hydro-venturi equipment that uses high power water jets to dislodge whole plants from the substrate, including their roots, is a promising eradication method. This method limits fragmentation and plants float to the surface from where they can be collected manually or by harvesting boats.

Further research that aims to reveal factors that determine the invasiveness of *C. caroliniana* at Loosdrecht and in the Oranjekanaal region is required. Establishing the conditions that allowed the plant to become invasive will allow nature managers to better predict the likelihood that *C. caroliniana* will invade other water-bodies in the Netherlands.

1. Introduction

1.1. Background and problem statement

Fanwort (*Cabomba caroliniana*) is a member of a genus that is endemic to South America. Five species and three varieties are recognised: *C. aquatica*, *C. palaeformis*, *C. furcata*, *C. haynesii* and *C. caroliniana* including var. *caroliniana*, var. *pulcherrima* and var. *flavida* var. nov. (Ørgaard, 1991). *C. caroliniana* is a popular aquarium plant in North America and Europe (De Wit, 1966). It was first recorded in the Netherlands in 1986 at Maasbracht harbour in the south east of the country (Cortenraad, 1988). The recorded distribution of *C. caroliniana* remained limited to this location till 2005, when it was discovered at Loosdrecht, North of Utrecht. The species has become invasive at this location and has subsequently spread to the nearby Tienhovense lakes. Since 2007, *C. caroliniana* has been recorded at isolated locations in the canals of Utrecht, in the Provinces of Drenthe, Groningen, Overijssel, South Holland, North Brabant and Friesland.

At the start of this project, there was a lack of knowledge regarding the pathways for introduction, vectors for spread, key factors for establishment and invasiveness, and (potential) effects of *C. caroliniana* in the Netherlands.

To support decision making with regard to the design of measures to prevent ecological, socio-economical and public health effects, the Invasive Alien Species Team of the Netherlands Food and Consumer Product Safety Authority (Ministry of Economic Affairs) requested that a risk assessment of *C. caroliniana* be undertaken. The present report reviews available knowledge and data in order to perform a risk assessment of the species.

1.2. Research goals

The major goals of this study are:

- To describe the species and habitat characteristics of *C. caroliniana.*
- To describe the global distribution and to analyse the current spread of *C. caroliniana* in the Netherlands.
- To identify the key factors for dispersal (pathways, vectors, invasiveness) and successful establishment of *C. caroliniana*.
- To assess (potential) ecological, socio-economical and public health effects of *C. caroliniana* in the Netherlands, taking into account the impacts of this species in other geographical areas.
- To summarize available risk classifications of *C. caroliniana* in other countries.
- To review possible management options for the control of spread, establishment and negative effects of *C. caroliniana*.

1.3. Outline and coherence of research

The coherence between various research activities and outcomes of the study are visualised in a flow chart (Figure 1.2). The present chapter describes the problem statement, goals and research questions in order to identify key factors for the dispersal, establishment, effects and management of *C. caroliniana* in the Netherlands. Chapter 2 gives the methodological framework of the project and describes the literature review, data acquisition and field surveys. Chapter 3 describes the identity, taxonomical status and reproductive biology of the species and briefly mentions differences with similar species. Habitat characteristics of *C. caroliniana* are summarized in chapter 4. The geographical distribution and trends in distribution in the Netherlands, including relevant pathways and vectors for dispersal are given in chapter 5. Chapter 6 analyses the ecological, economic and public health effects of the species. Formal risk assessments and available risk classifications are summarized in chapter 7. Chapter 8 describes the scope of management options and focuses on prevention, eradication measures and control of the species. Finally, chapter 9 draws conclusions and gives recommendations for management and further research. Appendices with raw data and background information complete this report. The report will be used as background information for an expert meeting in order to assess the dispersion, invasiveness, (potential) risks and management options of this species in the Netherlands (Risk analysis).

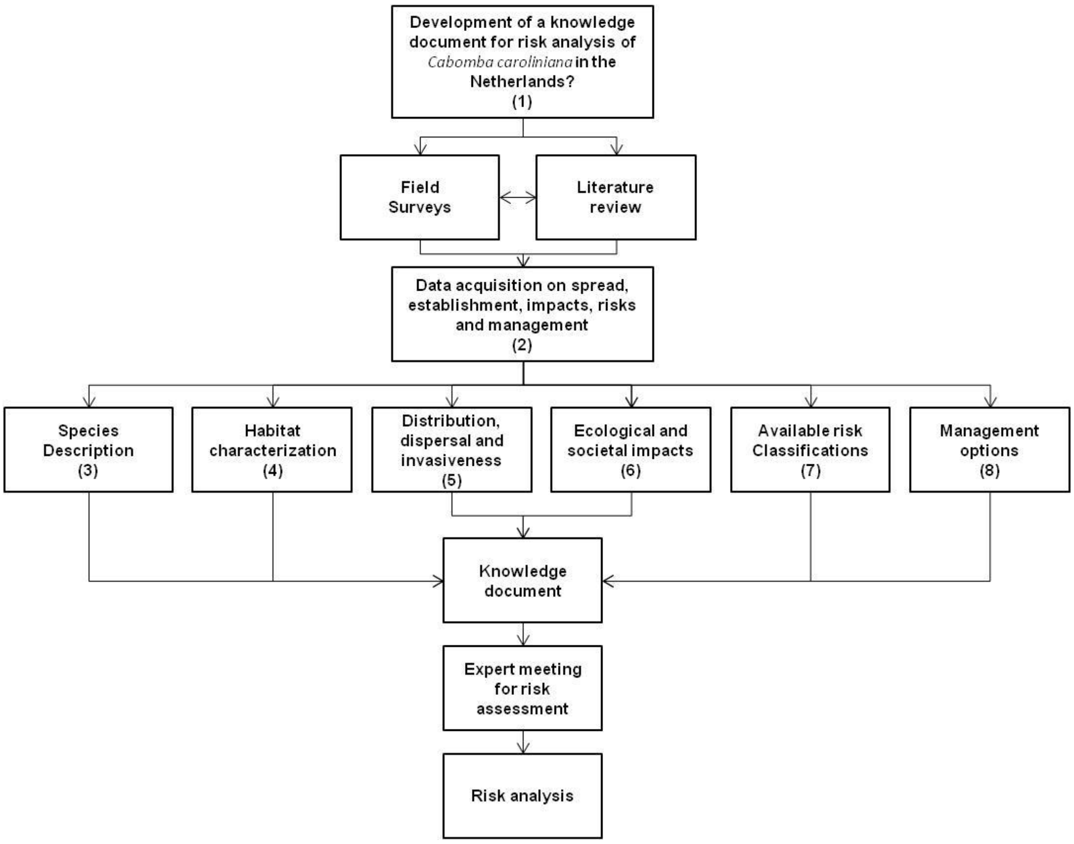


Figure 1.2: Flow chart visualising the coherence of various research activities in order to develop a knowledge document for risk analysis of Fanwort (*Cabomba caroliniana*) in the Netherlands. Chapter numbers are indicated in brackets.

2. Materials and methods

2.1. Literature review

A literature study was carried out to provide an overview of the current knowledge on the distribution and invasion biology of Fanwort (*Cabomba caroliniana*). Literature data were collected on the physiological tolerances, substrate preference, colonization vectors, ecological and socio-economic impacts and potential measures for the management of this species. Our search was largely internet based, supported by the use of a university library. Academic and non-academic search engines and websites were systematically searched using the Web of Knowledge and Google Scholar. All search results from the Web of Knowledge were examined while the first 50 results from Google Scholar were examined due to the decreasing relevance of search results returned using this search engine. Search terms used to carry out the literature study were: *Cabomba caroliniana*, Fanwort and Waterwaaier.

An analysis of search engine hits via Google.nl was performed in order to analyse the Dutch general public's perception of *C. caroliniana* and to give an insight into its availability from retailers. The first 50 websites found were categorized according to their content. Google was searched using the term *Cabomba caroliniana,* and the Dutch common name 'Waterwaaier'. An additional search was made for the species *Cabomba aquatica* as *C. caroliniana* is often misidentified as this species and imported in large quantities under this name (Section 5.3.2.). Websites that contained names not referring directly to a species e.g. where only *Cabomba* was mentioned, were omitted. Attention was focussed on retailer's country of origin, as this was assumed to influence the buying behaviour of hobbyists. Search results relating to videos and pdf documents were analysed but images were not. Scientific articles were omitted from the perception study as the analysis was aimed at information accessible to the general public only. Websites were classified into four groups, 1) retail; 2) educational / regulatory, including the websites of universities, nature organisations, governments and water-boards; 3) hobbyists, including forums and websites containing information on ponds and aquaria; 4) organisations focussed specifically on invasive species, e.g. the Global Invasive Species Database. Websites were further subdivided into two categories, 1) no direct reference is made to the plants invasive nature and / or measures recommended to prevent introduction; 2) a direct reference is made to the plants invasive nature and / or measures recommended to prevent introduction. The total number of websites contained within each category was calculated.

2.2. Data acquisition on current distribution

Most distribution data in the Netherlands originated from the National Database Flora & Fauna (NDFF). This database also includes data from the internet-portals waarneming.nl and telmee.nl. These data were supplemented with data of herbarium specimens in the Q-bank Invasive Plant database (http://www.q-bank.eu/Plants/), with data provided by the Werkgroep Flora Kartering Drenthe (WFD); Roelf Pot Research and Consultancy; Grontmij and J. van Valkenburg. During the years 2010 and 2011, data from the Rivierenland, Hollandse delta and Vallei and Veluwe waterboards and Waternet were included.

2.3. Additional field surveys

On the 6th and 8th of August, 2013 field surveys at 7 locations in the Netherlands were performed (the Oranjekanaal at Orvelterbrug, Orveltersluis, Elperbrug and Zwiggelterbrug; the Musselkanaal at Spoorlaan; in Nunspeet at Zandenberg and in the Tienhovenskanaal / De Strook). These sampling locations were supplemented by 3 additional locations surveyed at Loosdrecht in 2010 by Wil Leurs for Waternet, Amsterdam (Appendix 1). At each site plants were collected for herbarium specimens. Population size was estimated and the vegetation was described with a Tansley survey, using the following abundance / dafor codes: d: dominant; a: abundant; f: frequent; o: occasional; r: rare. Data collected were species, location, date of field search, coordinates, water depth (cm), transparency / Secchi depth (cm), width of water body (m), width of emergent zone (m), water flow, water type, surface area covered by *C. caroliniana* (m^2), surface area covered by all floating species (m^2), surface area covered by all submerged species (m^2), number of individuals / shoots and phenology.

3. Species description

3.1. Nomenclature and taxonomical status

Fanwort (*Cabomba caroliniana*) is a species in a genus that is well described by Fassett (1953) and by Ørgaard (1991). The original, legal definition of the species is by Gray (1847) derived from specimens in North America, although the genus originates from South America. Other species of the genus are found in the tropical areas of South America. The genus *Cabomba* was revised in 2008. Five species and three varieties are recognised: *C. aquatica*, *C. palaeformis*, *C. furcata*, *C. haynesii* and *C. caroliniana* including var. *caroliniana*, var. *pulcherrima* and var. *flavida* var. nov. (Ørgaard, 1991). An overview of taxonomy, common names found in the Netherlands and the United Kingdom and the native range of *C. caroliniana* is given in table 3.1.

Table 3.1: Nomenclature and taxonomical status.

<table>
<tr><td colspan="2">Scientific name:
Cabomba caroliniana A. Gray (1837)</td></tr>
<tr><td colspan="2">Synonyms:
None</td></tr>
<tr><td colspan="2">Taxonomic tree</td></tr>
<tr><td>According to CABI (2013):
Domain: Eukaryota
Kingdom: Plantae
Phylum: Spermatophyta
Subphylum: Angiospermae
Class: Dicotyledonae
Order: Nymphaeales
Family: Cabombaceae
Genus: Cabomba
Species: Cabomba caroliniana</td><td>According to Naturalis Biodiversity Center (2013):
Domain: Eukaryota
Kingdom: Plantae
Phylum: Tracheophyta
Class: Spermatopsida
Order: ANITA-group
Family: Cabombaceae
Genus: Cabomba
Species: Cabomba caroliniana</td></tr>
<tr><td colspan="2">Preferred Dutch name:
Waterwaaier</td></tr>
<tr><td colspan="2">Other Dutch names:
Cabomba</td></tr>
<tr><td colspan="2">Preferred English name:
Fanwort</td></tr>
<tr><td colspan="2">Other English names:
Carolina fanwort, cabomba, carolina water-shield, fish grass, gray fanwort, green cabomba, green grass chrysanthemum, washington grass, washington plant, water shield grass</td></tr>
<tr><td colspan="2">Native range:
Fanwort is native to southern Brazil, Paraguay, Uruguay and northeast Argentina. It is also considered to be native to the south-eastern USA indicating a disjunct distribution (Ørgaard, 1991; CABI, 2013; CAIP, 2013). However, the spread northwards into continental North America is a more recent phenomenon.</td></tr>
</table>

Since other species of *Cabomba* are distributed in the aquarium trade, and at least one of them (*C. furcata*) is supposed to be able to settle in the Netherlands, use of the more specific name 'Carolina fanwort' would be preferable (CABI, 2013; USDA, 2013). Nevertheless, since most English language publications use the common name Fanwort, especially those describing the plant as a nuisance species, and the other species are only referred to by their scientific names, we have chosen Fanwort as the preferred English name for *C. caroliniana*.

3.2. Species characteristics

C. *caroliniana* is a perennial, submerged aquatic plant with opposite, dissected leaves. Solitary, white emergent flowers with three petals and three sepals appear in early summer together with a few small, complete floating leaves on the flowering branches (Figure 3.1).

Figure 3.1: Non-native Fanwort (*Cabomba caroliniana*) growing in the Netherlands (Photo: R. Pot).

Stems can grow to up to 10 metres in length and are often branched. Young stems have white or reddish-brown hairs. Rhizomes are short with numerous fibrous roots. Submerged leaves grow in opposition to each other and are petiolated (Figure 3.2). The myriophylloid leaves are finely dissected, creating over 80-150 final divisions that are 0.5 to 1 mm wide, arranged in a horizontal plane (De Wit, 1966; Hutchinson, 1975). The petiole grows to a maximum of 1-2 (4) cm long, (Figure 3.2b). The overall shape of the dissected leaf is semi-circular, fan-like and grows to a maximum of five cm in diameter. One or two flowers and floating leaves appear at stem tops when the water's surface is reached (Figure 3.2). Floating leaves are complete, oblong to elliptical and often diamond shaped and are up to four cm long and seven mm wide and purple coloured on the underside (De Wit, 1966). *Cabomba* species grow groups of floating leaves that develop to support aerial floral axes (Cook, 1996). The flower supporting stems grow to up to one to two centimetres long (Figure 3.3). Flowers are usually solitary and occur at the tips of the stems. They have three sepals and six petals of equal size (10 to 12 mm), shape (ovate) and colour (white to pinkish with a yellow base). The flowers are made up of three to six stamens, (2-)3(-4) separate carpels and are female on the first day becoming male on the second day after flowering. The fruit is bottle shaped, leathery, indehiscent and possesses a three seed follicle (Cook, 1996). Seeds are oblong, 1.5-3 mm long and 1-1.5 mm wide with rows of minute wart-like projections.

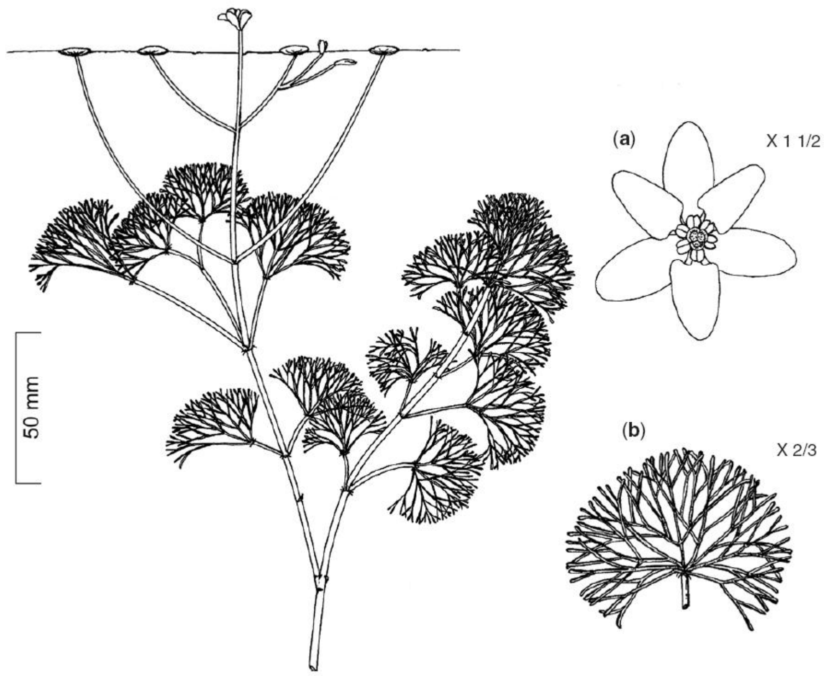


Figure 3.2: Fanwort (*Cabomba caroliniana*). Plant parts on the right: a, flower; b, leaf. (Drawn by W. Roux, first published in Henderson & Cilliers (2002), ARC-Plant Protection Research Institute, Pretoria).

Figure 3.3: Detail photo of Fanwort (*Cabomba caroliniana)* in flower (Photo: W. Weijs).

Three varieties of *C. caroliniana* are distinguished by flower colour: white flowers: var. *caroliniana*, purple flowers: var. *pulcherrima* and yellow flowers: var. *flavida*. Several cultivars are grown and used in the aquarium trade. No hybrids have been reported in the genus *Cabomba*, although they may possibly occur (Ørgaard, 1991; Mackey & Swarbrick, 1997).

3.3. Differences with visually similar species

A number of species are visually similar to *C. caroliniana* and it is therefore important to differentiate these species in order to prevent misidentification. Also known as fanwort, *Cabomba aquatica* is particularly easily confused with *C. caroliniana*. *C. aquatica* has yellow flowers, the floating leaves are circular and submerged leaves are not strictly arranged in one plane but are three dimensionally arranged. *C. caroliniana* var. *flavida* also features yellow flowers, but the leaves do not differ from the basic variety. Other species that may be easily confused with *C. caroliniana* are *Cabomba furcata*, *Ceratophyllum* sp., *Myriophyllum* sp. and *Ranunculus circinatus*. *Cabomba furcata* has purple flowers, the leaves are positioned in whorls of three and the submerged leaves are purplish as well. *C. caroliniana* var. *pulcherrima* also possesses purple flowers, but the leaves do not differ from the basic variety. *Ceratophyllum* sp. have bifurcate leaves that are regularly divided either two or three times and positioned in whorls of four to eight. *Myriophyllum* sp. have pinnate leaves positioned in whorls of three to five. *Ranunculus* sp. have leaves that are alternately arranged on the stems. *R. circinatus* is the only *Ranunculus* species to feature submerged leaves with sections arranged in one plane (R. Pot, personal communication).

3.4. Reproduction

C. caroliniana may be pollinated by flies and bees but compared to other genera of the family Cabombaceae, pollen fertility of *C. caroliniana* is low (Philbrick & Les, 1996; Mackey & Swarbrick, 1997). However, *C. caroliniana* grows and disperses mainly via asexual vegetative reproduction through fragmentation, and displays low genetic variability (Xiaofeng *et al.,* 2005). In the Netherlands, *C. caroliniana* reproduces vegetatively through the development of rhizomes and separate stem fragments. Seeds appear only in the plants tropical native range and in tropical and subtropical regions of its non-native range (Sanders, 1979; Ørgaard, 1991).

Figure 3.4: Floating fragments of Fanwort (*Cabomba caroliniana*) and Yellow water-lily (*Nuphar lutea*) after control measures were implemented (Photo: R. Pot).

