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Reports Environmental Science 468

Content

Summary

Brazilian waterweed (*Egeria densa* Planchon) (Hydrocharitaceae) is native to South America. *E. densa* is a popular cold water aquarium plant in the Netherlands and other parts of Europe and often sold together with the goldfish (*Carassius auratus* (L.)). The plant was first recorded in Dutch nature near Dordrecht in 1944. It was subsequently recorded in nature in Bussum and in the municipality of Doorn. After the year 2000, recordings of *E. densa* have been made nearly every year 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 for a risk analysis of *E. densa.*

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

E. densa thrives in various types of freshwater habitats. In its native range, *E. densa* is found in slow flowing, shallow waters. Outside of its native range it is also found in lakes, ponds, quarry pools and sluggish rivers, streams and canals. Optimum water temperatures for *E. densa* occur between 16 and 28°C and growth occurs in temperatures ranging from 10 to 30°C. Mortality occurs at 3°C and freezing is lethal, however, *E. densa* can survive winter conditions under ice. The plant tolerates a wide range of nutrient, oxygen, carbon dioxide and pH conditions and grows (establishes) best on fine substrates with a high organic content where it tends to dominate. *E. densa* is able to tolerate turbid conditions and low light levels. In very clear water it may not tolerate the high light conditions present near the surface and may be overgrown by other aquatic macrophytes. Future increases in water temperature and continuous introduction pressure will increase the probability of establishment and invasiveness of this species in the Netherlands supposing phosphorus is not limiting in water and substrate.

Introduction of *E. densa* to the Netherlands can be attributed to the trade. The species constitutes approximately 34% of all aquatic plant imports to the Netherlands for use in aquaria and garden ponds. A study carried out in 2006 showed that the Netherlands imported circa 1.7 million units of *E. densa* plants. The plant is sold freely at garden centres, pet shops and over the internet.

Global introductions of *E. densa* have been attributed to the discarding or deliberate planting of aquarium plants in natural waterways. A small proportion of hobbyists also report the disposal of water plants into local watercourses in the Netherlands. The sale of *E. densa* through the plant trade associated with the dumping of unwanted plants to the freshwater network may be an important path of introduction for this species. In the Netherlands, *E.*

densa reproduces vegetatively through branching and fragmentation. Therefore, secondary dispersal of this species will rely on the presence of dispersal vectors that transport fragments to new locations. The most important vectors of secondary dispersal, apart from water current, are related to human activity e.g. boats, anglers, weed harvesters, shoes and clothing.

In the Netherlands *Egeria densa* was first recorded in 1944 near Dordrecht. In 1951, herbarium samples were taken from a pond in Bussum. According to the label that accompanied the sample, the species had already been present for 10 years prior to the time of sampling and had flowered regularly during this time. No *E. densa* records are available in the Netherlands for the 1960s. The next record occurs in the summer of 1976 when *E. densa* was observed in a small canal in the municipality of Doorn. In 1977 the plant was also found at a second location close by in the Gooyerwetering to the Southeast of Doorn. Further records were made from the Doorn area till 1991 after which no further records were made at his location. After the year 2000, records of *E. densa* have been made in nearly every year in the Netherlands. The number of kilometre square grids wherein the species is recorded varied from 0 to 8 per year. In 2008 and 2014, *E. densa* was recorded in seven new kilometre squares where the plant had not been earlier observed. Since 1944, *E. densa* has been recorded in 54 kilometre squares in the Netherlands.

No ecological or socio-economic impacts resulting from *E. densa* have been reported in the Netherlands. Neighbouring countries have experienced few impacts relating to *E. densa*. The lack of major negative ecological or socio-economic impacts in the United Kingdom is attributed to *E. densa*'s low abundance. In Germany, *E. densa* suppressed the formerly widely distributed native broad leaved pondweed (*Potamogeton natans* L.) and fennel pondweed (*Potamogeton pectinatus* L.) in the river Erft, North Rhine-Westphalia. However, since 2003, the abundance of *E. densa* in the river Erft has declined. Moreover, the river Erft is not representative of the German climate as it is a thermally polluted river whose temperature does not dip below 10°C in winter. In Belgium, despite *E. densa* becoming more abundant, it has not yet become invasive. In countries where *E. densa* has become highly abundant such as Australia, the United States and New Zealand, significant ecological and socio-economic impacts have resulted. Some of these locations feature a similar climate to the Netherlands i.e. North and South Carolina, Virginia and Delaware in the USA. At high abundances *E. densa* has been described as an ecosystem engineer whose presence leads to alterations in aquatic habitats and local species composition. Other impacts include restrictions to recreational activity, reduced visual amenity, increased potential for local flooding, obstruction of industrial water intakes and the high cost of remedial management.

In the Dutch code of conduct for aquatic plants (2010), *E. densa* has been declared a list 2 species. This means that it should only be sold when accompanied with a warning about its invasiveness. This should help to stop the release of plants into open water by hobbyists who are unaware of the plants invasive nature or how to properly dispose of it. The results of a 2012 survey of stakeholder groups including aquarists, water gardeners and plant retailers examining the effectiveness of the Dutch code of conduct revealed that *E. densa* was included in a group of species that were most often named by respondents as non-native. However, *E. densa* is often sold in bunches containing several species. In 2012, 40 out of a total of 44 Dutch retailer sites sampled were offering *E. densa* for sale as part of oxygenating plant bunches. Of these, around 18 percent were correctly labelled in line with the guidelines

4

of the code of conduct. Improvements to labelling in garden centres to help inform the public about non-native plants potential invasiveness will help prevent the disposal of *E. densa* to water bodies and reduce further introductions of this plant in the Netherlands. Canadian pondweed (*Elodea canadensis*) and Nuttall's waterweed (*Elodea nuttallii*) may be used as alternatives for use in ponds and aquariums.

Limiting traditional management intervention appears to be the best method to prevent the spread of *E. densa* in the Netherlands. 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 the total removal of the plants is guaranteed. Retaining nets can be used to minimise the spread of fragments released during cutting by isolating the area. The removal of the whole plant, including the root system should be made a priority. Complete eradication is difficult. Cuttings may be composted to prevent them from re-entering the freshwater system. Small populations may be eradicated by covering a treatment area with opaque material such as geo-textile. The lack of light will kill *E. densa* along with non-target species.

Lake drawdown may facilitate the removal of *E. densa*, however, there have been conflicting reports over its effectiveness. Multiple drawdowns lasting between one and five hours in colder temperatures have been most effective in promoting larger decreases in *E. densa* populations. Drawdown may be an effective measure in areas of low ecological value such as artificial channels and reservoirs.

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

The reasons given for the limited distribution and dispersal capacity of *E. densa* at the majority of locations in the Netherlands are based on expert knowledge. Further research is required to support or reject these expert opinions. Establishing the specific conditions that allow the plant to become invasive will allow nature managers to better predict the likelihood that *E. densa* will colonise and become invasive in the Netherlands. This will offer insight into key factors for cost effective management in the future.

1. Introduction

1.1. Background and problem statement

Brazilian waterweed (*Egeria densa* Planchon) is a member of a genus that is endemic to South America. *E. densa* is a popular cold water aquarium plant in the Netherlands and other parts of Europe (Brunel, 2009; Qbank, 2014). It is often sold together with the goldfish (*Carassius auratus* (L.)). The plant was first recorded in Dutch nature near Dordrecht in 1944 (Van Ooststroom *et al.,* 1964). Subsequently, it was recorded in 1951, in a pond in Bussum, and in 1976 and 1977 in the municipality of Doorn. After the year 2000, new recordings of *E. densa* have been made nearly every year.

At the start of this project, there was a lack of knowledge regarding the pathways for introduction, vectors for spread, key factors for establishment and invasiveness, and (potential) effects of *E. densa* in the Netherlands. To support decision making with regard to the design of measures to prevent ecological, socio-economical and public health effects, the Invasive Alien Species Team of the Netherlands Food and Consumer Product Safety Authority (Ministry of Economic Affairs) requested that a risk assessment of *E. densa* be undertaken. The present report reviews available knowledge and data in order to perform a risk assessment of the species.

1.2. Research goals

The major goals of this study are:

- To describe the species and habitat characteristics of *E. densa.*

- To describe the global distribution and to analyse the current spread of *E. densa* in the Netherlands.

- To identify the key factors for dispersal (pathways, vectors, invasiveness) and successful establishment of *E. densa*.

- To assess (potential) ecological, socio-economical and public health effects of *E. densa* in the Netherlands, taking into account the impacts of this species in other geographical areas.

- To summarise available risk classifications of *E. densa* in other countries.

- To review possible management options for the control of spread, establishment and negative effects of *E. densa*.

