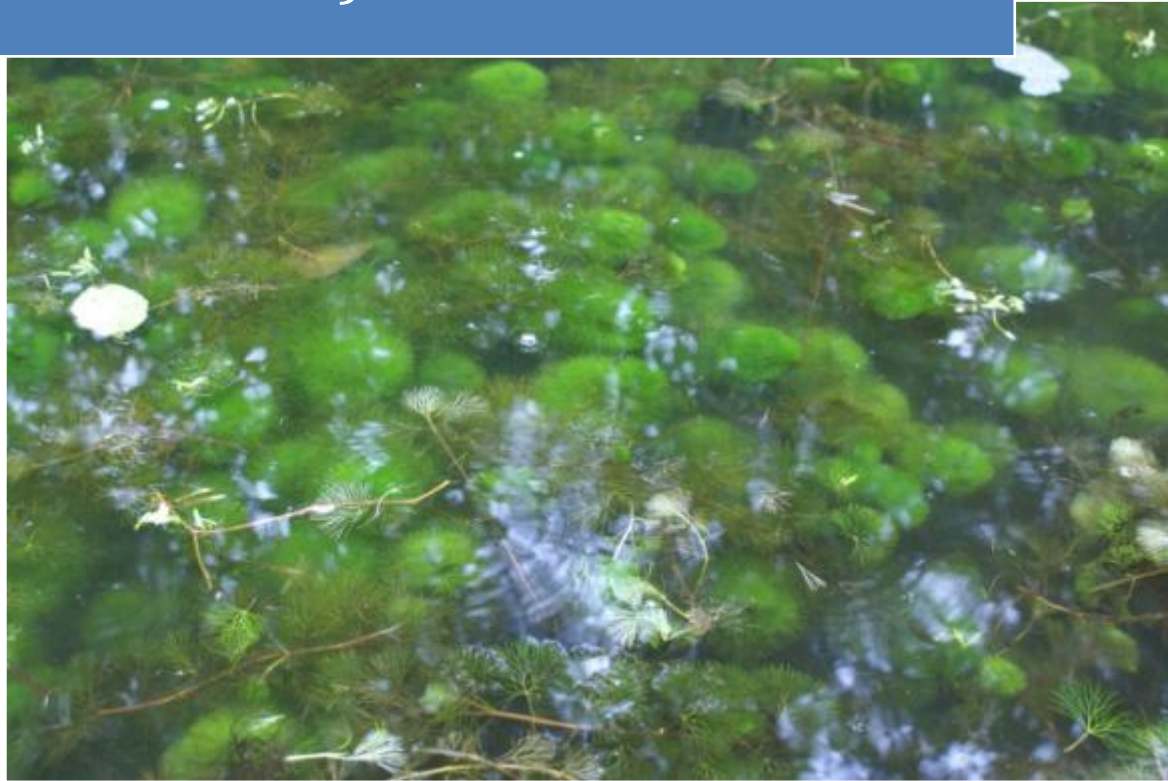# 2013

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

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Contents

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 and the United States of America, Canada, Australia, India, China and Japan. It has been declared an invasive species in many of these countries. *C. caroliniana* was first recorded in the Netherlands in 1986 at Maasbracht harbour, in the south of the country. Since then it has been recorded at a number of locations and has become invasive in at least 2 locations, Loosdrecht to the north of Utrecht and in the Oranjekanaal region. Previously, there was a lack of knowledge regarding the probability of arrival, establishment and spread and (potential) impacts of *C. caroliniana* and options for management in the Netherlands. This report is the synthesis of results obtained from a literature study, field observations and expert consultation that address this knowledge gap in the form of a knowledge document. The knowledge document was used to assess ecological risk using the Belgian Invasive Species Environmental Impact Assessment (ISEIA) protocol. Socio-economic and public health risks were assessed separately as these risk categories do not form part of the ISEIA protocol. Subsequently, recommendations were made regarding management options relevant to the situation found in the Netherlands.

The probability of *C. caroliniana* arriving in the Netherlands is determined largely by the plant trade. *C. caroliniana* is one of the most frequently imported aquarium plants to the Netherlands*,* representing over 30% of the total import volume, and is widely available from Dutch and Belgian online retailers and in shops. It is one of the best selling aquatic plants in Dutch pet shops. 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. However, during a survey including Dutch, Belgian and other foreign retail websites, no information regarding the invasive nature of *C. caroliniana* or the importance of avoiding introductions of this species to the freshwater network could be found on the retail page of any of the websites visited. Plants classified as *Cabomba aquatica,* which are very often mislabelled examples of *C. caroliniana*, are the second most frequently imported aquatic plant to the Netherlands.

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. The Fanwort species present in nature in the Netherlands is the same species that is sold via the aquatic plant trade in this country. Moreover, a small proportion of Dutch aquatic plant hobbyists report the disposal of water plants into local watercourses. *C. caroliniana* is often found in urban / suburban areas and in the freshwater channels and ponds of recently built housing estates. This suggests that humans are responsible for the initial stages of *C. caroliniana* introduction in the Netherlands. We predict that without management intervention, *C. caroliniana* introductions will continue, leading to potential increases in its distribution within the Netherlands. After considering the above information the probability of arrival in the Netherlands was judged to be high.

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 had not previously been seen. In 2011 it was recorded in 30 new kilometre squares, mostly in the Oranjekanaal region. However, in that year the Oranjekanaal 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. In Barendrecht, *C. caroliniana* has proliferated in a number of waterways in a new housing development. The current recorded distribution of *C. caroliniana* in the Netherlands is characterised by a restricted range, this despite being first recorded here in 1986. However, evidence suggests that *C. caroliniana* will not be restricted by the habitat conditions present in a wide variety of Dutch water-bodies. All shallow slow flowing and still waters in the Netherlands are considered to be potentially at risk of future colonisation by *C. caroliniana*. The main limiting factor for colonisation of locations that satisfy the chemical and physical requirements of *C. caroliniana* (Table 3.1) is the availability of plant fragments for vegetative reproduction which is influenced by the availability of dispersal vectors (Table 3.2). Therefore, the probability of establishment in the Netherlands was judged to be medium.

Seeds are only produced within *C. caroliniana's* native range and in the tropical and subtropical parts of its non-native range. In other areas, reproduction and spread are facilitated by the detachment of plant fragments. These fragments subsequently become rooted, developing into new plants. A detached fragment can regenerate into a full plant as long as it has at least one pair of leaves, and fragments as short as 10 mm may be viable and may survive floating in water for 6 to 8 weeks. The availability of dispersal vectors that facilitate the movement of plant fragments to new locations is, therefore, of primary importance in the Netherlands. Vectors can be ordered in terms of importance: the plant trade, hobbyists, boats and water flow (high); weed harvesters, fishing equipment (medium); aquatic birds (low). The probability of spread in the Netherlands was judged to be high. This is due to the strong competitive ability of *C. caroliniana,* particularly effecting submerged aquatic plants, the occurrence of recreational and management activities that may increase the risk of plant fragmentation, and *C. caroliniana*'s ability to reproduce vegetatively and spread over a wide area under the influence of a number of dispersal vectors.

Four factors are considered as part of the ISEIA protocol: dispersion potential and invasiveness, colonisation of habitats with high conservation values, adverse impacts on native species and alteration of ecosystem functions.

- Dispersion potential and invasiveness: *C. caroliniana* has a strong reproductive potential and spreads via fragmentation in the Netherlands mediated by mainly human vectors. It can disperse via hydrochory. *C. caroliniana* has become invasive in at least two large areas in the Netherlands, the area around Loosdrecht and in the Oranjekanaal region and has spread from its initial point of colonisation at Giessendam. Currently, it is unknown if the plant has become invasive at other locations.

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- Colonisation of high conservation value habitats: *C. caroliniana* has been recorded in three Natura 2000 areas. In the Vechtplassen area *C. caroliniana* is widely distributed. In the Gelderse Poort and in the Veluwe it is recorded only once in each area. In the Vechtplassen and the Gelderse Poort area *C. caroliniana* may appear in EU habitat type H3150 (Natural eutrophic lakes with Magnopotamion or Hydrocharition type vegetation). In 2013, *C. caroliniana* could not be found at the Gelderse Poort site where the plant was recorded in 2012. In the Veluwe area, *C. caroliniana* was apparently introduced to an old artificial pond.

- Adverse impacts to native species: in the Netherlands at Loosdrecht, *C. caroliniana* is said to have smothered native aquatic plants. However, in most instances there was no other macrophyte growth in areas where *C. caroliniana* became established. At Lake Tienhoven, the Netherlands, *C. caroliniana* has been seen to outcompete other macrophytes, except for floating leaved species and helophytes. In future changes to habitat resulting from climate change, increasing water clarity and the legacy of high phosphate concentration in substrates may increase impacts on native species due to increases in *C. caroliniana* distribution. Ontario, Canada has been climate matched with the Netherlands which suggests that impacts seen there may also occur in the Netherlands. Adverse impacts due to *C. caroliniana* colonisation of an Ontario lake were reduced light conditions, reduced abundance of native macrophytes, changes in epiphytic algal biomass and increased macroinvertebrate biomass and abundance. Moreover, *C. caroliniana* exhibits an induced chemical response that reduces the palatability of the plant to herbivores.

- Alteration to ecosystem functions: There is limited evidence in literature demonstrating negative impacts on the functioning of ecosystems in the Netherlands. The main difference between *C. caroliniana* and native macrophyte beds in a lake in Ontario, Canada was a significant reduction in light conditions in the *C. caroliniana* bed. In general, the presence of dense stands of macrophytes can change nutrient availability, alter resource pools and alter macroinvertebrate communities, effecting both primary and secondary productivity rates. Mass *C. caroliniana* death and decay may deplete the available dissolved oxygen and cause foul-smelling water. The resulting low oxygen conditions may lead to fish kills and harm other aquatic organisms.

C. caroliniana was rated as a high risk species for ecological impacts using the ISEIA protocol for a risk assessment within the context of the Netherlands.

