EUPHRESCO DeCLAIM Final report

A State-of-the-art June 2011

Cabomba caroliniana Gray

Plant Protection Service
Aquatic Ecology and Water Quality Management Group, Wageningen UR
Centre for Ecology and Hydrology- Wallingford

This report contains the result of research on *Hydrocotyle ranunculoides* and was part of a larger project EUPHRESCO DeCLAIM (Decision Support Systems for ControL of Alien Invasive Macrophytes). A project initiated to generate a prototype decision support system for optimal control measures for the four most troublesome invasive alien aquatic weeds at present in the UK and NL.

Cabomba caroliniana, a representative for the Myriophyllids growth form, representing 35% of the import volume of aquarium plants in The Netherlands. In 2009 it was found at three sites in The Netherlands, posing serious problems at one.

Hydrocotyle ranunculoides, a representative for the Stratiotids *s.l.* growth form, is at present the most troublesome invasive alien aquatic weed in the United Kingdom and The Netherlands, and is showing increased distribution in neighbouring countries as well as in the Australia, Uganda and Zimbabwe.

A second representative for the Stratiotids *s.l.* growth form, *Ludwigia grandiflora*, has demonstrated significant detrimental ecological impact in France and is gaining importance in The Netherlands. In the UK early intervention management strategies using herbicides have been developed and deployed (DEFRA website).

A third representative of the Stratiotids *s.l* growth form is *Myriophyllum aquaticum*. This species has been sold extensively by the aquatic nursery trade as an ornamental species for domestic ponds. It is now present in many natural lowland static water sites in the UK. The species is still very popular in The Netherlands, and the number of infestations is increasing.

The overall project was a joint effort between four partners.

Plant Protection Service

Plant Research International, Wageningen UR

Aquatic Ecology and Water Quality Management Group, Wageningen UR

Aquatic Plant Management Group, Centre for Ecology and Hydrology- Wallingford

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1. Executive summary

- **Range:** In its native range, Fanwort (*Cabomba caroliniana*) is restricted to clear and acidic low nutrient-content waters. In South America the species is present in Brazil, Paraguay, Uruguay and Argentina and in North America in the southeast along the Gulf and Atlantic coast. *Cabomba caroliniana* is an invasive species in the UK and the Netherlands, where the species has been recorded since the 1990s. It is considered an invasive species in various States of the United States and Canada, China, Japan, Malaysia, India, New Guinea and Australia. In Europe the species is also reported in France and Hungary.

- **Growth characteristics:** *C. caroliniana* has a relatively low photosynthetic rate a high light compensation point, and a high fraction of light reduced by epiphytes colonisation of its highly dissected leaves.

- **Areas at risk:** We can consider all shallow slow flowing and still waters in the Netherlands to be potentially at risk. For the UK we have indicated a temperature related altitudinal maximum for areas to be at risk, although these areas will be better defined with increased temperature data input.

- **Reproductive strategy:** In cold temperate climates, *C. caroliniana* overwinters mainly vegetatively and the main mode of spread is by plant fragments. Buoyant fragments can be carried over long distances. One single stem node can produce a new plant. Fragments rarely can survive exposure in air for more than 24 hours. However, they can stay moist and survive for weeks in mud, even under hot and dry conditions. *Cabomba* flowers but does not set viable seed in the Netherlands or the UK

- **CHARISMA:** Simulations with the CHARISMA model indicated that the percentage of overwintering biomass of *C. caroliniana* is a crucial factor that can completely modify the dynamics of the aquatic plant community. In competition with *Chara aspera* and *Potamogeton pectinatus* it was shown that *C. caroliniana* was not able to establish successful populations after 10 years when grown from a wintering fraction of 0.50. However, with a wintering fraction of 0.75. *C. caroliniana* is able to establish and grow for the whole length of the time series. However, *Potamogeton pectinatus* dominates after 20 years. With a wintering fraction of 0.90 *C. caroliniana* completely out competes the other species and dominates the macrophyte community. However, actual field observations do not corroborate the outcome of the simulations, with *Cabomba* dominating from a very small overwintering biomass. This implies that other physiological factors may confer dominance on this species in European habitats.

- **Management:** In field experiments, lasting for over one year, several management techniques were studied. <u>Blocking the sunlight</u> will kill all underwater vegetation. It is to be expected that after re-exposing the water column to sunlight, dependent on the inflow of fragments *C. caroliniana* can re-enter. Coverage of the sediment did not result in a suppression of *Cabomba*, as plants colonized the new sediment on top of the geotextile. Regular dredging will not result in a permanent removal of this macrophyte. Even if dredging is applied twice a year, it will just result in a temporary decrease of the plant's biomass. The major cause of the excessive growth of *C. caroliniana* is the influx of fragments and the weak competition by other water plants, as shown by cage experiments. A new technique, in which the loose sediments together with the rooted macrophytes are vigorously re-suspended through a water jet stream, turned out to be quite successful. This technique can still be improved, particularly in the collecting and removal of the re-suspended plant material. Experiments with the cages indicated that the inflow of plant fragments is the major route for recolonization by *C. caroliniana*. Particularly in the ditches where the shoreline vegetation consists of reed, shrubs and trees, it will be difficult to remove the fragments completely.

- **DSS:** The main objective of this project was to produce a support system that could be used by field operatives and office based managers to identify the species accurately, and to enable a rapid risk assessment to be made in the field that could be reported in a consistent manner, enabling a rapid response to be made against the species with the aim of preventing further spread and eventually eradication the species from the affected watercourse. In order to make the response to aquatic non-native species consistent and proportionate a pictorial field and office guide has been produced that provides descriptive photographs of characteristic features, areas at risk, typical habitat types, and available management techniques. We have deliberately left out costs of management as these vary within each country and certainly between countries. In addition, each species chapter will be made available at www.declaim.eu[1]. The DSS was submitted to the Non Native Species Secretariat in the UK for comment before being used by managers. In the Netherlands the DSS was submitted to representatives of various water boards that are actively involved in trials to control invasive macrophytes The comments received were positive and helpful and led to developments in the current version.

[1] This domain is not hosted within any of the project organisations and should be migrated to a partner organisation web site as soon as possible.

2. Habitat requirements and areas at risk

2.1. Objectives

- Analyse from literature what the (a)biotic factors are that characterize the habitat of *Cabomba caroliniana*.
- These (a) biotic factors will be used to identify in existing databases (STOWA-databases on ditches, streams, canals, lakes and ponds for The Netherlands; MTR, SNIFFER, LEAFPACS and existing CEH databases for the UK) localities at risk.
- Using these data maps of "at risk areas" of The Netherlands and the UK will be produced

2.2. Literature Analysis of Growth conditions

Cabomba caroliniana is native to subtropical-temperate regions of eastern America along the Atlantic and Gulf coast and South-eastern America (figure 1; Orgaard 1991). Julien and Schooler (2004) have recently surveyed the native range of *C. caroliniana* in South America; they have found populations in the south of Brazil, in Paraguay, Uruguay and northern Argentina.

Recent infestations have been recorded in Australia, Japan, Malaysia, India, United States and Canada (Orgaard 1991; Mackey and Swarbrick 1997; Wilson 2007). *C. caroliniana* has been reported in the Basingstoke canal in North Hampshire, England, where it has been spreading since 1990, and was collected again in 2011. In The Netherlands, it has been found in several sites; at one of theses sites - Loosdrecht Lakes - the population represents a serious threat. In figure 2 and 3 the present distribution of *C. caroliniana* is given for the UK and The Netherlands respectively.

In the native range of *C. caroliniana*, floating plants tend to dominate in turbid and nutrient-rich water bodies (Carignan and Neiff 1992). This seems to restrict the growth of *C. caroliniana* to clear and acidic low nutrient-content waters. It has been observed to grow in patchy patterns (as opposed to monospecific stands in the introduced range) which also may be due to competition with floating plants and herbivory. *C. caroliniana* is found in protected inlets of lakes and rivers with slow water velocity and accumulated sediments (up to 2m thick) such as organic silt. It generally grows down to a maximum of 3.5m depth (Schooler *et al.* 2007b).

In the introduced range, *C. caroliniana* has a wide potential distribution; it seems to grow in a wide array of ecological conditions. It is present from tropical (Australia) to cold temperate climates (The Netherlands). It even seems to be able to survive under ice in continental cold climates (Canada) (Hogsden *et al*. 2007). Table 1 presents some environmental conditions that have been reported to be favourable for its growth.

Populations of *C. caroliniana* are found in lakes, reservoirs, streams, rivers, and irrigation canals. It is often seen near bridges because of slow moving waters. In Australia, it has been observed to have its greatest biomass at a depth of 2-3m. In deeper water, the plant still grows (up to 6m depth) but the density decreases (Schooler *et al*. 2007b). *C. caroliniana* grows mainly in fine soft sediments so that its thin roots can anchor.

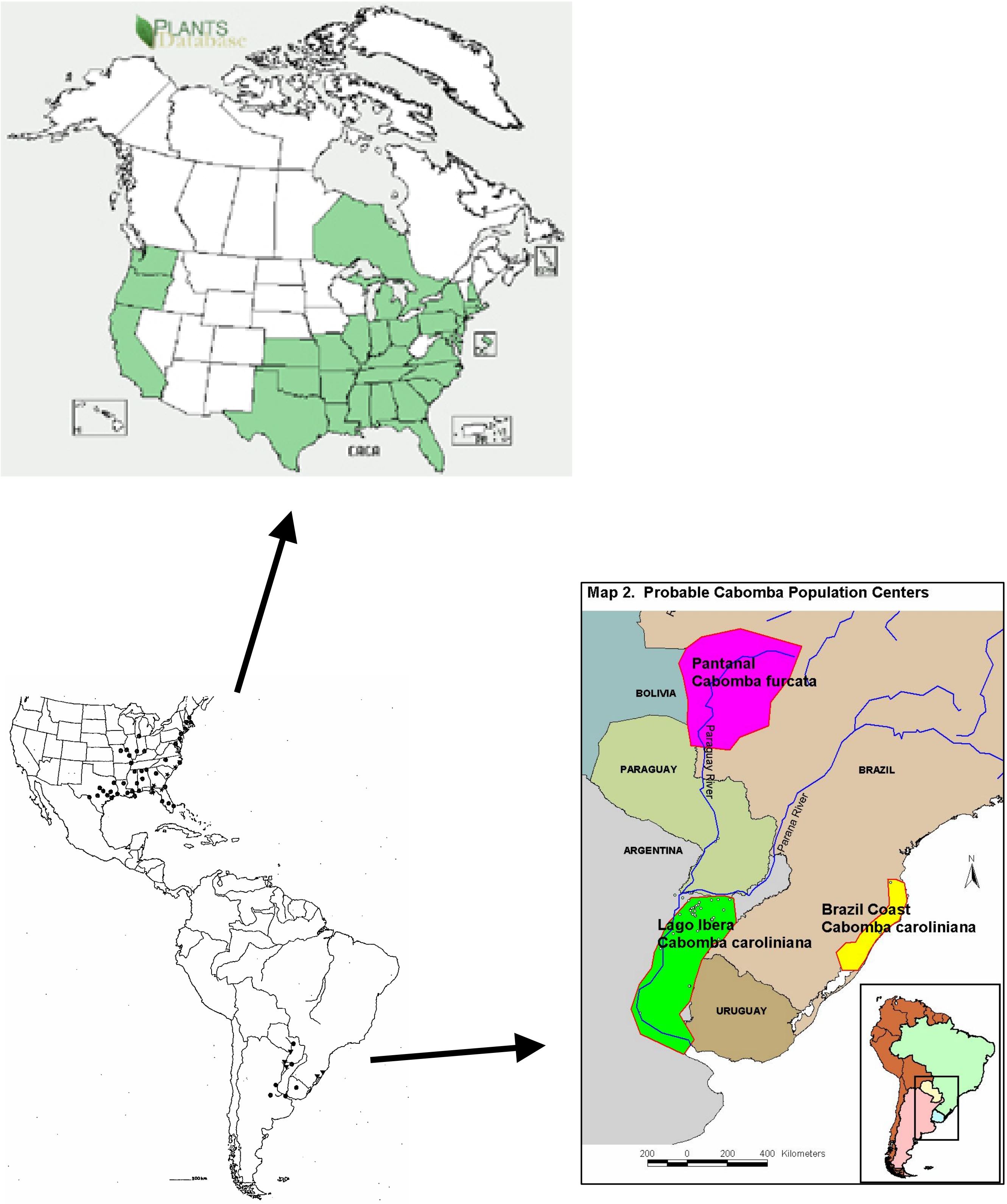


Figure 1. Map of the native range of *Cabomba caroliniana.*

Table 1. Environmental variables favourable for *Cabomba caroliniana*

Environmental variables	**values**	**reference**
Mean depth	3m	Wilson 2001; Schooler *et al*. 2007b
Maximum depth	10m	Wilson 2001
Mean annual temperature	13-27^{o}C	Mackey and Swabtick 1997
pH	4-8	Mackey and Swabtick 1997; Orgaard 1991
substrate	silty	Mackey and Swabtick 1997
Water velocity	low	Schooler *et al*. 2007b
Nutrient availability	variable	Wilson 2001

2.3. Areas at Risk

Databases in the UK and NL could not provide the detailed information we had hoped for. Previous studies at the 4 sites in the Netherlands already revealed the wide tolerance of *C. caroliniana* for abiotic factors (Roijackers 2008). Therefore we can consider all shallow slow flowing and still waters in the Netherlands to be potentially at risk. For the UK we have indicated a temperature related altitudinal maximum to be at risk.