1.3. Outline and coherence of research

The coherence between various research activities and outcomes of the study are visualised in a flow chart (Figure 1.2). The present chapter describes the problem statement, goals and research questions in order to identify key factors for the dispersal, establishment, effects and management of *E. densa* in the Netherlands. Chapter 2 gives the methodological

framework of the project and describes the literature review, data acquisition and field surveys. Chapter 3 describes the identity, taxonomical status and reproductive biology of the species and briefly mentions differences with similar species. Habitat characteristics of *E. densa* are summarized in chapter 4. The geographical distribution and trends in distribution in the Netherlands, including relevant pathways and vectors for dispersal are given in chapter 5. Chapter 6 analyses the ecological, economic and public health effects of the species. Formal risk assessments and available risk classifications are summarized in chapter 7. Chapter 8 describes the scope of management options and focuses on prevention, eradication measures and control of the species. Finally, chapter 9 draws conclusions and gives recommendations for management and further research. Appendices with raw data and background information complete this report. The report will be used as background information for an expert meeting in order to assess the dispersion, invasiveness, (potential) risks and management options of this species in the Netherlands (Risk analysis).
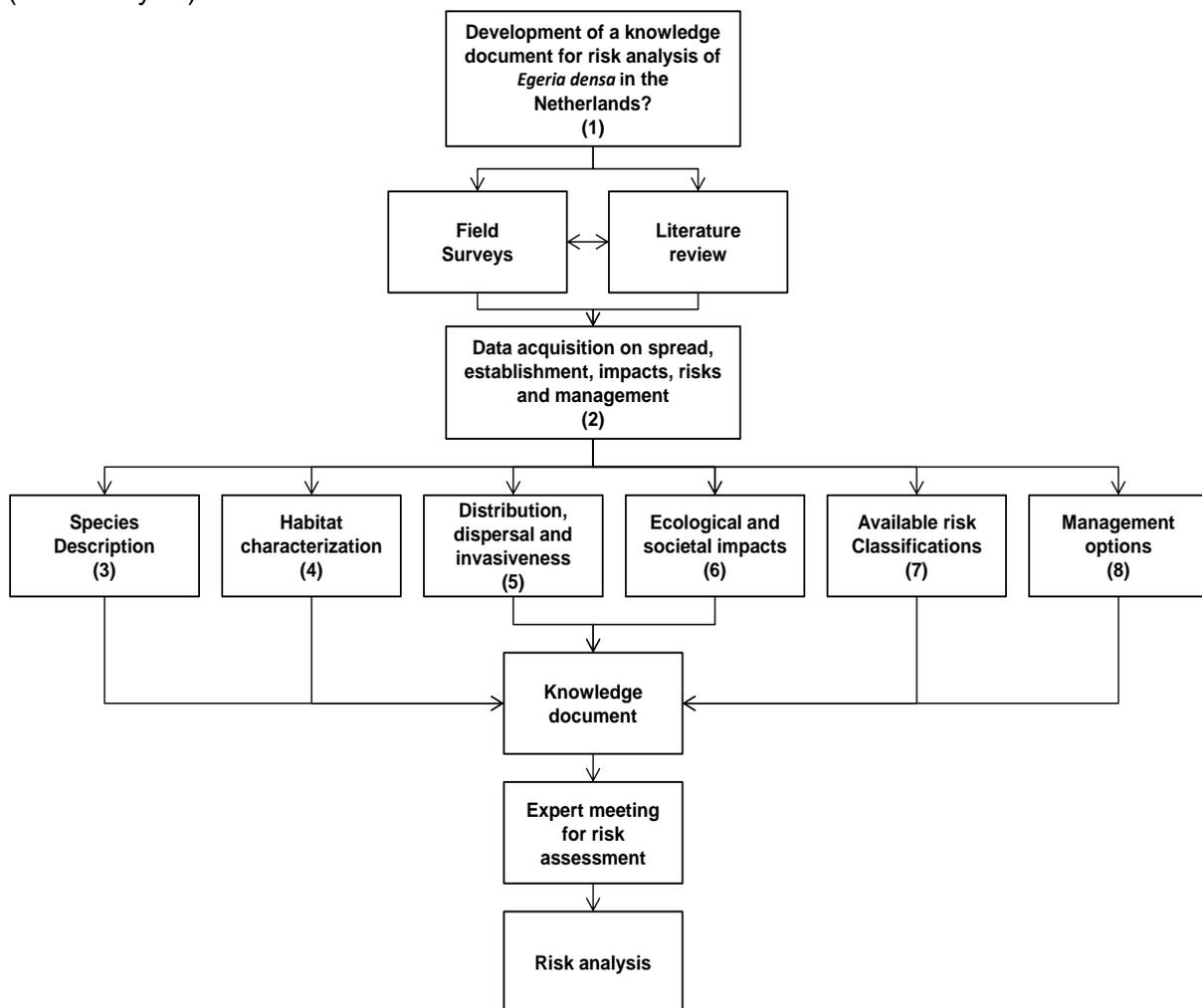
Figure 1.2: Flow chart visualising the coherence of various research activities in order to develop a knowledge document for risk analysis of Brazilian waterweed (*Egeria densa*) in the Netherlands. Chapter numbers are indicated in brackets.

2. Materials and methods

2.1. Literature review

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

An analysis of search engine hits via Google.nl was performed in order to analyse the Dutch general public's perception of *E. densa* and to give an insight into its availability from retailers. The first 50 websites found were categorized according to their content. Google was searched using the terms '*Egeria densa*', '*Egeria densa* kopen'*,* the Dutch common names 'Braziliaanse waterpest' or 'Argentijnse waterpest', and 'Braziliaanse waterpest kopen' or 'Argentijnse waterpest kopen'. Websites that contained names not referring directly to a species e.g. where only the genus *Egeria* was mentioned, were omitted. Attention was focussed on retailer's country of origin, as this was assumed to influence the buying behaviour of hobbyists. Search results relating to videos and pdf documents were analysed but images were not. Scientific articles were omitted from the perception study as the analysis was aimed at information accessible to the general public only. Websites were classified into four groups, 1) retail; 2) educational / regulatory, including the websites of universities, nature organisations, governments and water-boards; 3) hobbyists, including forums and websites containing information on ponds and aquaria; 4) organisations focussed specifically on invasive species, e.g. the Global Invasive Species Database. Websites were further subdivided into two categories, 1) no direct reference is made to the plants invasive nature and / or measures recommended to prevent introduction; 2) a direct reference is made to the plants invasive nature and / or measures recommended to prevent introduction. The total number of websites contained within each category was calculated. If the same website was found using two or three different search terms, it was included in the calculations of both or all three of these search terms. This gives an impression of the accessibility of the websites using different search terms which reflects the ease with which the public have access to them, and the potential level of impact of the information contained.

2.2. Data acquisition on current distribution

Distribution data used in this report are validated data that originate from the National Database Flora & Fauna (NDFF). This database includes data from the internet-portals waarneming.nl and telmee.nl. These data were supplemented with data of herbarium specimens in the Q-bank Invasive Plant database (http://www.q-bank.eu/Plants/) and older

records obtained from W. Holverda (Naturalis Biodiversity Center, National Herbarium of the Netherlands). To generate more insight into the consistency of the species occurrence, voluntary observers were asked, via the FLORON newsletter, to confirm the presence of *E. densa* in kilometre square grids where the species had been recorded in the past. (http://www.verspreidingsatlas.nl/biodiversiteit/actualisering-vaatplanten.aspx?soort=5059).

2.3. Additional field surveys

In August, 2014 several sites where *E. densa* had been earlier reported were visited to check its current presence. At a site near Hoogeveen, the Netherlands (Latitude 52 42.827, Longitude 6 29.658), population size was estimated and the vegetation was described with a Tansley survey method (appendix 1), using the following abundance / dafor codes: d: dominant; a: abundant; f: frequent; o: occasional; r: rare. Data collected were species, location, date of field search, coordinates, water depth (cm), transparency / Secchi depth (cm), width of water body (m), width of emergent zone (m), water flow, water type, surface area covered by *E. densa* (m^2), surface area covered by all species (m^2), number of individuals/shoots and phenology.

3. Species description

3.1. Nomenclature and taxonomical status

Brazilian waterweed (*Egeria densa*) belongs to a genus that is well described by Cook & Urmi-König (1984). The original, legal definition of the species is by Planchon (1849). Table 3.1 gives an overview of the nomenclature and taxonomical status of *E. densa*.

Table 3.1: Nomenclature and taxonomical status of Brazilian waterweed (*Egeria densa*).

Scientific name:
Egeria densa Planchon

Synonyms:
Anacharis densa (Planch.) Vict.
Elodea densa (Planch.) Casp.
Philotria densa (Planch.) Small & St. John

Taxonomic tree

According to Cronquist (1981), CABI (2014):	According to Mabberley (2008), Naturalis Biodiversity Center (2014), Encyclopedia of Life (2014):
Domain: Eukaryota	
Kingdom: Plantae	Domain: Eukaryota
Phylum: Spermatophyta	Kingdom: Plantae
Subphylum: Angiospermae	Phylum: Tracheophyta
Class: Monocotyledonae / Liliidae	Class: Spermatopsida / Liliopsida
Order: Hydrocharitales	Order: Alismatales
Family: Hydrocharitaceae	Family: Hydrocharitaceae
Genus: *Egeria*	Genus: *Egeria*
Species: *Egeria densa*	Species: *Egeria densa*

Preferred Dutch name:
Egeria (Leewis *et al.*, 2013)

Preferred English name:
Brazilian waterweed

Other Dutch names:
Argentijnse waterpest, Braziliaanse waterpest

Other English names:
Large-flowered waterweed (UK), Brazilian elodea, Brazilian-waterweed, dense waterweed (AUS), egeria, leafy elodea (CABI, AUS, NZ), common waterweed, South American waterweed

Native range:
Argentina, Brazil, Uruguay (CABI, 2014).

3.2. Species characteristics

E. densa is a submerged perennial that can live either rooted or free floating (State of Indiana, undated). The plant can grow very rapidly under suitable conditions, stems are approximately 3 mm thick and can reach lengths of between 1.8 to 3 m but are commonly less than 1 m long (Dadds & Bell, undated; State of Indiana, undated; Qbank, 2014). Stems

are erect, cylindrical, sparsely branched, with short internodes and grow until they reach the water surface (Csurhes *et al.,* 2008; Darrin, 2009; Millane & Caffrey, 2014).

Figure 3.1: Brazilian waterweed (*Egeria densa*) showing the whorled leaf structure (Photo: Kristian Peters; Source: Wikimedia commons).

The green leaves are smooth and whorled, 10 to 30 mm long, in general 2 to 6 mm wide and 0.5 to 1 mm wide below the leaf tip. The leaf margins are very finely toothed which is only visible with a hand lens (State of Indiana, undated). Plants usually have four leaves per node but can also have up to five or six (Fig. 3.1) (Csurhes *et al.,* 2008; Millane & Caffrey, 2014; State of Indiana, undated; Dadds & Bell, undated). However, there can be as many as ten leaves at a fertile node (Darrin, 2009). Internode length ranges from 2.5 to 24 mm, depending on nutrients and light availability (Yarrow *et al.*, 2009). Short internodes tend to give the plant a 'leafy' appearance (Csurhes *et al.,* 2008).