Currently, the recorded distribution of *C. caroliniana* in the Netherlands has been classified as 'restricted range'. This combined with the high risk result obtained from the ISEIA risk assessment results in a global environmental risk score of A2. The A2 classification indicates a non-native species exhibiting a restricted range and high environmental hazard (i.e. ecological risk) that should be placed on the black list of the BFIS list system. Future habitat alteration due to climate change and increasing water clarity associated with high concentrations of phosphate in substrates may result in local widening of *C. caroliniana's* distribution (depending on potential management interventions). However, the overall distribution classification of *C. caroliniana* is

expected to remain as 'restricted range'. This means that the global environmental risk score is also expected to remain the same.

Evidence of socio-economic impacts of this species in the Netherlands are limited to the Loosdrechtse plassen. Management was implemented at this site to mitigate impacts related to loss of recreational amenity and visual appeal. The cost of management action over a single year was 350,000 Euros. 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). Future habitat changes resulting from rising water temperature, increasing water clarity and the legacy of high phosphate concentration in substrates may lead to a local increase in *C. caroliniana* distribution and worsening socio-economic impacts.

There was minimal evidence relating *C. caroliniana* to possible effects on public health. Local increases in the distribution of *C. caroliniana* may result in an increase in abundance of trematode carrying aquatic snails which cause swimmers itch.

The most effective interventions for preventing new introductions and controlling further spread of *C. caroliniana* are banning it from sale and the creation of consumer and water manager awareness. Based on current dispersion and potential invasiveness and risk, it is recommended that *C. caroliniana* be banned from sale in the Netherlands. Moreover, measures should be taken to correctly identify *C. caroliniana* before it is imported to the Netherlands. A ban on the sale of *C. caroliniana* will not be effective if *C. caroliniana* plants are misidentified, imported and sold as *C. aquatica*. Efforts are being made to correctly distinguish similar Cabomba species using genetic bar-coding. In laboratory tests, different Cabomba species have been distinguished 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.

In order to facilitate the removal of *C. caroliniana* from the retail sector, 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*).

Once established, the management of *C. caroliniana* is challenging. Limiting management intervention appears to be the best method for the prevention of 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 the Maasbracht 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 of *C. caroliniana* 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 a high power water jet to dislodge whole plants from the substrate, including their roots, is a promising eradication method. Fragmentation is limited and plants float to the surface from where they can be collected manually or by harvesting boats.

1. Introduction

1.1 Background and problem statement

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 and the United States of America, Canada, Australia, India, China and Japan. It has been declared an invasive species in many of these countries. *C. caroliniana* was first recorded in the Netherlands in 1986 at Maasbracht harbour, in the south east of the country, close to the Belgian border. Since then it has been recorded at a number of locations and has become invasive in at least 2 locations, Loosdrecht to the north of Utrecht and in the Oranjekanaal region. Previously, there was a lack of knowledge regarding the probability of arrival, establishment and spread and (potential) impacts of *C. caroliniana* and options for management in the Netherlands.

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. The present report assesses relevant available knowledge and data which is subsequently used to perform a risk analysis of this species.

1.2 Research goals

The major goals of this study are:

- To perform a risk analysis based on the probability of arrival, establishment and spread, endangered areas, the (potential) ecological, socio-economic and public health impacts of *C. caroliniana* in the Netherlands.

- To assess the dispersion, invasiveness and (potential) ecological effects of *C. caroliniana* in the Netherlands using the Belgian Invasive Species Environmental Impact Assessment protocol.

- To describe effective risk management options for control of spread, establishment and negative effects of *C. caroliniana* into and within the Netherlands.

1.3 Outline and coherence of research

The present chapter describes the problem statement, goals and research questions in order to undertake a risk analysis of *C. caroliniana* in the Netherlands (described above). Chapter 2 gives the methodological framework of the project, describes the Belgian Invasive Species Environmental Impact Assessment (ISEIA) protocol and approaches to assess socio-economic risks and public health risks, and analyses management approaches applicable in the Netherlands. Chapter 3 describes the results of the risk assessment, assesses the probability of arrival, establishment and spread, summarizes the results of the literature study of socio-economic and public health risks and analyses

risk management options. Chapter 4 discusses gaps in knowledge and uncertainties, other available risk analyses and explains differences between risk classifications. Chapter 5 draws conclusions and gives recommendations for further research. An appendix containing background information in the form of a knowledge document completes this report. The coherence between various research activities and outcomes of the study are visualised in a flow chart (Figure 1.1).
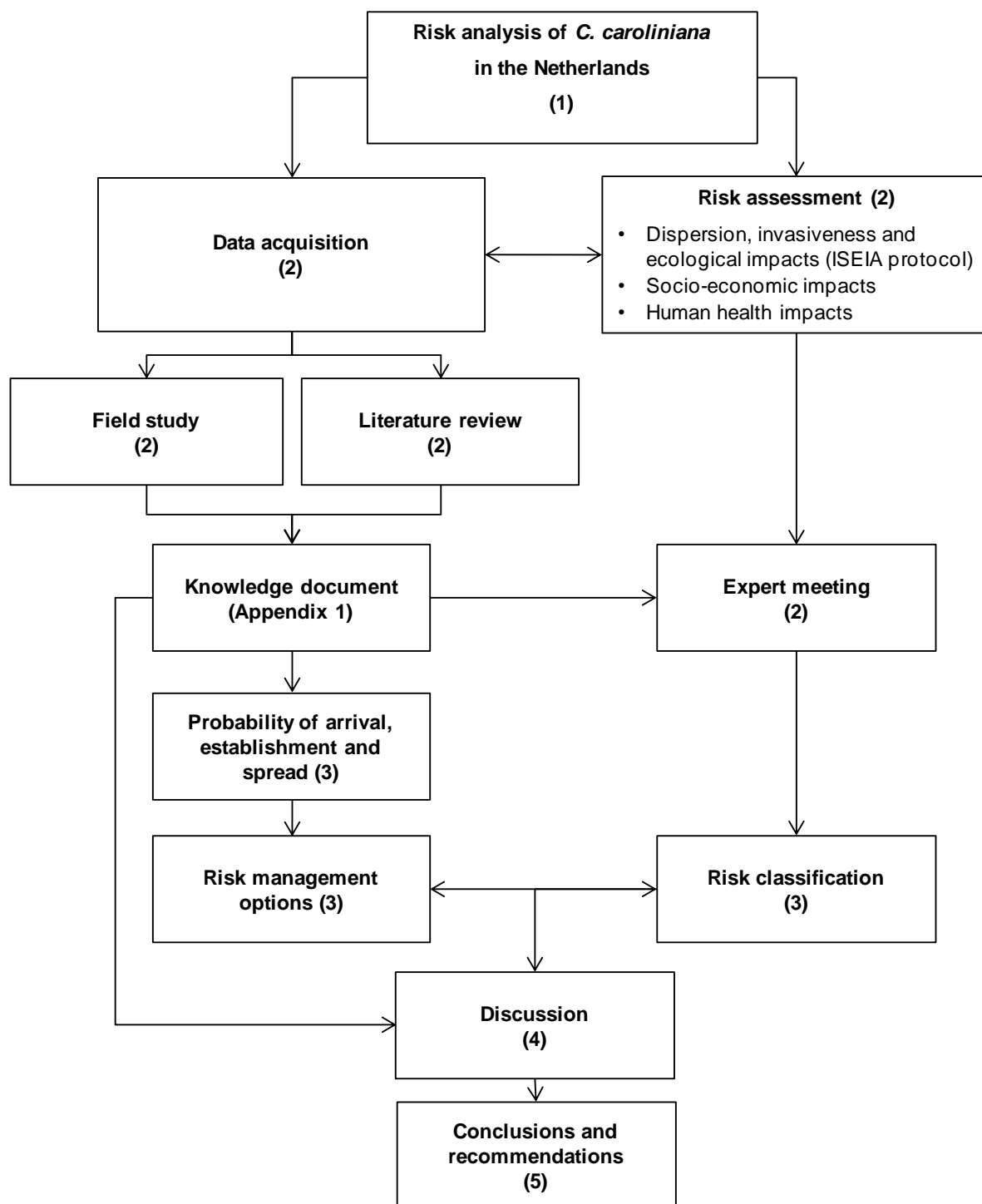

Figure 1.1: Flowchart visualising the coherence of various components of the risk analysis of Fanwort (*Cabomba caroliniana*) in the Netherlands. Chapter numbers are indicated in brackets.

2. Methods

2.1 Components of the risk analysis

The risk analysis of Fanwort (*Cabomba caroliniana*) in the Netherlands was comprised of analyses of probability of arrival to and within the Netherlands, establishment and spread within the Netherlands and an ecological risk assessment using the Belgian Invasive Species Environmental Impact Assessment (ISEIA), developed by the Belgian Biodiversity Platform (Branquart, 2007; ISEIA, 2009). Separate assessments of socio-economic, public health impacts and risk management options were made. Background information and data used for the risk analysis were summarised in the form of a separate knowledge document (Section 2.2).

2.2 Knowledge document

A literature search and data analysis describing the current body of knowledge with regard to taxonomy, habitat preference, dispersal mechanisms, current distribution, ecological and socio-economic impacts and management options for *C. caroliniana* were undertaken. The results of the literature search were presented in the form of a knowledge document (Matthews *et al.*, 2013; Appendix 1) and distributed to an expert team in preparation for the risk assessment.

2.3 Risk assessment

2.3.1 Dispersion potential, invasiveness and ecological impacts

The ISEIA protocol assesses risks associated with dispersion potential, invasiveness and ecological impacts only (Branquart, 2007; ISEIA, 2009). The *C. caroliniana* risk assessment was carried out by an expert team. This team consisted of 6 individuals. One from the Netherlands Food and Consumer Product Safety Authority; one from the Dutch plant research and conservation organisation FLORON; one from the Roelf Pot Research and Consultancy firm and three from the Radboud University, Nijmegen. Each expert completed an assessment form independently, based on the contents of the knowledge document. Following this preliminary individual assessment, the entire project team met, elucidated differences in risk scores, discussed diversity of risk scores and interpretations of key information during a risk assessment workshop. Discussion led to agreement on consensus scores and the level of risk relating to the four sections contained within the ISEIA protocol (Table 2.1).