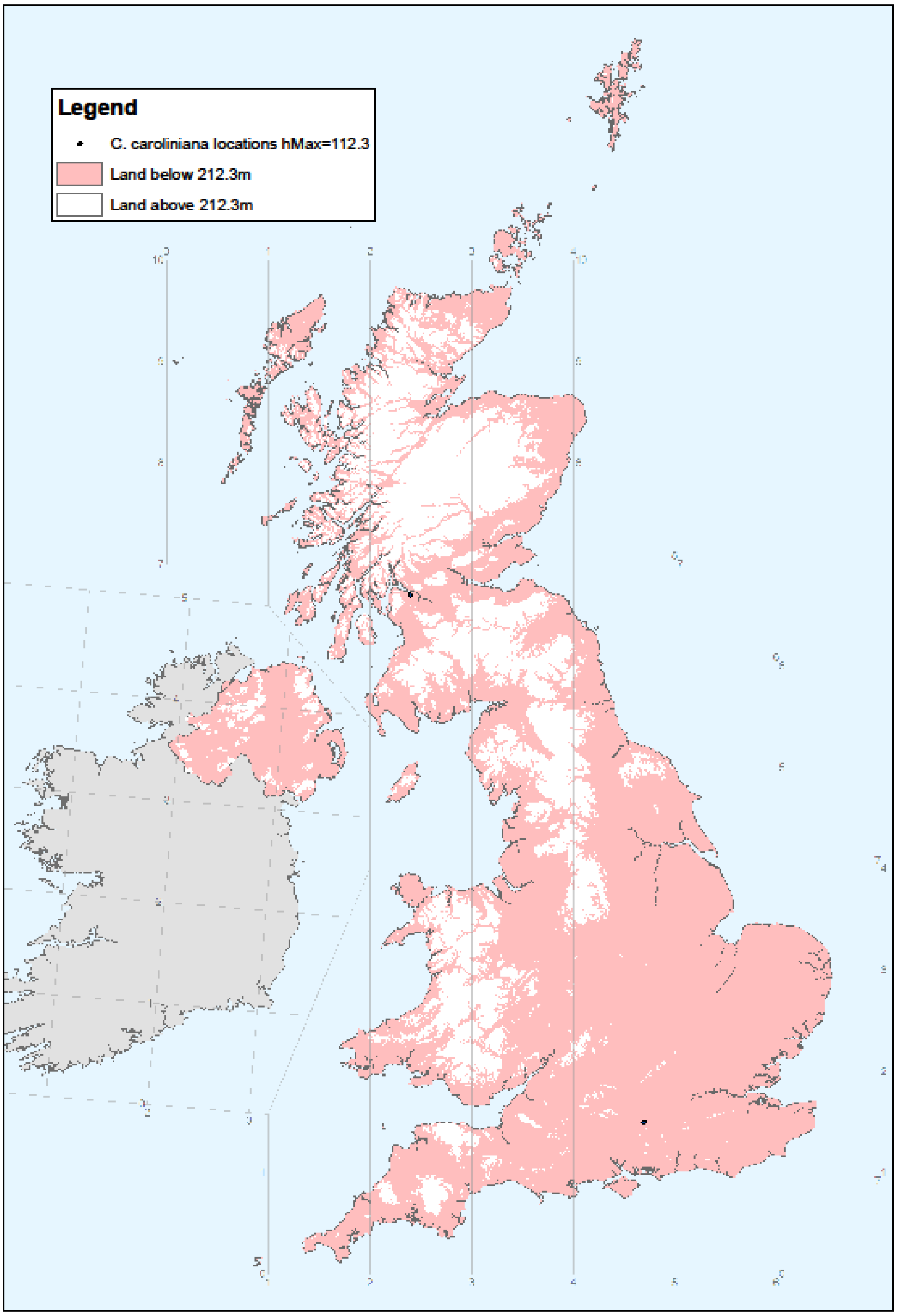


Figure 2. Distribution of *Cabomba caroliniana* in the UK (black dots) and area at risk (in pink).

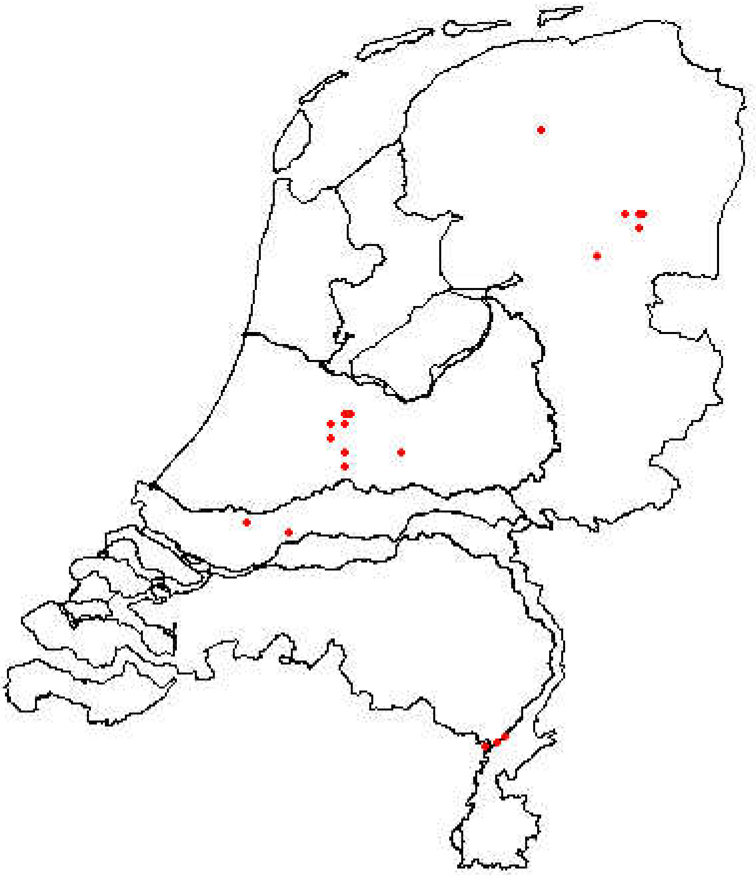


Figure 3. Distribution of *Cabomba caroliniana* in The Netherlands.

3. Ecology and Growth Modelling using CHARISMA

3.1. Objectives

- Review ecological literature on the life cycle of Cabomba.
- Based on the available information come to a preliminary parameterization of the individual based macrophyte model CHARISMA(Van Nes *et al*. 2003).
- Gaps in published literature will be identified and attempts to gain information required for CHARISMA will be made.

3.2. Life Cycle

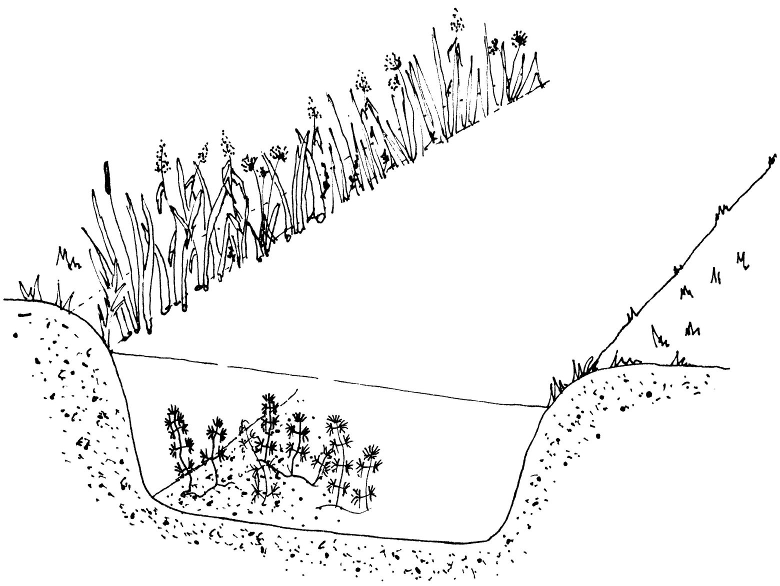
Cabomba caroliniana can spread in three different ways: by seeds, by broken fragments, and by detached stems. In its introduced range, only a few populations of *C. carolinina* are known to produce viable seeds: in Southern USA and in the northern part of Australia. The mechanism limiting seed production is not yet known (environmental conditions or hybrid sterility). When present, seeds drop to the sediment after maturation and can stay viable for two years. Dried seeds showed higher germination (85%), than seeds kept in moist conditions (25%) (Sanders 1979).

In cold temperate climates, *C. caroliniana* overwinters mainly vegetatively (Schooler *et al*. 2007; Wilson *et al*. 2007). In autumn, *C.caroliniana* forms ‘turion-like’ structures at the apical stem-tips. These structures can break from the plant. Buoyant fragments can be carried over long distances – across lakes or down rivers, but mostly fall close to the mother plant. The ‘turion-like’ tips can also stay attached to the stems. They lose their buoyancy at the beginning of the winter and sink to the sediment surface. In the spring, the nodes near the tips form roots and new growing tips. The connecting stem of attached tips will disintegrate, separating the daughter plant from the mother plant. One single stem node can produce a new plant (Sanders 1979). Fragments can rarely survive exposure to dry air for more than 24 hours. However they can stay moist and survive for weeks in mud, even under hot and dry conditions.

C. caroliniana has other intriguing characteristics such as a low photosynthetic rate (Saitoh *et al.* 1970; Van *et al*. 1976), a high light compensation point (Van *et al*. 1976), and a high fraction of light reduced by epiphyte colonisation of its highly dissected leaves (Hogsden *et al*. 2007). These should indicate that it should not grow fast, but under stress, C_4 type metabolism is induced which increases the capacity of *Cabomba* to absorb CO_2 at the expense of other macrophytes (reduced carbon compensation point)(Salvucci and Bowes, 1981). This metabolic adaptation is probably responsible for the dominance of *Cabomba* in European systems. The extent of C_4 metabolism in *Cabomba* under temperate latitudes has not been investigated to our knowledge.

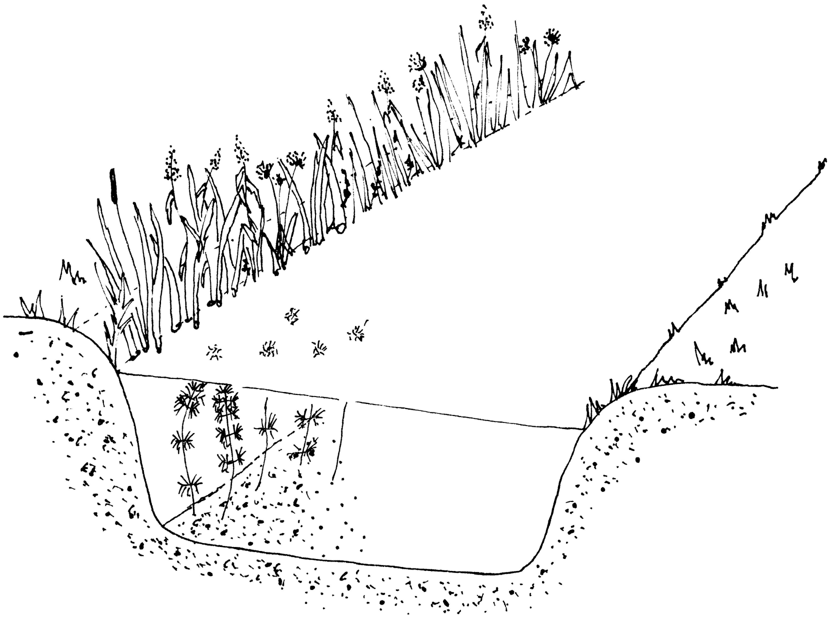
3.2.1. Life cycle diagrams

The following diagrams illustrate the growth form through the seasons



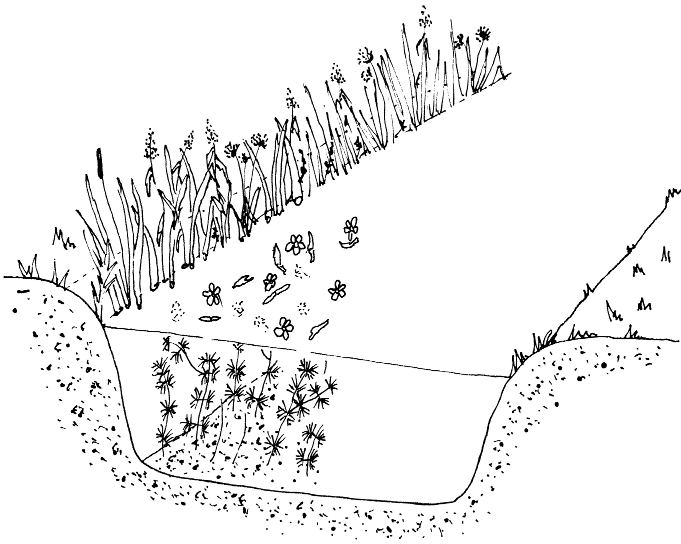
Cabomba caroliniana in early Spring

In spring, single stems grow from horizontal overwintering shoots. The internode length is large at the base of the plant and decreases as the stems get closer to the surface. Plants remain as single stems and branching is absent.



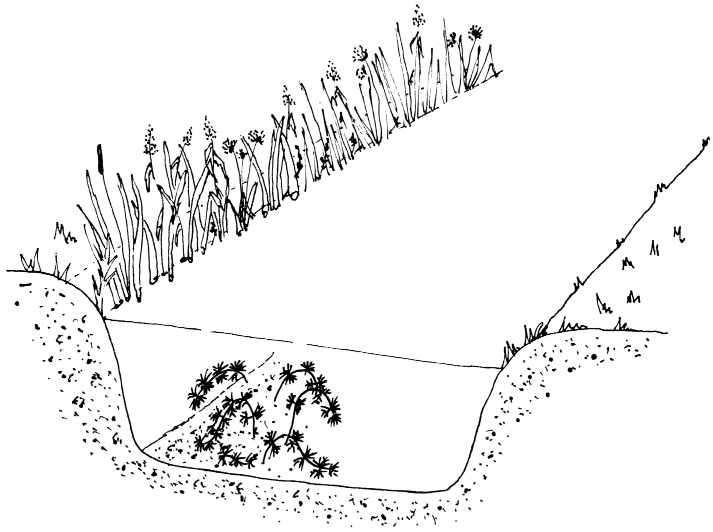
Cabomba caroliniana in Spring

In late spring, the single stems reach the surface. Plants remain as single stems and branching is absent, but the single stem density increases because more shoots grow and reach the surface from submerged tissue.