In late summer and winter *C. caroliniana* forms ‘turion-like’ structures at the apical stem-tips, the stems themselves become brittle and these ‘turion-like’ structures can easily separate into fragments (EUPHRESCO DeCLAIM, 2011). Buoyant fragments can be carried over long distances across lakes or down rivers, but mostly fall close to the mother plant (Figure 3.4). A detached fragment can regenerate into a full plant as long as it has at least one pair of leaves and may survive floating in water for 6 to 8 weeks. Fragments as short as 10 mm may be viable (EPPO, 2007; Luijten & Odé, 2007). Adventitious roots develop from stem fragments leading to the development of a mature plant (Beringen, 2011). Fragments can rarely survive exposure to dry air for more than 24 hours, however they can stay moist and survive for weeks in mud, even under hot and dry conditions (EUPHRESCO DeCLAIM, 2011).

The ‘turion-like’ tips can also stay attached to the plant’s stem. The attached tips lose their buoyancy at the beginning of the winter and sink to the bottom. In the spring, the nodes near the tips form new roots and new growing tips. The connecting stem then disintegrates, separating the daughter plant from the mother plant. Just a single stem node is enough to produce a new plant (Sanders, 1979).

Seeds are only produced within *C. caroliniana’s* tropical native range and in the tropical and subtropical parts of its non-native range (e.g. in Australia and in the south-eastern United States of America). The seeds are probably spread by waterfowl, stuck to legs and webbed feet with mud and occasionally attached between feathers. The seeds may also be distributed in water flow (Sanders, 1979; Ørgaard, 1991). Aerial fruit becomes submerged because the peduncle bends toward the water (Sculthorpe, 1967).

4. Habitat characteristics

4.1. Habitat description

Table 4.1 gives an overview of the physiological tolerances of Fanwort (*C. caroliniana*). *C. caroliniana* grows on muddy, sandy, silty or peaty soils of slow flowing or stagnant freshwaters and prefers direct sunlight and shallow water (Figure 4.1), (Mackey & Swarbrick, 1997; EPPO, 2007; Van den Berg *et al.,* unpublished results). It is found in ponds, ditches, small shallow lakes and slow flowing streams in the coastal vegetation of swamp forests and bogs, and inland areas of savannah (Ørgaard, 1991). In the Netherlands, *C. caroliniana* grows in substrates with nitrogen concentrations of 0.83-21.00 mg/l; phosphorus concentrations of 0.08-2.59 mg/l and organic matter concentrations of 3-66 % (Roijackers*,* 2008).

Figure 4.1: Almost 100% cover of the sediment by Fanwort (*Cabomba caroliniana*) in Lake Tienhoven, the Netherlands, September 2010. Other macrophytes have been outcompeted, except for floating leaved species, nymphaeids and helophytes (Photos: L. Lamers).

In 2011, Van den Berg *et al.* (unpublished results) carried out field surveys examining all locations in the Netherlands where *C. caroliniana* was recorded. *C. caroliniana* was found at eight of the 15 locations where it had been reported previously, and mainly in the Loosdrechtse plassen area. A comparison of physico-chemical conditions between water obtained from sites where *C. caroliniana* was present and absent was made. Potential differences in phosphate, phosphorus, pH, alkalinity and turbidity were examined. The only statistically significant difference was found for phosphate. At the locations where *C. caroliniana* was absent, phosphate concentrations in the surface water were significantly higher (on average 1.5 µmol/l; 0.047 mg/l) than at locations where it was present (0.5 µmol/l; 0.016 mg/l). These higher phosphate concentrations are known to increase the risks of algal blooms (Van den Berg *et al.,* unpublished results). *C. caroliniana* has been found in the Netherlands in waters with phosphorus concentrations of 0.00-0.23 mg/l; inorganic nitrogen concentrations of 0.68-4.42 mg/l; nitrate + nitrite concentrations of 0.01-3.80 mg/l; phosphate concentrations of between 0.00-0.21 mg/l, ammonium concentrations of 0.00-0.64 mg/l and carbon concentrations of 3.5-20.6 mg/l (Roijackers, 2008). In the Veluwe in 2013, *C. caroliniana* has been observed to grow in a relatively nutrient poor, mesotrophic pond. However, it is probable that high light levels and the shallowness of the water stimulate growth at this location

(R. Beringen, personal communication). A Japanese study defined a number of habitat conditions based on nutrients where *C. caroliniana* was able to grow. These were 3.2-8.23 mg/l chemical oxygen demand (COD), 0.68-1.76 mg/l inorganic nitrogen and 0.06-0.25 mg/l organic nitrogen (Oki, 1992). Additional analyses of field conditions in the Netherlands revealed that *C. caroliniana* is able to grow in waters featuring iron concentrations of between 0.00-1.65 mg/l; Potassium concentrations of 2.8-8.7 mg/l; magnesium concentrations of 3.54-8.74 mg/l and sodium concentrations of 11.9-57.1 mg/l (Roijackers, 2008).

C. caroliniana mainly occurs in a warm-temperate, humid climate, with rain throughout the year (Mackey, 1996). Although it can withstand temperatures of less than 0 °C, its optimal temperature range is 13-27 °C (Leslie, 1986; Mackey, 1996; Mackey & Swarbrick, 1997; Hogsden *et al.*, 2007). Figure 4.2 shows *C. caroliniana* growing in the Netherlands in March 2013, the seventh coldest March in the Netherlands since 1901 indicating that *C. caroliniana* is able to survive harsh Dutch winters (KNMI, 2013). In Canada, the plant overwinters under prolonged snow and ice cover and continues to thrive and spread (EPPO, 2007). However, in Australia, prolonged snow cover is said to be detrimental to *C. caroliniana* (Australian Department of the Environment and Heritage, 2003). In the Netherlands, *C. caroliniana* has been found in waters with oxygen concentrations varying between 56-137 % and electrical conductivities ranging between 252-656 µS/cm (Roijackers, 2008). *C. caroliniana* is sensitive to drying out and requires permanent contact with water, although it can survive wide fluctuations in water depths (EPPO, 2007). It can grow in shallow (0.5-3 m) or deep (10 m) water but the plants grow most commonly in shallow (average 3 m deep) water (Mackey, 1996; Wilson & Watler, 2001; Lyon & Eastman, 2006; Hogsden *et al.,* 2007).

Figure 4.2: Early re-growth of Fanwort (*Cabomba caroliniana*) from fragments in Lake Tienhoven, the Netherlands, March 2013. No other aquatic macrophytes were present at this point (Photos: L. Lamers).

Experiments in aquaria exposing *C. caroliniana* to different turbidities, measured in Jackson turbidity units (JTU), have demonstrated that *C. caroliniana* displayed most rapid growth at medium turbidities (70-110 JTUs), followed by higher turbidities (300-2350 JTUs). Moderate turbidity was found to enhance stem length whereas moderate to high turbidities enhanced adventitious root development (Gregory & Sanders, 1974; Sanders, 1979; Mackey & Swarbrick, 1997). However, in these experiments turbidity

Table 4.1: Physiological conditions tolerated by Fanwort (*Cabomba caroliniana*).

Parameter	Medium	Data origin	Tolerance	References
pH	Water	Netherlands, international	4.0-8.8	Riemer (1965); Gregory & Sanders (1974); Tarver & Sanders (1977); Ontario Ministry of the Environment (1979); Ørgaard (1991); Mackey & Swarbrick (1997); Hogsden *et al.* (2007); Van den Berg *et al.* (unpublished results); Roijackers (2008)
Alkalinity (meq/l)	Water	Netherlands	1.8-2.9	Van den Berg *et al.* (unpublished results)
Oxygen (mg/l)	Water	Netherlands	5.7-13.6	Roijackers (2008)
Oxygen (%)	Water	Netherlands	56-137	Roijackers (2008)
Temperature (°C)	Water	International, Netherlands	<0 (minimum), 13-27 (optimal)	Leslie (1986); Mackey (1996); Mackey & Swarbrick (1997); Hogsden *et al.* (2007); Roijackers (2008)
Light compensation point (µmol/m^2/s)	Water	International	55	Canfield *et al.* (1985)
Light requirement (µmol/m^2/s)	Water	Netherlands	200 (insufficient for optimal growth)	Van den Berg *et al.* (unpublished results)
Turbidity (NTU)	Water	Netherlands	2-6	Van den Berg *et al.* (unpublished results)
Turbidity (JTU)	Water	International	70-110 (most rapid growth)	Gregory & Sanders (1974)
Depth range (m)	Water	Netherlands, international	0.5-10	Mackey (1996); Wilson & Watler (2001); Van den Berg *et al.* (unpublished results)
Mean depth (m)	Water	International	3	Mackey (1996); Wilson & Watler (2001); Hogsden *et al.* (2007); Lyon & Eastman (2006)
Secchi depth (cm)	Water	Netherlands	20-80	Roijackers (2008)
Water velocity	Water	Netherlands, international	low	EPPO (2007); Roijackers (2008); Beringen (2011)
EGV (µS/cm)	Water	Netherlands	252-656	Roijackers (2008)
Optimal calcium concentration (ppm)	Water	International	4	Riemer (1965)
Calcium concentration (mg/l)	Water	Netherlands	21.8-77.4	Roijackers (2008)
Iron (mg/l)	Water	Netherlands	0.00[1]-1.65	Roijackers (2008)
Potassium (mg/l)	Water	Netherlands	2.8-8.7	Roijackers (2008)
Magnesium (mg/l)	Water	Netherlands	3.54-8.74	Roijackers (2008)
Sodium (mg/l)	Water	Netherlands	11.9-57.1	Roijackers (2008)
Phosphorus (mg/l)	Water	Netherlands	0.00[1]-0.23	Roijackers (2008); L. Azevedo (personal communication)
Average phosphate (mg/l)	Water	Netherlands	0.016	Van den Berg *et al.* (unpublished results)
Phosphate (mg/l)	Water	Netherlands	0.000[1]-0.206	Roijackers (2008)
Carbon (mg/l)	Water	Netherlands	3.5-20.6	Roijackers (2008)
COD (mg/l)	Water	International	3.2-8.23	Oki (1992)
Inorganic N (mg/l)	Water	International, Netherlands	0.68-4.42	Oki (1992); Roijackers (2008)
Organic N (mg/l)	Water	International	0.06-0.25	Oki (1992)
Nitrate + Nitrite (mg/l)	Water	Netherlands	0.01[1]-3.80	Roijackers (2008)
Ammonia (mg/l)	Water	Netherlands	0.00[1]-0.64	Roijackers (2008)
Substrate	Not applicable	Netherlands, international	Mud, silt, sand, peat	Mackey & Swarbrick (1997); Van den Berg *et al.* (unpublished results); EPPO (2007)
Nitrogen (g/kg)	Substrate	Netherlands	0.83-21	Roijackers (2008)
Phosphorus (g/kg)	Substrate	Netherlands	0.079-2.585	Roijackers (2008)
Organic matter (%)	Substrate	Netherlands	3.0-65.6	Roijackers (2008)

[1]Measurement that falls below the accurate detection limit of the measuring apparatus

was maintained by stirring the hydro-soil. This could have led to an increased release and availability of nutrients for plant growth (Sanders, 1979). Moreover, in other experiments it has been shown that *C. caroliniana* is easily limited by light if waters become more turbid due to algae and / or suspended matter. Van den Berg *et al.,* (unpublished results) concluded that light levels of 200 µmol/m^2/s appear to be insufficient for optimal growth and that *C. caroliniana* tolerated turbidities of between two and six nephelometric turbidity units (NTU). Roijackers (2008) sampled plants in Dutch waters where the Secchi depth ranged between 20-80 cm. *C. caroliniana* has a low photosynthetic rate (Saitoh *et al.,* 1970; Van *et al.,* 1976) and has a light compensation point of 55 µmol/m^2/s (Canfield *et al.,* 1985). Increased incidence of clear water in Dutch water-bodies resulting from management measures, together with the high concentration of phosphate in substrates, may well lead to increased growth of this species in the future (Lamers *et al.,* 2012).

High calcium levels have been found to inhibit the growth of *C. caroliniana* (Australian Department of the Environment and Heritage, 2003). Optimal growth occurs at calcium levels of 4 ppm (Riemer, 1965). In the Netherlands, *C. caroliniana* has been found to occur in waters with calcium concentrations between 21.8 and 77.4 mg/l (Roijackers, 2008). *C. caroliniana* prefers acidic waters and above pH 8 stems become defoliated and growth is inhibited (Riemer, 1965; Gregory & Sanders, 1974; Tarver & Sanders, 1977). However, *C. caroliniana* appears to be able to photosynthesise at high pH levels in conditions where carbon dioxide (CO_2) availability is low. Aquatic plants adapted to these conditions are able to utilize carbon sourced from bicarbonate (HCO_3^-) for photosynthesis. Van den Berg *et al.* (unpublished results) carried out experiments in the Netherlands examining the effect of high pH on the photosynthesis rate of *C. caroliniana*. At pH 8.4 and higher, photosynthetic rates were 75% lower than those achieved at pH 6.4. Although this means that *C. caroliniana* has a preference for CO_2 (like most aquatic macrophytes), it shows that it is very well able to grow in more highly alkaline waters and is better adapted than a number of other well-known bicarbonate users able to photosynthesise at this pH (J. Roelofs, personal communication). Moreover, under stress, C_4 type metabolism is induced which increases the capacity of *C. caroliniana* to absorb CO_2 at the expense of other macrophytes (reduced carbon compensation point; Salvucci & Bowes, 1981). This metabolic adaptation is probably responsible for the dominance of *C. caroliniana* in European systems (EUPHRESCO DeCLAIM, 2011). In the Netherlands in 2011, water at all known locations of *C. caroliniana* was sampled and analysed for pH and alkalinity. The plant was present in conditions of pH 7.1 to 8.8 and alkalinities between 1.8 and 2.9 meq/l (Van den Berg *et al.,* unpublished results).

Jacobs & MacIsaac (2009) created a model to predict the vulnerability of Canadian water bodies for *C. caroliniana* invasion. Overall model predictive ability was high and of the predictors considered, pH was most important, followed by temperature, dissolved calcium, conductivity, total phosphorus, dissolved oxygen, alkalinity and ammonia (Jacobs & MacIsaac, 2009). Jacobs & MacIsaac (2009) predicted that two rivers in northern Ontario (51^o and 52^o'N latitude) constituted suitable habitat, illustrating that *C. caroliniana* will not be limited to tropical areas. This is consistent with the occurrence of the species in the Loosdrecht lakes, the Netherlands, which share similar latitude with Northern Ontario, even though climate differs between the areas (Schooler *et al.,* 2008).

Van den Berg *et al.* (unpublished results) concluded that although *C. caroliniana* is able to grow in different water types in the Netherlands, it appears to concentrate in the Loosdrechtse plassen area, but also occurs in Drenthe and Zuid-Holland. Low turbidity (requiring low to moderate nutrient levels in the surface water) and higher CO_2 levels in the water (peat sediments, seepage CO_2-rich groundwater) seem to facilitate this species. *C. caroliniana* is, however, also very well able to use bicarbonate and can therefore grow in many different Dutch water types.

4.2. Associations with other species

A number of sites in the Netherlands have been surveyed and the species accompanying *C. caroliniana* identified.

In the Oranjekanaal, *C. caroliniana* was first recorded near Orvelte in 2007 (Excursion report PKN 1011, R. Pot, submitted). In 2011, it was abundantly present in vegetation dominated by another alien species, Twoleaf watermilfoil (*Myriophyllum heterophyllum*). Other accompanying species were present in low densities: Duckweed (*Lemna minor* and *Spirodela polyrhiza*), Water soldier (*Stratiotes aloides*), Yellow water-lily (*Nuphar lutea*), Frogbit (*Hydrocharis morsus-ranae*), Common reed (*Phragmites australis*), Broad-leaved pondweed (*Potamogeton natans*), Arrowhead (*Sagittaria sagittifolia*) and Hornwort (*Ceratophyllum demersum*).

In 2006 in the Loosdrecht area, *C. caroliniana* was accompanied by Yellow water-lily (*Nuphar lutea*), Hornwort (*Ceratophyllum demersum*), Common bladderwort (*Utricularia vulgaris*), Fan-leaved water-crowfoot (*Ranunculus circinatus*), Duckweed (*Lemna minor*), Frogbit (*Hydrocharis morsus-ranae*), Water soldier (*Stratiotes aloides*), Reed mannagrass (*Glyceria maxima*), Bur reed (*Sparganium erectum*), Yellowflag iris (*Iris pseudacorus*), and various other riparian species (R. Pot, unpublished results). In 2010, *M. heterophyllum* was found in increasing density at this location (J. van Valkenburg, personal communication; Van Valkenburg *et al*., 2011).

In 1989, at Maasbracht, *C. caroliniana* was accompanied by low densities of Yellow water-lily (*Nuphar lutea*), Eurasian watermilfoil (*Myriophyllum spicatum*), Whorled water milfoil (*Myriophyllum verticillatum*) [doubtful identification, Roelf Pot], Longleaf pondweed (*Potamogeton nodosus*), Curly-leaf pondweed (*Potamogeton crispus*), Fennel pondweed (*Potamogeton pectinatus*), Arrowhead (*Sagittaria sagittifolia*) and European bur-reed (*Sparganium emersum*) (Maenen, 1989). In 2010, *M. heterophyllum* was found in increasing density at this location (J. van Valkenburg, personal communication; Van Valkenburg *et al.,* 2011).

A number of aquatic macrophyte species share habitats and habitat requirements with *C. caroliniana.* Possible future increases in water temperature and water clarity together with the high concentration of phosphate in substrates, may result in *C. caroliniana* displaying increased competitive ability resulting in a reduction in the abundance of associated submerged macrophyte species in the Netherlands.

4.3. Climate match and bio-geographical comparison

A comparison of climate and biogeography was made between *C. caroliniana's* invasive, non-indigenous range and the Netherlands. A climate match between the Netherlands and *C. caroliniana's* indigenous range was not available for inclusion in this report.

Climatic match with Ottawa (Canada)

In Canada, *C. caroliniana* was first identified in 1991, northeast of Peterborough, Ontario, in the North River just downstream of Kasshabog Lake. It has been shown to grow as virtual monocultures in several bays of Kasshabog Lake near Peterborough, Ontario (Wilson *et al.,* 2007). Kasshabog Lake is described as oligotrophic (nutrient-poor) to mesotrophic (moderately enriched), with soft, slightly acidic water (pH between 6.5 - 6.9), an average depth of 4.5 m, and a moderately low amount of apparent colour (Ontario Ministry of the Environment, 1979) (Table 4.1). From here it is likely that *C. caroliniana* will spread passively or assisted by boat traffic southward towards Round, Belmont and Marmora Lakes, and / or southwest to nearby Stony Lake, resulting in its introduction to the Trent-Severn Waterway (Wilson *et al.,* 2007). This appears to be the most northern site colonized by *C. caroliniana* to date in North America, and possibly in the world (exact localisation in Japan is unknown) (Wilson *et al.,* 2001). In Canada, *C. caroliniana* overwinters under prolonged snow and ice cover and continues to thrive and spread (EPPO, 2007), indicating that it can survive winter conditions more severe than those encountered in the Netherlands.

The CLIMEX model is a computer programme that aims to predict the potential geographical distribution of an organism in relation to its climatic requirements (EPPO, 2007). Temperature data from weather stations is inputted along with species temperature tolerances to determine the species (potential) geographical distribution. Using the CLIMEX model. The Netherlands has been matched climatically with Ottawa which lies in close proximity to Kasshabog Lake (Figure 4.1). Therefore, low winter temperatures alone, while outside *C. caroliniana's* preferred temperature range, may not form a barrier to colonisation within the Netherlands. A number of ecological impacts have occurred in Ontario as a result of *C. caroliniana* establishment (Sections 6.1.1 and 6.1.2). A climate match between this location and the Netherlands increases the possibility that similar effects may be seen here.