The ISEIA protocol contains twelve criteria that match the last steps of the invasion process (i.e., the potential for spread, establishment and adverse impacts on native species and ecosystems). These criteria are divided over the following four risk sections: (1) dispersion potential or invasiveness, (2) colonisation of high conservation habitats, (3) adverse impacts on native species, and (4) alteration of ecosystem functions. Section 3 contains sub-sections referring to (i) predation / herbivory, (ii) interference and exploitation competition, (iii) transmission of diseases to native species (parasites, pest organisms or pathogens) and (iv) genetic effects such as hybridisation and introgression with native species. Section 4 contains sub-sections referring to (i) modifications in

nutrient cycling or resource pools, (ii) physical modifications to habitats (changes to hydrological regimes, increase in water turbidity, light interception, alteration of river banks, destruction of fish nursery areas, etc.), (iii) modifications to natural successions and (iv) disruption to food-webs, i.e. a modification to lower trophic levels through herbivory or predation (top-down regulation) leading to ecosystem imbalance.

Table 2.1: Definitions of criteria for risk classifications per section used in the ecological risk assessment protocol (Branquart, 2007; ISEIA, 2009).

1. Dispersion potential or invasiveness risk

Low	The species does not spread in the environment because of poor dispersal capacities and a low reproduction potential.
Medium	Except when assisted by man, the species doesn't colonise remote places. Natural dispersal rarely exceeds more than 1 km per year. However, the species can become locally invasive because of a strong reproduction potential.
High	The species is highly fecund, can easily disperse through active or passive means over distances > 1km / year and initiate new populations. To be considered here are plant species that take advantage of anemochory, hydrochory and zoochory, insects like *Harmonia axyridis* or *Cemeraria ohridella* and all bird species.

2. Colonisation of high conservation habitats risk

Low	Population of the non-native species are restricted to man-made habitats (low conservation value).
Medium	Populations of the non-native species are usually confined to habitats with a low or a medium conservation value and may occasionally colonise high conservation habitats.
High	The non-native species often colonises high conservation value habitats (i.e. most of the sites of a given habitat are likely to be readily colonised by the species when source populations are present in the vicinity) and forms therefore a potential threat for red-listed species.

3. Adverse impacts on native species risk

Low	Data from invasion histories suggest that the negative impact on native populations is negligible.
Medium	The non-native is known to cause local changes (<80%) in population abundance, growth or distribution of one or several native species, especially amongst common and ruderal species. The effect is usually considered as reversible.
High	The development of the non-native species often causes local severe (>80%) population declines and the reduction of local species richness. At a regional scale, it can be considered as a factor for precipitating (rare) species decline. Those non-native species form long standing populations and their impacts on native biodiversity are considered as hardly reversible. Examples: strong interspecific competition in plant communities mediated by allelopathic chemicals, intra-guild predation leading to local extinction of native species, transmission of new lethal diseases to native species.

4. Alteration of ecosystem functions risk

Low	The impact on ecosystem processes and structures is considered negligible.
Medium	The impact on ecosystem processes and structures is moderate and considered as easily reversible.
High	The impact on ecosystem processes and structures is strong and difficult to reverse. Examples: alterations of physico-chemical properties of water, facilitation of river bank erosion, prevention of natural regeneration of trees, destruction of river banks, reed beds and / or fish nursery areas and food web disruption.

Each criterion of the ISEIA protocol was scored. Scores range from 1 (low risk) to 2 (medium risk) and 3 (high risk). Definitions for low, medium and high risk, according to the four sections of the ISEIA protocol are given in table 2.1. If knowledge obtained from the literature review was insufficient, then the assessment was based on expert judgement and field observation leading to a score of 1 (unlikely) or 2 (likely). If no answer could be given to a particular question (no information) then no score was given (DD - deficient data). Finally, the highest score within each section was used to calculate the total score for the species.

Consensus on the risk score of each section was reached using a hierarchical method where evidence from within the Netherlands was given priority over evidence derived from impacts occurring outside the Netherlands. It was also considered that the suitability of habitats in the Netherlands may change due to e.g. water temperature rise due to climate change and increases in water clarity. Potential changes in future risk score were assessed without considering the effects of future management intervention.

Subsequently, the Belgian Forum Invasive Species (BFIS) list system for preventive and management actions was used to categorise the species of concern (Branquart, 2007; ISEIA, 2009). This list system was designed as a two dimensional ordination (Environmental impact * Invasion stage; Figure 2.1). It is based on guidelines proposed by the Convention on Biological Diversity (CBD decision VI/7) and the European Union strategy on invasive non-native species. Species environmental impact was classified based on the total risk score (global environmental risk) which is converted to a letter / list: score 4-8 (C), 9-10 (B - watch list) and 11-12 (A - black list). This letter is then combined with a number representing invasion stage: (0) absent, (1) isolated populations, (2) restricted range, and (3) widespread.
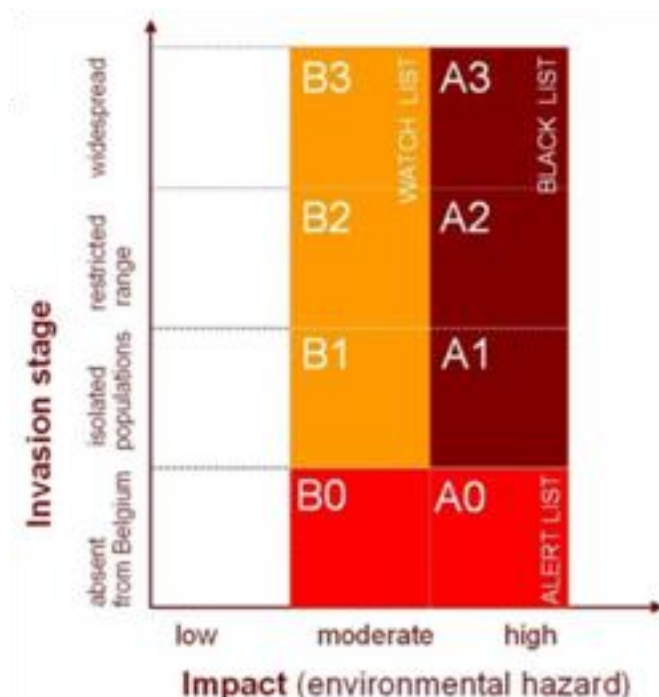
Figure 2.1: BFIS list system to identify species of most concern for preventive and mitigation action (Branquart, 2007; ISEIA, 2009).

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2.3.2 Socio-economic and public health impacts

Potential socio-economic and public health impacts did not form part of the ISEIA protocol risk analysis. However, these potential risks should be considered in an integrated risk analysis. Socio-economic and public health risks were examined as part of the literature study (Matthews *et al.*, 2013) and in discussions with project partners. Socio-economic risks occurring at present or in the future dependent on alterations in habitat suitability were considered.

2.4 Risk management options

Management options were examined as part of the literature study and extensively described in the knowledge document (Appendix 1) and in discussions with project partners. A description of effective management options is given. These are specifically relevant to, and therefore recommended for, the Netherlands.

3. Risk analysis

3.1 Probability of arrival

Fanwort (*Cabomba caroliniana*) was initially recorded in the Netherlands in 1986. The current distribution of *C. caroliniana* is characterised by a restricted range. Further introductions may result in a local widening of *C. caroliniana* distribution in the Netherlands.

The ornamental pond and aquarium plant trade is a major pathway for the distribution of aquatic plants globally (Champion *et al.,* 2010). The Netherlands is a major importer of *C. caroliniana,* which represents over 30% of the total import volume of aquarium plants imported to this country (J. van Valkenburg, personal communication; EUPHRESCO DeCLAIM, 2011). *C. caroliniana* is one of the best selling aquatic plants in pet shops in the Netherlands (Verbrugge *et al.,* 2013). Moreover, the main component of another imported aquatic macrophyte, *Cabomba aquatica*, actually consists of *C. caroliniana* (Van Valkenburg, unpublished results). Brunel (2009) undertook a survey examining the importation of non-native aquatic plants to 10 countries in Europe. The results of this survey indicated that *Egeria densa* (1,878,098 plants imported per year) and plants labelled as *C. aquatica* (1,344,915 plants imported per year), were by far the most frequently imported aquatic plants for aquarium use by the 10 countries examined, the bulk of which were imported to the Netherlands. Moreover, the increase in e-commerce has exacerbated the problem of invasive plant sales giving international retailers the ability to advertise online and send plants in the post (Kay & Hoyle, 2001).

Cabomba species are often confused leading to the importation of misidentified species. This is particularly problematic if limits are placed on the importation and sale of particular Cabomba species. A genetic bar-coding study was able to distinguish different Cabomba species using the chloroplast loci trnH-psbA and rbcL (Ghahramanzadeh *et al.,* 2013). This study will assist in efforts to correctly identify Cabomba species prior to importation. 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).