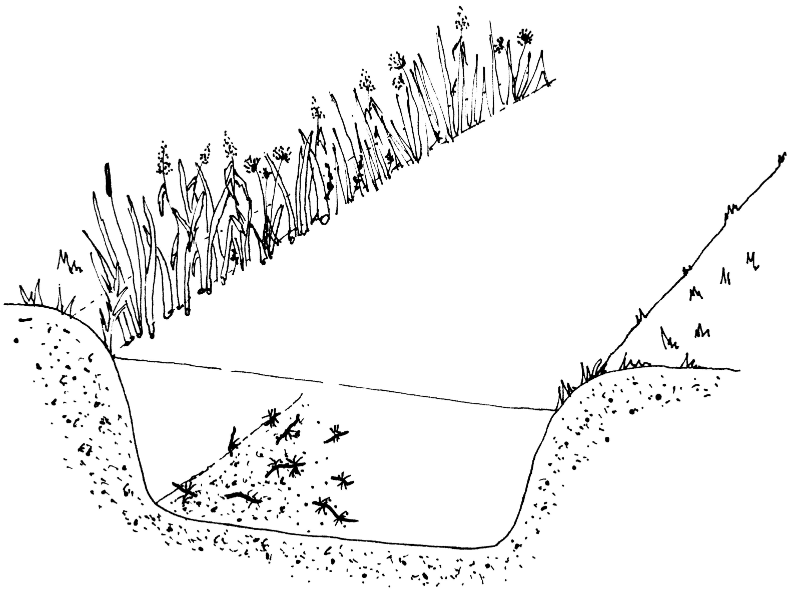
Cabomba caroliniana in Summer

In summer, floating leaves are formed and the single stem branches at flowering initiation time. Petioles arise from the point on the stem where floating leaves originate and white and yellow flowers are borne at the surface. Stems become buoyant and branching occurs further down the stem, increasing potential propagule numbers and flowering stems.



Cabomba caroliniana in Autumn

In autumn, the stem tips bend over and fall to the bottom, the stem breaks up easily and falls close to the "parent" plant. Rooted fragments disperse and root where they come into stable contact with sediment with sufficient light.



Cabomba caroliniana in Winter

In winter the stems settle onto the sediment and break up, leaving viable nodes and stem apices to regrow in spring. Fragments are shed and move away from the parent plant during flow events.

3.3. CHARISMA Model development

The objective of this work package is to review ecological literature on the life cycle of *Cabomba* and based on the available information come to a preliminary parameterization of the individual based macrophyte model CHARISMA (Van Nes *et al*. 2003). Gaps in published literature will be identified and attempts to gain information required for CHARISMA will be made.

The basis of this spatial explicit model is the seasonal cycle. Plants can survive the winter as shoots and as different types of overwintering structures. At a pre-set day in spring, growth is initiated and the plants get a certain amount of energy from the overwintering structures and an increasing amount from primary production. At a pre-set age, the macrophytes start allocating a part of their biomass to overwintering structures. At the end of the growing season, this part of the plants is transformed into biomass and the plants die off.

We used the literature review to parameterize the model CHARISMA. The model has been parameterized for *Potamogeton pectinatus, P. perfoliatus* and *Chara aspera* (Van Nes *et al*. 2002, 2003; Coops *et al*. 2002) and can readily be applied to *Cabomba*. These parameter sets will be used as basis.

For several growth parameters insufficient parameter values are available in literature to run the CHARISMA model accurately. Most papers only give a general description of favourable or unfavourable conditions for *C. caroliniana* growth. To be able to further adapt CHARISMA to accommodate for *C. caroliniana* growth, this information should be obtained from experimental work.

3.3.1. The CHARISMA model

The CHARISMA model is an individual-based and spatially explicit model in which individual plants and overwintering structures are positioned on grid cells (figure 4). This allows modelling spatial ecological processes such as seed or tuber dispersal. CHARISMA allows modelling of 3D competition for light and nutrients between two or more aquatic plant species.

The model is based on a seasonal cycle. Plants survive the winter as shoots or overwintering structures. In the spring, growth is initiated from the energy from the overwintering structures. At the beginning of the summer, primary production and respiration determine plant growth. In the autumn, individual plants start allocating biomass to overwintering structures. At the end of the growing season, shoot biomass is transferred to overwintering structures and the plants die off.

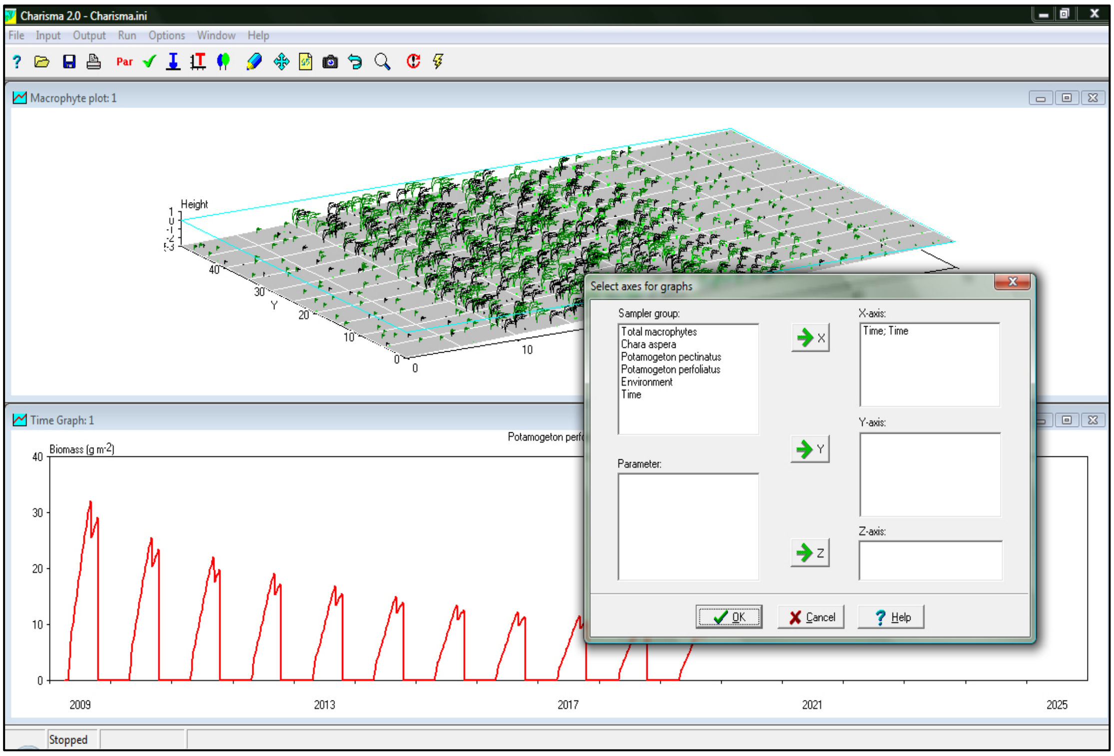


Figure 4. The CHARISMA model.

3.3.1.1. Growth form

The weight of plants is determined by a fixed root/shoot ratio. Part of the biomass during the growing season will be allocated to reproductive organs. The length of young shoots increases underwater proportionally with biomass. After reaching the water surface, there is a proportional increase of the biomass over the whole length of the plant. Optionally, a fraction of the biomass can be allocated to spread just under the water surface.

3.3.1.2. Growth rate and mortality

The daily growth rate depends mainly on the gross photosynthesis rate and the respiration rate. Mortality can be caused by high plant densities, wave damage, grazing, or seasonal die-off.

3.3.1.3. Environmental variables

The CHARISMA model allows you to modify a wide array of environmental variables such as light levels, temperature, turbidity, bicarbonate concentrations in the water and water levels (figure 5). Model parameters, including comments on significant gaps are presented in Table 2. An exhaustive list of all the parameters that can be adjusted In CHARISMA is presented in the annex 1.

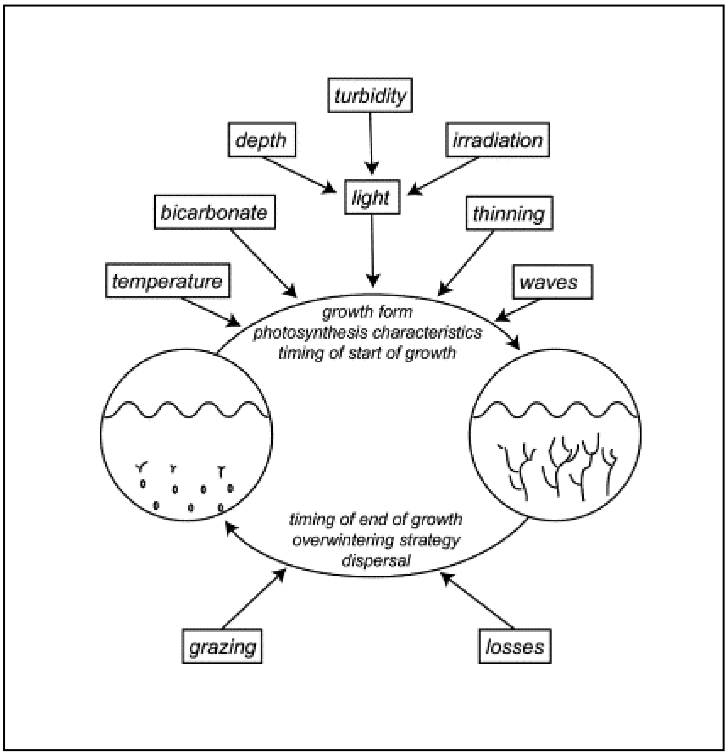


Figure 5. Seasonal cycle and environmental variables in the CHARISMA model

3.3.2. Summary of available data for CHARISMA variables

Table 2 contains the different parameters that have been adjusted specifically for modelling the life cycle of *C. caroliniana*.

The P_{Max}, the maximal gross photosynthetic rate at the plant top at 20°C in the absence of light limitation, has been adjusted for *C. caroliniana* to 0.004/h which is a lower value compared to other aquatic plants (Saitoh et al. 1970; Van et al. 1976). The light compensation point (hPhotoLight) was fixed to 160 µE/m^2/s (Van et al. 1976) which in turn is a high value. The respiration rate was fixed at 0.001/day. The PlantK is the specific light attenuation coefficient created by the plant (light shading). It has been set to 0.0569, considering the plant has fan-shaped leaves that create a lot of self-shading. The fraction of light reduced by periphyton on plant leaves was fixed to a quite high fraction –28%– considering the highly dissected leaves that create an important surface for colonization by periphtyon (Hogsden *et al*. 2007).

All the parameters related to seed production have been set to 0 because of the absence of seed production for *C. caroliniana* in cold temperate climates. The tuber fraction is the fraction of the biomass allocated to tubers or other wintering structures (for simplicity, all the overwintering structures are called 'tubers' in CHARISMA). For *C. caroliniana*, the whole plant can overwinter and produce new shoots in the spring. However, from field observations (Roijackers, personal comm. 2009), we estimated at 20% the minimum fraction of the total plant biomass allocated to stem tips (turion-like) that sinks in the winter and produce new individuals in the spring. Each stem tip was estimated to weigh 0.0013g. CTuber, which is the daily fraction of 'tuber' weight lost after germination for growth and respiration of the sprout, has been fixed to 1 because in the case of *C. caroliniana*, all the biomass of the plant fragments will turn into shoot biomass; there is no storage in the overwintering structure. The 'tuber start age', the age of the plant when it starts to allocate biomass to 'tubers' has been fixed to 125 days, which means *C. caroliniana* starts to produce special stem-tips 4 months after the beginning of the growing season (or the day of germination of the wintering stem-tips, which has been fixed to the beginning of April). In our parametization, *C. caroliniana* stops producing special stem-tips for overwintering one month later (at age 155 days). We also decided for the duration of the simulations not to have any import of new fragments (tuber import=0).

From field measurements made in the summer 2009, we estimated the maximum length of one individual of *C. caroliniana* to be 10 m. The root/shoot has been estimated to 0.07 and the maximum weight/length ratio to 0.53, which is quite high compared to the default values of 0.003 for *Chara aspera* or 0.1 for *Potamogeton pectinatus*. This difference can be explained by the high amount of highly dissected leaves of *C. caroliniana* which have a higher weight.

Table 2. Values of the parameters adjusted for modelling the growth of *Cabomba caroliniana.*

Parameter	**value**	**remarks**
PMax	0.004 /h	
hPhotoLight	160 microE/m^2/s	
PlantK	0.0569 m^2/g	
Resp20	0.001 /day	
FracPeriphyton	0.28	
ReproDay	0	No seed
Germination day	0	No seed
Seed Germination	0	No seed
Seed Mortality	1	No seed
Seed fraction	0	No seed
Seed Biomass	0	No seed
Seed start age	0	No seed
SeedsStartAge	0	No seed
SeedImport	0	No seed
tuberfraction	0.2	% of turion-like structures
TuberGerminationDay	Day#92	April 1st
Tuberbiomass	0.0013 g	weight of one turion-like structure
TuberImport	0	
cTuber	1	

TuberStartAge	125
TuberEndAge	155
maxWeightLen ratio	0.53
RootShootRatio	0.07
MaxLenght	10 m

3.3.3. Results

After adjusting the model for all the required parameters, we ran simulations of the growth of *Cabomba caroliniana* over time with and without other competing species (*Chara aspera, Potamogeton pectinatus*).

The aim of the first set of simulations without competition was to understand better the growth patterns of *Cabomba caroliniana* within the seasonal cycles. The first simulations were performed with the wintering fraction (the 'tuber fraction' in CHARISMA) set at 20%, meaning that 20% of the biomass of *C. caroliniana* is allocated to wintering structures (figure 6a). Because of its relatively low photosynthetic rate (compared to other aquatic plant species), this winter survival rate was not enough to support a sustainable growth of *C. caroliniana* over 10 years. Adjusting that fraction at 75%, then the species could sustain its population and grow (figure 6b).