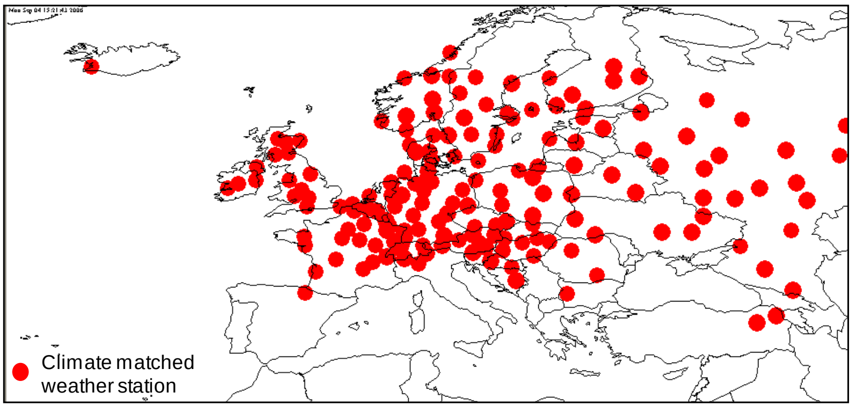


Figure 4.1: Climate match between Ottawa (Canada) and Europe (EPPO, 2007).

European eco-region match

The European Water Framework Directive, 2000/60/EC (European Union, 2000), defines a number of eco-regions that reflect similarities in aquatic species living in European river and lake systems (Figure 4.2). The Netherlands lies within eco-regions 13 and 14. The southernmost part of the Netherlands falls within eco-region 13 (the western plains) which is shared with France, Belgium and a small part of western Germany. The remaining area within the Netherlands to the north of eco-region 13, falls under eco-region 14 (the central plains). Eco-region 14 is shared with northern Germany, western Poland, Denmark and southern Sweden.

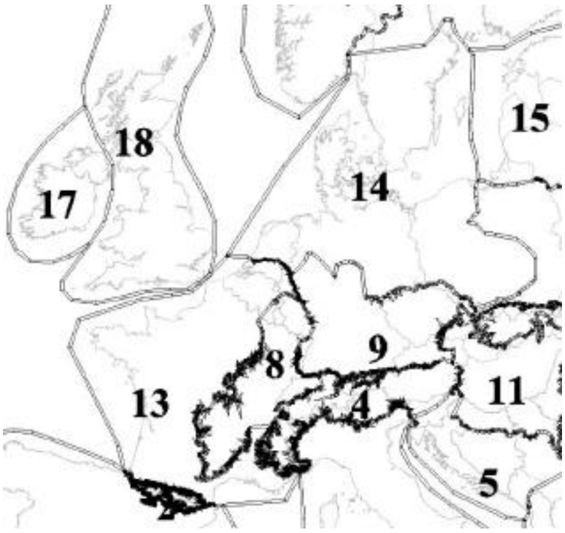


Figure 4.2: Eco-regions defined within the European Water Framework Directive (European Union, 2000). 4) Alps; 5) Dinaric western Balkan; 8) Western highlands; 9) Central highlands; 11) Hungarian lowlands; 13) Western plains; 14) Central plains; 15) Baltic province; 17) Ireland and Northern Ireland; 18) Great Britain.

C. caroliniana has been recorded in, among other countries, Sweden, Germany, Belgium and France (Hussner, 2012; Q-bank invasive plants, 2013). These countries share their eco-regions with the Netherlands. This suggests that rivers and lakes within eco-regions 13 and 14 may provide suitable habitats for *C. caroliniana.* Moreover, large areas within these countries have been climate matched with Ottawa (Canada) and the Netherlands (Figure 4.1). *C. caroliniana* was recorded in the hydrologically isolated Holsbeek pond in the province of Vlaams Brabant, Belgium (eco-region 13). Holsbeek pond contains indigenous species such as *Potamogeton* spp., *Myriophyllum* spp. (Denys *et al.,* 2003). However, *C. caroliniana* did not show invasive behaviour at this location and did not reach other ponds in the area (EPPO, 2007). The pond has since been cleared and by 2006 no trace of *C. caroliniana* was left over (L. Denys, pers. comm.). *C. caroliniana* was first recorded in Germany in 2008 at Teverener Heide nature reserve, Noordrijn-Westfalen (Q-bank invasive plants, 2013). It has not been recorded outside of this location. Information relating to the location and extent of *C. caroliniana* colonisation in Sweden was not found during the literature review. It appears that the most detailed information relating to *C. caroliniana* colonisation within eco-region 13 and 14 countries is available for the Netherlands itself.

5. Distribution, dispersal and invasiveness

5.1. Global distribution

Fanwort *(Cabomba caroliniana)* has spread from its indigenous habitat in South America to several European locations (Cook, 1996). These include Belgium, England, Germany, Hungary, the Netherlands, Scotland, Sweden and France (Hussner, 2012; Q-bank invasive plants, 2013). *C. caroliniana* has also been recorded in a number of other countries including the United States, Canada, India, China, Australia and Japan. A single record is available for Papua New Guinea where *C. caroliniana* was found in a small shallow artificial pond (Leach & Osborne, 1985). In its introduced range, *C. caroliniana* has a wide potential distribution; it seems to grow in a wide array of ecological conditions (EUPHRESCO DeCLAIM, 2011). Figure 5.1 gives an overview of its current world distribution. It should be noted that a single record of *C. caroliniana* was enough to categorise a country as colonised.

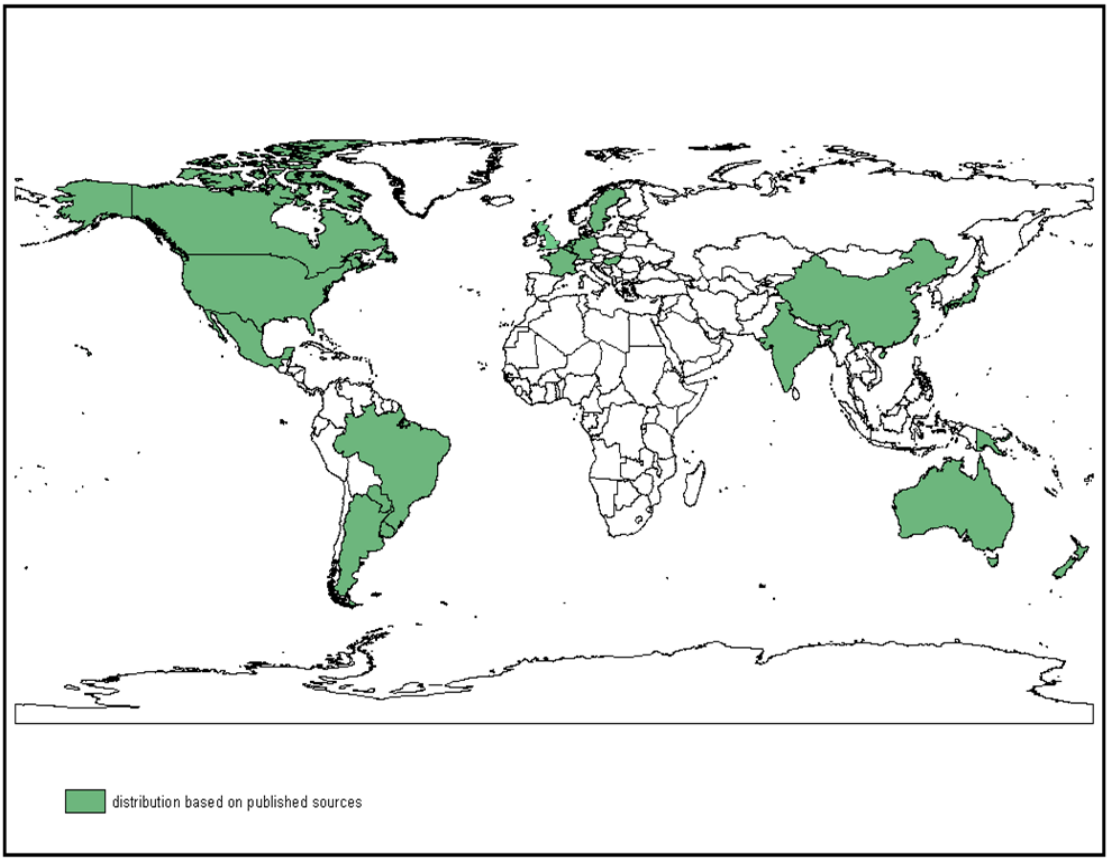


Figure 5.1: International distribution of Fanwort (*Cabomba caroliniana*) based on published sources (www.q-bank.eu).

5.2. Current distribution in the Netherlands

5.2.1 Geographical distribution and trends in range extension

C. caroliniana was first recorded in the Netherlands in 1986 after first being misidentified as *Cabomba aquatica* (Cortenraad, 1988; Van Valkenburg & Rotteveel, 2010). The species was recorded in the harbour of Maasbracht, situated along the river Meuse (Figure 5.2).

For a long period there were no other *C. caroliniana* observations, until in 2005 it was observed in canals and ditches near Loosdrecht. Soon it became evident that the species was locally very abundant, impeding swimming and sailing (Van Valkenburg & Rotteveel, 2010). Despite control measures, the species managed to establish in the surrounding nature reserves, where it grows in shallow lakes (Van Valkenburg & Rotteveel, 2010).

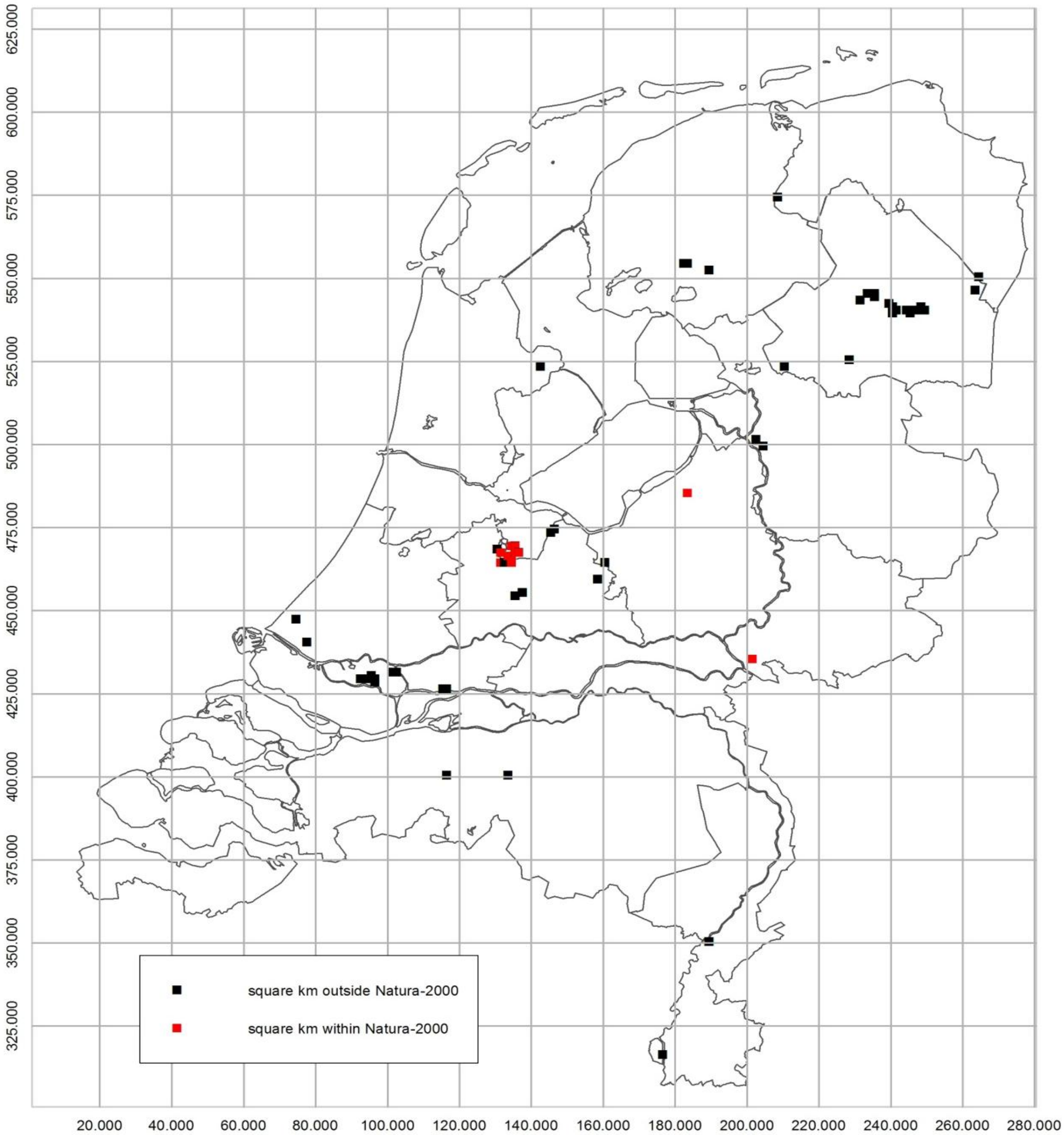


Figure 5.2: Distribution of Fanwort (*Cabomba caroliniana*) in the Netherlands (Data source: see chapter 2.2).

A second stronghold in the Netherlands was formed from 2007 onwards in the Oranjekanaal in the province of Drenthe. This canal has not been used by shipping for decades and is therefore extensively managed. Water plants had been scarce and turbidity relatively high until 2004 when non-native *Myriophyllum heterophyllum* invaded the canal and turbidity decreased strongly. In 2007, *C. caroliniana* was discovered in the Oranjekanaal in the neighbourhood of Orvelte. In 2010, a fragment of *C. caroliniana* was found in the harbour of Maastricht. This area is situated along the river Meuse, ±35 km south of Maasbracht, the location where *C. caroliniana* was first discovered in the Netherlands. The real extend of the population at this site is still unknown. In subsequent years, numerous new sites were discovered in this canal and in the immediate vicinity, particularly in 2011. *C. caroliniana* was observed in at least 17 kilometre squares of the Oranjekanaal area by 2012. In 2013, *M. heterophyllum* remains dominant at this location accompanied by a high number of *C. caroliniana* stands. However, *C. caroliniana* is present at far lower densities than *M. heterophyllum.* The general pattern has remained unchanged here for a number of years and mowing continues to be a management approach applied by the water-board (R. Pot, pers. comm.).

Apart from the above mentioned growing sites, *C. caroliniana* is usually found in urban areas, evenly spread across the north-western part of the Netherlands. A concentration of *C. caroliniana* occurrence in urban sites is found around the cities of Barendrecht, Sliedrecht and Ridderkerk. In Barendrecht, *C. caroliniana* has proliferated in a number of waterways in a new housing development. In urban areas, *C. caroliniana* is often found in recently built neighbourhoods that incorporate large areas of urban waters, for example in Joure, Heerenveen, Hoogeveen, Beilen, Zwolle, Tilburg, Breda and Lutjebroek. In the old town of Utrecht, *C. caroliniana* grows in a shallow canal.

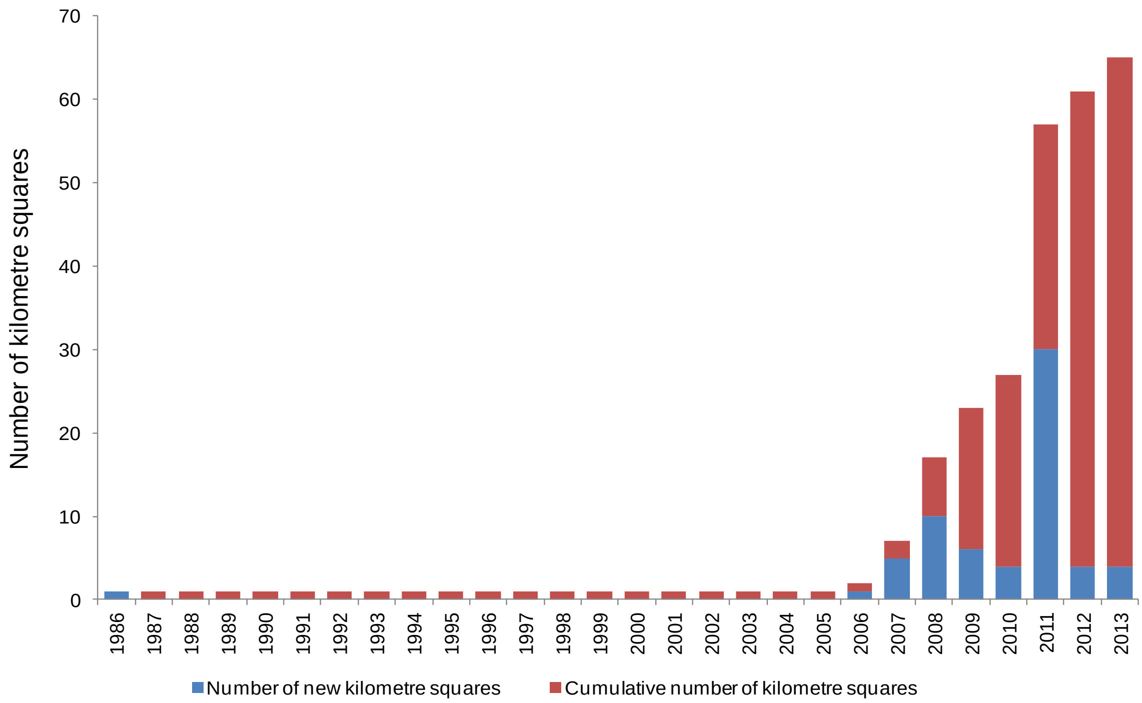


Figure 5.3: Number of kilometre squares with Fanwort (*Cabomba caroliniana*) records in the Netherlands since it was first recorded in 1986.

Since 1986 *C. caroliniana* has been recorded in 65 kilometre squares in the Netherlands (Figure 5.3). Beyond 2006 there has been a rapid increase in recordings. Every year the species was recorded in several new kilometre squares where it was not seen before. In 2011 it was recorded in 30 new kilometre squares, mostly in the Oranjekanaal region. In that year, however, this canal was intensively surveyed. In the year 2012 there were only four new kilometre square recordings. In 2013, *C. caroliniana* has been recorded in four new kilometre squares, an urban water-body in Tilburg and Breda (the first records in the province of North Brabant), the Musselkanaal and Breukeleveen. At Zwolle in 2013, *C. caroliniana* was found at only one of the two locations that were recorded in 2011. At the other location only one moribund example was found which was immediately removed.

5.2.2. Colonisation of high conservation value habitats

To date, *C. caroliniana* has been recorded in three Natura 2000 areas (Table 5.1). *C. caroliniana* has spread most prolifically in the Vechtplassen area. In 2012, it was also recorded in the Gelderse Poort (Rijnstrangen) area. However, During an intensive survey in 2013, *C. caroliniana* could not be found at the location in the Gelderse Poort where it had been discovered in the previous year. To date there are no signs of *C. caroliniana* becoming invasive in this area. In the Vechtplassen area and in the Gelderse Poort (Rijnstrangen), *C. caroliniana* may appear in EU habitat type H3150 (Natural eutrophic lakes with a Magnopotamion or Hydrocharition type of vegetation). *C. caroliniana* has been recorded in an old artificial pond located near a road in the Natura 2000 Veluwe region. This location was rechecked in 2013 and *C. caroliniana* was still present here covering an area of approximately six m^2 in the centre of the pond. The plant was apparently introduced to this site. The natural vegetation here (o.a. *Carex rostrata*, *Eleocharis multicaulis*, *Juncus bulbosus* and *Utricularia minor*) indicate oligotrophic and acidic conditions (poorly developed habitat types H3130: oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or of the Isoëto-Nanojuncetea or H3160: natural dystrophic lakes and ponds). It is unlikely in the long-term that the plants will thrive in this environment. Impacts in the Oostelijke Vechtplassen may be of particular importance as there are specific Natura 2000 targets for aquatic plants in this area. In the Oostelijke Vechtplassen, targets relate to improving the balance of the water-system and the aquatic plant community: habitat type H3140 and H3150. References to habitat type H3150 relate to water-bodies containing the Water soldier (*Stratiotes aloides*) and Pondweeds (*Potamogeton* spp.).