A search of Google.nl, while not representative of the total current availability of *C. caroliniana* on the Dutch horticulture market, revealed a number of examples where it was advertised for sale on plant retailer websites (Figure 3.1). the search term 'Waterwaaier', revealed three online retail websites advertising plants for sale. However, these were all located in Belgium. The term '*Cabomba caroliniana*' also produced three search 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 on the retail page of any of the retail websites visited. 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 featured the websites of retailers located in the Netherlands. The high number of retailers advertising *C. aquatica* for sale, and its frequent confusion with *C. caroliniana,* suggests 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.
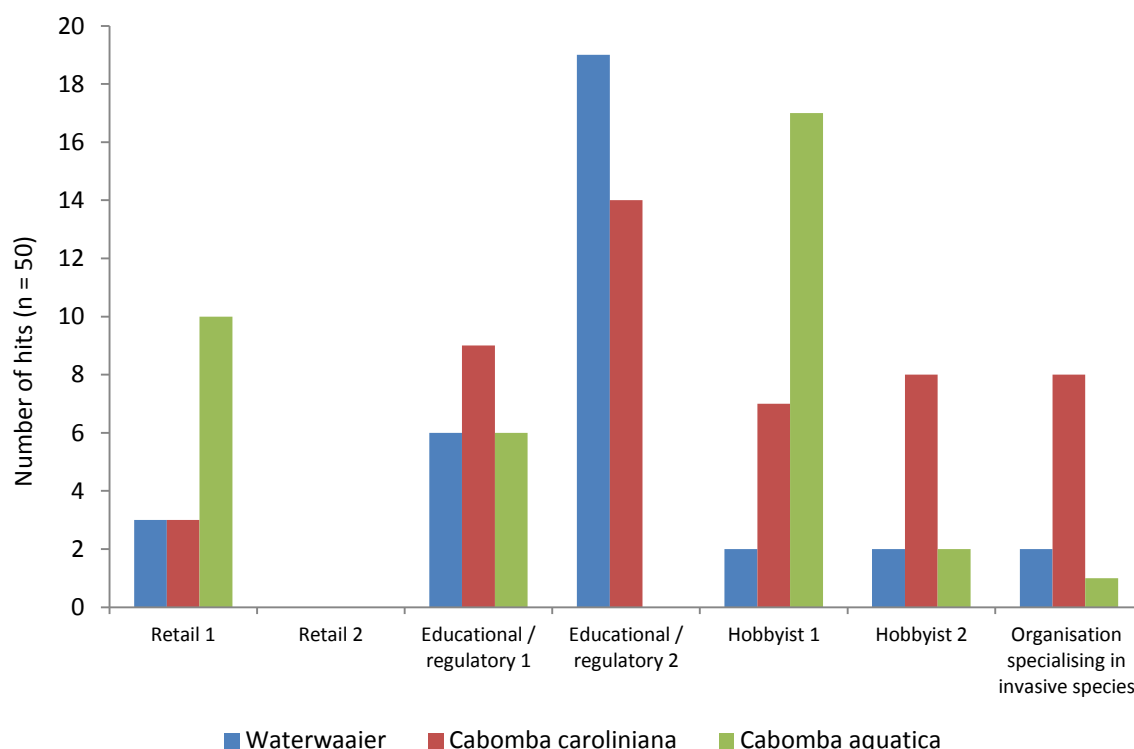
1: No direct reference is made to the plants invasive nature and / or measures recommended to prevent introduction; 2: A direct reference is made to the plants invasive nature and / or measures recommended to prevent introduction

Figure 3.1: Type of websites (in Dutch and English) featuring Fanwort (*Cabomba caroliniana*) found via Google.nl using different search terms.

Over 50% of 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 the 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 import under this name and possible confusion between the two species by aquatic plant 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.

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, personal communication). 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 3.2.1). 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). Moreover, in Dutch waters, common garden pond plants occur 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). This gives further credence to species disposal as a potential route for the introduction of invasive plants and animals.

3.1.1   Conclusion

We predict that without management intervention, *C. caroliniana* introductions will continue, leading to potential increases in its distribution within the Netherlands. After considering the above information the probability of arrival was judged to be high.

3.2 Probability of establishment

3.2.1   Distribution in the Netherlands

C. caroliniana was first recorded in the Netherlands in 1986, after first being misidentified as *C. aquatica* (Cortenraad, 1988; Van Valkenburg & Rotteveel, 2010). The species was

recorded in the harbour of Maasbracht, situated along the river Meuse. Since 1986, *C. caroliniana* was 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 had not been seen before. In 2011 it was recorded in 30 new kilometre squares, mostly in the Oranjekanaal region. This canal was intensively surveyed in that year, however. In the year 2012, there were only four new kilometre square recordings. The current recorded distribution of *C. caroliniana* in the Netherlands is characterised by a restricted range (Figure 3.2).
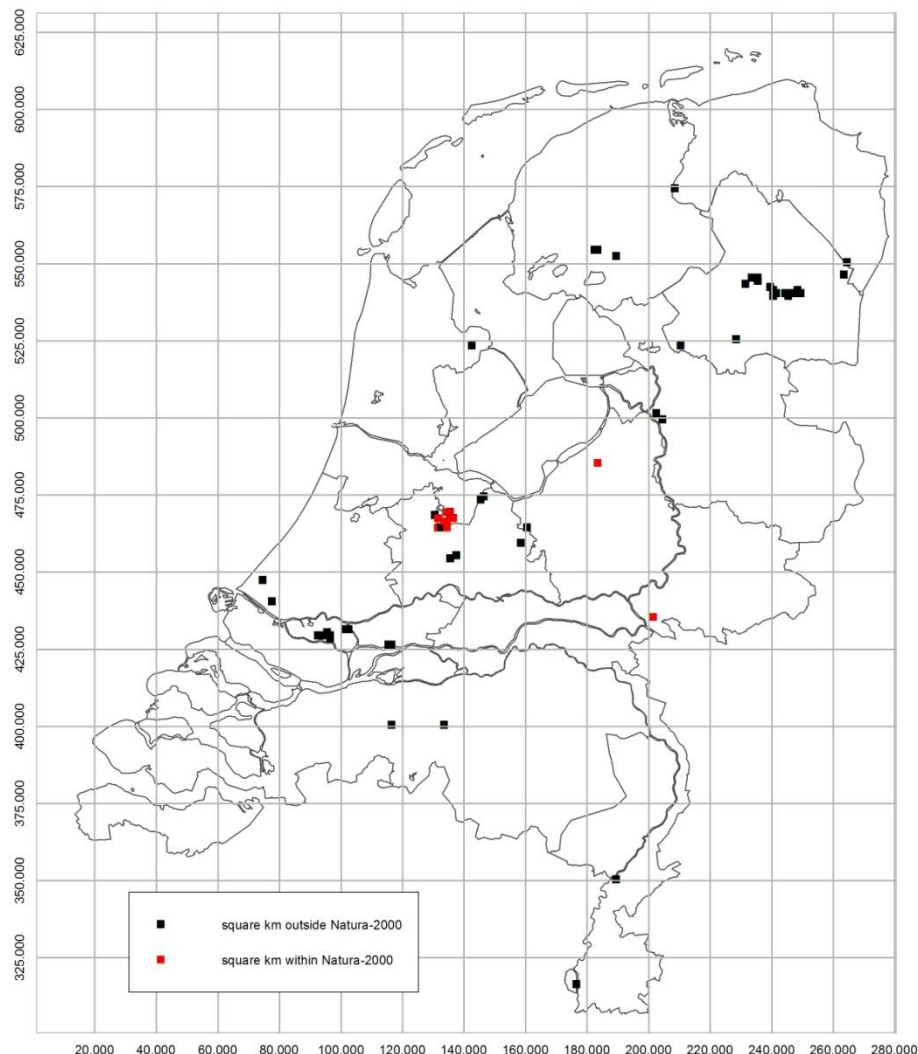
Figure 3.2: Distribution of Fanwort (*Cabomba caroliniana*) in the Netherlands (Data National Database Flora en Fauna, complemented with data sources mentioned in Matthews *et al.*, 2013).

C. caroliniana is present at Loosdrecht, north of the city of Utrecht, where it has become locally very abundant and in the Oranjekanaal in the neighbourhood of Orvelte in the province of Drenthe where it was observed in at least 17 kilometre squares to 2012. In 2013, *M. heterophyllum* remains dominant in the Oranjekanaal 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 (R. Pot, personal communication). Elsewhere, *C. caroliniana* is usually found in urban areas. A concentration of urban sites where *C. caroliniana* occurs is found around the cities of Barendrecht, Sliedrecht and Ridderkerk. 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. *C. caroliniana* grows in a shallow canal in the old town of Utrecht. In 2012, *C. caroliniana* was newly recorded in the Rijnstrangen region, a part of the Natura 2000 area of Gelderse Poort. However, During an intensive survey in 2013, *C. caroliniana* could not be found at any 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. In 2013, *C. caroliniana* was 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 can, in principle colonise all shallow, nutrient rich waters featuring a low water velocity. All shallow slow flowing and still waters in the Netherlands are considered to be potentially at risk of future colonisation by *C. caroliniana* (EUPHRESCO DeCLAIM, 2011). The main limiting factor for colonisation of locations that satisfy the chemical and physical requirements of *C. caroliniana* is the availability of plant fragments for vegetative reproduction (Roijackers, 2008).

3.2.2 Habitat and physiological tolerances

Table 3.1 gives an overview of the physiological tolerances of Fanwort (*C. caroliniana*) identified during the literature search. *C. caroliniana* grows in muddy, sandy, silty or peaty soils of slow flowing or stagnant freshwaters and prefers direct sunlight and shallow water, (Mackey & Swarbrick, 1997; EPPO, 2007; Van den Berg *et al.,* unpublished results). 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 3.3: 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).

Although it can withstand temperatures of less than 0 $^{\circ}$C, its optimal temperature range is 13-27 $^{\circ}$C (Leslie, 1986; Mackey, 1996; Mackey & Swarbrick, 1997; Hogsden *et al.*, 2007). Figure 3.3 shows *C. caroliniana* growing in the Netherlands in March 2013, the seventh coldest March in the Netherlands since 1901 (KNMI, 2013). This indicates that *C. caroliniana* appears able to withstand harsh Dutch winters. Ability to withstand cold temperatures gives *C. caroliniana* an important competitive advantage with respect to other macrophytes and algae in the Netherlands (Van den Berg *et al.,* unpublished results).