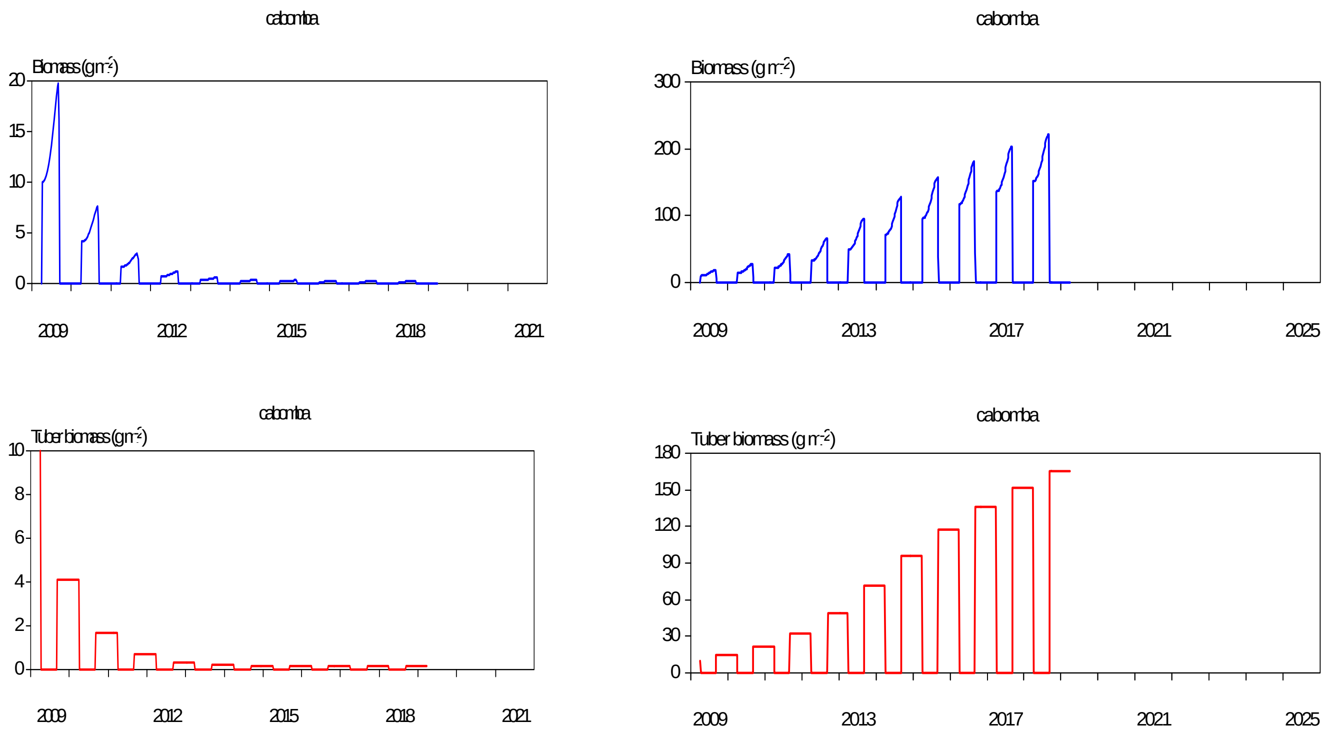


Figure 6. Simulations of the growth of *C. caroliniana* over ten years without competition. a) with a wintering fraction of 0.20. b) with a wintering fraction=0.75. The blue line is the shoot biomass and the blue line is the wintering biomass (‘tuber biomass’ in CHARISMA).

We performed a parameter analysis to be able to identify the threshold value of wintering survival for a sustainable growth of *C. caroliniana* (figure 7). We also ran a backward analysis. The analysis identified the value at which the growth of *C. caroliniana* is sustainable to be around 0.55. This means that to be able to develop viable populations, more than half of the biomass of *C. caroliniana* needs to survive the winter. If we look at the backward path of the analysis, we can see that if a population of *C. caroliniana* is established, the population will die off only if less than 42% of the biomass dies in the winter.

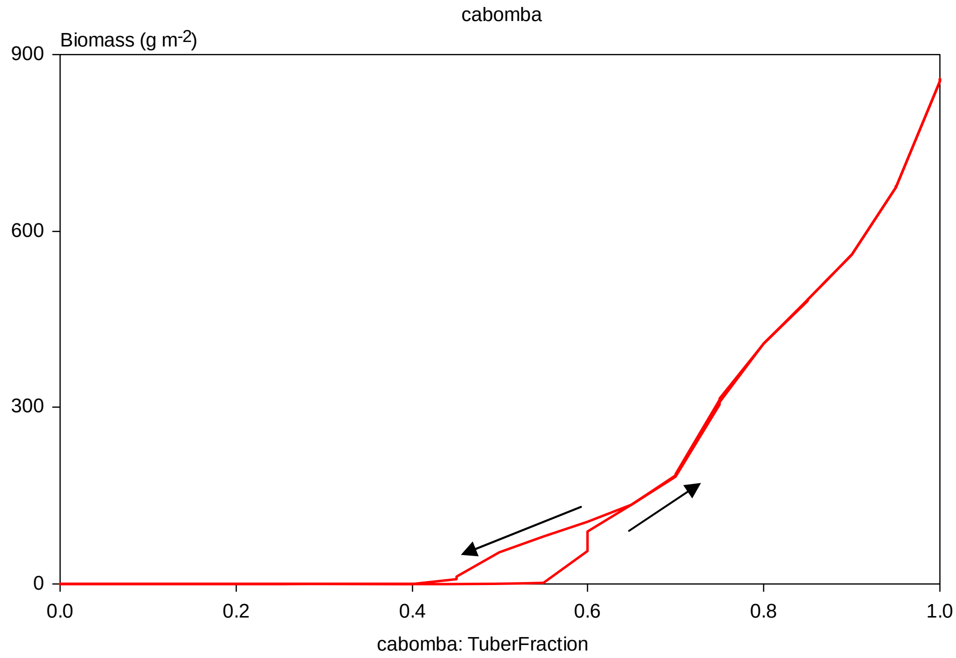
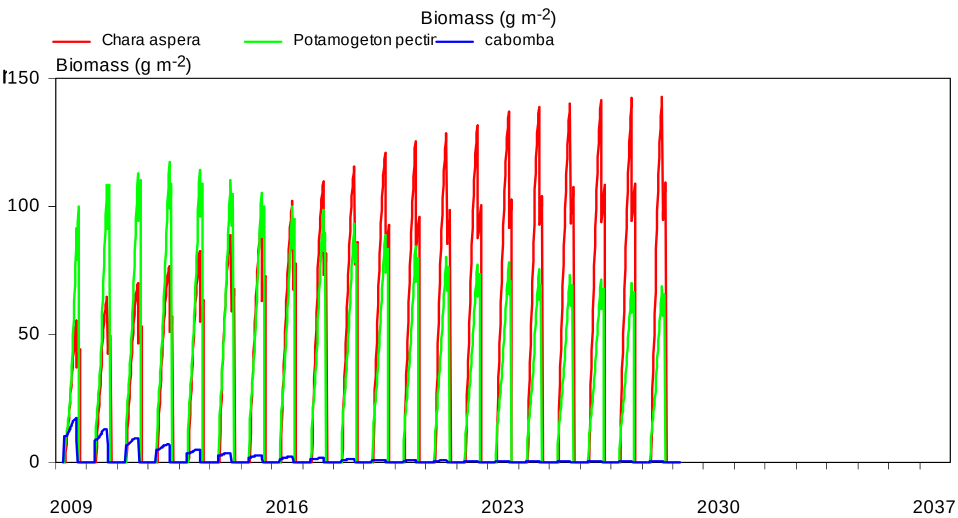
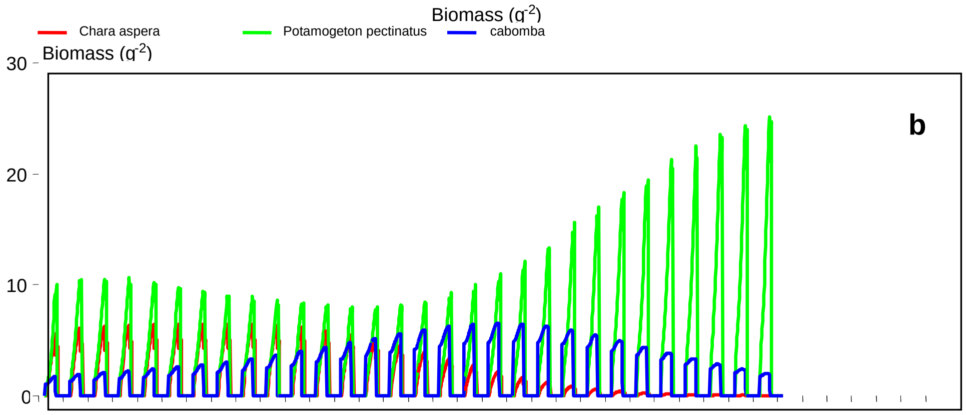


Figure 7. Relationship between the wintering fraction of *C. caroliniana* and its biomass

We then performed simulations of the growth of *C. caroliniana* with two competing species, *Chara aspera* and *Potamogeton pectinatus*. We performed three simulations of growth over a 20 year period. The first simulation was run with a wintering fraction of 0.50, which is below the sustainable threshold of 0.55. We can indeed see that in such a scenario, *C. caroliniana* is not able to establish successful populations; the biomass reaches zero after 10 years and *Chara aspera* becomes the dominant species (figure 8a). The second scenario was run with a wintering fraction of 0.75. *C. caroliniana* is then able to establish and grow for the whole length of the time series (figure 8b). However, *Potamogeton pectinatus* dominates after 20 years. Finally, with a scenario where 90% of the biomass of *C.caroliniana* survives the winter, we can see that not only it grows and has a sustainable population but completely out-competes the other species and dominates the macrophyte community (figure 8c).


Biomass (g m-2)
Chara aspera
Potamogeton pectir
cabomba
Biomass (g m-2)
150
100
50
0
2009
2016
2023
2030
2037


Biomass (g-2)
Chara aspera
Potamogeton pectinatus
cabomba
Biomass (g-2)
30
20
10
0
b

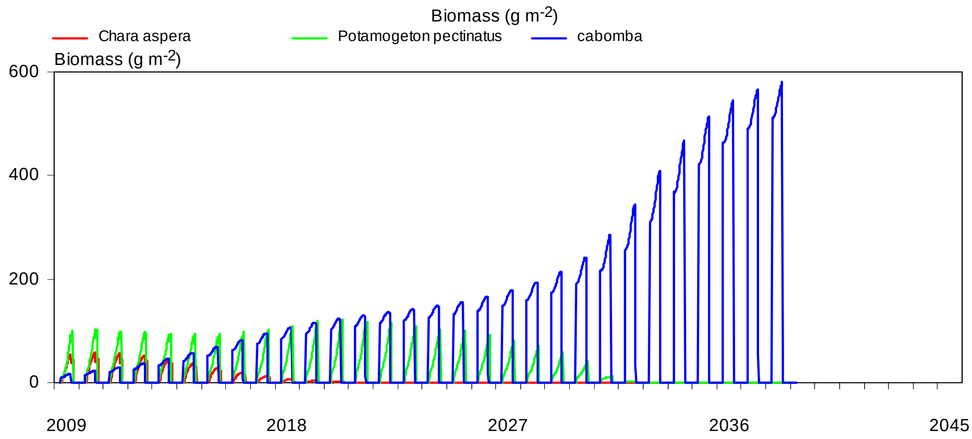

Biomass (g m-2)
Chara aspera
Potamogeton pectinatus
cabomba
Biomass (g m-2)
600
400
200
0
2009
2018
2027
2036
2045

Figure 8. Simulations of the growth of *C. caroliniana* with competition by *Chara aspera* and *Potamogeton pectinatus* over ten years. a) with a wintering fraction of 0.50; b) with a wintering fraction=0.75; c) with a wintering fraction =0.90.

3.4. Discussion

Despite adaptations to the model based on field observations the predictions of growth and competition do not match the actual observed situation in the field. The assumptions on minimum required biomass appear to under estimate the growth potential of the species. The results of the management trials already indicate the critical role of the root system. Further information on parameters related to photosynthesis appears crucial for the understanding of this species.

4. Management

4.1. Objectives

The objective of this work package is to derive from the results of Work packages 2 and 3 new practical control options that can be tested by water boards and other bodies involved in management of surface water.

Since chemical weed control in an aquatic environment is extremely restricted in the Netherlands and because the results should be of practical use for both NL and UK, and other EU countries, the practical control options will focus on prevention and non-chemical methods. Data on suitable habitat characteristics and life cycle will be used to:

- Indicate how and when in the season the colonization of *Cabomba caroliniana* can be prevented or markedly restricted by influencing the growth requirements (substrate, light conditions and other environmental characteristics that result from Work package 2).
- Conceptualize physical control options that combine a very high control efficacy with a minimum dispersal of vegetative parts of the aquatic weed. The current mechanical control options generally strongly induce further vegetative reproduction.
- Test at least one concept management option output under practical field conditions.

4.2. Introduction

After consulting available published sources, discussions with field staff and common sense, four different methods were tested under practical field conditions (Van Valkenburg & Rotteveel 2010).

- **blocking sunlight**:
  The surface of a canal with a 100% presence of *Cabomba* is covered with black woven geo-textile over a distance of 100 meters. The experiment was duplicated . Research hypothesis: is blocking sunlight during one growing season sufficient to stop the development of *Cabomba*?
  The bottom of a canal was covered with 10 x 10 m stretch black woven geo-textile. Research hypothesis: is coverage of the sediment during one growing season sufficient to stop the development of *Cabomba*?
- **regular dredging**: a canal with a 100% presence of *Cabomba* is completely cleared of vegetation (using a weed cutting bucket scraping the soft sediment layer) over a distance of 100 meters (in triplicate). Research hypothesis: how effective are standard cleaning methods in the case of *Cabomba* abatement?

- **removing soft sediment by new techniques**: a canal with a 100% presence of *Cabomba* is completely freed from vegetation over a distance of 100 meters by using a powerful water jet to re suspend the vegetation as well as the soft sediment after which the loose material is removed (figure 10). Research hypothesis: is application of this method sufficient to combat *Cabomba*? .
- **blocking the inflow of plant fragments**: within the areas of experiment 2 and 3 several exclosures (figure 11) were placed to block the influx of material (*Cabomba* fragments). Research hypothesis: Is regrowth observed after treatment the result of new growth of residual plants or the result of recolonisation by fragments from elsewhere?

Figure 9. Location of the field experiments, i.e. shading (1), standard dredging (2), dredging with the new technique (3). On location 1a the shading started July 2008(results not included); at the locations indicated with E the standard dredging was repeated in November 2009.

The experiments started in July 2009. Standard dredging in The Netherlands is always in autumn (October/November), so the July dredging was in fact not so standard. At two locations the autumn dredging was also carried out (indicated with E(xtra) in figure 9).