Table 5.1: Occurrence of Fanwort (*Cabomba caroliniana*) in Natura 2000 areas.

Natura 2000	Number of kilometre squares
Gelderse Poort	1
Oostelijke Vechtplassen	10
Veluwe	1

5.3. Pathways and vectors for dispersal

5.3.1. Dispersal potential by natural means

As *C. caroliniana* reproduces vegetatively through fragmentation and rhizome production in the Netherlands, natural vectors that transport plant fragments are of utmost importance. Water current and certain animals may be partly responsible for the secondary spread of the plant (Table 5.2). A detached fragment of the plant can regenerate into a full plant as long as it has at least one pair of leaves, and pieces as short as 10 mm may be viable and survive floating in water for 6 to 8 weeks (EPPO, 2007; Luijten & Odé, 2007). Clonal multiplication happens quickly (Wilson *et al.,* 2007), with growth rates of up to 5 cm per day (Mackey, 1996).

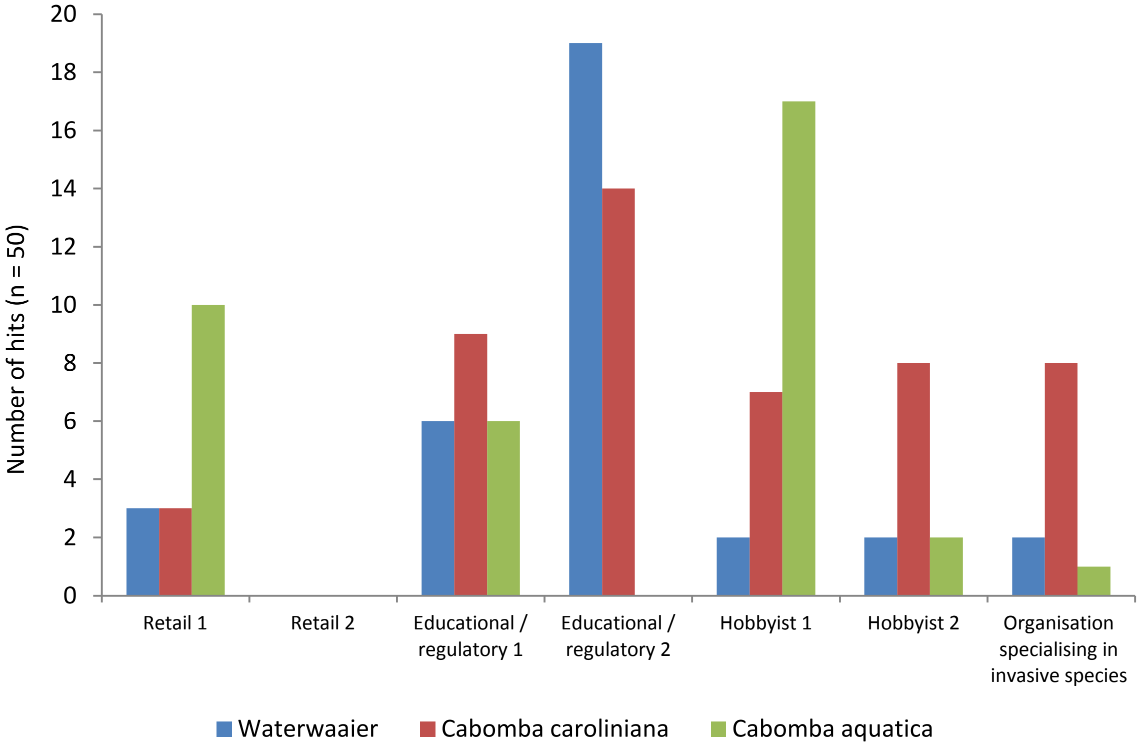
5.3.2. Dispersal potential with human assistance

The ornamental pond and aquarium plant trade is a major pathway for the distribution of aquatic plants globally (Champion *et al.,* 2010). The introduction of non-native aquatic macrophytes into a country has almost certainly been via the trade in live aquarium plants, legal or otherwise (Bowmer *et al.,* 1995). *Cabomba* is transported throughout the world because they have attractive foliage and are used in aquaria (De Wit, 1966; Cook, 1996). Brunel (2009) undertook a survey examining the importation of non-native aquatic plants to 10 countries in Europe. The Netherlands imported circa 5 million units of aquatic plants in 2006 and was the largest importer, coming top of a list of countries constituting France, the Czech Republic, Germany, Hungary, Switzerland, Austria, Latvia, Turkey and Estonia. 514,450 examples of *C. caroliniana* were imported to the countries studied per year. The Netherlands is a major importer of *C. caroliniana. C. caroliniana* represents over 30% of the total import volume of aquarium plants imported to this country (J. van Valkenburg, pers. comm.; EUPHRESCO DeCLAIM, 2011). Moreover, *C. caroliniana* is one of the best selling aquatic plants in pet shops in the Netherlands (Verbrugge *et al.,* 2013). *C. caroliniana* is imported from Indonesia, Singapore and Hungary (EPPO, 2007).

Brunel (2009) found that *Egeria densa* (1,878,098 plants imported per year) and *Cabomba aquatica* (1,344,915 plants imported per year), were by far the most frequently imported aquatic plants for aquarium use by the countries examined, and were mainly imported to the Netherlands. It should be emphasised that the main component of imported *C. aquatica* to the Netherlands actually consists of *C. caroliniana* (Van Valkenburg, unpublished results). Misidentification of plants is particularly problematic if limits are placed on the importation and sale of particular *Cabomba* species. However, efforts are being made to differentiate *Cabomba* species on a molecular level. A genetic bar-coding study was able to distinguish different *Cabomba* species using the chloroplast loci trnH-psbA and rbcL (Ghahramanzadeh *et al.,* 2013). Moreover an additional study is being performed to investigate genetic similarities and dissimilarities between various strains of *C. caroliniana* and the populations that have become invasive in the Netherlands. Preliminary results indicate that samples taken from field visits in the Netherlands and samples of plants sold in the Dutch plant trade are genetically virtually identical (Van de Wiel *et al.,* unpublished results).

The increase in e-commerce has exacerbated the problem of invasive plant sales, giving retailers the ability to advertise online and send plants in the post (Kay & Hoyle, 2001). E-commerce has allowed importers direct access to customers and increasing access to plants sourced from other countries. Once bought, there is a risk that unwanted plants may be disposed of in the freshwater system.

A search of Google.nl using the search term 'Waterwaaier', uncovered three online plant retailer websites advertising plants for sale. However, these were all located in Belgium. The term '*Cabomba caroliniana*' also produced three results, two retailers located in the Netherlands and one in the United Kingdom. However, no information regarding the invasive nature of *C. caroliniana* or the importance of avoiding introductions of this species to the freshwater network was included in the retail page on any of the retail sites visited (Figure 5.4). The term '*Cabomba aquatica*' revealed 10 retailers (20 % of the total number of websites examined) offering plants for sale. Seven out of the 10 results pertained to retail websites originating in the Netherlands. The high number of retailers advertising *C. aquatica* for sale and its frequent confusion with *C. caroliniana* suggest that many examples of *C. caroliniana* may be sold labelled as *C. aquatica*. The mislabelling of *C. caroliniana* increases the possibility of further introductions of this potentially invasive aquatic plant to the freshwater network in the Netherlands.



1: No direct reference is made to the plants invasive nature and / or measures recommended to prevent introduction; 2: A direct reference is made to the plants invasive nature and / or measures recommended to prevent introduction

Figure 5.4: Type of websites (in Dutch and English) featuring Fanwort (*Cabomba caroliniana*) found via Google.nl using various search terms (search terms are visualised using different colours).

Over 50% of the hobbyist websites referring to *C. caroliniana* or the Waterwaaier also contained information on the invasive nature of this plant and its potential threat to native biodiversity. However, the number of hobbyist websites and amount of content within hobbyist forums referring to *C. aquatica* suggest that this is a popular and highly discussed aquarium plant in the Netherlands. There were two examples where hobbyists confused *C. caroliniana* and *C. aquatica* in forums suggesting that some hobbyists may struggle to differentiate between these two species.

Waterwaaier was referred to in 25 educational or regulatory websites. These were all written in the Dutch language. 19 of the 25 websites contained information relating to the invasive nature of the Waterwaaier and the potential threat that it poses to biodiversity. This highlights a high level of awareness of the potential invasive nature of the Waterwaaier in these organisations and a wish to communicate this to the public. The high level of educational material present may be an indication of the effect of the Dutch code of conduct for aquatic plants, introduced in 2010, that stimulates government and water-boards to carry out educational campaigns to inform the public about the risks associated with invasive aquatic plants (Verbrugge *et al.,* 2013). 23 educational or regulatory websites referred to *C. caroliniana* and of these, 14 contained information relating to the invasive nature of *C. caroliniana* and the potential threat that it poses to biodiversity. The majority of these were English language websites, however.

Organisations focussing solely on invasive species were best represented when the search term '*Cabomba caroliniana*' was used. However, little evidence could be found of efforts to inform the public of the confusion that appears to exist between *C. caroliniana* and *C. aquatica* within any website categories.

According to these results, information in the Dutch language relating to the invasive nature of the Waterwaaier is readily available on educational and regulatory websites via Google.nl. Moreover, the number of online retailers selling the plant identified as either the Waterwaaier or *Cabomba caroliniana* is limited, particularly in the Netherlands. However, the misidentification of *C. caroliniana* as *C. aquatica* in the plant trade, high level of importation under this name and possible confusion between the two species by hobbyists may result in its continued use in aquaria and ponds and potential disposal to the freshwater network, despite attempts by Dutch nature organisations and water-boards to educate the public.

In 2012 a survey of aquatic plant retailers in the Netherlands was conducted to assess the effectiveness of the Dutch code of conduct for aquatic plants. The code of conduct was introduced in 2010 in the Netherlands and is a non-binding agreement between government and water-plant retailers that aims to limit the supply of potentially invasive water-plants and inform buyers of their correct disposal. *C. caroliniana* is categorised in appendix 2 of the code of conduct meaning that it is not banned from sale, but should be supplied with information relating to its potential invasiveness and correct disposal. Of the 76 retailers surveyed, 43 were found to be selling *C. caroliniana*, of these only 19% offered information in line with the requirements of the code of conduct (J. van Valkenburg, personal communication).

Global introductions of *C. caroliniana* in several Asian, Pacific and European countries have been attributed to the discarding or deliberate planting of aquarium plants in natural waterways (Wilson *et al.,* 2007). The *C. caroliniana* species present in nature in the Netherlands is the same species that is sold via the aquatic plant trade in this country (J. van Valkenburg, pers. comm.). Moreover, *C. caroliniana* is often found near sites of human activity suggesting that humans are responsible for the initial stages of *C. caroliniana* introduction in the Netherlands (section 5.2.1). The results of a recent survey examining the behaviour of aquarium and water garden owners in the Netherlands showed that 2.9% (n = 7) of the 239 respondents had disposed of aquatic plants in open water (Verbrugge *et al.,* 2013). This number is virtually unchanged in comparison with a similar survey undertaken by Verbrugge *et al.* in 2010. Moreover, further proof of voluntary introductions is provided by the occasional occurrence of common garden pond plants and animals in Dutch waters with examples of pumpkinseed sunfish (*Lepomis gibbosus*). This fish species was introduced to the Netherlands in 1902 as an aquarium and garden pond fish (Van Kleef *et al.,* 2008). The disposal of aquatic plants in open water potentially contributes to the introduction and spread of invasive aquatic plants.

The potential for introduction of a species repeatedly and on a large scale into a new area is one of the most important factors that lead to invasiveness (Randall & Marinelli, 1996; Riis *et al.,* 2010). Therefore, the high level of importations, recent increase in e-commerce and consumer behaviour increase the likelihood that invasive species such as *C. caroliniana* will establish or increase their distribution in the Dutch freshwater network.

Table 5.2: Potential dispersal vectors / mechanisms of Fanwort (*Cabomba caroliniana*).

Vector / mechanism	Mode of transport	Examples and relevant information	References
Trade	Overland (cross border)	E-commerce, plants transported in the post	Bowmer *et al.* (1995); Brunel (2009); EPPO (2007)
Hobbyists	Overland	Disposal of unwanted plants	Bowmer *et al.* (1995); EPPO (2007); Verbrugge *et al.* (2013); Wilson *et al.* (2007)
Boats / trailers (hull, anchor line, engine, other parts of a boat)	Upstream / downstream, overland	Occurs as a result of improper cleaning and movement from water body to water body	Bowmer *et al.* (1995); Les & Mehrhoff (1999); Jacobs & MacIsaac (2009); Schooler *et al.* (2005)
Weed harvesters	Upstream / downstream, overland	Machinery not properly cleaned and moved from water body to water body	Australian Department of the Environment and Heritage, (2003); EPPO, 2007
Water current	Downstream	Plant fragments transported in flowing water	Bowmer *et al.* (1995); Cook (1996); Les & Mehrhoff (1999) ; Jacob & MacIsaac (2009)
Fishing equipment	Upstream / downstream, overland	Occurs as a result of improper cleaning and movement from water body to water body	Schooler *et al.* (2005)
Aquatic birds	Upstream / downstream, overland	Rare occurrence	Cook (1996); Les & Mehrhoff (1999); Schooler *et al.* (2005)

Following the introduction of *C. caroliniana* to the freshwater network, secondary spread may be facilitated by fragmentation and vegetative reproduction. Seeds only appear within *C. caroliniana's* native range of South America and in the tropical and subtropical parts of its non-native range (EPPO, 2007). Therefore, vectors that transfer plant fragments are of great importance (Table 5.2). Vegetative fragments are transferred between water bodies by boats and trailers, fishing, vehicles crossing fords, weed harvesters and other maintenance equipment; though rarely, if at all, by birds (Bowmer *et al.,* 1995; Johnstone *et al.,* 1985; Howard-Williams, 1993). Dispersal of plant fragments by boats is an important dispersal mechanism for *C. caroliniana* (Jacobs & MacIsaac, 2009). In Massachusetts and Connecticut in the United States, *C. caroliniana* fragments abound in lakes used heavily by motor boats and the plant is widely dispersed within such lakes. Its long, trailing stems easily become entwined on boat trailers which facilitate its dispersal between lakes (Les & Mehrhoff, 1999). Moreover, mechanical methods aimed at the control of established infestations such as mechanical harvesting, hydroraking and rotovation, may result in the breakup of plant stems resulting in the dispersal of plants to new areas (Bowmer *et al.*, 1995; Massachusetts Department of Conservation and Recreation, 2005; EPPO, 2007; Wilson *et al.,* 2007).

5.4. Invasiveness

Since 1986, *C. caroliniana* has been recorded in 65 kilometre squares in the Netherlands. After 2006 there has been a rapid increase in recordings. Every year the species was recorded in several new kilometre squares where it was not seen before. In 2011 it was recorded in 30 new kilometre squares, mostly in the Oranjekanaal region. In that year, however, this canal was intensively surveyed. In the year 2012 there were only four new kilometre square recordings. In 2013, *C. caroliniana* has been recorded in four new kilometre squares, an urban water-body in Tilburg and Breda (the first records in the province of North Brabant), the Musselkanaal and Breukeleveen. *C. caroliniana* has become invasive in at least two large areas, the area around Loosdrecht and in the Oranjekanaal region. At a third location at Giessendam, *C. caroliniana* has spread from its initial point of colonization. In Barendrecht, *C. caroliniana* has proliferated in a number of waterways in a new housing development. Currently, it is unknown if the plant has become invasive at other locations in the Netherlands.

In general, disturbance by boats, grazing waterfowl, waves, lowered water levels, and ice scour have been highlighted as possible mechanisms of niche creation for invasive water plants (Capers *et al.,* 2007). A study in the Netherlands suggested that *C. caroliniana* requires a ‘window of opportunity’ where the original vegetation is removed or strongly reduced giving it the space to establish. Once established, rapid growth of dense vegetation and a reduction in light levels will result in *C. caroliniana* outcompeting other submerged aquatic plants (Roijackers, 2008).

In the Netherlands, the observed fast growth of *C. caroliniana* from fragments early in the growing season and the high number of asexual propagules further increase its competitive strength. In the future, this will become more significant as a result of warmer winters and spring times (Van den Berg *et al.,* unpublished results). Moreover, as a result of the phosphorus legacy in the underwater sediments of many Dutch waters, and a lowering of phosphorus in the surface water with concomitant improvements in light availability, *C. caroliniana* can be expected to become more invasive in the near future, especially in the peat district and other peaty areas (Lamers *et al.,* 2012; Van den Berg *et al.,* unpublished results).

C. caroliniana has not spread in England and Belgium. In England, in 1991, *C. caroliniana* was found in the Basingstoke Canal, and was considered naturalized by 1995, but was not considered invasive (Preston *et al.,* 2002). In Belgium, the plant became naturalized in a pond containing indigenous species such as *Potamogeton* spp. and *Myriophyllum* spp. It was present in only a part of the pond, but did not show invasive behaviour and did not reach the other ponds (EPPO, 2007). The pond has since been cleared and by 2006 no trace of *C. caroliniana* was left over (L. Denys, pers. comm.). In France, the plant has colonised a canal near the city of Dijon in Burgundy (CBNBL, 2007). In North America, the inability of aquatic plant communities to resist invasion of *C. caroliniana* except at the very highest plant density levels indicates that niche space is available for colonizers, unlike grassland systems, where competition is an important structuring force and where resistance has more usually been found (Capers *et al.,* 2007)

6. Impacts

6.1. Ecological effects

6.1.1 Impacts on native species

Adverse effects

The major adverse impacts of Fanwort (*Cabomba caroliniana*) on native species are related to interference and exploitation competition. *C. caroliniana* is a highly competitive, densely growing and persistent plant. Upon introduction into a new water body it progressively colonizes near shore areas, where it intercepts sunlight to the exclusion of other submerged plants and crowds out native plants (EPPO, 2007). *C. caroliniana* grows prolifically and forms dense populations, which can displace native macrophyte species, may alter nutrient cycling and fish habitat (Sheldon, 1994; Mackey & Swarbrick, 1997; Wilson *et al.,* 2007).

C. caroliniana was discovered in 2005 in eutrophic water in full sunshine at a camp site at Loosdrecht, the Netherlands. It was able to establish and become invasive in eutrophic water in larger water channels surrounding this camp site, and in less nutrient-rich waters of small streams at 'De Ster' to the east of the camp site (Van Valkenburg & Rotteveel, 2010). At this location it was perceived to have smothered submerged native plants. However, in most instances there was no other macrophyte growth in areas where *C. caroliniana* became established. In well vegetated smaller ditches in the area, *C. caroliniana* did manage to colonize, but seemed to be unable to compete seriously with the species already present (R. Pot, pers. comm.). Herbivory of *C. caroliniana* by birds seems to be limited. In cage experiments in Loosdrecht, Nuttall's waterweed (*Elodea nuttallii*) increased in density much faster than *C. caroliniana* in cages that excluded grazing birds. Since *E. nuttallii* is known to be a preferred food of these herbivores, *C. caroliniana* appears to benefit from selective grazing at this location. (J. van Valkenburg, pers. comm.; Van Valkenburg *et al.,* 2011). However, *C. caroliniana* has been observed to grow in patchy patterns (as opposed to monospecific stands) in its introduced range, which may be due to competition with floating plants and herbivory (EUPHRESCO DeCLAIM, 2011). Growth form appears to play an important role in the competitive ability of *C. caroliniana. Myriophyllum spicatum* and the non-native *Myriophyllum heterophyllum* feature the same growth form as *C. caroliniana* and these plants often appear together in the Netherlands. Where plants with a similar growth form appear, *C. caroliniana* appears to have either a limited chance to grow e.g. in Loosdrecht where *Myriophyllum spicatum* occurs, or is reduced in abundance e.g. at the port of Maasbracht where *Myriophyllum heterophyllum* is highly developed (Roijackers, 2008). Fast flowing currents may also limit the possibility that *C. caroliniana* will become widespread at Maasbracht (R. Pot, pers. comm.). At Lake Tienhoven, the Netherlands, *C. caroliniana* has been seen to outcompete other macrophytes, except for floating leaved species and helophytes (Van den Berg *et al.,* unpublished results). No further details defining the nature of *C. caroliniana's* impact on native species in the Netherlands were found in literature.