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Table 3.1: 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 de 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)
Ammonium (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

C. caroliniana mainly occurs in acidic water and stems become defoliated and growth is inhibited above pH 8 (Riemer, 1965; Gregory & Sanders, 1974; Tarver & Sanders, 1977). However, *C. caroliniana* appears 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 and survive in water-types featuring a wide range of pHs. Van de 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 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 water systems (EUPHRESCO DeCLAIM, 2011).
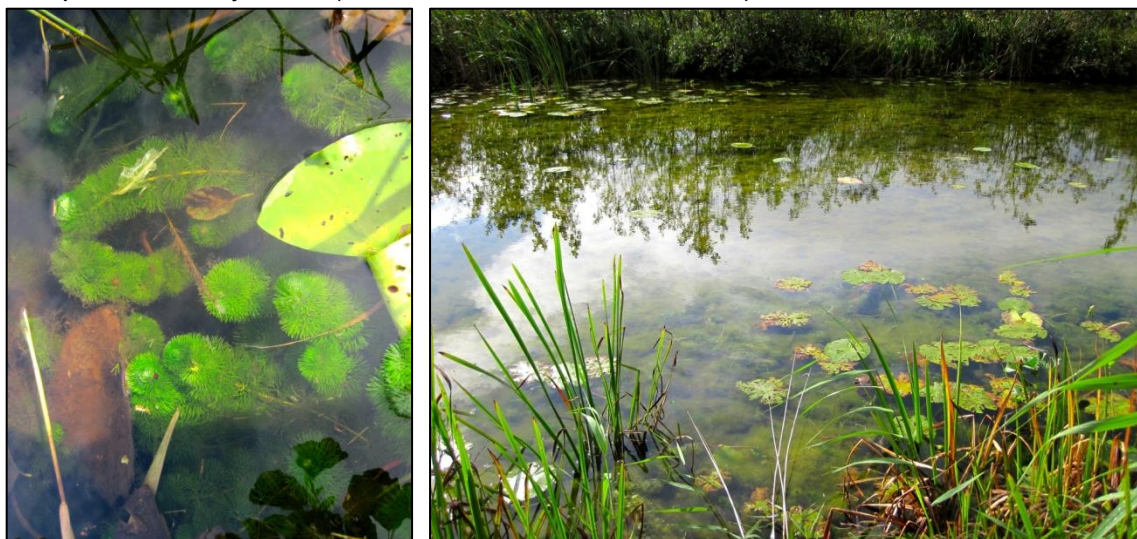
Figure 3.4: Almost 100% coverage of the sediment by Fanwort (*Cabomba caroliniana*) in Lake Tienhoven, the Netherlands, September 2010. Other macrophytes have been outcompeted, except for floating leaved species, nymphaeids and helophytes (Photos: L. Lamers).

In 2011, Van den Berg *et al.* (unpublished results) carried out field surveys examining all locations in the Netherlands where *C. caroliniana* has been recorded. *C. caroliniana* was found at 8 of the 15 locations where it had been reported previously, and mainly in the Loosdrechtse plassen area (Figure 3.4). A comparison of physico-chemical conditions between 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. High phosphate concentrations in water may lead to eutrophication and a reduction in water clarity that hinders the growth of aquatic plants. 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 risk of algal blooms and reduce water clarity (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 0.000-0.206 mg/l, ammonium concentrations of 0.00-0.64 mg/l and carbon concentrations of 3.5-20.6 mg/l (Roijackers, 2008). Additional field analyses 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 appears to require high light levels to grow optimally, 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). Lamers *et al.* (2012) suggests that reduction in nutrients dissolved in the water column, the result of water quality improvements driven by nature managers, will result in an increase in the clarity of water-bodies and increased light penetration. An increase in water clarity associated with high concentrations of phosphate in the substrate that stimulates the growth of rooted aquatic plants may result in a future increase in abundance and spread of *C. caroliniana* in the Netherlands (Lamers *et al.,* 2012). *C. caroliniana* has been found in Dutch waters with oxygen concentrations varying between 56-137% and electrical conductivities ranging between 252-656 µS/cm (Roijackers, 2008).

3.2.3   Climate and bio-geographical comparison

A comparison of climate and biogeography was made between *C. caroliniana's* invasive non-indigenous range and the Netherlands.

Climatic match with Ottawa, Canada
In Canada, *C. caroliniana* was first recorded in 1991, northeast of Peterborough, Ontario, in the North River just downstream of Kasshabog Lake. It was observed growing 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 3.1). 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 3.5). This supplements evidence indicating that low winter temperatures alone, while outside *C. caroliniana's* optimal temperature range, are unlikely to form a barrier to the colonisation of this plant in the Netherlands. A number of ecological impacts have occurred in Ontario

as a result of *C. caroliniana* establishment (Sections 3.4.4 and 3.4.5). A climate match between this location and the Netherlands increases the possibility that similar effects may be seen in the Netherlands.
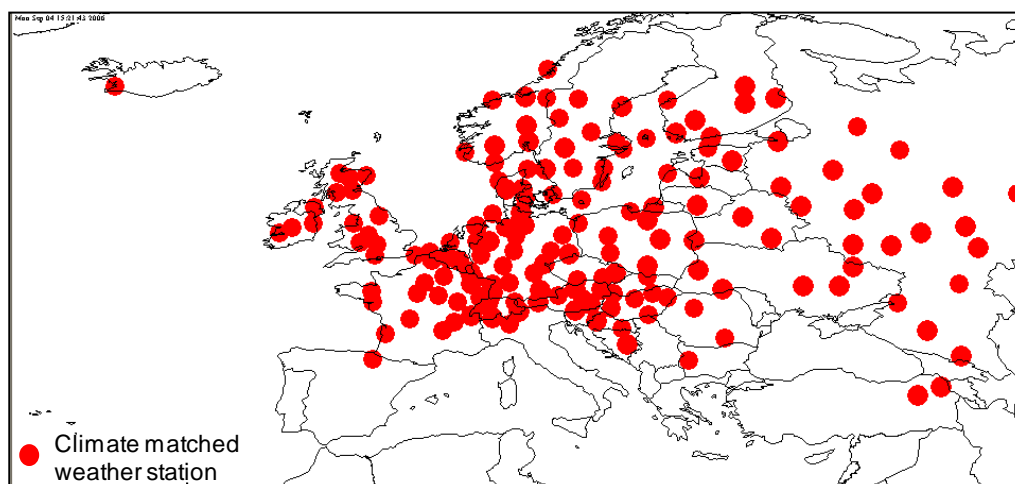
Figure 3.5: Climate match between Ottawa (Canada) and Europe (EPPO, 2007).

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 3.6). 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.
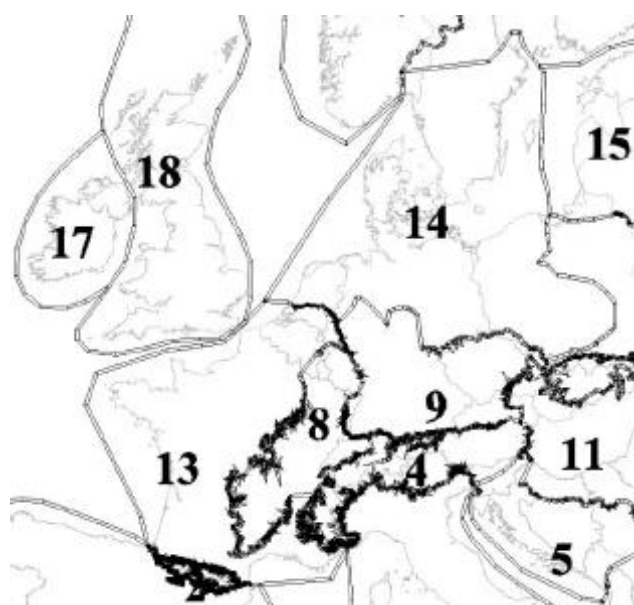
Figure 3.6: Eco-regions defined within the European Water Framework Directive (EU, 2000) 4) Alps; 5) Dinaric western Balkan; 8) Western highlands; 9) Central highlands; 11) Hungarian lowlands; 13) Western plains; 14) Central plains; 15) Baltic province; 17) Ireland and Northern Ireland; 18) Great Britain.

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 3.5). The plant 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, personal communication). *C. caroliniana* was first recorded in Germany 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.

3.2.4   Conclusion

C. caroliniana's range is restricted in the Netherlands, this despite it first being recorded here in 1986. However, evidence suggests that *C. caroliniana* will not be restricted by the habitat conditions present in a wide variety of Dutch water-bodies. Moreover, until recently, *C. caroliniana* has been limited due to poor water quality. Recent improvement in water clarity and quality may encourage the further establishment of *C. caroliniana*. Therefore, the probability of establishment in the Netherlands was judged to be medium.

3.3 Probability of spread

Seeds are produced within *C. caroliniana's* native range in South America and in the tropical and subtropical parts of its non-native range (EPPO, 2007). In other areas, *C. caroliniana* grows and disperses via asexual vegetative reproduction through fragmentation, and displays low genetic variability (Xiaofeng *et al.,* 2005). Buoyant fragments can be carried over long distances across lakes or down rivers, but mostly fall close to the mother plant. A detached fragment can regenerate into a full plant as long as it has at least one pair of leaves, and fragments as short as 10 mm may be viable and may survive floating in water for six to eight weeks (EPPO, 2007; Luijten & Odé, 2007). Clonal multiplication happens quickly, with growth rates of up to five cm per day (Mackey, 1996; Wilson *et al.,* 2007).

As all reproduction of *C. caroliniana* occurs through fragmentation or vegetatively in the Netherlands, potential vectors that transfer plant fragments from colonised to uncolonised water bodies are of great importance (Table 3.2). This is further emphasised when it is considered that, in its introduced range, *C. caroliniana* has a wide potential distribution and seems to grow in a wide array of ecological conditions (EUPHRESCO DeCLAIM, 2011). Vegetative fragments are transferred between water bodies by boats and trailers, fishing equipment, 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 & MacIsaacs, 2009). In Massachusetts and Connecticut, 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 leading to the dispersal of plants to new areas (Bowmer *et al.*, 1995; Massachusetts Department of Conservation and Recreation, 2005; EPPO, 2007; Wilson *et al.,* 2007).

Table 3.2: 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); 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	Les & Mehrhoff (1999); Schooler *et al.* (2005)

3.3.1 Conclusion

The probability of spread in the Netherlands was judged to be high. This is due to the strong competitive ability of *C. caroliniana* that particularly effects submerged aquatic plants, recreational and management activities that may increase the risk of plant fragmentation and *C. caroliniana*'s ability to reproduce vegetatively and spread over a wide area under the influence of a number of dispersal vectors.