Water samples were taken to follow the P-concentrations in the dredged canals; these samples were taken immediately before dredging, immediately after dredging and three weeks later. The results for total-P and ortho-P are given in figure 12.

Figure 10. Dredging by the new technique. The head with the water jet is raised above water to illustrate its operation.

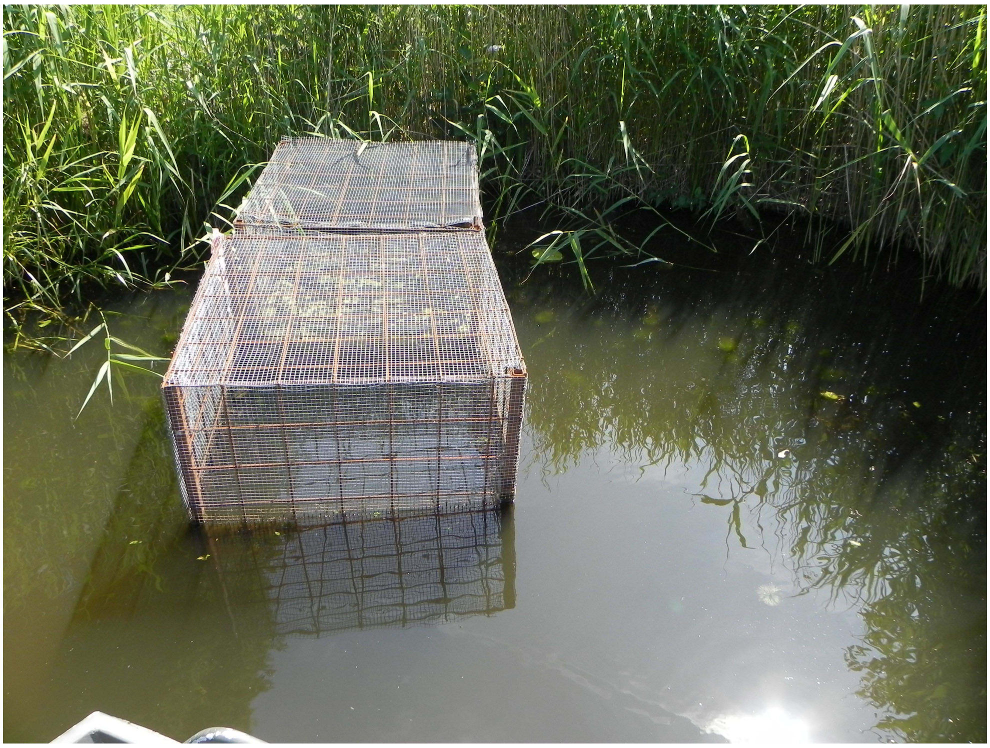


Figure 11. Two cages used to exclude the inflow of plant fragments.

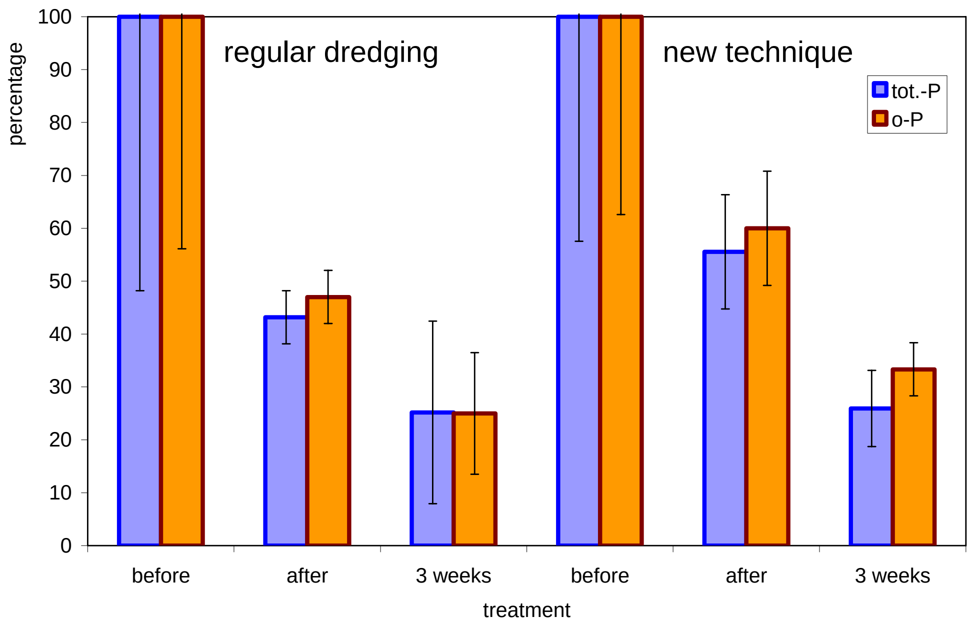


Figure 12. Percentage change in total-P and ortho-P in the water phase for both dredging methods (regular and the new technique). Water samples are taken immediate before dredging, immediate after dredging and long after dredging (over 3 weeks).

4.3. Results

Blocking sunlight.

Two stretches of approximately 115 m were covered by black woven geotextile in June 2009. In June 2010 both stretches were checked for regrowth of *C. caroliniana*. All macrophytes under the cover died, whereas in the stretch of app. 100 m between the covered areas, the plants flourished. Again in July 2010 we visited the sites and still no regrowth was seen under the geo-textile.

In July 2010, we removed part of the geo-textile in one stretch, in such way that open stretches of 20 meter were created (as sketched in figure 13). The visit of August 2010 showed that even in those re-opened stretches no re growth of macrophytes was observed.

Figure 13. The re-opened stretch in experiment 1. The covered stretches (black) of each 25 m were alternated with re-opened stretches (white) of 20 m.

Conclusion: Blocking the sunlight will kill all underwater vegetation. What the effect of re-opening will be over a longer time period than one month is not – yet – clear from this experiment. It is, however, to be expected that after re-opening regrowth of macrophytes with a rhizome will gradually occur and, dependent on the inflow of fragments also *C. caroliniana* can re-enter and establish in the open areas.

The experimental coverage of the sediment did not result in a suppression of *Cabomba*. Sedimentation on top of the geo-textile and re colonisation by propagules from the surrounding areas resulted in re-establishment of *Cabomba*

Regular dredging.

This experiment was carried out in triplicate over stretches of app. 100 m, alternating with untreated stretches of app. 100 m. The experiment started in June 2009 and site visits were made in June 2010 and August 2010. In one of the treated stretches the dredging was repeated in November 2009 (stretches E and 2+E in figure 1). In each of the treated stretches cages were placed to create an area (1 m^2) where influx of *C. caroliniana* fragments was blocked (Figure 13).

In June 2010 *C. caroliniana* covered 75-90 % of the dredged ditch stretches; this was also true for the stretch that was dredged twice in 2009. In August 2010 the cover was 80-90 %. Excluding the inflow of *C. caroliniana* fragments had major effects on the vegetation. This was also due to the fact that grazing by water fowl was also excluded. Most of the cages were filled with *Elodea nuttallii* (15-40 % cover), clearly a result if both the absence of grazing and the very low cover and consequently low competition with *C. caroliniana*. In June 2010 we counted an average of 9 (3-30) short shoots of *C. caroliniana* in each of the cages; in August 2010 this was the same, when *E. nuttallii* increased to 40-100 % cover and most of the cages were completely covered with flab (floating algal beds). Other plants that were encountered - in low numbers - in the cages were *Myriophyllum spicatum*, *Spirodela polyrhiza, Lemna minor, Utricularia vulgaris* and *M. heterophyllum* (!).

Conclusion: Regular dredging of the ditches to get rid of *C. caroliniana* will not result in a permanent removal of this (and other) macrophytes. Even if dredging is applied twice a year, it will just result in a temporary decrease of the plant's biomass. Major cause of the excessive growth of *C. caroliniana* is the influx of fragments and the absence of competition by other waterplants, as shown by the cage experiments. Interesting was the fact that *E. nuttallii* and also *U. vulgaris* were dominating when *C. caroliniana* was absent and also grazing was excluded.

<u>Removing soft sediment by new techniques</u>.

This experiment was carried out over three different stretches of over 100 m. In two of the stretches 3 double cages were placed to study the effect of excluding both the inflow of plant fragments and the effect of grazing by water fowl. The experiment started in June 2009 and site visits were made in June 2010 and August 2010.

In June the percentage cover by *C. caroliniana* in the three stretches varied from less than 5–10 % and in August this increased to 25-50 %. Other macrophytes were *M. spicatum, M. heterophyllum* and *Ceratophyllum demersum* in low densities.

In most of the cages *C. caroliniana* was completely absent both in June and in August. In those cages we encountered *Hydrocharis morsus-ranae, S. polyrhiza, E. nuttallii, Potamogeton crispus* and *M. spicatum* in low numbers in June and in August also *P. obtusifolius* and *U. vulgaris* in low numbers, but in the more exposed cages there was a 100 % cover of flab, whereas in most cages *E. nuttallii* reached a cover of 25-100 %. In one stretch we found a few shoots of *C. caroliniana* in the cages, growing from the side of the cages or from the sediment.

Conclusion: This new technique, in which the loose sediments together with the rooted macrophytes are vigorously re-suspended through a water jet stream, turned out to be quite successful. This technique can still be improved, particularly in the collecting and removal of the re-suspended plant material. The experiments with the cages indicated that the inflow of plant fragments is the major route for recolonisation by *C. caroliniana*. Particularly in the ditches where the shoreline vegetation consists of reed, shrubs and trees, it will be difficult to remove the fragments completely. During our field visits we noticed that the main source of recolonisation by *C. caroliniana*, and also by *M. heterophyllum* was from those shorelines. Although very promising, also this technique of improved dredging will only result in a temporary removal of *Cabomba* when the species is still present in connecting waters at close proximity.

4.4. Discussion

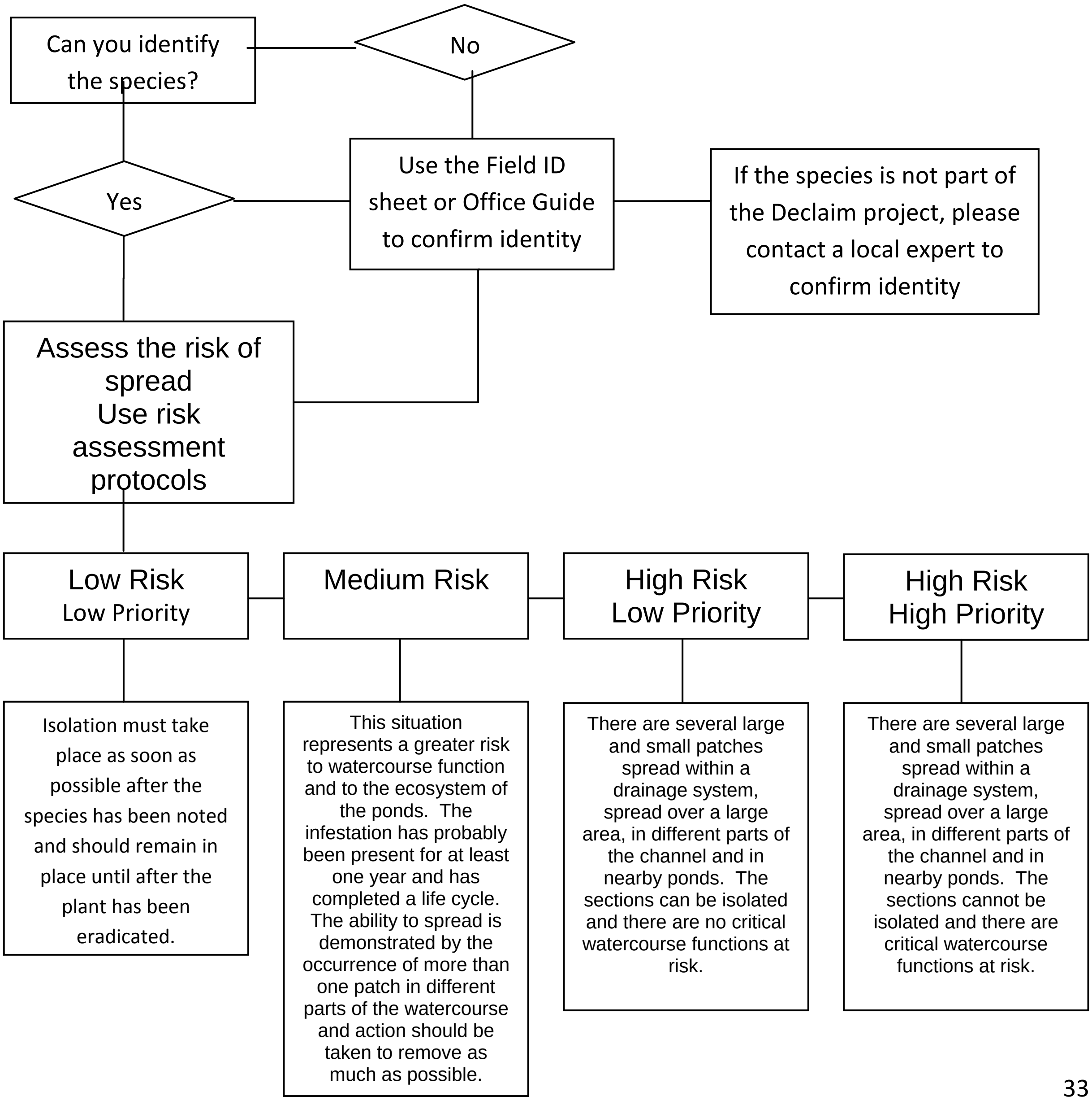
The technique, in which the loose sediments together with the rooted macrophytes are vigorously re-suspended through a water jet stream, has to be further developed. This has to be tested on a longer time scale including control experiments, in which conventional dredging techniques are applied. The use of cages in which the inflow of plant fragments is blocked, is essential.

5. Decision Support System

5.1. Objectives

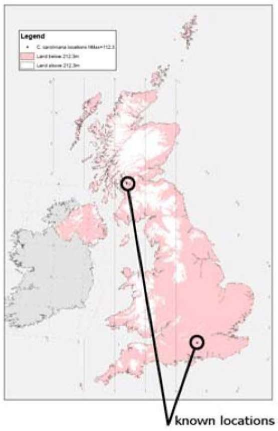
The objective of this work package is to derive from the current practices in aquatic weed management and from the results of Work packages 2, 3 and 4 a prototype DSS. This DSS will be disseminated amongst bodies involved in water management for review.