A number of examples were found where *C. caroliniana* was observed to impact native aquatic plant species abroad. Ontario (Canada) has been climate matched with the Netherlands (section 4.3), increasing the possibility that similar impacts may be observed here. In a study of an Ontario lake, significant differences were discovered in underwater light conditions, macrophyte equitability, and epiphytic algae biomass between *C. caroliniana* and native macrophyte beds (Hogsden *et al.,* 2007). The authors found that, while native macrophytes were present in dense *C. caroliniana* beds, abundance was considerably low and unevenly distributed. A study from Canada found a significant relationship between the presence *C. caroliniana* and reduced native macrophyte species richness (Lyon & Eastman, 2006) and *C. caroliniana* has been observed to displace native macrophyte species in New Hampshire in the United States (Barko *et al.,* 1994). In China, species diversity at 24 sites showed changes following the invasion of *C. caroliniana*. Here it was shown that longer invasion time and stronger *C. caroliniana* dominance led to a lowering of biodiversity (Yang *et al.,* 2007). In Australia, *C. caroliniana* can smother native, submerged plants such as pondweeds (*Potamogeton* spp.), stoneworts (*Chara* spp.), Hornwort (*Ceratophyllum demersum*), and Water nymph (*Najas tenuifolia*) (Mackey & Swarbrick, 1997). It may also reduce germination in desirable native emergent plants (EPPO, 2007).

However, other studies have shown that *C. caroliniana* has no effect on measures of macrophyte biodiversity and abundance. For example, in Ontario (Canada), no differences were detected in macrophyte biomass and diversity between plots dominated by native plants and *C. caroliniana*, whereas in Connecticut (northeastern USA), no differences were found between native species richness and lake area in invaded temperate lakes (Hogsden *et al.,* 2007; Capers *et al.,* 2007). Moreover, a study has shown that *C. caroliniana* had no significant impact on either native or other introduced plants under experimental conditions in New Zealand (Champion *et al.,* 2007). However, Hogsden *et al.* (2007) suggested that uneven distribution of other species within dense stands of *C. caroliniana* signalled potential future losses of macrophyte diversity, particularly for low-growing native species.

Limited information was found on the effects of *C. caroliniana* on native aquatic animals. In a study of an Ontario lake (Canada), significant differences between *C. caroliniana* and native beds were discovered for macroinvertebrate biomass and abundance. The taxonomic composition of macroinvertebrates was similar between *C. caroliniana* and native beds, however abundance was substantially higher in *C. caroliniana* beds, owing to high densities of coenagrionids and chironomids (Hogsden *et al.,* 2007). In Northern Queensland, Australia, native animal numbers such as platypus and water rat are lower in infested creeks (Australian Department of the Environment and Heritage, 2003). In a study by Morrison & Hay (2011), *C. caroliniana* was found to exhibit an induced chemical response during herbivory that reduced the palatability of the plant to the crayfish *Procambarus clarkii* and the snail *Pomacea canaliculata.* Herbivore feeding was reduced by 71–83% following chemical induction. Moreover, growth was significantly lower in snails fed on induced *C. caroliniana* which may suggest that the plant was avoided to prevent a suppression of fitness (Morrison & Hay, 2011).

In the laboratory, *C. caroliniana* has been demonstrated to absorb higher levels of lead at different concentrations from surrounding water compared to the macrophyte species

Hornwort (*Ceratophyllum demersum*), Water wisteria (*Hygrophilia difformis*) and Water primrose (*Ludwigia hyssopifolia*) (Yaowakhan *et al.,* 2005). In comparison with other aquatic plants, high levels of sodium, copper and zinc have been measured in *C. caroliniana* tissue (Hutchinson, 1975). Higher concentrations of heavy metals in *C. caroliniana* compared with other macrophytes may increase the exposure of aquatic herbivores in *C. caroliniana* dominated water-bodies.

The result of the literature search revealed no information relating to the transmission of parasites and diseases to native species. Impact criteria related genetic effects are not relevant for the Netherlands. Hybridisation or introgression with natives will not occur because closely related species are absent in north western Europe.

Positive effects
No information regarding the positive impact of *C. caroliniana* on native species in the Netherlands was found in the literature.

In Ontario (Canada), an analysis demonstrated that the taxonomic composition of macroinvertebrates was similar between *C. caroliniana* beds and native beds, while abundance was substantially higher in *C. caroliniana* beds, owing to high densities of coenagrionids and chironomids (Hogsden *et al.,* 2007). Mean overall abundance and the abundance of chironomids, coenagrionids and heptageniid mayflies were all significantly higher in *C. caroliniana* beds. Finely dissected leaves and complex architectures are known to provide superior habitats for invertebrates and may provide an explanation for these observations (Dvorak & Best, 1982; Walker *et al.,* 2013).

In a study examining the effect of native macrophyte abundance on *C. caroliniana* invasion and other invasive aquatic plants in North America, it was concluded that there was no evidence that invasive aquatic plants affect the relationship between native species richness and lake area.

In Ontario (Canada), the biomass of epiphytic algae, estimated by chlorophyll *a*, was significantly greater on the upper shoots of *C. caroliniana* plants when compared to the upper shoots of native plants in an Ontario lake (Hogsden *et al.,* 2007). The authors attributed this difference to the plants growth form (i.e., highly divided leaves; growing just below the surface of the water where light levels are greatest and competition from other plants is minimized).

At the Netherlands Institute of Ecology (NIOO-KNAW) in Wageningen, an experiment is being undertaken to elucidate the outcomes of possible inter-specific competition between native and non-native aquatic plants as well as to gain insight into seasonal variation and the effect of eutrophication on non-native plant success (Figure 6.1). The relative influence of eight morphologically comparable native and non-native plants (including *C. caroliniana*) on typical Dutch vegetation is being tested in a large outdoor experiment. Nutrients has been added to half of the artificial systems to simulate eutrophication. The experiment began in late summer, 2012 and will run until August 2014.

Figure 6.1: Experiment to elucidate the outcomes of possible inter-specific competition between native and non-native aquatic plants at the Netherlands Institute of Ecology (NIOO-KNAW) in Wageningen (Photo: B. Grutters).

6.1.2. Alterations to ecosystem functioning

Adverse effects

No information regarding the negative impact of *C. caroliniana* on ecosystem functioning in the Netherlands was found in the literature.

Figure 6.2: Dense vegetation of Fanwort (*Cabomba caroliniana*) at Loosdrecht, the Netherlands (Photo: R. Pot).

One of the main physical habitat modifications that *C. caroliniana* inflicts on an invaded water-body is due to the plant's canopy (Figure 6.2). When compared to native macrophyte beds in a lake in Ontario (Canada), light conditions in *C. caroliniana* beds were significantly reduced (Hogsden *et al.,* 2007). The presence of dense stands of macrophytes can have a number of other effects including changes in nutrient availability and resource pools. Moreover, the displacement of structurally diverse native macrophyte beds can alter resource and habitat availability for macroinvertebrates, affecting both primary and secondary productivity rates (Hogsden *et al.,* 2007). When dense mats of *C. caroliniana* decay, the available oxygen in the water may be depleted, causing foul-smelling water. The resulting low oxygen conditions can lead to fish kills and harm other aquatic organisms (EPPO, 2007).

The presence of invasive aquatic plant species impacts on fish populations. Heavy infestations confer no oxygen benefit to fish or other animals (Ramey, 2001). Food webs involving fish species may be effected directly due to the change of species food source availability following *C. caroliniana* invasion. Moreover, dense beds of invasive exotic macrophytes have been linked with reduced foraging efficiency and success of fish (Engle, 1995).

Positive effects
No information regarding the positive impact of *C. caroliniana* on ecosystem functioning in the Netherlands was found in the literature. However, it is probable that structural changes to habitat resulting from mature *C. caroliniana* stands will better suit cyprinid, perch and pike populations than salmonid species. Salmonids have a preference for open water conditions while the cyprinids, perch and pike commonly seek the cover provided by dense weed beds (Caffrey & Acavedo, 2007). Moreover, the height and complexity of the plant canopy in beds of non-native species results in a physical change in habitat that appears to provide more habitat for zoobenthic prey, more resting areas for benthic fish such as bullies, and greater refuge from top predators than in native beds (Gilinsky, 1984; Keast, 1984; Gotceitas, 1990; Schriver *et al.*, 1995; Valley & Bremigan, 2002).

In an experiment by Penning *et al.* (2009), *C. caroliniana* was found to attenuate the action of waves by on average 72%. *C. caroliniana* was compared to two other morphologically different macrophytes: the red water lily (*Nymphaea rubra*) and the large burhead (*Echinodorus grandiflorus*) and was found to be the most effective wave attenuator. Wave attenuation reduces sediment re-suspension contributing to a better light climate and thus more suitable habitat for macrophytes themselves (Penning *et al.,* 2009).

6.2. Socio-economic effects

Adverse effects
In a survey of Dutch water-boards, *C. caroliniana* was positioned 8th in a list ranking invasive plants in order of undesirability (Zonderwijk, 2008). In the Netherlands at Loosdrecht, *C. caroliniana* completely clogged the canal so that boating, fishing and swimming became impossible. The cost of management action for one invaded site over a single year was 350,000 Euros. Management intervention reduced the infestation by 75% (T. Rotteveel, pers. comm., 2007). Management of *C. caroliniana* has also been required in the Oranjekanaal and at Giessendam in the Netherlands. The yearly economic cost of *C. caroliniana* incurred in Europe has been estimated to be 0.35 million Euros (Kettunen *et al.,* 2009).

In its native range (South America), as well as in introduced areas, prolific growth of *C. caroliniana* clogs waterways and impedes water-flow, interfering with commercial navigation and water-based recreation, particularly in slow moving water-bodies such as irrigation channels, ponds, dams and lakes (Wilson *et al.,* 2007; EPPO, 2007; Richardson *et al.,* 2006). Water velocity is slowed in dense beds of aquatic plants, particularly in those where there is a canopy and under-storey (Frodge *et al.*, 1990).

Dense infestations can degrade aesthetic and scenic quality, directly influencing tourism and real estate values (EPPO, 2007). Impacts on fish stocks may impact recreational anglers. The forced closure of fishing camps in the USA due to *C. caroliniana* invasion resulted in significant losses of income (Mackey & Swarbrick, 1997). Moreover, an increase in the abundance of chironomids (non-biting midges) has been significantly related to the presence of *C. caroliniana* stands compared with native macrophyte stands in Ontario (Canada) (Hogsden *et al.,* 2007).

The banning of *C. caroliniana* from sale may have significant impact on the aquatic plant trade. *C. caroliniana* is one of the most frequently imported aquatic plant species to the Netherlands and is a popular aquarium plant. Attempts at banning the plant may result in resistance from the retail sector (Verbrugge *et al.,* 2013).

Positive effects
No information regarding the positive socio-economic effects of *C. caroliniana* in the Netherlands was found in the literature.

6.3. Public health effects

Adverse effects
No information regarding the adverse public health effects of *C. caroliniana* in the Netherlands was found in the literature. However, *C. caroliniana* may under certain circumstances leak phosphate that encourages epiphytic algal growth. The abundance of aquatic snails that carry trematodes that cause the condition swimmer's itch may increase due to increased algal food availability. Increasing snail abundance may lead to an increase in the occurrence of swimmer's itch in recreational swimmers in the Netherlands (L. Lamers, pers. comm.; B. bij de Vaate, pers. comm.).

In Australia, *C. caroliniana* has significantly reduced water storage capacity and tainted drinking water supplies. Water treatment costs can be increased by up to $50 per 1000 m^3 (Australian Department of the Environment and Heritage, 2003).

Positive effects
No information regarding positive public health effects of *C. caroliniana* in the Netherlands was found in the literature.

C. caroliniana has been shown to inhibit the growth of blue-green algae in the laboratory through the production of allelopathic compounds (Nakai *et al.,* 1999).

7. Available risk classifications

7.1 Formal risk assessments

Risk classifications are available for a number of European countries and Australia (Table 7.1). A full formal risk assessment has been carried out in Belgium only.

Table 7.1: Overview of risk classifications previously performed for Fanwort (*Cabomba caroliniana*).

	Belgium	United Kingdom	Spain	Australia
Scope	Ecological risk assessment	Based on the Australian Weed Risk Assessment	Weed risk assessment	Victorian Weed Risk Assessment
Method	ISEIA	Rapid risk assessment	WRA	WRA
Year	2009	2010	2010	2011
Risk classification	**Moderate (10)**	**Critical (22)**	**Rejected for introduction (27)**	**High risk**
Source	http://ias.biodiversity.be/species/show/120	http://publications.naturalengland.org.uk/publication/40015?category=47020	Andreu & Vila (2010)	http://vro.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/impact_cabomba
Additional information		Added to schedule 9 of the Wildlife and Countryside Act.		

In Belgium, Fanwort *(Cabomba caroliniana)* scored 10 out of a possible 12 using the ISEIA protocol. Following this, the Belgium Forum on Invasive Species (BFIS) categorised *C. caroliniana* as a B0 species defining the species as absent from Belgium but displaying moderate environmental hazard (Baus *et al.*, 2009). The assessment was carried out following the removal of *C. caroliniana* from Holsbeek pond in the province of Vlaams Brabant, the only location where it has ever been recorded in Belgium. As a result, *C. caroliniana* was placed on an alert list indicating exotic species that are not observed in Belgium but are invasive in neighbouring countries where they are considered as highly detrimental to biodiversity.

7.2 Other risk classifications

Limited risk assessments have been carried out in the United Kingdom, Spain and Australia. In the UK the species received a score of 22 out of a possible 28. As a precautionary measure, *C. caroliniana* was placed on the critical (red) list meaning that the taxa was recommended for more detailed risk assessment as a matter of priority. In addition, the species was added to schedule 9 of the Wildlife and Countryside Act which features a list of species that are not ordinarily resident in or do not regularly visit Great Britain in a wild state. The release of any species on this list is prohibited (Natural England, 2011). In Spain, the species received a score of 27 out of 29 and was rejected as a potential species for safe introduction (Andreu & Vila, 2010). Finally, in Australia, the Victorian Weed Risk Assessment (WRA), while not giving an overall score, categorised *C. caroliniana* as high risk for adverse impacts to tourism, water quality, water flow, increased biomass, species composition, community structure and benefits to fauna (Department of Environment and Primary Industries, 2011).

8. Management options

8.1. Prevention

Combating the introduction of invasive plant species involves a number of stages that should be applied in order. The first stage involves the prevention of spread of the species across international borders. The second stage involves the prevention of the release of plants to the freshwater system from isolated locations such as aquaria or garden ponds, by accident or deliberately. The third stage involves the prevention of dispersal through connected waterways and overland via vectors from the site of introduction. The main distribution channel or vector for plant spread is the trade in plants for aquaria and garden ponds.

In the Dutch code of conduct for aquatic plants (2010), Fanwort (*Cabomba caroliniana*) has been declared a list-2 species. This means that it should only be sold when accompanied with a warning about its invasiveness. This should help stop the release of plants into open water by hobbyists who are unaware of the plants invasive nature or how to properly dispose of it. The selling of alternative, similar aquatic plants in place of *C. caroliniana* may also be considered. the following alternative aquatic plant species are suggested for use in cold water aquaria and garden ponds:

- Fan leaved water crowfoot (*Ranunculus circinatus*) or Common water crowfoot (*Ranunculus aquatilis*). These plants display similarly coloured and shaped leaves as *C. caroliniana.*
- Water violet (*Hottonia palustris*). This plant displays similarly coloured and shaped leaves as *C. caroliniana*, however the leaves are somewhat larger.
- Hornwort (*Ceratophyllum demersum*) or Nuttall's waterweed (*Elodea nuttallii*). These plants are easy to maintain and relatively cheap to produce.

C. caroliniana is often imported under the name *Cabomba aquatica* (J. van Valkenburg, personal communication). The correct identification of *C. caroliniana* and other plant species imported to the Netherlands should be prioritised in order to avoid confusion with species that are not listed in the Dutch code of conduct for aquatic plants. A recent study used genetic bar-coding to distinguish *C. caroliniana* from other similar species (Ghahramanzadeh *et al.,* 2013). The results of this study will enable the correct identification of *C. caroliniana* prior to importation to the Netherlands.

Public awareness is an important component in a strategy aimed at controlling or removing an invasive species from a catchment area. This is especially true of species such as *C. caroliniana* where people are a major vector of dispersal. Awareness leaflets, press releases, calendars, lakeside notifications and an information website, warning of the environmental, economic and social hazards posed by this plant will contribute to public awareness (Caffrey & O'Callaghan, 2007).

Education of anglers and boaters may be especially useful as they can assist in reporting sightings of the plant. Moreover, instruction on the cleaning of boating and angling equipment is necessary to prevent dispersal of *C. caroliniana* facilitated by these vectors. In the Netherlands, a simple photographic aid to the identification of a number of invasive species was produced in conjunction with the Dutch ‘Code of conduct for invasive aquatic plants’ by Van Valkenburg (2011). Its aim is to create awareness and assist in the monitoring of non-native aquatic plants.

8.2. Eradication and control measures

The use of propeller driven boats that cut plants into fragments has been identified as a cause for the rapid expansion of the *C. caroliniana* population at Loosdrecht (Bouwer, 2009). In infested water-bodies, the banning of propeller driven boats prior to management intervention may minimise fragment spread. However, this policy was applied at Loosdrecht in the Netherlands and was difficult to implement and regulate.

The removal of aquatic macrophytes from a lake system should be done under careful consideration. Removal of non-native macrophytes can lead to the proliferation of algae rather than re-colonisation by native macrophytes (Perrow *et al.,* 1997; Donabaum *et al.,* 1999). A number of management strategies that have been employed in an attempt to combat infestation are described in the following paragraphs.

8.2.1. Manual and mechanical control

Manual and mechanical management techniques involve the direct cutting and / or removal of unwanted plant material from the affected area (Wilson *et al.,* 2007). A guide describing the procedure for the mowing of nuisance aquatic macrophytes is given in the Rijkswaterstaat guide for the mowing of aquatic plants (Rijkswaterstaat, 2012). Rijkswaterstaat is a department of the Dutch government responsible for all major freshwater bodies in the Netherlands. The guide recommends that no more than 10% of the colonised area should be mowed to prevent the disappearance of native macrophytes. This figure is increased to 50% for non-native macrophytes. However, mechanical methods aimed at the control of established infestations such as mechanical harvesting, hydroraking and rotovation, may result in the breakup of plant stems resulting in the dispersal of plants to new areas (Bowmer *et al.*, 1995; Massachusetts Department of Conservation and Recreation, 2005; EPPO, 2007; Wilson *et al.,* 2007). Therefore, physical cutting and removal of plant matter is a suitable method for closed water bodies with heavy infestations only and should not be carried out during the summer months when productivity is at its peak (EPPO, 2007; EUPHRESCO DeCLAIM, 2011). When used on large stands of *C. caroliniana* in the United States and Australia, mechanical methods have been only temporarily successful. In one experiment, where a standing crop of *C. caroliniana* was halved by a mechanical harvester, the population re-grew to its original size within three weeks (Mackey & Swarbrick, 1997). Moreover, the costs of mechanical removal from dams are very high: at Marlow lagoon (Northern Territory, Australia) more than $400,000 was spent initially trying to control *C. caroliniana* without eradicating it (EPPO, 2007). Interventions such as these will only be successful if the cutting of large populations on a large scale is followed by continued management intervention on a smaller scale. This has been widely demonstrated during the management of Floating pennywort (*Hydrocotyle ranunculoides*) in the Netherlands (R. Pot, personal communication).