3.4 Risk classification using the ISEIA protocol

3.4.1 Expert consensus scores

The risk classifications attributed to *C. caroliniana* for each section of the ISEIA protocol were all high apart from the classification dispersion potential or invasiveness, which was classified as medium (Table 3.3). The total risk score attributed to this species was 11 out of a maximum risk score of 12. This results in an overall classification of high risk for this species.

Table 3.3: Consensus scores and risk classifications for Fanwort (*Cabomba caroliniana*) in the current situation in the Netherlands.

ISEIA sections	Risk classification	Consensus score
Dispersion potential or invasiveness	medium risk	2
Colonization of high value conservation habitats	high risk	3
Adverse impacts on native species	high risk	3
Alteration of ecosystem functions	high risk	3
Global environmental risk	**A - list category**	**11**

3.4.2 Dispersion potential or invasiveness

Classification: **Medium risk**. *C. caroliniana* exhibits a strong reproduction potential and is able to reproduce vegetatively through fragmentation. Dispersal over a distance of greater than 1 kilometre per year may occur due to hydrochory. Moreover, *C. caroliniana* disperses via a variety of, mainly human, vectors. Pleasure boats, particularly those fitted with motors, have been identified as important dispersal vectors. Moreover, the incomplete collection of cut fragments during management interventions such as mowing will result in rapid re-colonisation and further spread of this species. The relevance of human modes of introduction is emphasised by the fact that many *C. caroliniana* populations are situated in suburban and urban areas in the Netherlands. Moreover, there continues to be a strong market for *C. caroliniana* in the Netherlands demonstrated by the high number of plant imports and the availability of plants for sale online.

C. caroliniana has become invasive in at least two large areas in the Netherlands, the area around Loosdrecht and in the Oranjekanaal region. At a third location, Giessendam, *C. caroliniana* has spread from its initial point of colonization. Currently, it is unknown if the plant has become invasive at other locations. In Barendrecht, *C. caroliniana* has proliferated in a number of waterways in a new housing development.

C. caroliniana was discovered in 2005 in eutrophic water in full sunshine at a camp site at Loosdrecht. It was able to establish and become invasive in eutrophic water in larger water channels surrounding this camp site, and less nutrient-rich waters of small streams at 'De Ster' to the east of the camp site (Van Valkenburg & Rotteveel, 2010). *C. caroliniana* was able to colonize well vegetated smaller ditches in the area, but seemed to be unable to compete seriously with the species already present (R. Pot, personal communication).

During the course of discussions within the expert team, a number of views were expressed arguing either for the classification of the species as medium or high risk for this section. *C. caroliniana's* current recorded range is restricted despite it first being recorded in the Netherlands in 1986 (Section 3.2.1). Moreover, *C. caroliniana* dispersal in the Netherlands is mediated by mainly human vectors (Table 3.2). This together with *C. caroliniana's* potential lack of seed production in northern Europe and possible limited ability in colonising areas where aquatic plants are already established despite its wide availability to the public via the aquatic plant trade (Section 3.3), suggests that its dispersion potential or invasiveness risk may be classified as medium. However, the ability of *C. caroliniana* to reproduce via fragmentation, spread to many empty niches by employing a number of dispersal vectors together with recent improvements in water quality and clarity that encourage the growth of aquatic plants, suggests that *C. caroliniana's* dispersion potential or invasiveness may be classified as high risk in the Netherlands. Risk related to the dispersion potential and invasiveness of *C. caroliniana* was classified as medium due to its current restricted distribution in the Netherlands and reliance on human mediated vectors of dispersal.

Future increases in water clarity, the legacy of high phosphate concentration in substrates and the omission of measures to prevent further human mediated introductions, may lead to an increase in the local distribution and competitiveness of *C. caroliniana* in the Netherlands resulting in an increase in dispersion potential or invasiveness.

3.4.3   Colonisation of high conservation value habitats

Classification: **High risk**. To date, *C. caroliniana* has been recorded in three Natura 2000 areas (Table 3.4). *C. caroliniana* has spread most prolifically in the Vechtplassen area. It is also present in the Gelderse Poort (Rijnstrangen). In the Vechtplassen area and in the Gelderse Poort (Rijnstrangen), *C. caroliniana* 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 any 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. *C. caroliniana* was recorded once in an old artificial pond in the Veluwe area close to a road. 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. Impacts in the Oostelijke Vechtplassen may be of particular importance as there are specific Natura 2000 targets for aquatic plants located 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 3.4: Occurrence of Fanwort (*Cabomba caroliniana*) in Natura-2000 areas.

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

During the course of discussions within the expert team, a number of views were expressed arguing either for the classification of the species as medium or high risk for this section. *C. caroliniana* occurs overwhelmingly in eutrophic waters in the Netherlands and field observations undertaken by the expert team in the Netherlands suggests that it has not spread to areas where species of high conservation value exist and competition with native species appears limited. However, the species has been recorded in a number of Natura 2000 areas in the Netherlands. This led to a discussion that attempted to establish whether these recordings are enough to classify *C. caroliniana* as high risk in this section and whether a division should be made between eutrophic and non-eutrophic systems.

The possibility that typical native species are affected through competition with *C. caroliniana* in the Netherlands cannot be ruled out. Moreover, there is evidence that species living in climate matched regions outside of the Netherlands are affected through competition with *C. caroliniana* (Section 3.4.4). In cases where both medium and high risk classifications are applicable it was decided to follow the precautionary principle and apply the higher risk classification.

Future increases in temperatures due to climate change, increasing water clarity, the legacy of high phosphate concentration in substrates and the omission of measures to prevent further human mediated introductions, may lead to an increase in the local distribution and competitiveness of *C. caroliniana* in the Netherlands resulting in a greater impact on high conservation value habitats.

3.4.4 Adverse impacts on native species

Classification: **High risk**. The result of the literature search revealed no information relating to the transmission of parasites and diseases to native species. Moreover, 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. Therefore, the risk classification is based on the competition and predation / herbivory sub-sections.

The major adverse impacts of *C. 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 and may alter nutrient cycling and fish habitat (Sheldon, 1994; Mackey & Swarbrick, 1997; Wilson *et al.,* 2007).

At Loosdrecht in the Netherlands, *C. caroliniana* has been said to smother submerged native plants. However, in most instances there was no other macrophyte growth in areas where *C. caroliniana* became established. 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 a preferred food source of these herbivores, *C. caroliniana* appears to benefit from selective grazing at this location. (J. van Valkenburg, personal communication; Van Valkenburg *et al.*, 2011). 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 and 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).

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 non-native *Myriophyllum heterophyllum* feature the same growth form as *C. caroliniana* and these two plants often appear together in the Netherlands. Where plants with a similar growth form appeared, *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, personal communication). At Lake Tienhoven, the Netherlands, *C. caroliniana* has been seen to outcompete all other macrophytes, except 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, increasing the possibility that impacts similar to those observed in Ontario will occur in the Netherlands. In a study of an Ontario lake, significant differences were discovered between *C. caroliniana* and native beds for underwater light conditions, macrophyte equitability, and epiphytic algal biomass (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. However, no differences were detected in macrophyte biomass and diversity between plots dominated by native plants and *C. caroliniana*. 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, significant differences between *C. caroliniana* and native macrophyte beds were discovered for macroinvertebrate biomass and abundance

(Hogsden *et al.,* 2007). The taxonomic composition of macroinvertebrates was similar between *C. caroliniana* and native beds, while abundance was substantially higher in *C. caroliniana* beds, owing to high densities of coenagrionids and chironomids.

In the laboratory, *C. caroliniana* has been demonstrated to absorb higher levels of lead from surrounding water at different concentrations compared to the macrophyte species Hornwort (*Ceratophyllum demersum*), Water wisteria (*Hygrophilia difformis*) and Water primrose (*Ludwigia hyssopifolia*) (Yaowakhan *et al.,* 2005). Higher concentrations of metals in *C. caroliniana* compared with other macrophytes may increase the risk of exposure of aquatic herbivores to heavy metals in *C. caroliniana* dominated water-bodies.

During the course of discussions within the expert team, a number of views were expressed arguing either for the classification of the species as medium or high risk for this section. *C. caroliniana* outcompetes underwater macrophytes through rapid growth and light occlusion however impacts on other species groups may be more limited. Moreover, unpublished field observations in the Netherlands suggest that *C. caroliniana* may find it difficult to replace already established aquatic plants. However, management intervention in the Netherlands by mowing has proven advantageous for *C. caroliniana* as it is able to recover more rapidly than other aquatic plants. *C. caroliniana* was classified as high risk in this section based on its ability to outcompete submerged water-plants, the high value placed on water systems where the plant has established in the Netherlands and the advantage that it acquires from current management practices.

Future increases in temperatures due to climate change, increasing water clarity, the legacy of high phosphate concentration in substrates and the omission of measures to prevent further human mediated introductions, may lead to an increase in the local distribution and competitiveness of *C. caroliniana* in the Netherlands resulting in a greater impact on native species.

3.4.5 Alteration of ecosystem functions

Classification: **High risk**. The risk classification is based on all four sub-sections contained within this section. There is no evidence of altered ecosystem functioning in the Netherlands available in the literature. The evidence presented here is from foreign studies, however, it was considered that similar impacts could occur in the Netherlands as Ontario has been climate matched with the Netherlands (Section 3.2.3). A major impact of *C. caroliniana* on ecosystem functioning is light interception. Where mature surface-reaching stands have become established, the canopy is able to shade out, and competitively exclude, submerged species (Figure 3.7). When compared to native macrophyte beds in a lake in Ontario (Canada), measures of 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 may be depleted causing foul-smelling water (L. Lamers, personal communication). The resulting

low oxygen conditions can lead to fish kills and harm other aquatic organisms (EPPO, 2007).