The DSS will permit the application of best practice derived from fundamental understanding of the ecology and growth strategy of the species in question, and the application of existing management techniques to achieve optimum control.



5.2. Information for use in the Field

5.2.1. Identification



Areas at Risk of Colonisation in the UK are marked in pink on the map.

Any suitable habitat (see below) in this area could be at risk from this species

Cabomba caroliniana
(Fanwort)

Field Recognition Guide

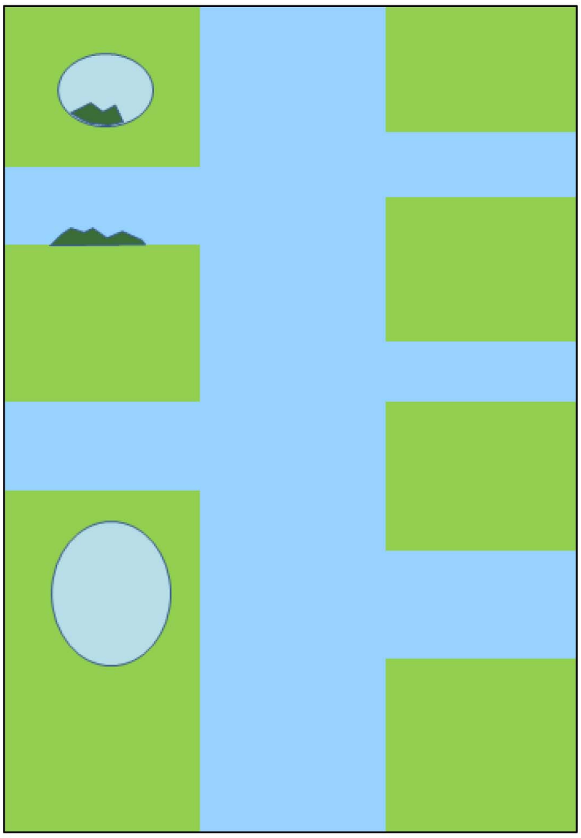
Preferred habitat: slow flowing or static shallow watercourses, ponds, ditches, predominantly with clear water. The plant visible from April onwards

Key features: leaves opposite on stem in fan shape, white flowers with yellow centre from July with floating leaves

Reporting: please inform the Non Native Species Secretariat at www.nnss.org giving grid reference, extent of infestation, photograph and date of observation, and the Biological records centre at http://www.brc.ac.uk/contact.htm

Further Action: Assess the risk of the population you have observed using the risk assessment sheet provided in this pack

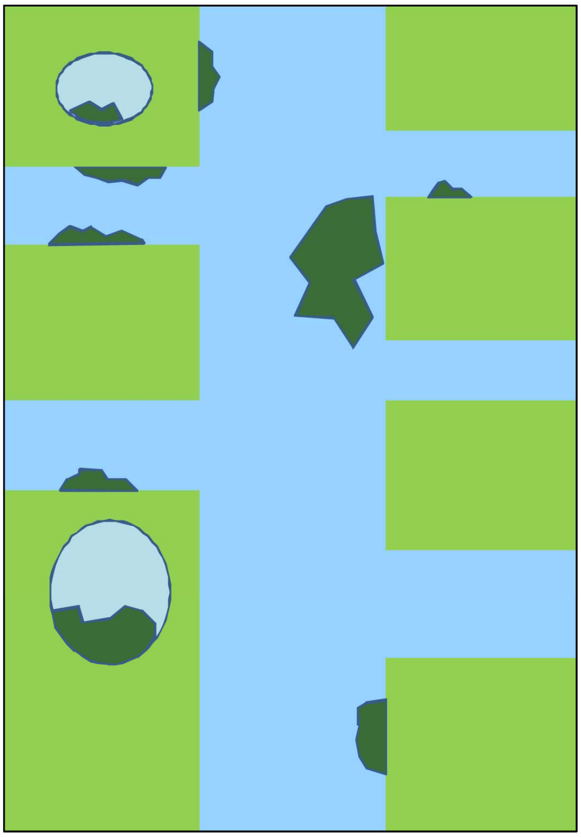
5.2.2. Risk assessment



LOW RISK
The occurrence is limited to a few square metres at one location.

ACTION:

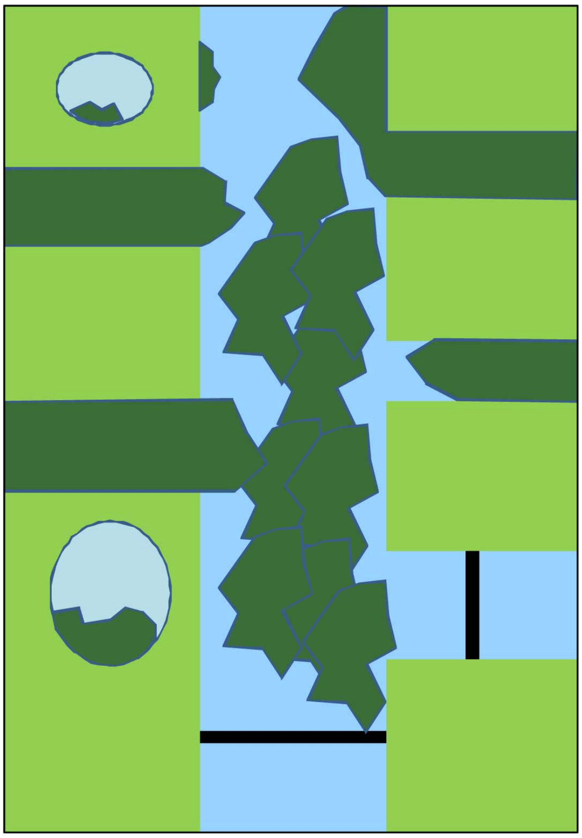
1. Inform appropriate manager, authority, national organisation
2. Arrange for removal by manual / hand picking.
3. Ensure no fragments get out of the side channel into the main river, or spread to nearby ponds.



MEDIUM RISK
There are several small patches of less than ten square meters spread within a short distance, but in different parts of the channel and in nearby ponds.

ACTION:

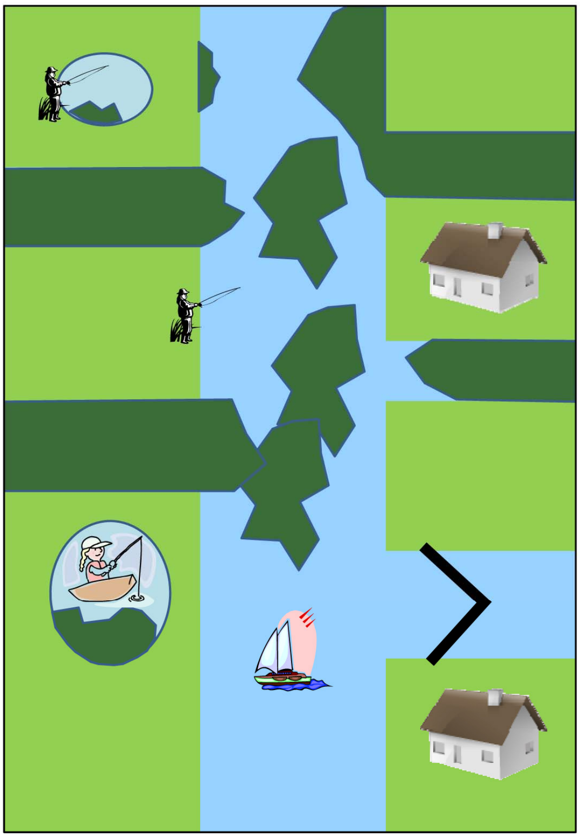
1. Inform appropriate manager, authority, national organisation
2. Arrange for removal by manual / hand picking.
3. Ensure no fragments spread form the small patches by isolating side channels or retaining patches in large channels by using floating barriers etc.
4. Monitor for regrowth at 4 week intervals



HIGH RISK – LOW PRIORITY
There are several large and small patches spread within a drainage system, spread over a large area, in different parts of the channel and in nearby ponds. The sections can be isolated and there are no critical watercourse functions at risk.

ACTION:

1. Inform appropriate manager, authority, national organisation
2. Arrange to isolate the section from water movement for as long as possible.
3. Arrange for treatment by manual / hand picking of small patches, mechanical removal of large patches followed by hand picking or by herbicide treatment
4. Ensure no fragments spread form the small patches by isolating side channels or retaining patches in large channels by using floating barriers etc.
5. Monitor for regrowth at 4 week intervals



HIGH RISK AND HIGH PRIORITY
There are several large and small patches spread within a drainage system, spread over a large area, in different parts of the channel and in nearby ponds. The sections cannot be isolated and there are critical watercourse functions at risk.

ACTION:

1. Inform appropriate manager, authority, national organisation
2. Arrange for removal by manual / hand picking and by any means possible. Try to contain each patch to prevent fragmentation and spread.
3. Protect pumps, sluices and other structures from becoming blocked by vegetation.
4. Ensure no fragments spread form the small patches by isolating side channels or retaining patches in large channels by using floating barriers etc.
5. Monitor for regrowth at 4 week intervals

5.3. Information for use in the Office

This information is produced as a separate document, both in printed form and in PDF form for access via the website http://www.q-bank.eu/Plants/ . Scroll for header: Control

Cabomba caroliniana A. Gray

A guide to Identification, Risk Assessment and Management

Background and Ecology

What is it?

Cabomba caroliniana A. Gray is a submerged rooted, freshwater perennial plant with short, fragile rhizomes. The erect shoots are upturned extensions of the horizontal rhizomes. The shoots are grass green to olive green. The leaves are of two types: submersed and floating. The submersed leaves are finely divided and arranged in pairs on the stem. The floating leaves, when present, are linear and inconspicuous, with an alternate arrangement. They are less than 15mm long and narrow (less than 6 mm). The leaf blade attaches to the centre, where there is a slight constriction. The flowers are white and small (less than 15 mm in diameter), and they float on the water surface (Fassett, 1953; Radford 1968; Ørgaard 1991). *Cabomba* is a small genus of aquatic plants originating in the neotropics and adjoining warmer temperate zones. There is a great deal of vegetative similarity among the taxa, making the genus taxonomically difficult (Ørgaard 1991). In addition it can be confused with several other aquatic species, including *Ceratophyllum demersum, Myriophyllum aquaticum* and *Ranunculus circinatus.*

Where does it grow?

This species grows rooted in the mud of stagnant to slow flowing water, including, lakes, ponds, canals, and ditches. The species was introduced to natural watercourses in the Netherlands and the UK via discarded or deliberately planted aquarium plants (Ørgaard 1991).

Identification

Cabomba is a small genus known only from the warm and temperate regions of the New World. Its systematic position is somewhat uncertain, but it is usually placed, along with *Brasenia*, in a subfamily of the Nymphaeaceae.

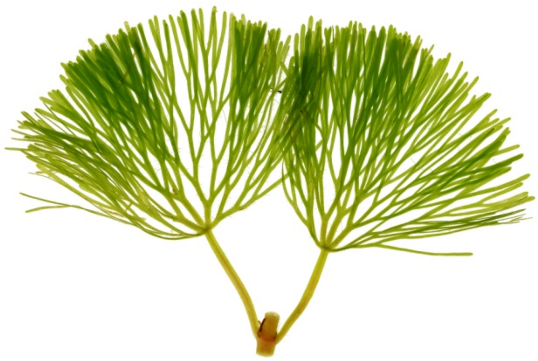
Unlike many aquatic plants, *C. caroliniana* is morphologically very similar in all locations, and does not vary its shape with altered environmental conditions. Only one specimen has been found with leaflets in a 3D formation, rather than as a flat fan. (Valkenburg, pers.obs., 2010). The plants are always strictly aquatic, completely submerged except for the flowers at flowering time and, sometimes, a few floating leaves. The submerged leaves are opposite and divided into 5-7 parts at the summit of the relatively long petiole; each part is divided dichotomously into many narrow segments.

Floating leaves, when present, are borne alternately on the stem; the blades are peltately attached to the petioles and have a firm texture like that of a water-lily. They may be very narrow and tapering to the ends, or narrow and forked, or broadly oval (Fassett, 1953)

Morphological description:

Flowers 6-12 mm. long and 6-15 mm in diameter; tepals in 2 rows of 3, rounded at tip, slightly wider above the middle, white, yellow on the auricles and sometimes purplish-tinged on the margins; carpels (2-)3(-4); stem with dense red tomentum on the uppermost unelongated internodes; terminal divisions of submersed leaves slightly spatulate, 0.3-0.8(-1.8) mm. wide near the tip and slightly narrower toward the base, sometimes with red flecks or short lines, the midrib obscure or obsolete; floating peltate leaves 1-3 mm. wide, entire or somewhat sagittate at base.