Figure 3.2: Flower of Brazilian waterweed (*Egeria densa*) (Photo: David Liu; Source: Wikimedia commons).

Male flowers present in groups of two to four from one spathe, the perianth formed by a calyx consisting of three green sepals, and a corolla made up of three white petals 10 to 15 mm long and stamens 9 mm long (Fig. 3.2) (Millane & Caffrey, 2014). The flowers emerge above the water surface via long stalks (Fig. 3.3) (State of Indiana, undated; Csurhes *et al.,* 2008). Female flowers are carried by an individual spathe, the perianth is similar to that of the male flowers, is ovary unilocular and formed by three carpels. The androecium is only residual with three yellow staminodes. Fruits are berry-like, ovate, 7-8 mm long and 3 mm

wide with a membranaceous and transparent pericarp. Seeds are numerous, fusiform, 7-8 mm long, with a 2 mm filament present at the end (CABI, 2014).

Figure 3.3: Detail photo of Brazilian waterweed (*Egeria densa*) in flower (Photo: QBANK, 2014).

3.3. Differences with visually similar species

A number of species are visually similar to *E. densa* and it is therefore important to differentiate these species in order to prevent misidentification. *E. densa* is easily identified by its large flowers if they are present (corolla leaves 8 to 11 mm). Plants without flowers resemble other *Egeria* species, and *Elodea* species (Fig. 3.4), *Hydrilla* species and *Lagarosiphon* species. *E. densa* can be distinguished from the other genera by examining the leaf whorls. Commonly, *Elodea* features whorls of three leaves, *Egeria* four, *Hydrilla* commonly five leaves and *Lagarosiphon* alternate spirals or pseudo-whorls of three to four. *E. densa* features the longest leaves (15 – 40 mm) of the four genera. In contrast to *E. densa*, *Hydrilla* features rough teeth on the underside of the leaves visible with the naked eye, and stem turions and tuberlike turions that grow underground in the rooting zone. *E. densa* is generally larger than *Elodea* and may grow up to three times the size of these species'. Other species of *Egeria* are best distinguished by the shape and attributes of the leaves. For example, narrow leaf Elodea (*Egeria najas* Planchon) has a toothed leaf edge.
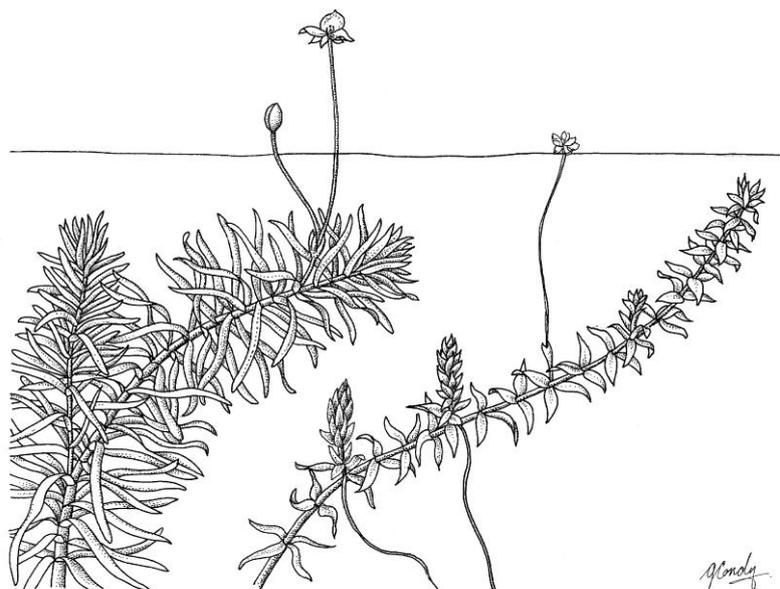
Figure 3.4: *Egeria densa* (left) and *Elodea canadensis* Michaux (right). Drawn by G. Condy, first published in Henderson (2001), ARC-Plant Protection Research Institute, Pretoria.

3.4. Reproduction

In Europe, only male *E. densa* are present in nature, because imported and cultivated plants are male (Haynes, 1988; Botanic Gardens, 2008; GB Non-native Species Secretariat, 2014; Washington State Department of Ecology, 2014). Female flowers are only found in the species' native range and in Chile (Washington State Department of Ecology, 2014; Haynes, 1988; GB Non-native Species Secretariat, 2014). Until now, seed formation has not been observed in *E. densa*'s European range (Lafontaine *et al.,* 2013). Potentially, female plants may also be imported in the Netherlands from countries where the species is native. Whether sexual reproduction and production of germinable seed may occur under environmental conditions in western Europe is unknown. However, it is not expected that successful sexual reproduction will significantly increase dispersal ability and invasibility of *E. densa* in the Netherlands because the plant's ability to spread vegetatively. In its native range as well as in areas where the species is introduced, the plant also reproduces and spreads through vegetative growth, branching and vegetative fragments only (Washington State Department of Ecology, 2001). This sole reproduction strategy leads to the genetically identical monocultures often seen in the United States, Canada, New Zealand and Europe which are genetically distinguishable from similar non-invasive species of aquatic plant (Darrin, 2009; Ghahramanzadeh *et al.,* 2013).

The root system and stems are not very strong and break easily, allowing plant fragments to be carried by currents to inhabit new areas (Yarrow *et al.,* 2009; Washington State Department of Ecology, 2014). Only stem fragments featuring double noded regions which produce lateral buds, branches, and adventitious roots can develop into new plants. These occur every six to 12 nodes along a stem and consist of two single nodes separated by a greatly shortened internode (Lafontaine *et al.,* 2013). *E. densa* has been shown to reproduce relatively well when compared to six other aquatic species that reproduce vegetatively. Of these species studied, *E. densa,* spiked milfoil (*Myriophyllum spicatum* L.) and clasped pondweed (*Potamogeton perfoliatus* L.) showed the best survival and rooting rates (survival rates: 95 %, 84 % and 84 %; rooting rates: 88 %, 45 % and 65 %, respectively) (Vari, 2013).

3.5. Life cycle

In Autumn, *E. densa* suffers a loss in biomass as a result of sloughing and decay of tips and branches. The remaining biomass overwinters at the bottom of the water body in an evergreen, dormant like state. Once a shoot sinks to the bottom, a new root crown may develop at a single or multiple double nodes along the shoot. *E. densa* survives winter by storing carbohydrate in stem tissues but lacks specialised storage organs such as tubers or rhizomes, and does not produce turions. Growth is intiated in spring once the water temperature reaches 10 °C (Washington State Department of Ecology, 2014; Center for Aquatic and Invasive Plants, 2014).

4. Habitat characteristics

4.1. Habitat description

Table 4.1 gives an overview of the physiological tolerances of Brazilian waterweed (*Egeria densa*).

Water type
E. densa thrives in various types of freshwater habitat (Fig. 4.1). Outside its native range, it is found in lakes, ponds, quarry pools and sluggish rivers, streams and canals. (Branquart, 2013; State of Indiana, undated; Dadds & Bell, undated).

Figure 4.1: Brazilian waterweed (*Egeria densa*) at Tilburg, the Netherlands. (Photo: J. van Valkenburg)

Temperature
Optimum conditions for *E. densa* occur between water temperatures of 16 and 28°C (Curt *et al.*, 2010; Yarrow *et al.*, 2009). *E. densa* grows at water temperatures ranging from 10 to 30°C (Getsinger & Dillon, 1984). Riis *et al.* (2012) demonstrated experimentally that growth rate and photosynthesis of *E. densa* are higher in water temperatures ranging from 25 to 30°C. Damage to the plant occurs above 30°C. Mortality occurs at 3°C and freezing is lethal (Washington State Department of Ecology, 2014; Yarrow *et al.,* 2009; Leslie, 1992). However, *E. densa* can survive winter conditions under ice (Haramoto & Ikusima, 1988). Moreover, in Hoogeveen, the Netherlands *E. densa* has been observed surviving under ice during the winter period (R. Pot & J. van Valkenburg, personal observation). The maximum time *E. densa* can survive at low water temperatures is unknown (Lafontaine *et al.,* 2013). The plant survives winter conditions by storing starch in its leaves and stem which it uses for

growth once temperatures rise above 10°C (Washington State Department of Ecology, 2014). *E. densa* requires water that is warmer than the other non-native waterweeds to flourish (GB Non-native Species Secretariat, 2014). In an outdoor competition experiment comparing *E. densa* with curly waterweed (*Lagarosiphon major* (Ridly) Moss), a non-native species recorded in the Netherlands, *E. densa* was found to be more competitive in water at 30°C than water at 20°C. *L. major* was found to be most competitive at a water temperature of 20°C. This suggests that *E. densa* may be more competitive in shallow warm water and *L. major* more competitive in deeper colder water given sufficient light availability (Riis *et al.,* 2012). It is expected that climate change may enable *E. densa* to widen its range to more northerly latitudes in the future (Dadds & Bell, undated).

Flow velocity
In its native range, *E. densa* is found in slow to moderate flowing (maximum 1 m s^{-1}), shallow waters and rarely is it present in fast flowing water sections (Hussner & Losch, 2005; Hussner *et al.,* 2010; Takahashi & Asaeda, 2014).

Depth
E. densa usually roots at depths between 0.15 to 3 m, but a 10 m rooting depth has also been observed (Mony *et al.,* 2007; Wells *et al.,* 1997; Tanner *et al.,* 1990; Hussner & Losch, 2005; Carrillo *et al.,* 2006; Csurhes *et al.,* 2008; Lafontaine *et al.,* 2013; Takahashi & Asaeda, 2014). In U.S. lakes and waterways colonised by *E. densa,* the near-shore areas with depths up to 7 m are most likely to be affected (Darrin, 2009).