In general, 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 affected directly due to changes in food availability following *C. caroliniana* invasion. Moreover, dense beds of invasive exotic macrophytes have been linked to reduced foraging efficiency and success of fish (Engle, 1995).

However, many of the negative effects listed in the literature may be viewed as positive effects in the Netherlands. For example, increase in plant biomass and changes in nutrient cycling usually lead to a higher water transparency and more complex invertebrate food web systems (Jeppesen *et al.*, 1998). This is regarded as an improvement in water quality according to the water quality assessment of the EC Water Framework Directive (Van der Molen & Pot, 2007).
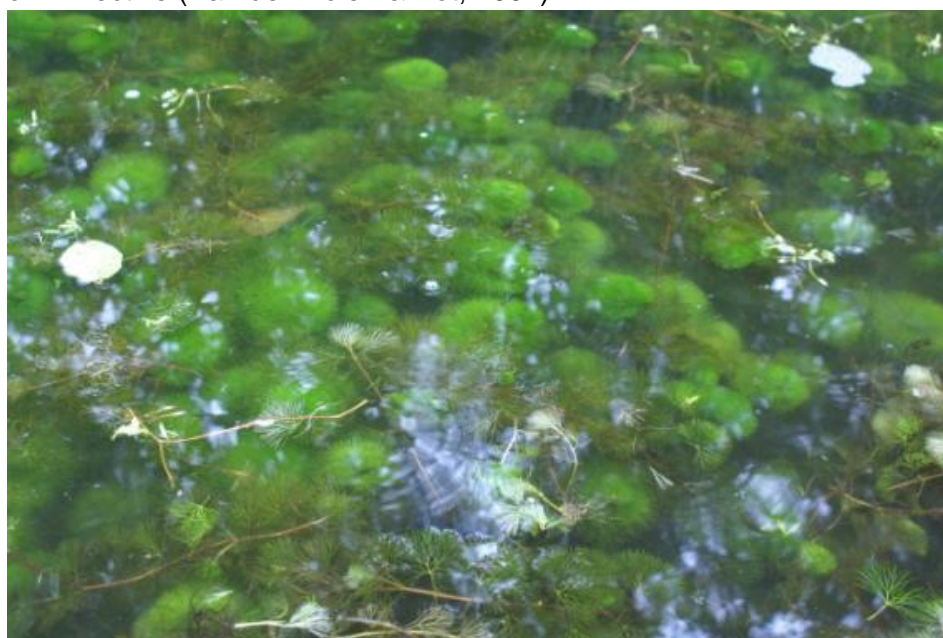

Figure: 3.7: Dense vegetation of Fanwort (*Cabomba caroliniana*) at Loosdrecht, the Netherlands (Photo: R. Pot).

During the course of discussions within the expert team, a number of views were expressed arguing for different risk classifications for the species in this section. Discussion was focussed on 'modification of nutrient cycling pools' and 'physical modifications of the habitat' as these received the highest scores of all the sub-criteria. It was argued that *C. caroliniania* may influence nutrient cycling pools in similar ways as other water plants already present and that it is not an ecosystem engineer. However, the plant can act as a phosphate pump moving phosphate from the substrate into the water column. This occurs due to the mass die-off of dense and widespread *C. caroliniania* stands that may lead to eutrophication and algal growth in the following year due to nutrient release as a result of plant decay. Moreover, it was emphasised that *C. caroliniania* can grow in dense stands that influence light penetration, turbidity and change physical habitat characteristics for fish and macroinvertebrate species. In some locations in the Netherlands *C. caroliniania* can cover 100 % of the water-body,

worsening these effects. *C. caroliniana* was classified as high risk in this section based on the score of three that it received for the sub-criteria 'physical modifications of the habitat'. It should be noted that there were also positive effects for food-webs in the presence of *C. caroliniana* (increased abundance of macroinvertebrate species for example). However, these were not included in the risk assessment as the ISEIA protocol only considers the negative impacts of species.

Future increasing water temperatures due to climate change, increasing water clarity, the legacy of high phosphate concentration in substrates and the omission of measures to prevent human mediated introduction, may lead to an increase in the local distribution and competitiveness of *C. caroliniana* in the Netherlands. An increase in the distribution of *C. caroliniana* may increase impacts on ecosystem functions e.g. modification of natural resources and disruption to food-webs.

3.4.6 Species classification

The species classification corresponds to the global environmental risk score of the ISEIA (Table 3.3) combined with the current distribution of the non-native species within the country in question. The species classification for *C. caroliniana* is A2 (Figure 3.8). This indicates a non-native species exhibiting a restricted range and high environmental hazard (i.e. ecological risk) that should be placed on the black list of the BFIS list system.
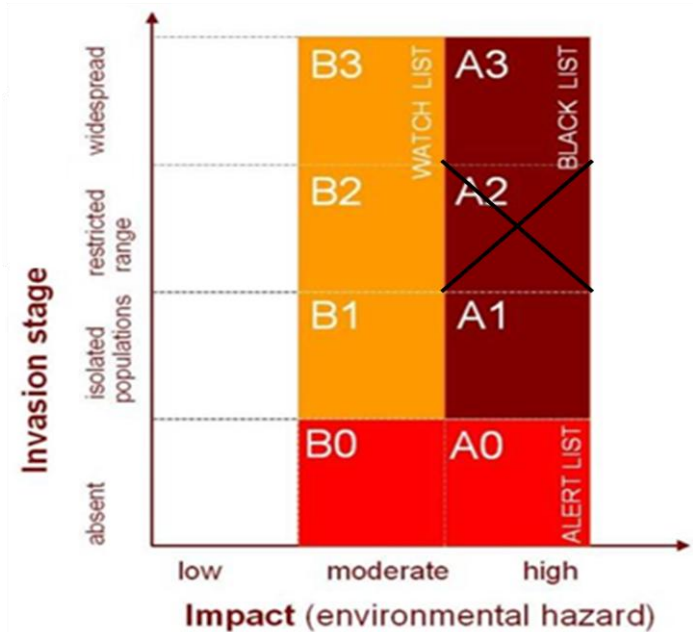
Figure 3.8: Fanwort (*Cabomba caroliniana*) classification according to the BFIS list system.

However, despite possible local increases in distribution, it is expected that *C. caroliniana* will not become widespread in the Netherlands but will remain limited to a restricted range. The main limiting factor for future colonisation of locations that satisfy the chemical and physical requirements of *C. caroliniana* (Table 3.1) is the availability of plant fragments for vegetative reproduction which is heavily influenced by the availability of dispersal vectors (Table 3.2). In these circumstances the classification would remain high risk according to the ISEIA protocol (Table 3.5). In this theoretical scenario the

distribution classification of *C. caroliniana* would remain the same. Therefore, the A2 classification under the BFIS list system would also remain the same.

Table 3.5: Fanwort (*Cabomba caroliniana*) theoretical classification according to a potential future habitat scenario.

ISEIA sections	Risk classification	Consensus score
Dispersion potential or invasiveness	medium risk	2
Colonization of high value conservation habitats	high risk	3
Adverse impacts on native species	high risk	3
Alteration of ecosystem functions	high risk	3
Global environmental risk	**A - list category**	**11**

3.5 Socio-economic impacts

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 this invaded site over a single year was 350,000 Euros. Management intervention led to a 75% reduction in infestation (T. Rotteveel, personal communication). In general, 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). 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).

3.6 Public health 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. Aquatic snail abundance may increase due to increased algal food availability. Aquatic snails are known to carry trematodes that can cause the condition swimmer's itch. Increasing snail abundance may lead to an increase in the occurrence of this condition in recreational swimmers in the Netherlands (L. Lamers, personal communication; B. bij de Vaate, personal communication).

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

3.7 Risk management options

3.7.1 Prevention

Public awareness is an important component in a strategy aimed at controlling or removing an invasive species from a catchment area. This is especially important in the Netherlands due to the high level of imports and trade of *C. caroliniana* in association with the fact that people are the major vector for dispersal of this species. In the Dutch code of conduct for aquatic plants (2010), *C. caroliniana* has been declared a list-2 species. This means that it should be sold only when accompanied with a warning about its invasiveness. Moreover, 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). Information campaigns should help stop the release of plants into open water by aquatic plant hobbyists who are unaware of the plants invasive nature or how to properly dispose of it. *C. caroliniana* is imported under the name *Cabomba aquatica* very often (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.

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*. A guide for the identification of aquatic invasive species, describing associated impacts and strategies for prevention of spread was produced in the Netherlands in conjunction with the Dutch code of conduct for aquatic plants (Van Valkenburg, 2011). Its aim is to create awareness and assist in the monitoring of non-native aquatic plants.

3.7.2 Elimination

Once populations of *C. caroliniana* have established, eradication is very difficult. Eradication of the plants can be achieved on a small scale by covering the plants 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 involves reversing the mud pump of a dredger (Van Valkenburg *et al.,* 2011). This produces a powerful water-jet that dislodges *C. caroliniana* (Figure 3.9). Application of the Hydro-venturi equipment seems to be a very promising eradication method because whole plants, including the root system, are collected and fragmentation is minimized (Figure 3.10). Plant re-growth is, therefore, limited.

Figure 3.9: Application of the Hydro-venturi system. The head and water jet are raised above water to illustrate its operation (Photo: L. van Kersbergen).

Figure 3.10: Application of the Hydro-venturi system results in the removal of the complete plant, including root system (Photo: R. Pot).

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.

3.7.3   Control

Limiting management intervention appears to be the best method of reducing the spread of *C. caroliniana*. A high level of fragment spread occurs when cutting machinery is used without the immediate collection of 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 plant establishment. However, the growing conditions for *C. caroliniana* were less favourable at Maasbracht than at Loosdrecht.

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 might be the best options for this (Figure 3.11), but only when the removal of plant material from the water-body is assured, preferably including the root system.

Figure 3.11: A weed cutting boat with adjustable mowing gear (left) and a harvesting boat (right) used for aquatic weed control in the Netherlands (Photos: R. Pot).