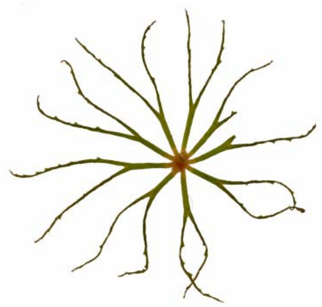
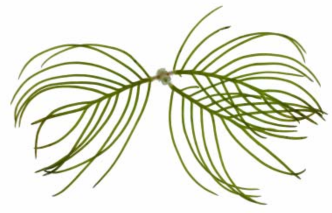
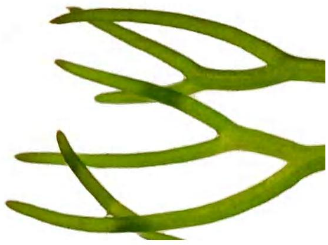
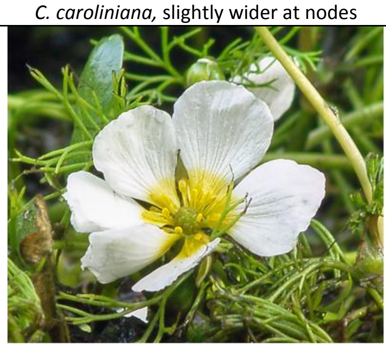
***Cabomba caroliniana* leaflet shape**



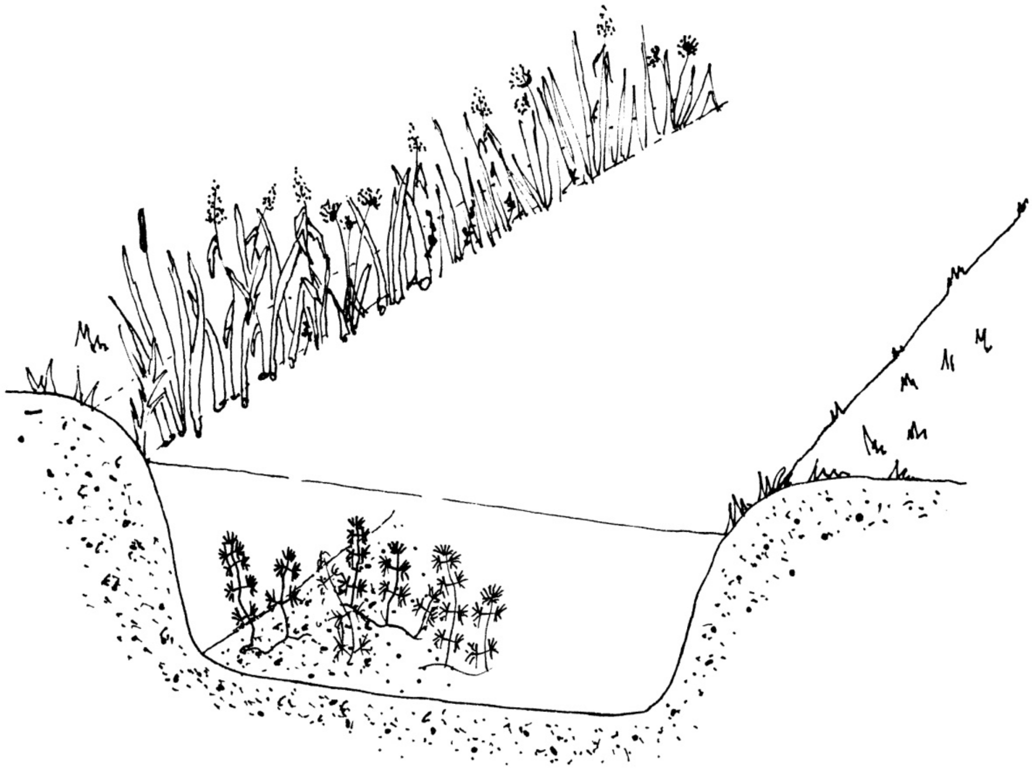
Leaflet arranged opposite on stem, dichotomous equal branching between 5 and 7 times, leaflets linear in outline with blunt ends. Floating leaf entire or sagittate (arrow head shaped). No flowers until floating leaf formed.

White flower petals in whorls of three with yellow centre and anthers. White stigmas.

Not to be confused with:

Ceratophyllum demersum	*Ranunculus circinatus*	*Myriophyllum spicatum*
		
Leaflet Leaflets arranged around stem	Leaflet Short petiole	Leaflet (3-)4-5(-6) leaflets arranged in whorl on stem. Leaflets feather like
		
Stem detail Red stems, frequent branching	Stem detail Frequent branching	Stem detail Almost equal internode length, occasional red stems
		
Detail of leaflet tip Horns evident	Detail of leaflet tip Tapering tips, sharper than *C. caroliniana,* slightly wider at nodes	Detail of leaflet tip Sharp tips, single branch
		
	Flower detail Petals in single whorl	Flower detail Male flowers held above female flowers on single stem

Life cycle



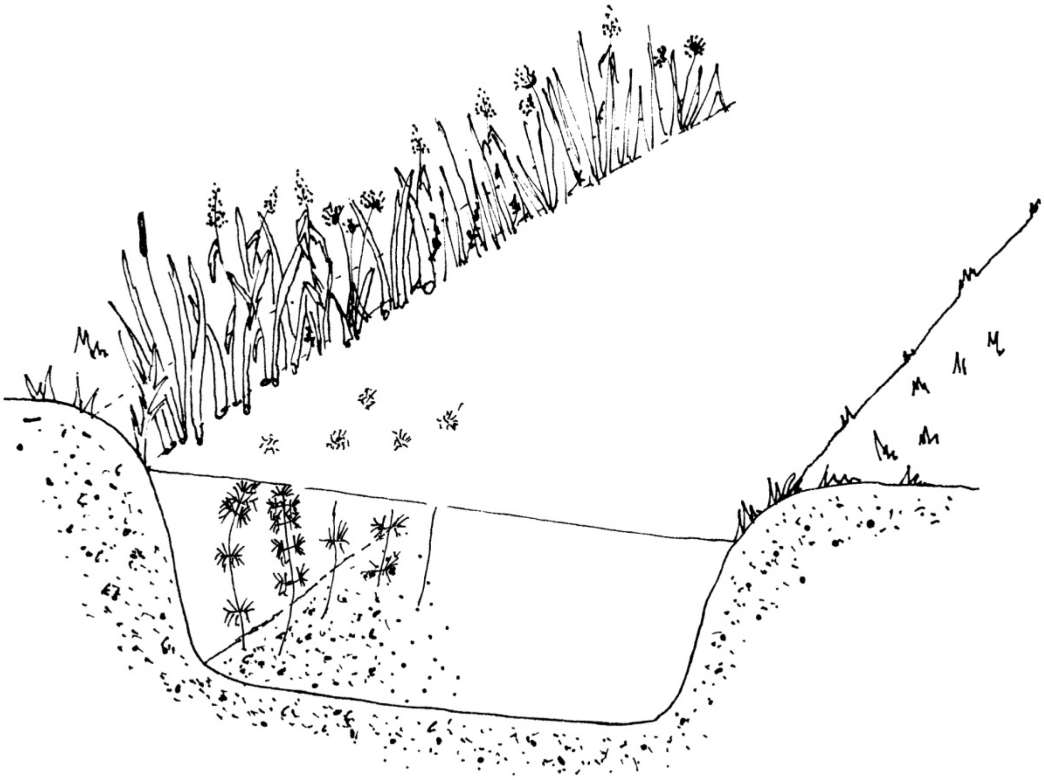
***Cabomba* in early Spring**

In spring, single stems grow from horizontal overwintering shoots. The internode length is large at the base of the plant and decreases as the stems get closer to the surface. Plants remain as single stems and branching is absent.

Management Weak Point: Shading, using either dyes if in static water, or floating fabric if located in flowing system, or drainage channel.

Management Restrictions: There are restrictions on mowing, dredging re-profiling and cutting between the middle of March and the end of May, and in addition these activities are not recommended between June and the middle of July.

Action: Cover with opaque floating material, or use dyes in still water.



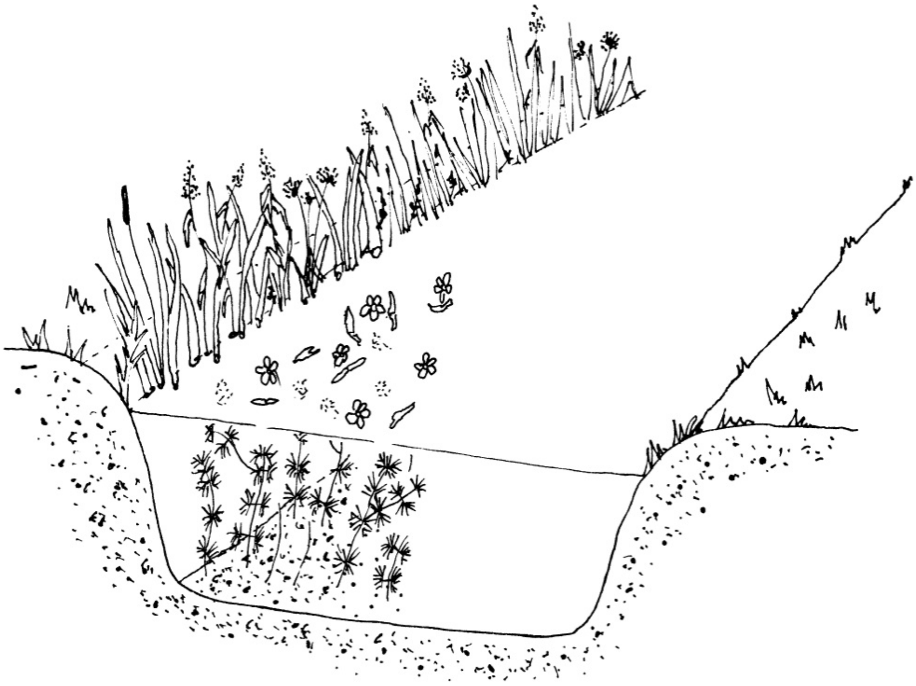
***Cabomba* in late Spring**

In late spring, the single stems reach the surface. Plants remain as single stems and branching is absent, but the single stem density increases.

Management Weak Point: Shading, using floating fabric as the plant is too close to the surface for dyes to have an effect.

Management Restrictions: There are restrictions on mowing, dredging re-profiling and cutting between the middle of March and the end of May, and these activities are not recommended between June and the middle of July.

Action: Cover with opaque floating material.



***Cabomba* in Summer**

In summer, floating leaves are formed and the single stem branches at flowering initiation time. Petioles arise from the stem with floating leaves and white and yellow flowers are borne at the surface. Stems become buoyant and branching occurs further down the stem, increasing propagule numbers.

Management Weak Point: Buoyant stems are suited to washing out using the hydro-jet equipment pictured below

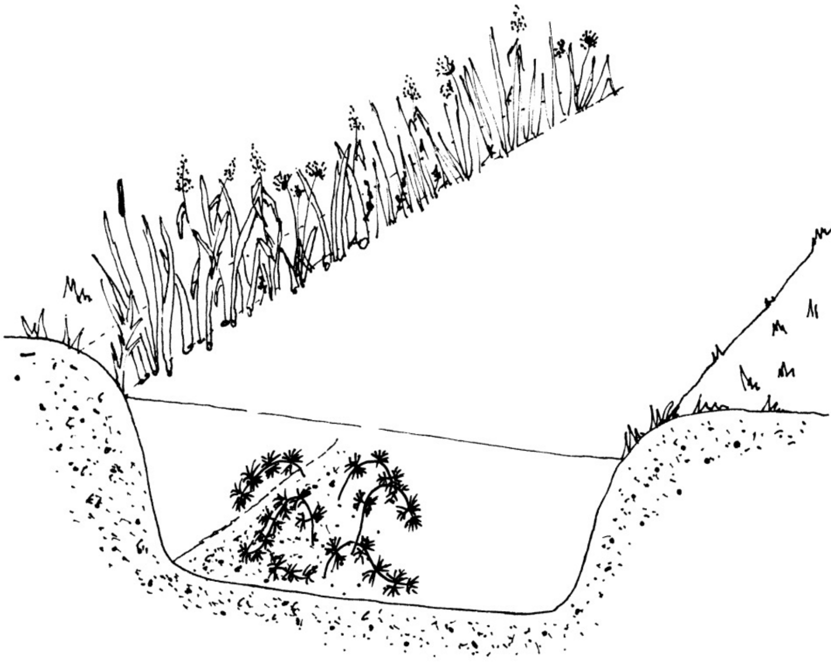
Management Restrictions: There are no restrictions on mowing, dredging re-profiling and cutting should only be undertaken after the middle of July. Please be aware that cutting has no long term effect on this species and may assist spread

Action: Wash out stems using a hydro-jet and collect stems.

***Cabomba* in Summer - Further information**

C. caroliniana reproduces mainly by fragmentation of stems after flowering, although this process occurs at any time of the growing season which is why cutting should be avoided. Collection of fragments after washing out or any other type of management activity is very important to reduce regrowth *in situ* or spread of fragments to new areas. Careful cleaning of equipment should be adopted as a standard practice to prevent transfer by machinery.


DO NOT CUT *Cabomba* in summer as multiple fragments are created and regrowth is very rapid, within 2 months



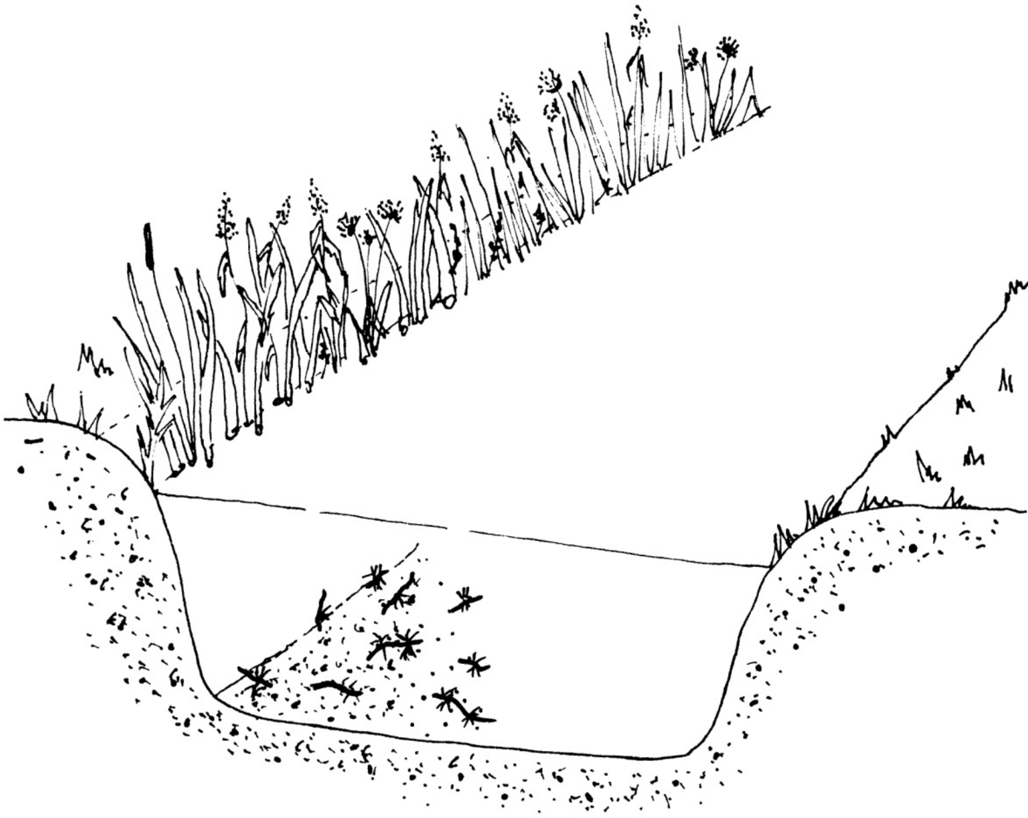
***Cabomba* in Autumn**

In autumn, the stem tips bend over and fall to the bottom, the stem breaks up easily and falls close to the "parent" plant. Rooted fragments disperse

Management Weak Point: None found during this study, cutting or harvesting will only spread fragments around, and as they are no longer buoyant they are difficult to collect

Management Restrictions: No applicable

Action: Cover with opaque floating material to prevent spring growth, or use dyes in still water.