Substrate
In the river Erft, Germany, *E. densa* dominated sections with muddy sediments, in largely sand or gravel sections the plants grew poorly (Hussner *et al.,* 2010). In a Japanese study, *E. densa* dominated cohesive soil or fine soil substrates, suggesting a high fertility and a tolerance to oxygen poor conditions (Matsui, 2014). *E. densa* biomass has been negatively correlated with sediment diameter suggesting it prefers fine grained substrates (Haga *et al.,* 2006).

Light
Light is an important factor for *E. densa* success (Hussner *et al.,* 2010). However, evidence from literature appears to be conflicting. According to Barko and Smart (1981), light availability had an overall stronger effect on *E. densa* growth rate and plant morphology than temperature. It cannot tolerate shade and displays the best growth rate at less than 75% cover (Barko & Smart, 1981). Suspended solids concentrations above 30 mg m^{-3}, or a light attenuation coefficient (Kd) above two, are likely to prevent the establishment of *E. densa* in natural systems (Tanner *et al.,* 1993). However, other authors suggest that *E. densa* is not light demanding and is able to grow in turbid waters, appearing to compete best under conditions of low light attenuation (Bini & Thomaz, 2005; Yarrow *et al.,* 2009; Hussner *et al.,* 2010; Branquart, 2013). Experimentation suggests that *E. densa* has a low light compensation point, supporting this view (7.5–16.2 µmol m^{-2} s^{-1}) (Rodrigues & Thomaz, 2010). These differences may be explained by the strong vertical growth displayed by the plant and the ability of detached shoots to float just below the surface allowing development in turbid water (Lafontaine *et al.,* 2013).

Table 4.1: Physiological conditions tolerated by Brazilian waterweed (*Egeria densa*).

Parameter	Medium	Data origin	Occurrence	References
pH	Water	Outside the Netherlands	5.5-8.3 Average 7.6	Bini *et al.* (1999); Hussner & Losch (2005); *Mony et al.* (2007)
pH optimum	Water	Outside the Netherlands	5.5-7.9 Average 7.6	Mony *et al.* (2007)
Temperature (°C)	Water	Outside the Netherlands	Survives under ice; mortality 3; growth: 10-30; optimum growth 16-28; 30 tissue damage; 35 maximum reported	Barko & Smart (1981); Getsinger & Dillon (1984); Haramoto & Ikusima (1988); Di Tomaso & Healy (2003); Yarrow *et al.* (2009); Hussner (2014)
Light compensation point (μmol m^{-2} s^{-1})	Water	Laboratory based study	7.5-16.2	Rodrigues & Thomaz (2010)
Light attenuation coefficient	Water	New Zealand	>2	Tanner *et al.* (1993)
Suspended solids (mg l^{-1})	Water	Outside the Netherlands	40 max	Marin *et al.* (2014)
Suspended solids (mg m^{-3})	Water	New Zealand	30 max	Tanner *et al.* (1993)
Depth range (m)	Water	Outside the Netherlands	0.15-3 usual; 10 max	Wells *et al.* (1997); Tanner *et al.* (1990); Hussner & Losch (2005); Carrillo *et al.* (2006); Yarrow *et al.* (2009); Takahashi & Asaeda (2014); Lafontaine *et al.* (2013)
Water velocity (m s^{-1})	Water	Outside the Netherlands	0-1	Hussner & Losch (2005); Takahashi & Asaeda (2014)
Conductivity (μS cm^{-1})	Water	Outside the Netherlands	34-802	Bini *et al.* (1999); Hussner & Losch (2005)
Salinity (ppt)	Water	Outside the Netherlands	5 max	Hauenstein & Ramirez (1986); Poirrier *et al.* (2010)
Total phosphorus (mg l^{-1})	Water	North Rhine-Westphalia, Germany	0.016-0.34	Bini *et al.* (1999); Roberts *et al.* (1999); Hussner & Losch (2005)
Nitrogen as nitrates (mg l^{-1})	Water	North Rhine-Westphalia, Germany	1.91-3.06	Hussner (2014)
Total organic carbon (mg l^{-1})	Water	North Rhine-Westphalia, Germany	2.88-5.62	Hussner & Losch (2005)
Ammonia-N (mg l^{-1})	Water	Laboratory based study	$\geq$10 affects growth	Su *et al.* (2012)
Substrate	Sediment	North Rhine-Westphalia, Germany; the Netherlands	Organic; fine in-organic (Ge); sand (Ge, NL)	Hussner & Losch (2005), own data

Nutrients

Studies indicate that nutrients are not a major limiting factor for *E. densa* in most systems and that the plant is able to tolerate a wide range of nutrient levels, particularly in the case of phosphorus (Csurhes *et al.,* 2008; Yarrow *et al.,* 2009). Rooted submerged macrophytes like *E. densa* are less vulnerable to differing nutrient concentrations because they are able to absorb nutrients from both the sediment and the water column (Yarrow *et al.,* 2009). Authors have demonstrated that adding additional nutrients to sand substrate within stands of *E. densa* does not result in increased biomass (Mony *et al.,* 2007). Moreover, Bini *et al.* (1999) observed that *E. densa* growth was correlated with low total phosphorus (TP) levels in the sediment and low TP in the water column. However, others report that *E. densa* prefers nutrient rich substrates and is vulnerable to iron deficiency (DiTomaso & Kyser, 2013).

Feijoó *et al*. (2002) suggest that given phosphorus, not nitrogen, is related to increased growth, phosphorus may be more a limiting factor for *E. densa* than nitrogen. Results from a Brazilian study suggest that in several habitats and during certain periods of the year, a shortage of inorganic carbon may limit the growth of *E. densa*. The authors state that inorganic carbon may be a more important limiting factor to *E. densa* than phosphorus and nitrogen because N and P are assimilated from sediment, where they are usually found in high concentrations (De Freitas & Magela Thomaz, 2011).

pH
E. densa is able to tolerate a wide range of pH (5,5 - 8,3), although it seems to prefer acid and humus rich conditions, it also grows in calcareous eutrophic water (Branquart, 2013; Lafontaine *et al.,* 2013; GB Non-native Species Secretariat, 2014). Optimal pH averages at 7.6, and ranges between 5.5 and 7.9 (Mony *et al.,* 2007).

Salinity, ammonia-N, conductivity total organic carbon
E. densa tolerates salinities to a maximum of 5 ppt (Poirrier *et al.,* 2010), and ammonia-N concentrations above 10 mg l^{-1} affect growth (Su *et al.,* 2012). In a German river, *E. densa* was observed in waters with a conductivity of between 715 and 802 µS cm^{-1}, a total phosphorus concentration of between 0.11 and 0.34 mg l^{-1}, and a total organic carbon concentration of between 2.88 and 5.62 mg l^{-1} (Hussner & Losch, 2005).

Metabolism
E. densa possesses adaptive physiological traits related to its metabolism that may contribute to its success as a non-native species (Yarrow *et al.,* 2009). Adaption to low CO_2 and high O_2 concentrations allows the species to continue to grow in difficult conditions (Yarrow *et al.,* 2009; Rascio *et al.,* 1991). *E. densa* shows leaf pH-polarity which generates a low pH at the leaf surface at high light intensities and low dissolved carbon concentration. Low pH shifts the equilibrium HCO_3^-/CO_2 towards CO_2, which passively diffuses into the cell (Lara *et al.,* 2002). The efficiency in using bicarbonate HCO_3^- depends on its concentration in the surrounding water (Pierini & Thomaz, 2004).

4.2. Associations with other species

In the Netherlands *Egeria densa* is usually found in urban waters in association with hornwort (*Ceratophyllum demersum*) or Nuttall's waterweed (*Elodea nuttallii*) and various eutraphent emergent and floating species. In August, 2014 several sites with earlier records of *E. densa* were visited to check its current presence. At most of them the plants were not observed again (see section 5.2). At one site near Hoogeveen, known since 2012, the species was still abundant (appendix 1). This site harboured also four other introduced species (*Lemna minuta*, *Nymphaea alba*-hybrid, *Limnobium leavigatum*, unidentified).

In the river Erft, North-Rhine Westfalia, Germany, at points of moderate flow velocity and turbidity, *E. densa* is often associated with the fennel pondweed (*Potamogeton pectinatus*) and broad-leaved pondweed (*Potamogeton natans*) (Hussner & Losch, 2005). In a California river delta in the USA, *E. densa* was associated with hornwort (*Ceratophyllum demersum* L.) and Eurasian watermilfoil (*Myriophyllum spicatum* L.) (Santos *et al.,* 2011).

4.3. Climate match and bio-geographical comparison

A comparison of climate and biogeography was made between *E. densa's* invasive, non-indigenous global range, native range and the Netherlands.