Mechanical methods may result in the breakup of plant stems resulting in the dispersal of plants to new areas (Bowmer *et al.*, 1995). The dispersal of plant fragments and subsequent vegetative reproduction has been observed following mechanical harvesting in the Netherlands (R. Pot, unpublished results). Retaining nets stretched from bank to bank that catch fragments and stop them floating away during cutting may be required to prevent this from occurring. 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 areas 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).

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

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

4. Discussion

4.1 Gaps in knowledge and uncertainties

A lack of information in the literature on the (potential) impact of Fanwort (*Cabomba caroliniana*) on species groups apart from aquatic macrophytes in the Netherlands has resulted in a reliance on expert knowledge and field observations to judge the level of certain impacts.

Future changes such as increases in water clarity and the legacy of high phosphate concentration in substrates may result in an increase in the distribution of *C. caroliniana* in the Dutch freshwater network as well as in isolated water bodies. Therefore, the risk of impacts may have to be reassessed in future.

The ISEIA protocol is limited to an assessment of invasiveness and ecological impacts. No assessment of socio-economic impacts or impacts to human health are considered and these are not taken into account in the calculation of the global environmental risk score. Socio-economic impacts or impacts to human health were therefore considered separately.

Risk criteria in the ISEIA protocol were sometimes restrictive, as there was an absence of quantitative data that allowed the criteria to be assessed e.g. one km per year dispersal criterion for the 'dispersion or invasiveness' section.

4.2 Comparison of available risk classifications

The ISEIA protocol was used to assess the risk of *C. caroliniana* in Belgium following its removal from the only recorded location there (Baus *et al.*, 2009). Belgium is categorised within eco-region 13, which is shared with the south of the Netherlands (Section 3.2.3, Figure 3.6). This increases the possibility that the potential impacts of *C. caroliniana* in Belgium may also occur in the Netherlands. *C. caroliniana* was classified as high risk for impacts relating to competition on native species and high risk for physical alteration and changes to nutrient cycling in the ecosystem impacts category. The overall score given to *C. caroliniana* in Belgium was 10 out of a possible 12 (moderate risk). 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).

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 that 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 species for potential 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).

The score of 12 obtained during our assessment of *C. caroliniana* places it at higher risk compared to assessments undertaken in other countries. This may be explained by the wider distribution of *C. caroliniana* in the Netherlands in comparison to other countries such as the UK and Belgium. The plant has also become invasive in the Netherlands whereas in other countries, such as Belgium and the UK, it has not. The invasive spread of *C. caroliniana* at locations such as Loosdrecht in the Netherlands has resulted in widespread impacts on submerged water plants and affected recreational activities leading to costly management intervention and a higher risk score here.

4.3 Risk management

The banning of sale of invasive plants via the plant trade and the creation of awareness in aquatic plant hobbyists and water managers continue to be the most potentially effective methods of controlling the introduction and spread of invasive plant species. *C. caroliniana* is categorised in appendix 2 of the Dutch water-plant 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. However, there is some evidence from online retailers suggesting that this does not occur. Moreover, foreign online retailers may be unaware of the requirements of the code of conduct. 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 code of conduct. Based on current dispersion and invasiveness potential and risk it is recommended that *C. caroliniana* be banned from sale in the Netherlands. In order to facilitate the removal of *C. caroliniana* from the retail sector, 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.

Once *C. caroliniana* is released to the environment, control and elimination becomes more difficult. In areas of heavy infestation, the use of recreational boating, particularly those with propellers, should be discouraged if the prevention of further spread is a priority. During management intervention using cutting boats, attention should be focussed on the collection of fragments released during cutting. Retaining nets should be used to isolate the managed area in order to prevent further dispersal, and facilitate the collection, of plant fragments. The application of elimination methods that avoid stem fragmentation and remove the entire plant, such as shading and the Hydro-venturi system should be encouraged.

5. Conclusions and recommendations

The main conclusions and recommendations of the risk analysis of non-native Fanwort (*Cabomba caroliniana*) in the Netherlands are as follows:

Probability of arrival

- The probability of *C. caroliniana* arriving in the Netherlands is determined largely by the plant trade. *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 and pet shops. A number of internet websites were found that featured traders who were advertising *C. caroliniana* for sale within the Netherlands and Belgium.

- Plants classified as *C. aquatica,* which are very often mislabelled examples of *C. caroliniana*, are the second most frequently imported aquatic plants to the Netherlands and are sold online and in shops.

- A genetic bar-coding study was able to distinguish different Cabomba species 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.

- The wide availability of *C. caroliniana* via the trade in aquatic plants and evidence showing that a small proportion of hobbyists dispose of plants into the freshwater network, suggests that humans are responsible for the initial stages of *C. caroliniana* introduction in the Netherlands.

- The probability of arrival in the Netherlands was judged to be high due to the continued trading of *C. caroliniana* in the Netherlands and the potential for plants to be disposed of in the freshwater system.

Probability of establishment

- Evidence suggests that *C. caroliniana* will not be restricted by the habitat conditions present in a wide variety of Dutch water-bodies. *C. caroliniana* can, in principle colonise all shallow, nutrient rich waters featuring a low water velocity. All shallow slow flowing and still waters in the Netherlands are considered to be potentially at risk of future colonisation by *C. caroliniana. C. caroliniana* is often found in and around urban areas and new housing estates that feature freshwater channels and ponds. However, *C. caroliniana's* range is restricted in the Netherlands, this despite it being first recorded here in 1986. Recent improvements in water quality and clarity may have facilitated the spread of *C. caroliniana* in more recent times.

- The main limiting factor for future colonisation of locations that satisfy the chemical and physical requirements of *C. caroliniana* is the availability of plant fragments for vegetative reproduction.

- The probability of establishment in the Netherlands was judged to be medium.

Probability of spread
- Reproduction and spread of *C. caroliniana* in the Netherlands are facilitated by the detachment and spread of plant fragments. These fragments subsequently become rooted and develop into new plants.

- The spread of fragments is facilitated by dispersal vectors. Vectors can be ordered in terms of importance: the plant trade, hobbyists, boats and water flow (high); weed harvesters, fishing equipment (medium); large aquatic birds (low).

- The probability of spread within the Netherlands was judged to be high due to *C. caroliniana's* ability to reproduce vegetatively and the wide availability of dispersal vectors in the Netherlands.

Risk classification according to the ISEIA protocol
- Dispersion potential or invasiveness. Classification: **Medium risk.** *C. caroliniana* has become invasive in at least two large areas in the Netherlands, the area around Loosdrecht and in the Oranjekanaal region and has spread from its initial point of colonization at Giessendam. Currently, it is unknown if the plant has become invasive at other locations in the Netherlands. In Barendrecht, *C. caroliniana* has proliferated in a number of waterways in a new housing development.

- Colonisation of high conservation value habitats. Classification: **High risk.** *C. caroliniana* has been recorded in three Natura 2000 areas. These are the Oostelijke Vechtplassen and Gelderse Poort. *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 at this time.

- Adverse impacts on native species. Classification: **High risk.** At Loosdrecht in the Netherlands, *C. caroliniana* has been observed to smother native aquatic macrophytes. At Lake Tienhoven, the Netherlands, *C. caroliniana* has been seen to outcompete other macrophytes, except for floating leaved species and helophytes. Moreover, there are examples of impacts on native species observed in Ontario (Canada), an area that has been climate matched with the Netherlands. Adverse impacts observed here are reduced light conditions, reduced abundance of native macrophytes, changes in biomass of epiphytic algae, increased macroinvertebrate biomass and abundance. Moreover, *C. caroliniana* exhibits an induced chemical response that reduces the palatability of the plant to herbivores.

- Alteration of ecosystem functions. Classification: **High risk.** *C. caroliniana* can act as a phosphate pump moving phosphate from the substrate into the water column. The mass die-off of dense and widespread *C. caroliniania* stands leads to nutrient release and possible eutrophication and algal growth in the following year. Moreover, *C. caroliniania* can grow in dense stands that influence light penetration, turbidity and change physical habitat characteristics for fish and macroinvertebrate species.

Species classification according to the BFIS system
- The current recorded distribution of *C. caroliniana* in the Netherlands is characterised by a restricted range according to the BFIS list system.

- *C. caroliniana* was rated as a **high risk** species for ecological impacts according to the ISEIA protocol. Its current restricted range in the Netherlands, combined with this high risk score, results in an **A2** classification in the BFIS list system.

- We predict that without management intervention, *C. caroliniana* introductions will continue. This, associated with a rise in water temperature due to climate change, increasing water clarity and the legacy of high phosphate concentration in substrates, increases the possibility that *C. caroliniana* will locally widen its distribution within the Netherlands. However, it is expected that this will not affect the overall classification of *C. caroliniana* distribution within the BFIS system. Therefore, it is expected that the A2 classification under the BFIS list system will also remain the same.

Socio-economic and public health impacts
- Socio-economic impacts in the Netherlands have mainly occurred at Loosdrecht where *C. caroliniana* has become invasive. Here the plant clogged canals 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. Intervention resulted in a 75% reduction of infestation. Potential future changes as a result of e.g. a rise in water temperature due to climate change, may increase the suitability and area of *C. caroliniana* habitat locally, increasing the socio-economic impacts of the species.

- Local increases in the distribution of *C. caroliniana* may result in an increased abundance of trematode carrying aquatic snails which cause swimmer's itch.

Recommendations
- *C. caroliniana* is 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 for reducing the spread of the species. Standard management techniques often encourage the spread of *C. caroliniana* through fragmentation.

- If control using cutting boats is required, attention should be focussed on the efficient removal of all plant material from the water-body, preferably including the root system. This will help prevent the further spread of *C. caroliniana* through fragmentation. The use of retaining nets to isolate the managed area in order to prevent further spread is recommended.

- The application of elimination methods that avoid stem fragmentation and remove the entire plant, such as shading or the Hydro-venturi system, should be encouraged.

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

- It is recommended that *C. caroliniana* is banned from sale in the Netherlands.

- In order to facilitate the removal of *C. caroliniana* from the retail sector, 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*).

6. Acknowledgements

7. References

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Appendix 1. Knowledge document used for the risk analysis