Several machine types are available for cutting and collecting plant material, examples of these are as follows (Wade, 1990; Wijnhoven & Niemeijer, 1995):

- Active cutting boats. Boats with cutter bars coupled to a hydraulic control mechanism that adjusts the depth and angle of the cutter bar in the water (Figure 8.1). Plants are cut more efficiently than with cutting boats using a V-blade. However, there is a risk that plant biomass may be collected inefficiently leading to further spread of *C. caroliniana* due to stem fragmentation.

Figure 8.1: A weed cutting boat with adjustable mowing gear used for aquatic weed control in the Netherlands (Photo: R. Pot).

- Harvesting boats. Small boats with a hydraulic controlled rack on the front that can collect floating plants and transport them to the banks (Figure 8.2). This method allows only partial collection of plant biomass and further spread is not prevented completely. Larger boats that cut and collect in one action are much more efficient but expensive and not practical in small water bodies.
- Mowing basket. A steel bucket with cutter bar attached to the hydraulic arm of a tractor or excavator that can be lowered into drainage channels, small rivers and ponds, and cut and collect plant material. Loss of plant material may be relatively low if the machinery is operated with care. Mowing baskets can therefore be effective in preventing the spread of unwanted plant species.

Figure 8.2: A harvesting boat with a hydraulically controlled rack for collecting floating plants, in use in the Netherlands (Photo: R. Pot).

All cutting machines have the disadvantage of only removing the above ground parts of plants, avoiding the root system. Mowing buckets can be operated as digging machines, removing (parts of) the roots as well, but application of this technique in the Loosdrecht area showed that *C. caroliniana* benefits from this approach. This is because species other than *C. caroliniana* are removed more efficiently and their re-growth is slower (J. van Valkenburg, unpublished results).

In response to the invasive spread of *C. caroliniana* at Loosdrecht in the Netherlands, a new method was tested which involved reversing the mud pump of a dredger. This results in a powerful water-jet that dislodges *C. caroliniana* which tends to root loosely (Figure 8.3).

Figure 8.3: Application of the Hydro-venturi system. The head and water jet is raised above water to illustrate its operation (Photo: L. van Kersbergen).

Complete plants with their root system attached float to the surface and are then removed (Figure 8.4). This method, known as the 'hydro-venturi' system, was compared to traditional weed cutting machines (Van Valkenburg *et al.,* 2011). Management using traditional cutting machines twice per year resulted in only a temporary reduction of plant biomass. The plants were able to re-grow due to the release of fragments and the relatively poor competitive ability of other aquatic plants. The hydro-venturi system was shown to be more successful at preventing rapid re-colonisation following management intervention. The technique may be further developed to improve the removal of nuisance plants along the shoreline and the collection of floating plant debris, particularly in the vicinity of vegetation consisting of reed, shrubs and trees that trap fragments and impede access. Although very promising, this technique will only result in a temporary removal of *C. caroliniana* if the species is still present in adjacent connecting waters, and where the control of shoreline populations is limited. Moreover, the results of the experiments indicated the critical role of the root system. Growth potential of the species was underestimated in model studies with the CHARISMA model (Van Nes, 2003) , despite adaptations to the model based on field observations (Van Valkenburg *et al.,* 2011).

Figure 8.4: Application of the Hydro-venturi system results in the removal of the complete plant, including root system (Photo: R. Pot).

Manual removal might be the most efficient approach if infestations of *C. caroliniana* are small scale. Whole plants, including roots, can be gathered with a rake. The use of divers to manually remove plants is easy and straightforward, with minimal environmental impacts, however, it is also labour intensive and therefore generally only cost-effective for small, localized infestations (Wilson *et al.,* 2007). Moreover, in 2011, in the river Buiten-Giessen at Hardinxveld-Giessendam in the Netherlands, scuba divers were employed to remove all visible plants. This proved to be ineffective because sediment disturbance during plant removal resulted in high turbidity. Plants were missed due to the reduced visibility. Diver-operated suction dredges may also be used. These are specialized, small-scale dredgers used to remove plants manually from the sediment (Madsen, 2000). Eichler *et al.* (1993) used a diver-operated suction dredger to control Eurasian water-milfoil in the United States and stated that it did not remove the invasive plant in one season but was a cost-effective way of reducing biomass and encourage the re-growth of native plant species.

Disposal of removed biomass can be carried out by drying and burning entire plants (EPPO, 2007). Plants may also be composted providing a source of bio-energy that may subsequently be sold to reduce costs.

8.2.2. Biological control

Management using herbicides, manual / mechanical removal and suction dredging have the disadvantages of being costly, ineffective over the long term and inflict potential environmental impacts (Tanner & Clayton, 1984; Haley, 2000). So far, no natural enemies of *C. caroliniana* have been reported in the Netherlands. This makes the prevention of plant establishment by natural enemies unlikely (EPPO, 2007). Therefore biological control should be considered as an alternative control method.

In its native habitat, *C. caroliniana* is only eaten by waterfowl and some fish and provides cover for some small fish and plankton (Ørgaard, 1991). However, two potential biological control agents from northern Argentina have been identified (Schoolar & Julien, 2008). These are a stem boring weevil (*Hydrotimetes natans* Kolbe) and a pyralid moth (*Paraponynx* spp.). The stem-boring weevil is expected to weaken stems, which will likely reduce the ability of *C. caroliniana* to tolerate deeper water, while leaf defoliation by moth larvae is expected to have a greater impact on competitive ability in shallow water (Schooler *et al.,* 2006). The entire life cycle of *H. natans* is completed on the plant, primarily underwater, except when the adults climb onto emergent flowers to mate. Moreover, field surveys of *C. caroliniana* and other submerged plant species, as well as results from preliminary laboratory host range trials suggest that the weevil is specific to *C. caroliniana* in its native range (Cabrera-Walsh *et al.,* 2011). In the field, adults were found on other plant species only when they were intertwined with *C. caroliniana* and did not move onto other plant species in aquaria trials. The distribution of *H. natans* larvae in the field was studied in relation to depth and plant size. No preferences for stem width or plant length were found, although a significant portion of the larval mines were located near the root crown of the plant. Both *H. natans* and *Paraponynx* spp. have shown potential for safe and effective control of *C. caroliniana* in Australia (Schooler *et al.,* 2009). The authors suggest that the results of their investigation may encourage research into the potential effectiveness of the weevil for biological control of *C. caroliniana* in its introduced range.

Biological control of *C. caroliniana* has been attempted in two eutrophic lakes in Florida, USA using the Grass carp (*Ctenopharyngodon idella*) producing mixed results. The Grass carp was introduced for the management of aquatic weed control in 1977 and is already present in certain areas of the Netherlands. In Koon lake, Lafayette County, *C. caroliniana* percentage area coverage was reduced from 96% to 62% nine years after the introduction of *C. idella*. However, in Linsey lake, Hernando county, *C. caroliniana* percentage area coverage increased from 36% to 100% six years after the introduction of *C. idella* (Hanlon *et al.,* 2000). Reasons given for these differences were different levels of fish mortality due to predation, water chemistry, handling stress, temperature change and differences in initial stock density. Moreover, during an experiment testing the food preference of the hybrid *C. idella* and the Israeli carp (*Cyprinus carpio*) comparing 16 different aquatic plants, *C. caroliniana* was not utilised as a food source (Duthu & Kilgen, 2006).

In general, the introduction of biological agents is a potential pest risk in itself and is only suitable after thorough testing.

8.2.3. Chemical control

Since the withdrawal of all herbicides for use in aquatic environments there is no appropriate chemical method for control of *C. caroliniana* in the Netherlands.

Nevertheless, experiences in other countries are reported in this document. An overview of the effectiveness of a number of herbicides against *C. caroliniana* is give in Table 8.1.

Table 8.1: Overview of the effectiveness of herbicides against *C. caroliniana* (Westerdahl & Getsinger, 1988).

Herbicide	Effectiveness against *C. caroliniana*
2,4-D Butoxyethyl Ester	Fair
2,4-D Dimethylamine (DMS)	Fair
Diquat	Good
Diquat+Complexed Copper	Excellent
Endothal Dipotassium Salt (K2)	Excellent
Endothal K2+Complexed Copper	Excellent
Endothal Dimethylamine Salts	Excellent
Fluridone	Good

In North America, the contact herbicide endothal has given excellent control of *C. caroliniana*, and the systemic herbicide fluridone has given good control (Commonwealth of Massachusetts, 2002). In Marloon Lagoon (Northern Territory, Australia), a $4000 herbicide programme successfully cleared an infestation of *C. caroliniana* after unsuccessful attempts at eradication by mechanical control (Australian Department of the Environment and Heritage, 2003). However, Anderson & Diatloff (1999) concluded that herbicides are largely ineffective against *C. caroliniana*.

Large scale decomposition of aquatic plants following the application of herbicides may cause severe oxygen depletion in treated water-bodies. In Australia, experience has shown that a slow action herbicide is needed to help prevent oxygen depletion following herbicide application (Agriculture & Resource Management Council of Australia & New Zealand, 2000). The favourable non-target toxicity profile of fluridone and slow plant death following its application have mitigated many concerns regarding widespread direct impacts of this pesticide to fish and wildlife and possible dramatic changes in water quality (Getsinger *et al.,* 2008). However, fluridone application rates and treatment timing are important considerations if damage to non-target vegetation is to be minimised (Netherland *et al.,* 1997). Moreover, Nelson *et al*. (2002) carried out tests with fluridone in the presence of water marigold (*Megalodonta beckii*) and concluded that there is limited potential for selectively controlling nuisance *C. caroliniana* populations.

Authors state that consideration of public sensitivities (e.g. the proximity to water intakes and recreational activity) as well as constraints in achieving adequate contact time (e.g. water velocity, weed bed size, density and location) need to be considered to encourage effective results (Clayton, 2006; Getsinger *et al.*, 2008). Public sensitivities for the usage of herbicides may be reduced by the use of containment nets that limit its spread to the target area (Clayton, 2006).

8.3. Ecosystem based management

Mechanical removal of *C. caroliniana* carries the risk of further spread due to the possible dispersal of plant fragments. Therefore, alternative methods that prevent the breakup of plant stems should be considered.

C. caroliniana's weakness is that it requires direct sunlight for growth. Therefore, shading by re-establishment of shoreline vegetation or by artificial means is a possible method of control (EPPO, 2007). In a subtropical Australian lake, three shade treatments (0%, 70%, and 99%) at depths of one, two and three m were applied to submerged vegetation using swimming pool covers. Biomass in the water column and within the sediment was reduced to zero within 120 days in the 99% shade treatment. The 70% treatment reduced biomass at two and three m depth, but did not affect biomass at the one m depth (Schooler, 2008). Shade experiments have also been carried out in the Netherlands. Van Valkenburg *et al.* (2011) covered the surface of a canal with black woven geo-textile over two stretches of over 100 m in length. Initially, the canal was colonised by *C. caroliniana* to 100% coverage. Following treatment, all plants situated under the cover had died, including *C. caroliniana*. If not applied thoroughly to the whole infested area, re-colonisation from remaining populations occurs quickly. Therefore, this method is best suited to small, early infestations (EPPO, 2007).

C. caroliniana prefers high nutrient habitats. High nutrient loading is thought to increase ecosystem invasibility and lend competitive advantage to invasive species relative to native species (Davis *et al.*, 2000; Daehler, 2003). In pond ecosystems, sediment dredging has been shown to be a successful restoration measure in reducing internal nutrient load (Søndergaard *et al.*, 2000).

C. caroliniana is sensitive to drying and winter and summer drainage may be an effective management measure in areas of low ecological value such as artificial channels and reservoirs. For example, water depth in Lake Benalla, Victoria, Australia, an artificial lake, was reduced by a maximum of 2.4 metres below normal pool stage between July and October 1972. Subsequent rainfall led to refilling to 2.1 metres above normal pool stage by May 1973. In August 1973, *C. caroliniana* abundance was reduced by 99% compared to the previous year (Goldsby & Sanders, 1975). However, *C. caroliniana* is able to survive drainage if the underlying sediment does not properly dry out and weather conditions remain favourable. In an experiment testing the effect of aerial exposure on *C. caroliniana,* 92% of stems remained viable following 69 days of exposure lying on saturated sediments in mounds of 1.5 cm thick on average (Dugdale *et al.,* 2013). The authors stated that the cool wet winter conditions without frequent frosts resulted in the high survival rate. Moreover, in a review examining the effect of annual winter lake drawdown on a number of native and non-native plants, no clear response or change in *C. caroliniana* was observed (Cooke, 1980). In Australia, control of aquatic macrophytes is aided by drainage followed by exposure of sediments to high summer temperatures or winter frosts. However, draining for sufficient time is not always feasible, especially in larger canals (Bowmer *et al.*, 1995). Moreover, this control technique will destroy fish, aquatic organism populations, possibly reptiles and amphibians, and may alter downstream conditions (Commonwealth of Massachusetts, 2002).

9. Conclusions and recommendations

9.1. Conclusions

Habitat description

- Fanwort (*Cabomba caroliniana*) has dispersed to a number of countries outside of its native range and has been declared an invasive species in many of these countries.

- *C. caroliniana* grows in the mud of slow flowing or stagnant freshwaters and prefers direct sunlight and shallow water. It is found in ponds, ditches, small shallow lakes and slow flowing streams in the coastal vegetation of swamp forests and bogs, and inland in areas of savannah.

- Research in the Netherlands indicates that low turbidity (requiring low to moderate nutrient levels in the surface water) and higher CO_2 levels in the water (peat sediments, seepage CO_2-rich groundwater) seem to facilitate this species. *C. caroliniana* is very well able to use bicarbonate and can therefore grow in many different water types. Moreover, high nutrient levels in the sediment are expected to stimulate growth.

Distribution, dispersal and invasiveness

- *C. caroliniana* constitutes more than 30% of all aquatic plants imported to the Netherlands for use in aquaria and garden ponds. The plant is sold freely at garden centres under its own name and is often mistaken for *Cabomba aquatica*. Plants classified as *C. aquatica,* which are very often mislabelled examples of *C. caroliniana*, are the second most highly imported aquatic plants to the Netherlands.

- *C. caroliniana* is available for sale online from Dutch, Belgium and UK retailers. However, plants classified as *C. aquatica* are more widely available than *C. caroliniana* from online retailers based in the Netherlands. The main component of plants labelled and sold as *C. aquatica* are misidentified examples of *C. caroliniana.*

- A genetic bar-coding study was able to distinguish different *Cabomba* species using using the chloroplast loci trnH-psbA and rbcL. Preliminary results from an additional study indicate that samples taken from field visits in the Netherlands and samples of plants sold in the Dutch plant trade are genetically virtually identical.

- Information describing the invasive nature of *C. caroliniana* is widely available from water-boards, nature organisations and hobbyist websites in the Dutch language.

- *C. aquatica* is a popular aquarium plant and is discussed frequently by hobbyists in forums. However, there was no evidence that hobbyists are aware that *C. caroliniana* is frequently mislabelled as *C. aquatica*. Hobbyists may confuse *C. caroliniana* and *C. aquatica*, as was demonstrated by discussions posted in hobbyist forums.

- Global introductions of *C. caroliniana* in several Asian, Pacific and European countries have been attributed to the discarding or deliberate planting of aquarium plants in natural waterways.

- Humans appear to be the main vector of secondary dispersal of *C. caroliniana* away from initial points of introduction. Examples of vectors found in literature are: boats, anglers, weed harvesters and large birds.

- Since 1986, *C. caroliniana* has been recorded in 65 kilometre squares in the Netherlands. After 2006 there has been a rapid increase in recordings. Every year the species was recorded in several new kilometre squares where it was not seen before. In 2011 it was recorded in 30 new kilometre squares, mostly in the Oranjekanaal region. In that year, however, this canal was intensively surveyed. In 2012 there were only four new kilometre square recordings. In 2013, *C. caroliniana* has been recorded in four new kilometre squares, an urban water-body in Tilburg and Breda (the first records in the province of North Brabant), the Musselkanaal and Breukeleveen.

Ecological and socio-economic impacts

- *C. caroliniana* has become invasive at Loosdrecht in the Netherlands, possibly smothering native vegetation and completely clogging the canal so that boating, fishing and swimming became impossible. The cost of management action for this one invaded site over a single year was 350,000 Euros. Moreover, at Lake Tienhoven, the Netherlands, *C. caroliniana* has been seen to outcompete other macrophytes, except for floating leaved species and helophytes. Local increases in the distribution of *C. caroliniana* may result in an increased abundance of trematode carrying aquatic snails which cause swimmers itch. Moreover, an increase in the abundance of chironomids (non-biting midges) has been significantly related to the presence of *C. caroliniana* stands compared with native macrophyte stands in Ontario (Canada).

- The Netherlands has been matched climatically with Ottawa (Canada) which lies in close proximity to Kasshabog Lake where *C. caroliniana* has established and grows extensively. At Kasshabog Lake, statistically significant differences between *C. caroliniana* beds and native macrophyte beds include: reduced light penetration in *C. caroliniana* beds, considerably lower abundance and uneven distribution of native macrophytes in *C. caroliniana* beds, more epiphytic algae and similar taxonomic composition but higher abundance of macroinvertebrates in *C. caroliniana* beds.

- In future, improvements in water clarity and the phosphate legacy present in hydro-soils will increase the possibility that *C. caroliniana* will spread and become invasive at more locations in the Netherlands.

Available risk classifications

- The only full risk assessment of *C. caroliniana* has been carried out in Belgium. *C. caroliniana* was categorised as displaying moderate environmental hazard to the Belgium freshwater system. Limited risk assessments have been carried out in the

United Kingdom, Spain and Australia. In the UK, *C. caroliniana* was placed on the critical (red) list meaning that the taxa was recommended for more detailed risk assessment as a matter of priority. In Spain, *C. caroliniana* was rejected as a potential species for safe introduction. In Australia, *C. caroliniana* was categorised as high risk for adverse impacts to tourism, water quality, water flow, increased biomass, species composition, community structure and benefits to fauna.

9.2. Effective management options

- *C. caroliniana* is often imported under the name *Cabomba aquatica*. The correct identification of *C. caroliniana* and other plant species imported to the Netherlands should be prioritised in order to avoid confusion with species that are not listed in the Dutch code of conduct for aquatic plants.

- The following alternative aquatic plant species are suggested for use in cold water aquaria and garden ponds: fan leaved water crowfoot (*Ranunculus circinatus*), Common water crowfoot (*Ranunculus aquatilis*), Water violet (*Hottonia palustris*), Hornwort (*Ceratophyllum demersum*) or Nuttall's waterweed (*Elodea nuttallii*).

- The literature review revealed that management interventions may not be very effective at removing *C. caroliniana*. Standard management techniques often encourage the spread of *C. caroliniana* through fragmentation. Once established, the plants are very hard to get rid of.

- Limiting management intervention appears to be the best method of limiting the spread of the species. A high level of fragment spread occurs when cutting machinery is used without the immediate and efficient collection of all plant material. The *C. caroliniana* population at Maasbracht was unmanaged and has not spread. The Loosdrecht population spread extremely fast after cutting with an inefficient harvesting machine within the first years following the establishment of the plant. However, growing conditions were different at the two locations.