Koppen-Geiger climate classification
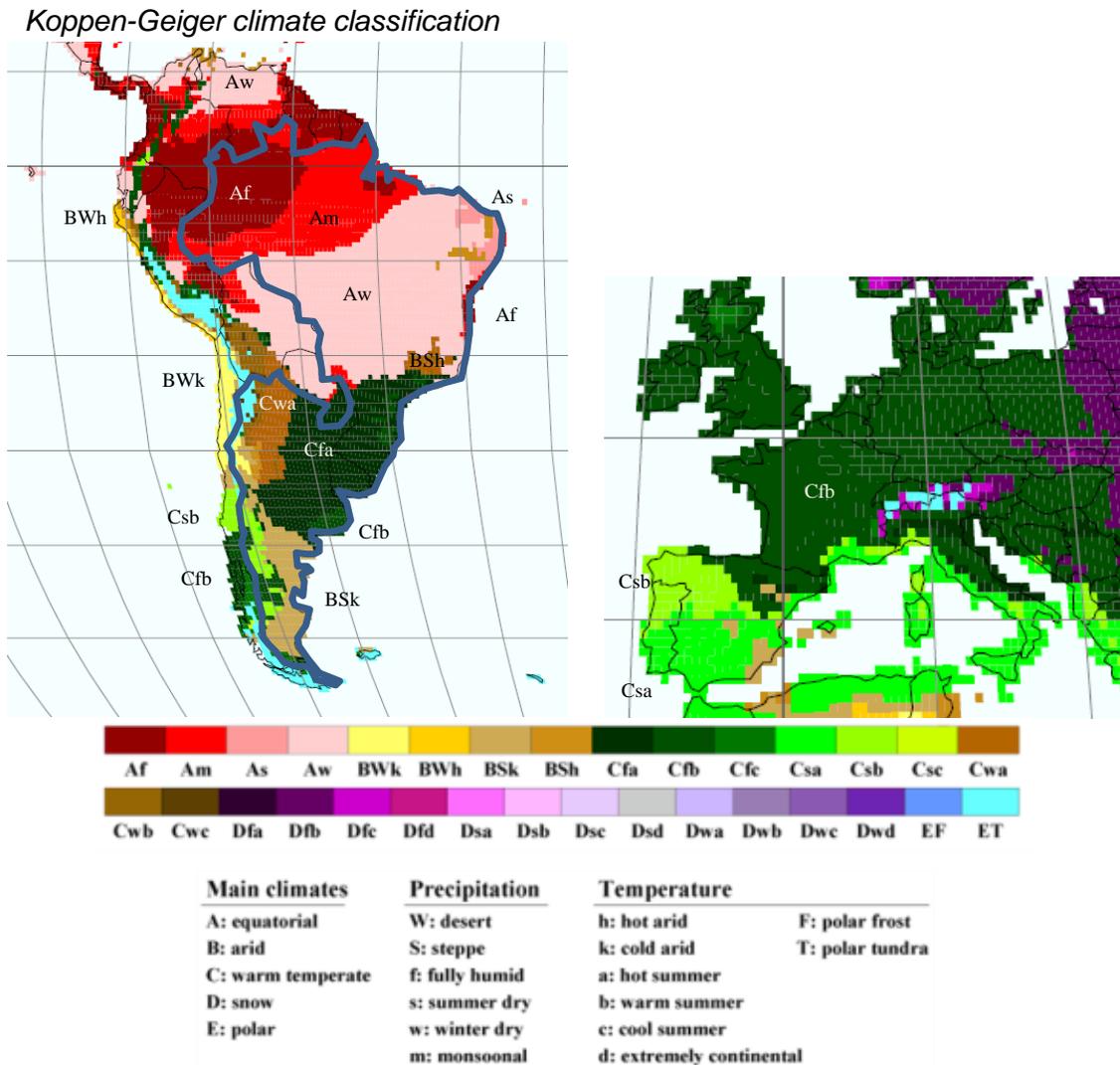
Figure 4.2: Brazilian waterweed (*Egeria densa*) native range climate (blue polygon) matched to the Netherlands (region Cfb). Adapted from Kottek *et al.* (2006).

The Koppen-Geiger climate classification bases its climate maps on recent data sets from the Global Precipitation Climatology Centre (GPCC) at the German Weather Service and the Climatic Research Unit (CRU) of the University of East Anglia in the United Kingdom (Rubel & Kottek, 2010). Climate regions are based on three elements: main climate, precipitation and air temperature. The Netherlands lies within region Cfb which is defined as warm temperate, fully humid, with a warm summer. This classification matches with some areas within the native range of *E. densa* in Brazil, Uruguay and Argentina (Rubel & Kottek, 2010; http://koeppen-geiger.vu-wien.ac.at/, figure 4.2). *E. densa* is recorded in Austria, Belgium, France, Germany, Italy, Southern Ireland, the United Kingdom (including Northern Ireland) and Switzerland, locations that are climatically matched with the Netherlands according to the Koppen-Geiger classification (Millane & Caffrey, 2014).

Larger areas within the *E. densa's* native range are classified within region Cfa (warm temperate, fully humid, with a hot summer). Moreover, some locations where according to CABI (2014) *E. densa* has become invasive, feature a Cfa classification i.e. North and South Carolina, Virginia and Delaware in the USA.

However, *E. densa* may be capable of spreading beyond the limits of what is suggested by climate matching. According to Walsh *et al.* (2013), *E. densa's* non-native range spreads wider than that warranted by its native distribution. This is thanks to its ability to store energy in its basal stems and root crown (Pennington & Sytsma, 2009) allowing recovery from winter senescence, and the rapid reinvasion of water bodies. Despite this, Lafontaine *et al.* (2013) state that *E. densa* is probably not well adapted to Belgium eco-climatic conditions as it can probably not survive the prolonged freezing temperatures in winter.

European eco-region match
The European Water Framework Directive, 2000/60/EC (European Union, 2000), defines a number of eco-regions that reflect similarities in aquatic species living in European river and lake systems (Figure 4.3). The Netherlands lies within eco-regions 13 and 14. The southernmost part of the Netherlands falls within eco-region 13 (the western plains) which is shared with France, Belgium and a small part of western Germany. The remaining area within the Netherlands to the north of eco-region 13, falls under eco-region 14 (the central plains). Eco-region 14 is shared with northern Germany, western Poland, Denmark and southern Sweden.
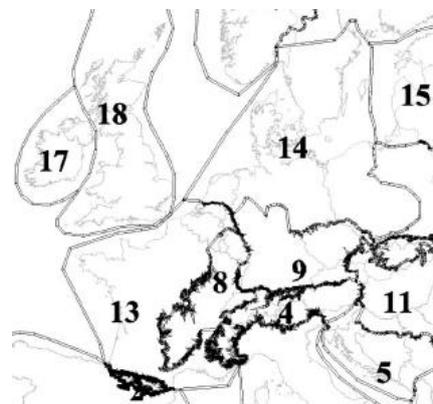
Figure 4.3: Eco-regions defined within the European Water Framework Directive (European Union, 2000). 4) Alps; 5) Dinaric western Balkan; 8) Western highlands; 9) Central highlands; 11) Hungarian lowlands; 13) Western plains; 14) Central plains; 15) Baltic province; 17) Ireland and Northern Ireland; 18) Great Britain.

E. densa has been recorded in countries that share eco-regions with the Netherlands: i.e., Belgium, France and Germany (section 5.1; Denys *et al.,* 2004; Lafontaine *et al.,* 2013). The presence in France and Belgium suggests that rivers and lakes within eco-region 13 may potentially provide suitable habitats for *E. densa*. Germany shares eco-region 14 with the Netherlands. However, the river Erft where *E. densa* has been recorded in Germany is thermally polluted (Hussner, 2014). Therefore, this German record cannot be considered representative of the eco-region 14.

Global climate niche modelling predicts that there will be a progressive increase in the suitable climatic range for *E. densa* outside its native range (Kelly *et al.,* 2014).

5. Distribution, dispersal and invasiveness

5.1. Global distribution

Brazilian waterweed *(Egeria densa)* has spread from its indigenous habitat in South America to several European locations. These include Austria, Denmark (possibly), France, Germany, Greece, Italy, the Netherlands, Portugal (Azores), Spain; Southern Ireland, Switzerland and the UK (including Northern Ireland) (Lafontaine *et al.,* 2013; Millane & Caffrey, 2014; Bracamonte *et al.,* 2014). Records also exist for Hungary, Russia, Georgia, and Turkey. *E. densa* has naturalized on all continents (except Antarctica) including Africa (Algeria, Kenya, South Africa, Swaziland), Asia (Japan; recently also Bangladesh (Alfasane *et al.* (2010), Indonesia, Nepal), North America (50 states in the USA, Canada, Mexico), part of South America (Bolivia, Chile, Colombia, Cuba, Nicaragua, Paraguay, Peru, Puerto Rica; Uruguay), and Oceania (Australia, Cook Islands, French Polynesia and New Zealand) (Mazzeo *et al.,* 2003; Darrin, 2009; Lafontaine *et al.,* 2013; Global Invasive Species Database, 2014; CABI, 2014; Millane & Caffrey, 2014). In its introduced range, *E. densa* has a wide potential distribution; it seems to grow in a wide array of ecological conditions (Yarrow *et al.,* 2009). Figure 5.1 gives an overview of its current world distribution. It should be noted that a single record of *E. densa* in free nature was enough to categorise a country as colonised.