***Cabomba* in Winter**

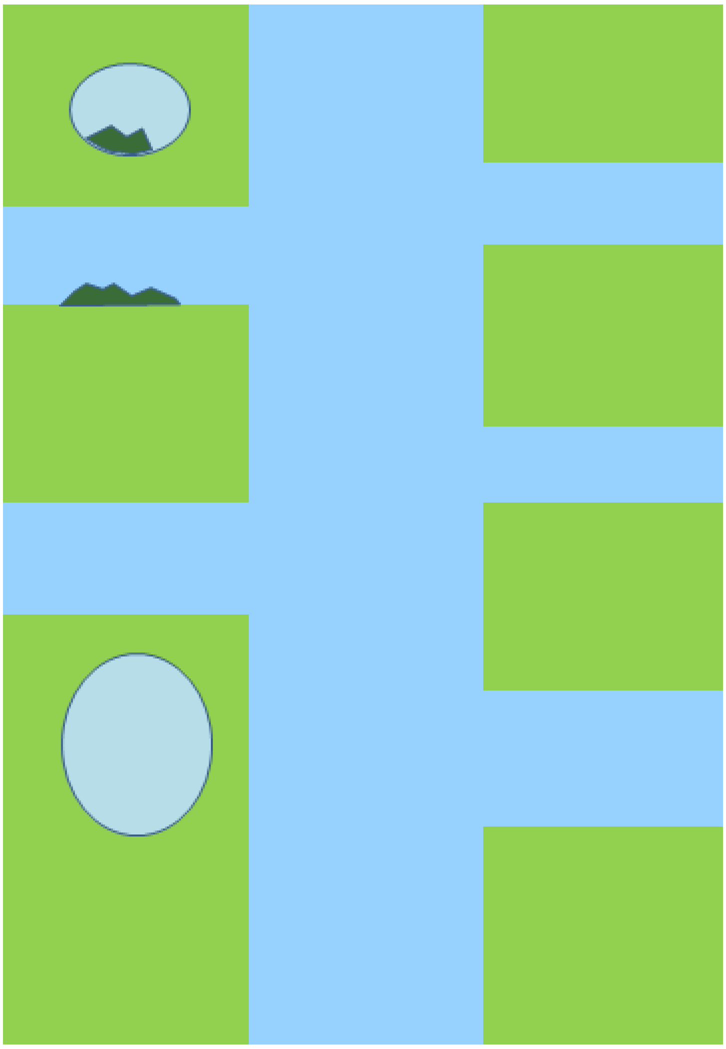
In winter the stems settle onto the sediment and break up, leaving viable nodes and stem apices to regrow in spring. Fragments are shed and move away from the parent plant during flow events.

Management Weak Point: Shading, using either dyes if in static water, or floating fabric if located in flowing system, or drainage channel.

Management Restrictions: There are restrictions on re-profiling the wetted channel and on weed cutting. Neither of which affect the recommended action.

Action: Cover with opaque floating material, or use dyes

Risk Assessment

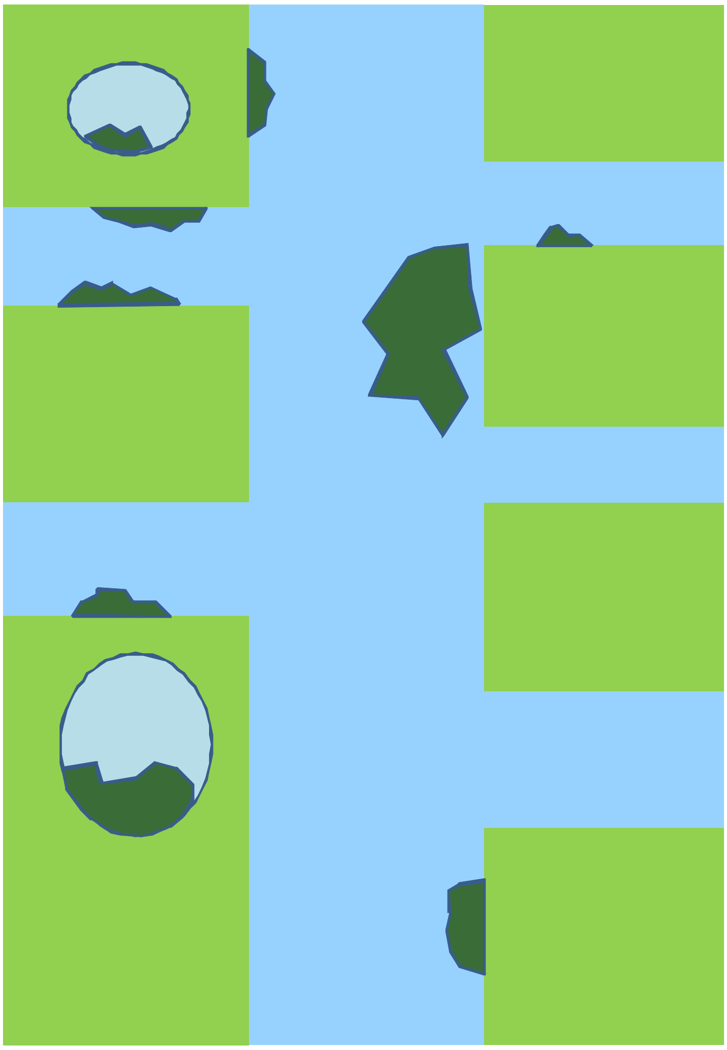


Low Risk High Priority

The occurrence of an invasive species in a new area should always be a case of low risk, because the isolated presence of a small amount of biomass does not present a risk to watercourse function or ecology. However, it should be a high priority to remove or isolate the infested area and to eradicate the species from the area as soon as possible.

In the situation described in the diagram to the left, eradication from the pond would be relatively easy. The patch in the channel should be isolated from the rest of the ditch network and removed as soon as possible. The isolation can take the form of a temporary dam, weighted net or other structure that does not represent a flood risk.

Isolation must take place as soon as possible after the species has been noted and should remain in place until after the plant has been eradicated, and probably for at least 1 year after no more plants have been observed in the area. This is to ensure that a re-occurrence does not occur, caused either by fragmentation of upstream patches, or by deliberate planting.

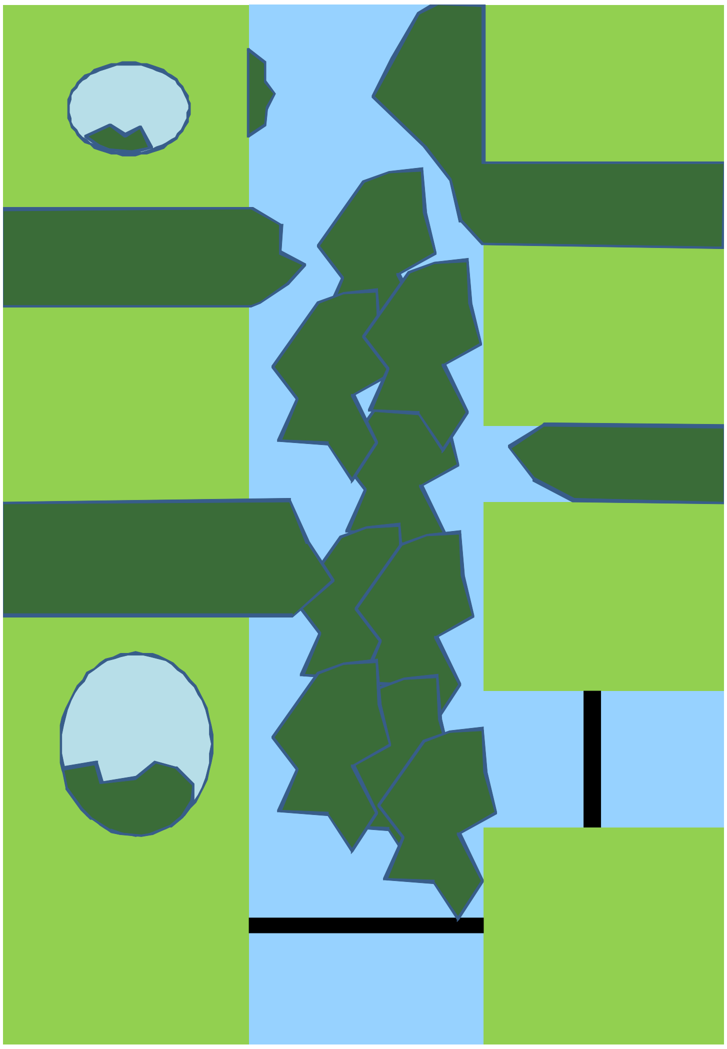


Medium Risk

There are several small patches of less than ten square meters spread within a short distance, but in different parts of the channel and in nearby ponds.

This situation represents a greater risk to watercourse function and to the ecosystem of the ponds. The infestation has probably been present for at least one year and has completed a life cycle. The ability to spread is demonstrated by the occurrence of more than one patch in different parts of the watercourse and action should be taken to remove as much as possible.

Sections of the watercourse that can be isolated must be isolated immediately. Removal of as much as possible of all the patches should be undertaken within 6 months of the first observation. A management plan for removal and eradication of the species could be used to prioritise resources for future observation and monitoring and immediate removal.



High Risk – Low Priority

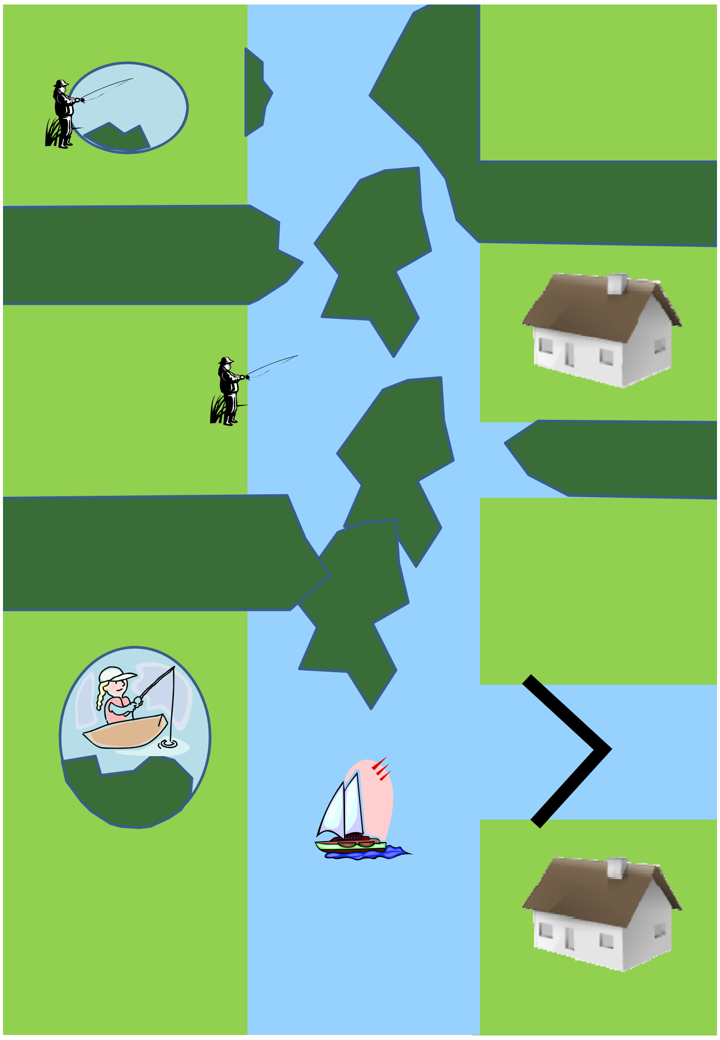
There are several large and small patches spread within a drainage system, spread over a large area, in different parts of the channel and in nearby ponds. The sections can be isolated and there are no critical watercourse functions at risk.

This situation represents perhaps an agricultural drainage network with no pumps, sluices, weirs or risk of flooding to populated areas. The infested section is either contained within an isolated section of watercourse, or can be easily contained.

The spread within this section can be easily monitored and a strategy for eradication or reduction can be implemented as and when resources are available.

Consideration should be given to the impact of the non-native species on the ecology of the drainage network, in terms of angling, bird and invertebrate populations.

Careful disposal of the biomass removed from the watercourse is required to prevent reinfestation of the cleared channel, or any channels along the transport route to the disposal site.



High Risk and High Priority

There are several large and small patches spread within a drainage system, spread over a large area, in different parts of the channel and in nearby ponds. The sections cannot be isolated and there are critical watercourse functions at risk.

This is a situation that should be rare, and results often from inappropriate management of small infestations, the presence of a very aggressive species, or as a result of favourable environmental conditions resulting in rapid spread within a system in less than one year.

Navigation functions are at risk, both from an inability to navigate and because movement of boats and ships will transport fragments of the species elsewhere in the network.

Fishing may be prevented by excessive growth of the target species.

Sluices, locks, weirs, pumps and other critical watercourse management structures may be at risk.

There is a serious risk of flooding of houses and commercial property as a result of the presence of this species.

Rapid and immediate management should take place to reduce the biomass of the target species. Sections, once cleared should be isolated to prevent further spread, and in the main channel a follow up maintenance operation should be undertaken, usually involving manual removal of fragments. Consideration should be given to educational notices and public awareness campaigns in the local are to encourage reporting of additional sites not normally monitored by the responsible authorities.

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