- If control of *C. caroliniana* is required, as in the Oranjekanaal and at Loosdrecht, it is best to focus on the prevention of fragment spread. Mowing baskets or harvesting boats may be the best options for this, but only when the removal of plant material from the water-body is assured, preferably including the root system. Retaining nets stretched from bank to bank that catch fragments and stop them floating away during cutting may be required.

- The use of propeller driven boats that cut plants into fragments is a contributory factor for the rapid expansion of the population of *C. caroliniana* at Loosdrecht. The banning of propeller driven boats prior to management intervention may minimise this.

- Eradication of the plants can be achieved on a small scale by covering them with opaque material e.g. geo-textile. However, this method destroys not only the target plant population, but all other plant and most animal life due to the creation of dark, anoxic conditions.

- The application of hydro-venturi equipment seems to be a very promising eradication method because whole plants, including the root system, are collected and fragmentation is minimised. Plant re-growth is, therefore, limited. A disadvantage of this method is that all non-target rooted plant species are removed as-well. Aquatic fauna living on submerged macrophytes may also be dislodged or removed. In difficult to access locations e.g. around structures and narrow spaces, not all plants can be removed and additional manual removal is often necessary. Also, there is a risk that re-infestation from nearby, untreated sites will occur. Moreover, this method is relatively expensive due to the machinery's slow work rate, but this may improve in the near future.

9.3. Recommendations for further research

The reasons given for the limited distribution and dispersal capacity of *C. caroliniana* at the majority of locations in the Netherlands are based on expert knowledge. Further research is required to support this expert judgement and explain why, in the Netherlands, *C. caroliniana* has become invasive at Loosdrecht and in the Oranjekanaal and has spread at Giessendam. Further research is required to establish the physico-chemical characteristics of habitats where *C. caroliniana* has become established, particularly at Loosdrecht and the Oranjekanaal. Establishing the specific conditions that allowed the plant to become invasive will allow nature managers to better predict the likelihood that *C. caroliniana* will colonise and become invasive at other locations. This will offer insight into key factors for cost effective management in the Netherlands in the future.

Acknowledgements

We thank the Netherlands Food and Consumer Product Safety Authority (Invasive Alien Species Team) of the Dutch Ministry of Economic Affairs for financially supporting this study (order number: 60001296, d.d. 14th May 2013). Dr. Trix Rietveld-Piepers of the Invasive Alien Species Team delivered constructive comments on an earlier draft of this report. The authors would also like to thank Dr. Liesbeth Bakker, Bart Grutters, W. Weijs and L. van Kersbergen for supplying background information and photo material, Lesley Henderson (ARC-Plant Protection Research Institute, Pretoria) for permission to reproduce drawings of Fanwort by W. Roux (Figure 3.2), Wil Leurs who collected additional sampling data that are included in this report and the many volunteers for delivering their data to FLORON's and other national databases.

References

Agriculture & Resource Management Council of Australia & New Zealand, Australian & New Zealand Environment & Conservation Council and Forestry Ministers, (2000). *Weeds of national significance Cabomba (Cabomba caroliniana) strategic plan.* National Weeds Strategy Executive Committee, Launceston, Australia.

Anderson, T. & Diatloff, G., (1999). *Cabomba management attempts in Queensland in:* Practical Weed Management: Protecting Agriculture and the Environment. 10th Biennial Noxious Weeds Conference, Ballina, Australia.

Andreu, J. & Vilà, M., (2010). Risk analysis of potential invasive plants in Spain. *Journal for Nature Conservation* **18**, 34-44.

Australian Department of the Environment and Heritage, (2003). *Cabomba* (*Cabomba caroliniana*). *Weeds of national significance: weed management guide.* Department of the Environment and Heritage and the CRC for Australian Weed Management, 2003. http://www.deh.gov.au/biodiversity/invasive/publications/c-caroliniana.html, last accessed 13-05-2013.

Barko, J.W., Smith, C.S. & Chambers, P.A., (1994). Perspectives on submersed macrophyte invasions and declines. *Lake and Reservoir Management* **10**, 1-3.

Baus E., Branquart E., Stiers I., Triest L., Vanderhoeven S., Van Landuyt W., Van Rossum F. & Verloove F., (2009). *Cabomba caroliniana - Fanwort. Invasive species Belgium.* http://ias.biodiversity.be/species/show/120, last accessed 29-05-2013.

Beringen, R., (2011). *Waterwaaier Cabomba caroliniana*. Nederlands Soortenregister versie 2.0. www.nederlandsesoorten.nl, last accessed 29-05-2013.

Bouwer, N., (2009). *Plantenziekten en plagen in openbaar groen, april 2009 - nummer 1*. Plantenziektenkundige Dienst, Wageningen, the Netherlands.

Bowmer, K.H., Jacobs, S.W.L. & Sainty, G.R., (1995). Identification, biology and management of *Elodea canadensis*, Hydrocharitaceae. *Journal of Aquatic Plant Management* **33**, 13-19.

Brunel, S., (2009). Pathway analysis: aquatic plants imported in 10 EPPO countries. *OEPP/EPPO Bulletin* **39**, 201-213.

CABI, (2013). *Invasive Species Compendium: Cabomba caroliniana*. http://www.cabi.org/isc/?compid=5&dsid=107743&loadmodule=datasheet&page=481&site=144, last accessed 24-05-2013.

Cabrera-Walsh, G., Schooler, S. & Julien, M., (2011). Biology and preliminary host range of *Hydrotimetes natans* Kolbe (Coleoptera: Curculionidae), a natural enemy candidate for biological control of *Cabomba caroliniana* Gray (Cabombaceae) in Australia. *Australian Journal of Entimology* **50**, 200-206.

CAIP, (2013). *Fanwort*. Center for Aquatic and Invasive Plants, University of Florida. http://plants.ifas.ufl.edu/node/76, last accessed: 24-05-2013.

Caffrey, J.M. & Acavedo, S., (2007). *Status and management of Cabomba caroliniana in Lough Corrib 2007*. Central Fisheries Board, Ireland.

Caffrey, J.M. & O'Callaghan, D., (2007). *A Guide to the Identification of Aquatic Invasive Species in Ireland.* Central Fisheries Board, Swords, Dublin.

Canfield, D.E., Langeland, K.A., Linda, S.B. & Haller, W.T., (1985). Relations between water transparency and maximum depth of macrophyte colonization in lakes. *Journal of Aquatic Plant Management* **23**, 25-28.

Capers, R.S., Selsky, R., Bugbee, G.J. & White, J.C., (2007). Aquatic plant community invasibility and scale-dependent patterns in native and invasive species richness. *Ecology* **88**, 3135-3143.

Champion, P.D., Clayton, J.S. & Hofstra, D.E., (2010). Nipping aquatic plant invasions in the bud: weed risk assessment and the trade. *Hydrobiologia* **656**, 167-172.

Champion, P.D., Hofstra, D.E. & Clayton, J.S., (2007). *Border control for potential aquatic weeds, stage 3. Weed risk management*. Science for conservation 271. Science & Technical Publishing, Wellington, New Zealand.

Clayton, J., (2006). *Assessment of the 2005/06 Cabomba caroliniana control programme in Lake Wanaka*. National Institute of Water & Atmospheric Research Ltd, New Zealand.

CBNBL, (2007). *Le Jouet du Vent Spécial "Les plantes invasives dans le nord-ouest de la France : enjeux de biodiversité, enjeux de société".* www.cbnbl.org/IMG/pdf/jouet_NS_Invasives.pdf, last accessed 03-07-2013.

Commonwealth of Massachusetts, (2002). *Fanwort: an invasive aquatic plant. Cabomba caroliniana.* Department of Conservation and Recreation, Office of Water Resources, Lakes and Ponds Program, USA. http://www.mass.gov/dcr/watersupply/lakepond/factsheet/Fanwort.pdf, last accessed 24-05-2013.

Cook, C.D.K., (1996). *Aquatic plant book (second revised edition)*. SPB Academic Publishing, Amsterdam / New York.

Cooke, G.D., (1980). Lake level drawdown as a macrophyte control technique. *Water Resources Bulletin* **16**, 317-322.

Cortenraad, J., (1988). Uit de flora van Limburg, aflevering 30. *Natuurhistorisch Maandblad* **77**, 45.

Daehler, C.C., (2003). Performance comparisons of co-occurring native and alien invasive plants: implications for conservation and restoration. *Annual Review of Ecology Evolution and Systematics* **34**, 183-211.

Davis, M.A., Grime, J.P. & Thompson, K., (2000). Fluctuating resources in plant communities: a general theory of invisibility. *Journal of Ecology* **88**, 528-534.

Department of Environment and Primary Industries, (2011). *Impact assessment - Cabomba (Cabomba caroliniana) in Victoria (Nox)* http://vro.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/impact_cabomba, last accessed 29-05-2013.

Donabaum, K., Schagerl, M. & Dokulil, M.T., (1999). Integrated management to restore macrophyte domination. *Hydrobiologia* **396**, 87-97.

De Wit, H.C.D., (1966). *Aquariumplanten*. Hollandia N.V., Baarn, the Netherlands.

Denys, L., Packet, J., Weiss, L. & Coenen, M., (2003). *Cabomba caroliniana* (Cabombaceae) houdt stand in Holsbeek (Vlaams-Brabant, België). *Dumortiera* **80**, 35-40.

Dugdale, T.M., Butler, K.L., Clements, D. & Hunt, T.D., (2013). Survival of cabomba (*Cabomba caroliniana*) during lake drawdown within mounds of stranded vegetation. *Lake and Reservoir Management* **29**, 61-67.

Duthu, G.S. & Kilgen, R.H., (2006). Aquarium studies on the selectivity of 16 aquatic plants as food by fingerling hybrids of the cross between *Ctenopharyngodon idella* and *Cyprinus carpio*. *Journal of Fish Biology* **2**, 203-208.

Dvorak, J. & Best, E.P.H., (1982). Macro-invertebrate communities associated with the macrophytes of Lake Vechten: structural and functional relationships. *Hydrobiologia* **95**, 115-126.

Eichler, L.W., Bombard, R.T., Sutherland, J.W. & Boylen, C.W., (1993). Suction harvesting of Eurasian water-milfoil and its effect on native plant communities. *Journal of Aquatic Plant Management* **31**, 144-148.

Engle, S., (1995). Eurasian watermilfoil as a fisheries management tool. *Fisheries* **20**, 20-27.

EPPO, European and Mediterranean Plant Protection Organization, (2007). *Data sheets on invasive alien plants: Cabomba caroliniana.* http://www.eppo.int/INVASIVE_PLANTS/ias_lists.htm, last accessed 29-05-2013.

EUPHRESCO DeCLAIM, Decision support systems for control of alien invasive macrophytes, (2011). *A state-of-the-art June 2011: Cabomba caroliniana Gray.* www.q-bank.eu/Plants/Controlsheets/Cabomba_State-of-the-Art.pdf, last accessed 29-05-2013.

European Union, (2000). *Directive 2000/60/EC.* http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0060:EN:NOT, last accessed 29-05-2013.

Fassett, N., (1953). A monograph of Cabomba. *Castanea* **18**, 116-128.

Frodge, J.D., Thomas, G. & Land Pauley, G.B., (1990). Effects of canopy formation by floating and submergent aquatic macrophytes on the water quality of two shallow Pacific Northwest lakes. *Aquatic Botany* **38**, 231-248.

Getsinger, K.D., Netherland, M.D., Grue, C.E. & Koschnick, T.J., (2008). Improvements in the use of aquatic herbicides and establishment of future research directions. *Journal of Aquatic Plant Management* **46**, 32-41.

Ghahramanzadeh, R., Esselink, G., Kodde, L.P., Duistermaat, H., Van Valkenburg, J.L.C.H., Marashi, S.H., Smulders, M.J.M. & Van de Wiel, C.C.M., (2013). Efficient distinction of invasive aquatic plant species from non-invasive related species using DNA bar-coding. *Molecular Ecology Resources* **13**, 21-31.

Gilinsky, E., (1984). The role of fish predation and spatial heterogeneity in determining benthic community structure. *Ecology* **65**, 455-468.

Goldsby, T.L. & Sanders, D.R., (1977). Effects of consecutive water fluctuations on submersed vegetation of Black lake, Louisiana. *Journal of Aquatic Plant Management* **15**, 23-28.

Gotceitas, V., (1990). Variation in plant stem density and its effects on foraging success of juvenile bluegill sunfish. *Environmental Biology of Fishes* **27**, 63-70.
Gray, A., (1837). *Annals of the Lyceum of Natural History of New York*. New York **4**, 47.
Gregory, P.E. & Sanders, D.R., (1974). *Some aspects of the life history of and ecology of Cabomba*. Abstracts of the 1974 meeting of the Weed Science Society of America.
Hanlon, S.G., Hoyer, M.V., Chichra, C.E. & Canfield jr., D.E., (2000). Evaluation of macrophyte control in 38 Florida lakes using triploid grass carp. *Journal of Aquatic Plant Management* **38**, 48-54.
Haley, N., (2000). *Weeds in New Zealand*. http://www.boprc.govt.nz/www/green/weeds.htm *cited in:* McGregor, P.G. & Gourlay, H., (2002). *Assessing the prospects for biological control of Lagarosiphon (Lagarosiphon major (Hydrocharitaceae))*. Department of Conservation, New Zealand.
Henderson, L. & Cilliers, C.J., (2002). *Invasive aquatic plants*. *Plant protection research institute handbook No. 16.* Agricultural Research Council, Pretoria, South Africa.
Hogsden, K.L., Sager, E.P.S. & Hutchinson, T.C., (2007). The Impacts of the non-native macrophyte *Cabomba caroliniana* on littoral biota of Kasshabog Lake, Ontario. *Journal of Great Lakes Research* **33**, 497-504.
Howard-Williams, C., (1993). Processes of aquatic weed invasions: the New Zealand example. *Journal of Aquatic Plant Management* **31**, 17-23 *cited in:* McGregor, P.G. & Gourlay, H., (2002). *Assessing the prospects for biological control of Lagarosiphon (Lagarosiphon major (Hydrocharitaceae))*. Department of Conservation, New Zealand.
Hutchinson, G.E., (1975). *A treatise on limnology, Vol. II: limnological botany.* John Wiley & Sons, New York, The United States of America.
Hussner, A., (2012). Alien aquatic plant species in European countries. *Weed Research* **52**, 297-306.
Jacobs, M.J. & MacIsaac, H.J., (2009). Modelling spread of the invasive macrophyte *Cabomba caroliniana. Freshwater Biology* **54**, 296-305.
Johnstone, I.M., Coffey, B.T. & Howard-Williams, C., (1985). The role of recreational boat traffic in interlake dispersal of macrophytes: A New Zealand case study. *Journal of Environmental Management* **20**, 263-279 *cited in:* McGregor, P.G. & Gourlay, H., (2002). *Assessing the prospects for biological control of Lagarosiphon (Lagarosiphon major (Hydrocharitaceae))*. Department of Conservation, New Zealand.
Kay, S.H. & Hoyle, S.T., (2001). Mail order, the internet and invasive aquatic weeds. *Journal of Aquatic Plant Management* **39**, 88-91.
Keast, A., (1984). The introduced aquatic macrophyte, *Myriophyllum spicatum*, as habitat for fish and their invertebrate prey. *Canadian Journal of Zoology* **62**, 1289-1303 *cited in:* Kelly, D.J. & Hawes, I., (2005). Effects of invasive macrophytes on littoral-zone productivity and foodweb dynamics in a New Zealand high-country lake. *Journal of the North American Benthological Society* **24**, 300-320.
Kettunen, M., Genovesi, P., Gollasch, S., Pagad, S., Starfinger, U., ten Brink, P. & Shine, C., (2009). *Technical support to EU stragegy on invasive alien species (IAS): Assessment of the impacts of IAS in Europe and the EU*. Institute for European Environmental Policy, London, UK.
KNMI, (2013). *Klimaatdata en –advies, Maart 2013: Zeer koud, droog en de normale hoeveelheid zon.* http://www.knmi.nl/klimatologie/maand_en_seizoensoverzichten/maand/mrt13.html, last accessed 31-05-2013.
Lamers, L., Schep, S., Geurts, J. & Smolders, F., (2012). Erfenis fosfaatrijk verleden: helder water met woekerende waterplanten. *H_2O* **13**, 29-31.
Leach, G.J. & Osborne, P.L., (1985). *Freshwater plants of Papua New Guinea.* University of Papua New Guinea Press, Port Moresby, Papua New Guinea.
Les, D.H. & Mehrhoff, L.J., (1999). Introduction of nonindigenous aquatic vascular plants in southern New England: a historical perspective. *Biological Invasions* **1**, 281-300.
Leslie, A.J., (1986). *A literature review of Cabomba*. Bureau of Aquatic Plant Research and Control, Florida Department of Natural Resources, Tallahassee, Florida, USA.
Luijten, S. & Odé, B., (2007). *Status en het voorkomen van een aantal belangrijke invasieve plantensoorten in Nederland.* FLORON-rapport 47. Stichting FLORON, Leiden, the Netherlands.
Lyon, J. & Eastman, T., (2006). Macrophyte species assemblages and distribution in a shallow, eutrophic lake. *Northeastern Naturalist* **13**, 443-453.
Mackey, A.P., (1996). *Cabomba (Cabomba* spp.*). Pest status review series - Land Protection Branch.* Queensland Government Department of Natural Resources and Mines, Australia.
Mackey, A.P. & Swarbrick, J.T., (1997). The biology of Australian weeds 32. *Cabomba caroliniana* Gray. *Plant Protection Quarterly* **12**, 154-165.