distribution based on published sources
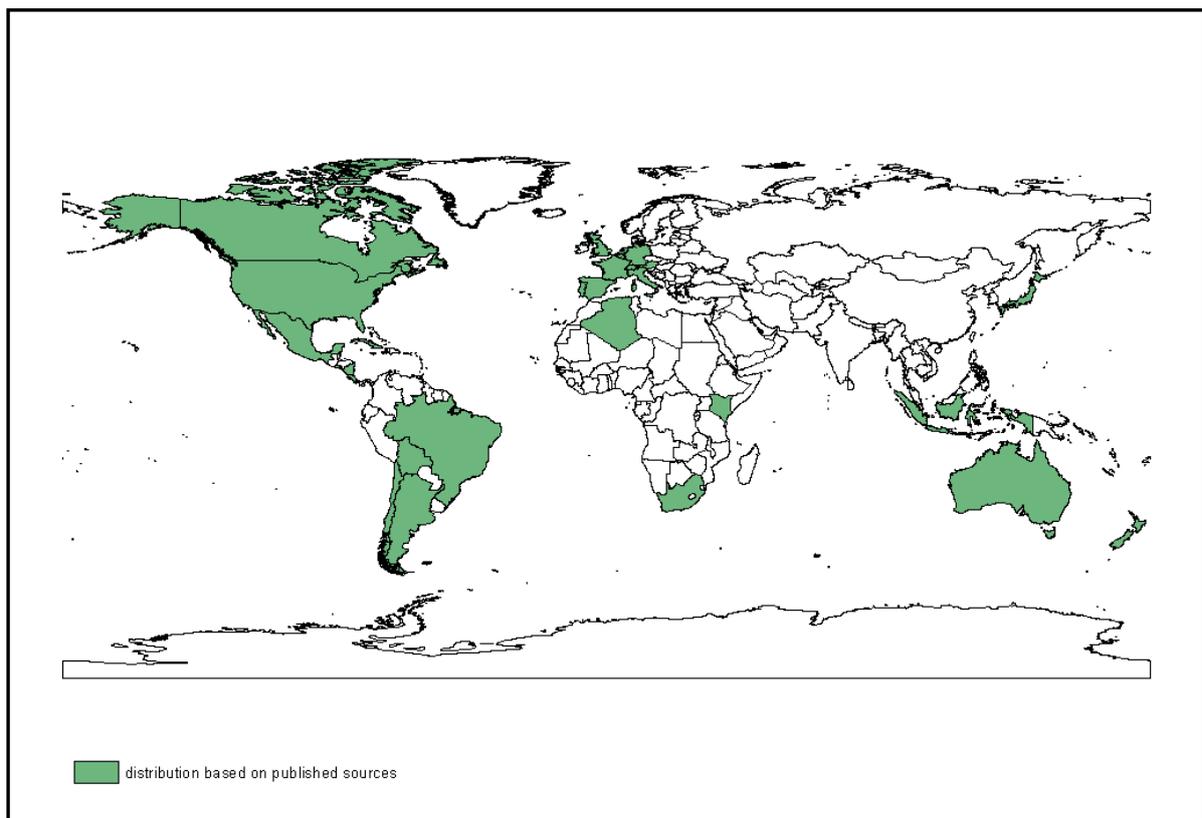
Figure 5.1: International distribution of Brazilian waterweed (*Egeria densa*) based on published sources (www.q-bank.eu).

5.2. Current distribution in the Netherlands

5.2.1 Geographical distribution and trends in range extension

The current recorded distribution of the species in the Netherlands is displayed in figure 5.2.
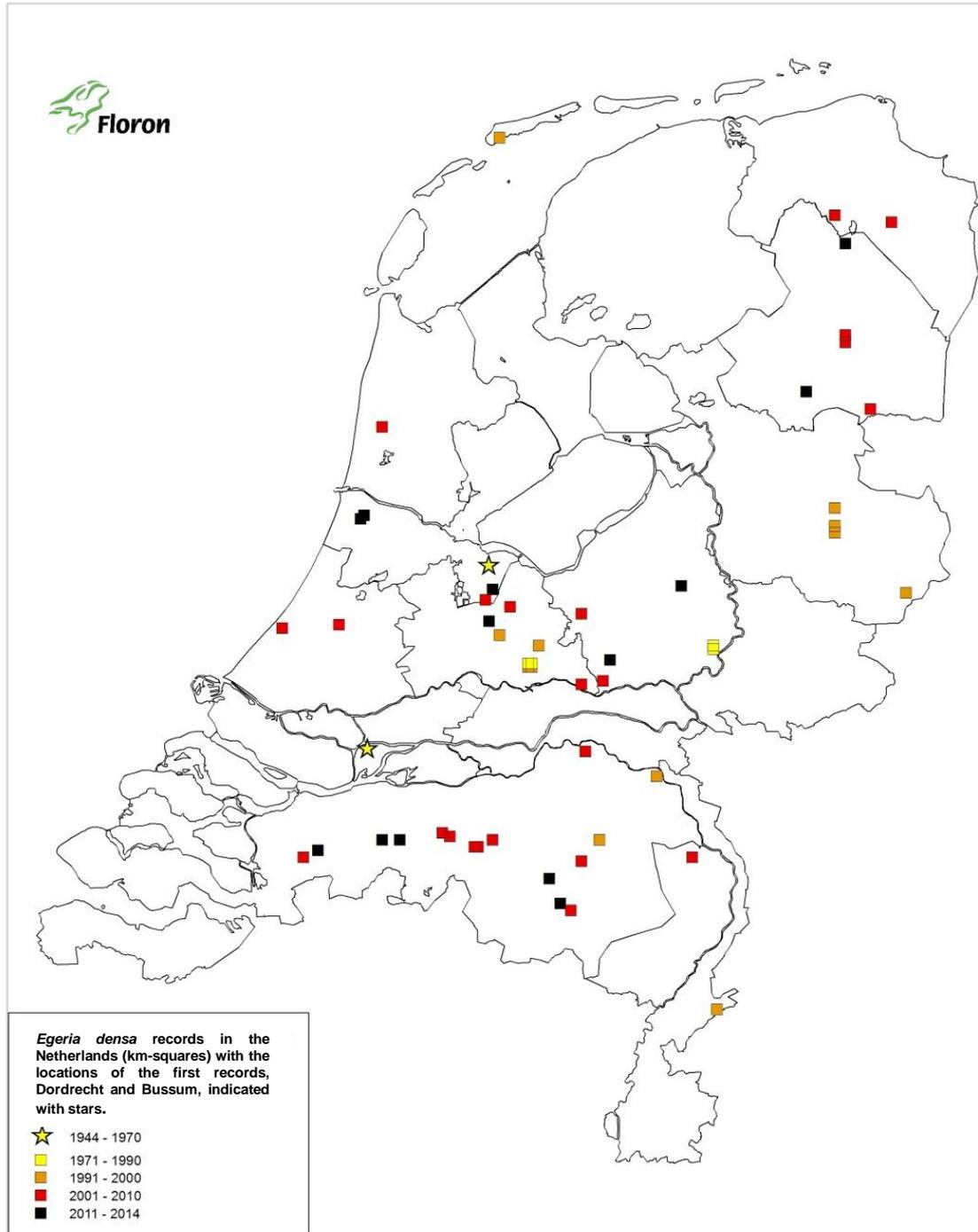
Figure 5.2: Distribution of Brazilian waterweed (*Egeria densa*) in the Netherlands (Data source: see chapter 2.2).

Egeria densa was first recorded in 1944 near Dordrecht. The species was discovered in a drainage ditch close to Groenedijk park during an excursion led by the Netherlands Youth Federation for the Study of Nature (NJN) (van Ooststroom *et al.,* 1964). In 1951, herbarium

samples were taken from a pond in Bussum. According to the label that accompanied the sample, the species had already been present for 10 years prior to the time of sampling and had flowered regularly during this time. This would seem to suggest that *E. densa* was present at Bussum before the official recording at Dordrecht. There are no later records of *E. densa* from either of these locations.

No *E. densa* records are available in the Netherlands for the 1960s, a period known for severe winters. The next record occurs in the summer of 1976 when *E. densa* was observed in a small canal in the municipality of Doorn. *E. densa* was present over an uninterrupted stretch extending for a few hundred metres and was noted for its large white flowers. The canal was dug in 1972, therefore, the plant must have been introduced to the canal only a short time after it was built. The plant blossomed again in 1977, and was also found at a second location close by in the Gooyerwetering area (Floristenclub Gelderse Vallei, 1978; Mennema & van Ooststroom, 1977). Further records exist from the Doorn area till 1991 after which no further records were made at this location.
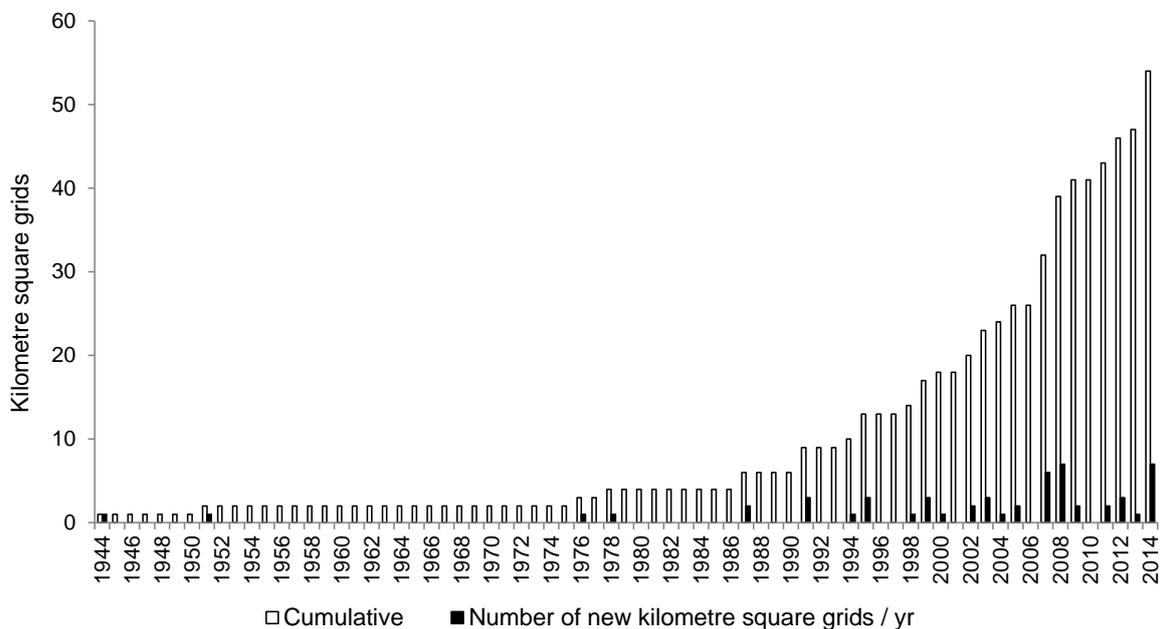
Figure 5.3: Yearly and cumulative records of Brazilian waterweed (*Egeria densa*) in the Netherlands.

After the year 2000, recordings of *E. densa* in the Netherlands have been made in nearly every year. The number of kilometre squares wherein the species is recorded per year varied from zero to eight, represented by the black columns in figure 5.3. In 2008 and 2014, seven *new* kilometre squares were recorded for *E. densa* where the plant had not been earlier observed. Since 1944, *E. densa* has been recorded in a total of 54 kilometre squares in the Netherlands (Figure 5.3). The cumulative total number of kilometre squares is represented by the white columns in figure 5.3 and is calculated by combining all new kilometre squares from the current and previous years. In some kilometre squares where *E. densa* was recorded in the past, more recent records have not been made, despite these areas being reasonably well surveyed. It can be assumed that the species no longer exists at these locations. The population recorded at Dodemanskisten on the island of Terschelling has definitely ceased to exist due to dredging and artificial drainage that occurred in 2013. Surveys of the area in 2014 found no evidence of the species. *E. densa* couldn't be found in

2014 at two other previously known locations, a ditch near Coevorden and a loam pit near Rhenen.

The number of new kilometre squares wherein *E. densa* was recorded per year is shown compared with the previous average winter temperature (December to February inclusive) in figure 5.4. The variation in the number of *E. densa* records per year is significantly correlated with the average temperature of the preceding winter ($R^2 = 0.080$; $P < 0.05$). The rank orders for severity of winters over the period 1901-2014 ($R^2 = 0.044$; $P > 0.05$) and the Hellmann values of winter periods (H; with H = -Σ average daily temperature below zero degrees) ($R^2 = 0.041$; $P > 0.05$) are not significantly correlated with the yearly number of records. To date, records of population persistence during (very) cold or severe winters (H > 100) are scarce (n=1). However, many new *E. densa* records in the Netherlands (n=25) were made in the top ten hottest years since 1901. The records originating from the Doorn area occurred following period of mild winters (1971-1978). No *E. densa* records were made in the year following the severe winter of 1995 to 1996. In contrast, relatively many records were made in the year following the relatively mild winter of 2006 to 2007. Following the relatively hard winter at the end of 2009, the number of records reduced again.

E. densa tends to be recorded in urban and suburban areas in the Netherlands (Leewis *et al.,* 2013; Van Valkenburg, 2014), which agrees with literature that states that anthropogenic-mediated pathways are largely responsible for the introduction of *E. densa* to water bodies in its non-native range (Section 5.3.2). More than half of the recorded populations of *E. densa* in the Netherlands lie within urban and suburban areas, and at least 70% of recorded populations lie within 1 km of these areas. *E. densa* is mostly found in urban / suburban waters such as ponds and small canals. Additional records have been established in (amphibian) pools, drainage ditches, larger canals and clay pits.
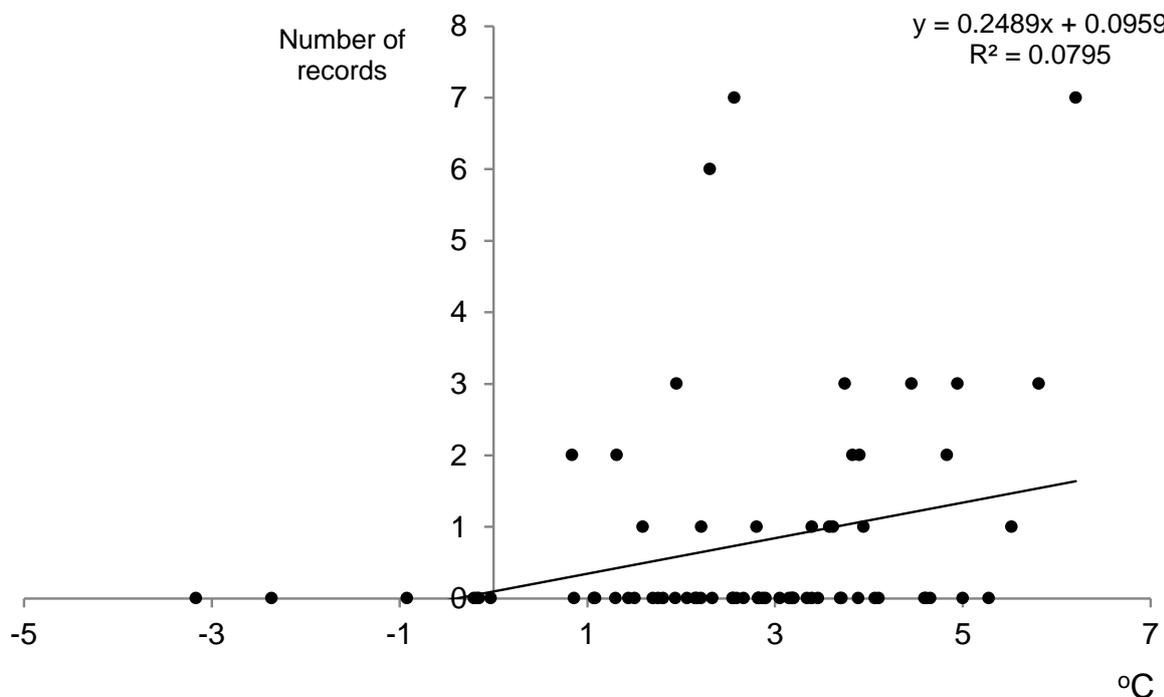
Figure 5.4: Number of new kilometre square grids featuring records of Brazilian waterweed (*Egeria densa*) in the Netherlands compared to the average previous winter temperature (1944-2014).

5.2.2. Colonisation of high conservation value habitats

To date, *E. densa* has been recorded in two kilometre squares within the Natura 2000 areas 'Meijendel & Berkheide' and 'Roerdal' in the Netherlands. However, during subsequent field visits to these kilometre squares, the species wasn't found, suggesting that the plants have since disappeared. Recently, a free floating stem was found in the marina at Nieuwkoop, just outside the Nieuwkoopse Plassen & De Haeck Natura 2000 area. It is as yet uncertain if there is a population of *E. densa* present at this location or where the stem originated from, or if the stem was purposely disposed of.

5.3. Pathways and vectors for dispersal

5.3.1. Dispersal potential by natural means

As *E. densa* reproduces vegetatively through branching, fragmentation and subsequent root production in the Netherlands, natural vectors that transport plant fragments are of utmost importance. Water current and certain animals may be partly responsible for the secondary spread of the plant (Table 5.2). Because of its poor root system that leads to easy detachment, *E. densa* is likely to naturally spread downstream, and is directed by the average wind direction (Mazzeo *et al.,* 2003). Plant fragments may be transported over long distances in flowing water, however, its North European range expansion appears to be limited (Lafontaine *et al.,* 2013).

5.3.2. Dispersal potential with human assistance

Overall, anthropogenic-mediated pathways are considered principally responsible for the establishment and spread of *E. densa* in its non-native range (Csurhes *et al.,* 2008; CABI, 2014). *E. densa* is a popular plant for hobbyists due to its hardiness, oxygenation capabilities and attractive bright green foliage and is introduced primarily via the aquarium trade, pet shops and water garden industry (State of Indiana, undated; Yarrow *et al.,* 2009; Lafontaine *et al.,* 2013). Moreover, it could be a contaminant in consignments of other aquatic plant and animal species (Coetzee *et al.,* 2011; CABI, 2014). For example, *E. densa* escaped from a pond close to Lake McLaren in the Bay of Plenty region, New Zealand after probable introduction as a contaminant on water lilies that were planted there (Howard-Williams *et al.,* 1987; De Winton *et al.,* 2009). *E. densa* is the preferred plant species for plant physiology studies, which may have also contributed to its spread (Coetzee *et al.,* 2011). Brunel (2009) undertook a survey examining the importation of non-native aquatic plants to 10 countries in Europe. The Netherlands imported circa 5 million units of aquatic plants in 2006 and was the largest importer, coming top of a list of countries constituting France, the Czech Republic, Germany, Hungary, Switzerland, Austria, Latvia, Turkey and Estonia. Almost 1.9 million units of *E. densa* plants (bundles of up to 10 stems) were imported to the countries studied per year, far exceeding any of the other plants examined. The Netherlands was the most prolific importer of *E. densa,* importing almost 1.7 million units in 2006, 90% of the total imports for all the countries studied. *E. densa* is mostly imported and sold in the Netherlands as *Elodea densa*, and sometimes as *Anacharis densa,* or *Philotria densa*.

The increase in e-commerce has exacerbated the problem of invasive plant sales, giving retailers the ability to advertise online and send plants in the post (Kay & Hoyle, 2001). E-

commerce has allowed importers direct access to customers and increasing access to plants sourced from other countries. Once bought, there is a risk that unwanted plants may be disposed of in the freshwater system. Internet sales and national advertising campaigns result in small quantities of plants being sent by mail to many tens of thousands of hobbyists distributed over wide areas. Moreover, the existence of dedicated websites results in the sharing and swapping of plants nationally and across international borders (Giltrap & Reed, 2009). A search of the Dutch marktplaats.nl in July 2014 using the term 'aquarium planten' (aquarium plants) produced more than 700 returns while a search for 'vijver planten' (garden pond plants) produced more than 300 returns. Marktplaats.nl is a website where both individuals and commercial enterprises list items for sale. National and international sales or sharing of water plants between individual consumers results in quarantine and regulation problems as small consignments sent by post are difficult to monitor and intercept (Giltrap & Reed, 2009).