Madsen, J.D., (2000). Advantages and disadvantages of aquatic plant management. *LakeLine* **20**, 22-34.
Maenen, M.M.J., (1989). *Water- en oeverplanten in het zomerbed van de Nederlandse grote rivieren in 1988: hun voorkomen en relatie met algemene fysisch-chemische parameters.* Project "Ecologisch Herstel Rijn", publicatie no. 13, Rijkswaterstaat, Lelystad, the Netherlands.
Massachusetts Department of Conservation and Recreation, (2005). *Rapid response plan for Fanwort (Cabomba caroliniana) in Massachusetts.* ENSR International, Massachusetts, USA.
Morrison, W.E. & Hay, M.E., (2011). Induced chemical defences in a freshwater macrophyte suppress herbivore fitness and the growth of associated microbes. *Oecologia* **165**, 427-436.
Nakai, S., Inoue, Y., Hosomi, M., Murakami, A., (1999). Growth inhibition of blue-green algae by allelopathic effects of macrophytes. *Water Science and Technology* **39**, 47-53.
Natural England, (2011). *Horizon-scanning for invasive non-native plants in Great Britain*. Natural England Commissioned Report NECR053. http://publications.naturalengland.org.uk/publication/40015?category=47020, last accessed 22-05-2013.
Naturalis Biodiversity Center, (2013). *Nederlands Soortenregister, Waterwaaier*. http://www.nederlandsesoorten.nl/nsr/concept/000000016976, last accessed 24-05-2013.
Nelson, L.S., Stewart, A.B. & Getsinger, K.D., (2002). Fluridone effects on fanwort and water marigold. *Journal of Aquatic Plant Management* **40**, 58-63.
Netherland, M.D., Getsinger, K.D. & Skogerboe, J.D., (1997). Mesocosm evaluation of the species selective potential of fluridone. *Journal of Aquatic Plant Management* **35**, 41-50.
Oki, Y., (1992). Integrated management of aquatic weeds in Japan: current status and prospect for improvement *in: Biological control and integrated management of paddy and aquatic weeds in Asia*. National Agriculture Research Centre. Proceedings of the International symposium on biological control and integrated management of paddy and aquatic weeds in Asia, 20-23 Oct. 1992, Tsukuba, Japan.
Ontario Ministry of the Environment, (1979). *Water quality survey of lakes in the Seven Links planning area, Peterborough County, field survey 1978. Parts 1 & 2*. Ontario Ministry of the Environment, Technical Support Section, Central Region, Ontario, Canada.
Ørgaard, M., (1991). The genus *Cabomba* (Cabombaceae) - a taxonomic study. *Nordic Journal of Botany* **11**, 179-203.
Penning, W.E., Maarsen, N.I.O.O.-C.L., Raghuraj, R. & Mynett, A.E., (2009). *The effects of macrophyte morphology and patch density on wave attenuation.* http://www.delftcluster.nl/website/files/Penning_Macrophytes_WaveAttenuation.pdf, last accessed 29-05-2013.
Perrow, M.R., Meijer, M.L., Dawidowicz, P. & Coops, H., (1997). Biomanipulation in shallow lakes: state of the art. *Hydrobiologia* **342**, 355-365.
Philbrick, C.T. & Les, D.H., (1996). Evolution of aquatic angiosperm reproductive systems. BioScience **46**, 813-826.
Preston, C.D., Pearman, D.A. & Dines, T.D., (2002). *New atlas of the British and Irish flora*. Oxford University Press, Oxford, UK.
Q-bank invasive plants, (2013). http://www.q-bank.eu/Plants/, accessed 16-07-2013.
Ramey, V., (2001). *Lagarosiphon major.* Center for Aquatic and Invasive Plants, University of Florida, http://aquat1.ifas.ufl.edu/seagrant/lagmaj2.html *cited in:* Department of primary Industries, (2011). *Impact Assessment Record – Lagarosiphon.* http://vro.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/impact_Lagarosiphon, last accessed 10-07-2012.
Randall, J. M. & Marinelli, J., (1996). *Invasive plants: weeds of the global garden.* Brooklyn Botanic Garden, Brooklyn, New York, USA *cited in:* Kay, S.H. & Hoyle, S.T., (2001). Mail order, the internet and invasive aquatic weeds. *Journal of Aquatic Plant Management* **39**, 88-91.
Richardson, F.J., Richardson, R.G. & Shepherd, R.C.H., (2006). *Weeds of the south-east.* R.G. & F.J. Richardson Publishers, Meredith, Australia.
Riemer, D.N., (1965). *The effect of pH, aeration, calcium and osmotic pressure on the growth of fanwort (Cabomba caroliniana Gray)*. Proceedings of the 19th Northeast Weed Control Conference.
Riis, T., Lambertini, C., Olesen, B., Clayton, J.S., Brix, H. & Sorrell, B.K., (2010). Invasion strategies in clonal aquatic plants: are phenotypic differences caused by phenotypic plasticity or local adaptation? *Annals of Botany* **106**, 813-822.

Rijkswaterstaat, (2012). *Handreiking waterplanten maaibeheer. Aanwijzingen voor het maaien van waterplanten in rijkswateren ten behoeve van recreatie*. www.rijkswaterstaat.nl, last accessed 08-05-2013.

Roijackers, R., (2008). *Bepaling van het effect van waterkwaliteit en standplaatsfactoren op het invasieve gedrag van Cabomba caroliniana*. Environmental Sciences Group, Aquatische Ecologie en Waterkwaliteitsbeheer, Wageningen, the Netherlands.

Saitoh, M., Narita, K., Isikawa, S., (1970). Photosynthetic nature of some aquatic plants in relation to temperature. *Botanical Magazine Tokyo* **83**, 10-12.

Salvucci, M.E. & Bowes, G., (1981). Induction of reduced photorespiratory activity in submersed and amphibious aquatic macrophytes. *Plant Physiology* **67**, 335-340.

Sanders, D.R., Sr., (1979). *The ecology of Cabomba caroliniana cited in*: Gangstad, E.O., (ed.). *Weed control methods for public health applications.* CRC Press, Boca Raton, Florida, USA.

Schooler, S.S., (2008). Shade as a management tool for the invasive submerged macrophyte, *Cabomba caroliniana. Journal of Aquatic Plant Management* **46**, 168-171.

Schooler, S., Cabrera-Walsh, W. & Julien, M., (2009). *Cabomba caroliniana Gray (Cabombaceae) in:* Muniappan, R., Reddy, G.V.P. & Raman, A., (eds.). *Biological Control of Tropical Weeds using Arthropods.* Cambridge University Press, Cambridge, U.K.

Schooler, S. & Julien, M., (2008). *Progress on the biological control of two invasive aquatic plants, cabomba (Cabomba caroliniana) and alligator weed (Alternanthera philoxeroides).* Sixteenth Australian Weeds Conference. http://www.caws.org.au/awc/2008/awc200812431.pdf, last accessed 8-05-2013.

Schooler, S., Julien, M. & Walsh, G.C., (2006). Predicting the response of *Cabomba caroliniana* populations to biological control agent damage. *Australian Journal of Entomology* **45**, 327-330.

Schooler, S.S., Williams, D.G., Stokes, K. & Julien, M., (2005). *Invasive plants: impacts and management in rivers and catchments.* Riversymposium. http://www.riversymposium.com, last accessed 22-05-2013.

Schriver, P., Bøgestrand, J., Jeppesen, E. & Søndergaard, M., (1995). Impact of submerged macrophytes on fish-zooplankton-phytoplankton interactions: large-scale enclosure experiments in a shallow eutrophic lake. *Freshwater Biology* **33**, 255-270.

Sculthorpe, C.D., (1967). *The biology of aquatic vascular plants*. Edward Arnold Publishers, London.

Sheldon, S.P., (1994). Invasions and declines of submersed macrophytes in New England, with particular reference to Vermont lakes and herbivorous invertebrates in New England. *Lake and Reservoir Management* **10**, 13-17.

Søndergaard, M., Jeppesen, E., Jensen, P.J. & Lauridsen, T., (2000). Lake restoration in Denmark. *Lake Reservoir Management* **5**, 151-159.

Tanner, C.C. & Clayton, J.S., (1984). *Control of submerged weeds in flowing water using viscous gel diquat*. Proceedings of the 37th New Zealand Weed and Pest Control Conference *cited in:* McGregor, P.G. & Gourlay, H., (2002). *Assessing the prospects for biological control of Lagarosiphon (Lagarosiphon major (Hydrocharitaceae))*. Department of Conservation, New Zealand.

Tarver, D.P. & Sanders, D.R., (1977). Selected life cycle features of fanwort. *Journal of Aquatic Plant Management* **15**, 18-22.

USDA, (2013). *Natural resources conservation service. Cabomba caroliniana A. Gray.* http://plants.usda.gov/java/profile?symbol=CACA, last accessed 21-06-2013.

Valley, R. D. & Bremigan, M.T., (2002). Effects of macrophyte bed architecture on largemouth bass foraging: implications of exotic macrophyte invasions. *Transactions of the American Fisheries Society* **131**, 234-244 *cited in:* Kelly, D.J. & Hawes, I., (2005). Effects of invasive macrophytes on littoral-zone productivity and foodweb dynamics in a New Zealand high-country lake. *Journal of the North American Benthological Society* **24**, 300-320.

Van, T.K., Haller, W.T., Bowes, G., (1976). Comparison of the photosynthetic characteristics of three submersed aquatic plants. *Plant Physiology* **58**, 761-768.

Van den Berg, L., Kaal, K., Geurts, J. & Lamers, L., (unpublished results). *Some preliminary biogeochemical and ecological information on Cabomba caroliniana in the Netherlands*. Department of Aquatic Ecology & Environmental Biology, Radboud University, Nijmegen, the Netherlands.

Van Kleef, H., Van der Velde, G., Leuven, R.S.E.W. & Esselink, H., (2008). Pumpkinseed sunfish (*Lepomis gibbosus*) invasions facilitated by introductions and nature management strongly reduce macroinvertebrate abundance in isolated water bodies. *Biological Invasions* **10**, 1481-1490.

Van Nes, E.H., Scheffer, M., Van den Berg, M.S. & Coops, H., (2003). Charisma : a spatial explicit simulation model of submerged macrophytes. *Ecological Modelling* **159**, 103-116.
Van Valkenburg, J.L.C.H. (ed.), (2011). *Invasieve waterplanten in Nederland*. nVWA, Wageningen; Bureau Waardenburg, Culemborg; Communicatiebureau de Lynx, Wageningen, the Netherlands.
Van Valkenburg, J.L.C.H., Roijackers, R.M.M. & Leonard, R., (2011). *Cabomba caroliniana Gray in The Netherlands.* 3rd International Symposium on Weeds and Invasive Plants, October 2-7, Ascona, Switzerland.
Van Valkenburg, J.L.C.H. & Rotteveel, A.J.W., (2010). *Cabomba caroliniana* Gray, een subtropische verassing in Loosdrecht. *Gorteria* **34**, 106-118.
Verbrugge, L.N.H., Van den Born, R.J.G. & Leuven, R.S.E.W., (2011). *Evaluatie convenant waterplanten: startmeting*. Radboud University, Nijmegen, the Netherlands.
Verbrugge, L.N.H., Van den Born, R.J.G. & Leuven, R.S.E.W., (2013). *Evaluatie convenant waterplanten 2010-2013.* Radboud University, Nijmegen, the Netherlands.
Wade, P.M., (1990). *Physical control of aquatic weeds in:* Pieterse, A. H. & Murphy, K.J., (eds.), *Aquatic Weeds - The ecology and management of nuisance aquatic vegetation.* Oxford University Press, Oxford, UK.
Walker, P.D., Wijnhoven, S. & Van der Velde, G., (2013). Macrophyte presence and growth form influence macroinvertebrate community structure. *Aquatic Botany* **104**, 80-87.
Westerdahl, H.E. & Getsinger, K.D., (1988). *Aquatic plant identification and herbicide use guide. Vol. 2. Aquatic plants and susceptibility to herbicides*. Technical Report A-88-9. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, United States of America.
Wijnhoven, A.L.J. & Niemeijer, C.M., (1995). *Natuurvriendelijke oevers in:* Spijker, J.H. & Niemeijer, C.M., (eds.). *Groenwerk, praktijkboek voor bos natuur en stedelijk groen.* Instituut voor Bos- en Natuuronderzoek (IBN-DLO), Misset Uitgeverij bv, Doetinchem, the Netherlands.
Wilson, C. E., Darbyshire, S. J. & Jones, R., (2007). The biology of invasive alien plants in Canada. 7. *Cabomba caroliniana* A. Gray. *Canadian Journal of Plant Science* **87**, 615-638.
Wilson, C. & Watler, D., (2001). *Weed risk assessment, Fanwort, Cabomba caroliniana Gray.* Canadian Food Inspection Agency. Plant Health Assessment Unit, Science Division, Nepean, Ontario, Canada.
Xiaofeng, J., Bingyang, D., Shuqin, G.A.O. & Weimei, J., (2005). Invasion and spreading of *Cabomba caroliniana* revealed by RAPD markers. *Chinese Journal of Oceanology and Limnology* **23**, 406-413.
Yang, D.B., Feng, J.X., Jian, Y.M., Jian, Y., Ming, S.H. & Feng, W.Y., (2007). Impact to native species by invaded subaqueous plant *Cabomba caroliniana*. *Oceanologia et Limnologia Sinica* **38**, 336-342.
Yaowakhan, P., Kruatrachue, M., Pokethitiyook, P. & Soonthornsarathool, V., (2005). Removal of lead using some aquatic macrophytes. *Bulletin of Environmental Contamination and Toxicology* **75**, 723-730.
Zonderwijk, M., (2008). *Zwarte lijst invasieve waterplanten, op basis van enquête onder waterbeheerders NL.* http://edepot.wur.nl/13104, last accessed 08-05-2013.

Appendix 1: Results of field surveys 2013.

Species	***Cabomba caroliniana***	***Cabomba caroliniana***	***Cabomba caroliniana***	***Cabomba caroliniana***
Location	**Oranjekanaal, Orvelterbrug**	**Oranjekanaal, Orveltersluis**	**Oranjekanaal, Elperbrug**	**Oranjekanaal, Zwiggelterbrug**
Date of field search	**6-8-2013**	**6-8-2013**	**6-8-2013**	**6-8-2013**
Latitude (dd mm,mmm)	N 52°50,901'	N 52°51,215'	N 52°51,941'	N 52°53,133'
Longitude (dd mm,mmm)	E 6°39,910'	E 6°39,649'	E 6°38,156'	E 6°35,099'
Amersfoort coordinates (RD, m)	241092	240790	239090	235622
	540890	541469	542784	544938
Water depth (cm)	80-200	80-200	60-200	70-200
Transparency	50	40	40	50
Width water (m)	20	10	10	10
Width emergent zone (m)	1	1	0.5	0
Water flow	standing	standing	standing	standing
Water type	canal in sandy soil	canal in sandy soil	canal in sandy soil	canal in sandy soil
Surface area covered Cabomba	1%	<1%	<1%	<1%
Surface area covered all submerged	30%	5%	5%	10%
Surface area covered all floating	0%	20%	0%	5%
Number of individuals/shoots	>100	>10	>10	<10
Phenology	veg	veg	veg	veg
Tansley survey				
Water zone				
Myriophyllum heterophyllum	d	f	a	ld
Cabomba caroliniana	f	o	o	r
Hydrocharis morsus-ranae	f	f	o	f
Nuphar lutea	o		f	o
Sparganium emersum	o			
Nymphaea		a		
Sagittaria sagittifolia		f		
Stratiotes aloides			r	
Nymphoides peltata				f
Nasturtium microphyllum				r
Emergent zone only				
Berula erecta	f	f		
Iris pseudacorus	f			
Schoenoplectus lacustris	f			
Stachys palustris	f	f	o	
Lythrum salicaria	f			
Phalaris arundinacea	f			
Typha latifolia		o		
Rumex hydrolapathum		o		
Alisma plantago-aquatica		o		
Persicaria amphibia		o		
Carex pseudocyperus		r		
Lycopus europaeus		r		
Bidens frondosa		r		
Mentha aquatica		o		
Myosotis palustris			r	

Tansley/DAFOR score a: abundant; d: dominant; f: frequent; o: occasional; r: rare (note: prefix l was used for local); Growth form code d: floating; e: emergent; s: submerged.

Species	*Cabomba caroliniana*	*Cabomba caroliniana*	*Cabomba caroliniana*	*Cabomba caroliniana*
Location	**Musselkanaal, spoorlaan**	**Nunspeet, Zandenberg**	**Tienhovenskanaal /De Strook**	**Loosdrecht, MBP407, camping**
Date of field search	**6-8-2013**	**8-8-2013**	**8-8-2013**	**18-8-2010**
Latitude (dd mm,mmm)	N 52°55,721'	N 52°21,530'	N52°10,146'	N52°11,725'
Longitude (dd mm,mmm)	E 7°00,736'	E 5°48,386'	E5°03,616'	E5°06,011'
Amersfoort coordinates (RD, m)	264271	183559	132633	135376
	550299	485743	464601	467517
Water depth (cm)	20-60	60	40-170	80
Transparency	50	50	>100	>80
Width water (m)	6	-	8	50
Width emergent zone (m)	1	30X20	0.5	1
Water flow	standing	standing	standing	standing
Water type	ditch in sandy soil	shallow pond/fen	canal in peaty soil	ditch in peaty soil
Surface area covered Cabomba	<1%	<1	100%	95%
Surface area covered all submerged	80%	1%	100%	95%
Surface area covered all floating	30%	2%	30%	0,10%
Number of individuals/shoots	<10	>10	>1000	>1000
Phenology	veg	veg	flowering	veg
Tansley survey				
Water zone				
Myriophyllum heterophyllum	a			
Cabomba caroliniana	o	r	d	d
Hydrocharis morsus-ranae	a			r
Nuphar lutea			f	r
Sparganium emersum	a			
Nymphaea	o			
Nymphaea alba	f	lo	f	
Stratiotes aloides	a			
Ceratophyllum demersum	o			
Potamogeton obtusifolius	o			
Elodea nuttallii	o			
Lemna minor	o			
Lemna trisulca	o			
Drepanocladus fluitans		a		
Sphagnum spec.		la		
Utricularia vulgaris				r
Emergent zone only				
Iris pseudacorus		r	f	
Stachys palustris			o	o
Lythrum salicaria				r
Typha latifolia	la			
Rumex hydrolapathum				r
Lycopus europaeus				o
Mentha aquatica			lf	o
Myosotis palustris				o
Butomus umbellatus	r			
Glyceria maxima	o			
Carex acutiformis		la		f
Carex rostrata		a		
Carex echinata		lo		
Juncus effusis		lf		
Menyanthes trifoliata		d		
Glyceria fluitans		r		
Salix cinerea		lo		
Drypteris carthusiana		r		
Epilobium tetragonum		s		
Rhododendron ponticum		r		
Acorus calamus			ld	
Phragmites australis			ld	o
Alnus glutinosa				r
Thelypteris palustris				r
Epilobium hirsutum				r
Eupatorium cannabinum				r
Salix				r
Solanum dulcamara				o

Tansley/DAFOR score a: abundant; d: dominant; f: frequent; o: occasional; r: rare (note: prefix l was used for local); Growth form code d: floating; e: emergent; s: submerged.

Species	***Cabomba caroliniana***	***Cabomba caroliniana***
Location	**Loosdrecht, MBP794, de ster**	**Loosdrecht, MBP796, side-ditch**
Date of field search	**18-8-2010**	**18-8-2010**
Latitude (dd mm,mmm)	N52°12,000'	N52°12,007'
Longitude (dd mm,mmm)	E5°06,559'	E5°06,045'
Amersfoort coordinates (RD, m)	136003 468017	135416 468039
Water depth (cm)	15	80
Transparency	>15	>80
Width water (m)	12	5
Width emergent zone (m)	1	1
Water flow	standing	standing
Water type	ditch in peaty soil	ditch in peaty soil
Surface area covered Cabomba	45%	60%
Surface area covered all submerged	70%	90%
Surface area covered all floating	10%	2%
Number of individuals/shoots	>100	>100
Phenology	veg	veg
Tansley survey		
Water zone		
Cabomba caroliniana	a	d
Nuphar lutea	f	o
Stratiotes aloides	r	
Ceratophyllum demersum	f	
Lemna minor	r	r
Utricularia vulgaris	f	o
Myriophyllum verticillatum	o	f
Spirodela polyrhiza	r	r
Nitella mucronata	r	
Potamogeton lucens	o	
Riccia fluitans		r
Emergent zone only		
Berula erecta		o
Iris pseudacorus	r	r
Phalaris arundinacea	o	
Rumex hydrolapathum		r
Alisma plantago-aquatica	o	
Mentha aquatica	o	o
Myosotis palustris	o	o
Butomus umbellatus	r	
Glyceria maxima	f	
Carex acutiformis	r	
Juncus effusis	o	
Glyceria fluitans	o	
Acorus calamus	o	o
Phragmites australis	f	a
Alnus glutinosa	r	
Equisetum fluviatile	o	o
Glechoma hederacea	o	o
Peucedanum palustre	r	r
Rorippa microphylla	o	o
Sparganium erectum	o	f
Thelypteris palustris		r
Agrostis stolonifera	o	
Betula		r
Bidens tripartita	o	
Cardamine pratensis		o
Carex acuta		o
Carex hirta	r	
Epilobium	r	
Epilobium ciliatum	f	
Filipendula ulmaria		r
Galium palustre	o	
Lotus uliginosus	o	
Phleum pratense	o	
Ranunculus repens	o	
Rorippa amphibia		o
Sium latifolium		r
Sparganium emersum	o	
Trifolium pratense	o	
Trifolium repens	o	

Tansley/DAFOR score a: abundant; d: dominant; f: frequent; o: occasional; r: rare (note: prefix I was used for local); Growth form code d: floating; e: emergent; s: submerged.