A search of Google.nl using the search term '*Egeria densa*', uncovered two online plant retailer websites advertising plants for sale. However, one was located in the United States and the other in Romania. The addition of the Dutch word 'kopen' (buying) to the search term '*Egeria densa*' led to 11 websites of Dutch retailers selling the plant. The terms 'Braziliaanse waterpest' and 'Argentijnse waterpest' resulted in four and seven retailer's websites, respectively. All of these results were from retailers located in the Netherlands. The addition of the word 'kopen' to Braziliaanse waterpest resulted in 5 Dutch retailer websites offering the plant for sale. The search term 'Argentijnse waterpest kopen' produced 6 results of retailer's websites, of which 5 were Dutch and one was Belgian. None of the retailer's websites visited gave information regarding the invasive nature of *E. densa* or the importance of avoiding introductions of this species to the freshwater network on the retail page of any of the sites visited (Figure 5.5).
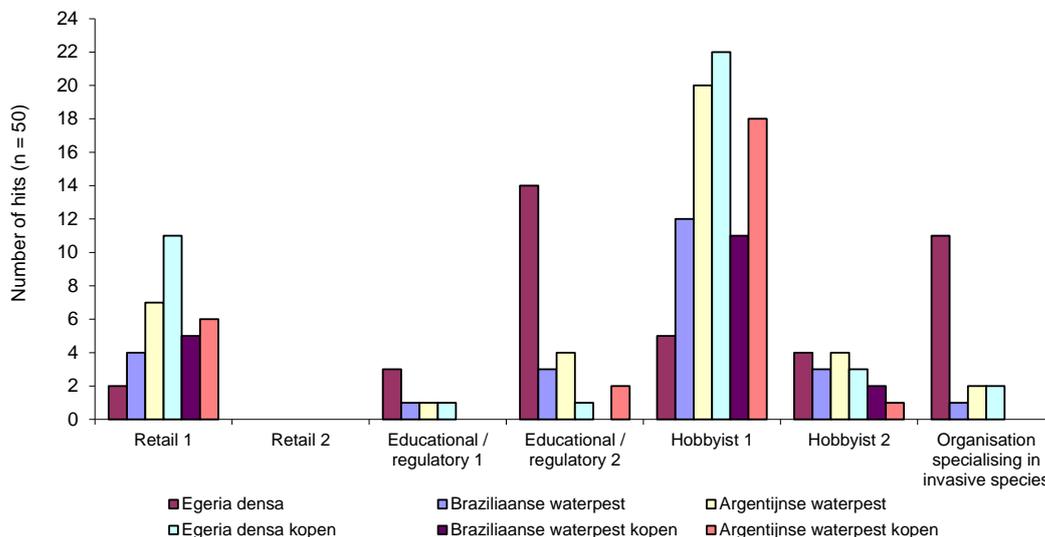
Figure 5.5: Type of websites (in Dutch and English) featuring Brazilian waterweed (*Egeria densa*) found via Google.nl using various search terms (search terms are visualised using different colours; 1: No direct reference is made to the plants invasive nature and / or measures recommended to prevent introduction; 2: A direct reference is made to the plants invasive nature and / or measures recommended to prevent introduction).

Less than 25% of the hobbyist websites referring to *E. densa* (kopen), Braziliaanse waterpest (kopen) or Argentijnse waterpest (kopen) also contained information on the

invasive nature of this plant and its potential threat to native biodiversity. However, the number of hobbyist websites and amount of content within hobbyist forums referring to Braziliaanse waterpest (kopen) and Argentijnse waterpest (kopen) suggest that this is a popular and frequently discussed aquarium plant in the Netherlands and Belgium.

Braziliaanse waterpest (kopen) and Argentijnse waterpest (kopen) were referred to in eleven educational or regulatory websites. These were all written in the Dutch language. Nine of the eleven websites contained information relating to the invasive nature of Braziliaanse waterpest and Argentijnse waterpest and the potential threat that they pose to biodiversity. This highlights a high level of awareness of the potential invasive nature of *E. densa* 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). In total, 19 educational or regulatory websites referred to *E. densa* (kopen) and of these, 15 contained information relating to the invasive nature of *E. densa* 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 '*Egeria densa*' was used. According to these results, information in the Dutch language relating to the invasive nature of the 'Braziliaanse waterpest' or 'Argentijnse waterpest' is moderately available on educational and regulatory websites via Google.nl. However, the number of online retailers selling the plant identified as either Braziliaanse waterpest, Argentijnse waterpest or *Egeria densa* shows that the plant is readily available in the Netherlands.

In 2012, a survey of aquatic plant retailers in the Netherlands was conducted to assess the effectiveness of the Dutch code of conduct for aquatic plants. The code of conduct was introduced in 2010 in the Netherlands and is a non-binding agreement between government and water-plant retailers that aims to limit the supply of potentially invasive water-plants and inform buyers of their correct disposal. *E. densa* is categorised in appendix 2 of the code of conduct meaning that it is not banned from sale, but should be supplied with information relating to its potential invasiveness and correct disposal. However, the results of a 2012 survey of retailers in the Netherlands supplying bunches of oxygenating plants containing *E. densa* showed that only 7 out of forty bunches examined were labelled correctly (Verbrugge *et al.,* 2014).

E. densa is often found near sites of human activity suggesting that humans are responsible for the initial stages of *E. densa* introduction in the Netherlands and elsewhere (section 5.2.1; Darrin, 2009; Compton *et al.,* 2012). If a plant is no longer wanted, owners are more likely to release plants to nearby water bodies than kill them (Kay & Hoyle, 2001; Lafontaine *et al.,* 2013). It is highly likely that most populations of *E. densa* in Western Europe (Belgium included) and in several Asian and Pacific countries are the result of separate successive disposal events of aquarium or pond plants into the wild (Lafontaine *et al.,* 2013). The results of a recent survey examining the behaviour of aquarium and water garden owners in the Netherlands showed that 2.9% (n = 7) of the 239 respondents had disposed of aquatic plants in open water (Verbrugge *et al.,* 2013). This number is virtually unchanged in

comparison with a similar survey undertaken in 2011. Moreover, further proof of voluntary introductions is provided by the occasional occurrence of common garden pond plants and animals in Dutch waters with examples of pumpkinseed sunfish (*Lepomis gibbosus* (L.)). This fish species was introduced to the Netherlands in 1902 as an aquarium and garden pond fish (Van Kleef *et al.,* 2008). Aquatic plants may be transported and released intentionally when they are used to buffer fish during illegal fish introductions or as packing for fish ova, or unintentionally if they accidentally accompany introduced fish (e.g., Johnstone *et al.,* 1985). In New Zealand, locations where *E. densa* was recorded were also colonised by other non-native macrophytes, consistent with introduction via the aquatic plant trade or plant disposal (Champion & Clayton, 2000). A Canadian study found that *E. densa* was among those species with the highest measured propagule pressure among thousands of non-indigenous plant propagules introduced to the St Lawrence Seaway each year as a result of the Montreal aquarium trade (Cohen *et al.,* 2007).

Explicit records on dispersal of *Egeria densa* by aquatic animals are not available. However, dispersal of seeds or plant fragments by water fowl is quite likely based on records of comparable species such as *Elodea Canadensis* (Brochet *et al.*, 2009).

Table 5.2: Potential dispersal vectors / mechanisms of Brazilian waterweed (*Egeria densa*).

Vector / mechanism	Mode of transport	Examples and relevant information	References
Trade	Overland (national / international)	E-commerce, plants transported in the post, bulk transport	Champion & Clayton (2000); De Winton *et al.* (2009); Brunel (2009); Meacham (2001); Yarrow *et al.* (2009); Lafontaine *et al.* (2013)
Hobbyists	Overland	Disposal of unwanted plants	Wilson *et al.* (2007); Lafontaine *et al.* (2013)
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	Westerdahl & Getsinger (1988); Meacham (2001); Department of Ecology Washington (2014); Lafontaine *et al.* (2013)
Flooding	Downstream, overland	Escape of plant fragments from the flooding of private ponds	Darrin (2009)
Weed harvesters	Upstream / downstream, overland	Machinery not properly cleaned and moved from water body to water body	De Winton *et al.* (2009); Lafontaine *et al.* (2013)
Water current	Downstream	Plant fragments transported in flowing water	De Winton *et al.* (2009); Csurhes *et al.* (2008)
Human clothes and footwear	Overland		Lafontaine *et al.* (2013)
Fishing equipment	Upstream / downstream, overland	Occurs as a result of improper cleaning and movement from water body to water body	Lafontaine *et al.* (2013)
Aquatic animals	Over land / via water	Seeds and plant fragments attached extremities or feathers of water fowl (e.g., ducks)*	Brochet et al. (2009)

* Explicit records for *Egeria densa* are not available, but records of comparable species (e.g., *Elodea canadensis*).

The potential for introduction of a species repeatedly and on a large scale into a new area is one of the most important factors that lead to invasiveness (Randall & Marinelli, 1996; Riis *et al.,* 2012). Therefore, the high level of imports, recent increase in e-commerce and consumer behaviour increase the likelihood that invasive species such as *E. densa* will establish or increase their distribution in the Dutch freshwater network.

Following the introduction of *E. densa* to the freshwater network, secondary spread may be facilitated by fragmentation and vegetative growth. Seeds only appear within *E. densa's* native range of South America (Darrin, 2009). Therefore, vectors that transfer plant fragments are of great importance (Table 5.2). Vegetative fragments are transferred between water bodies by boats and trailers, fishing, on human clothes and footwear, weed harvesters and other maintenance equipment (Westerdahl & Getsinger, 1988; Washington State Department of Ecology, 2014; Meacham, 2001; De Winton *et al.,* 2009; Lafontaine *et al.,* 2013). *E. densa* can tolerate desiccation for a short period which may facilitate its overland dispersal. Barnes *et al.* (2013) observed that at 25°C one hour of drying reduced viability to approximately 40 % and 3 hours of drying to approximately 8 %. The flooding of private ponds and infected water bodies within floodplains may also result in the spread of fragments overland (Darrin, 2009; Lafontaine *et al.,* 2013).

5.4. Invasiveness

Egeria densa was first recorded in the Netherlands in 1944 near Dordrecht (Van Ooststroom *et al.,* 1964). In 1951, herbarium samples were taken from a pond in Bussum. According to the label that accompanied the sample, the species had already been present for 10 years prior to the time of sampling and had flowered regularly during this time. No *E. densa* records are available in the Netherlands for the 1960s. The next record occurred in the summer of 1976 when *E. densa* was observed in a small canal in the municipality of Doorn. In 1977 the plant was also found at a second location close by in the Gooyerwetering area (Floristenclub Gelderse vallei, 1978; Mennema & van Ooststroom, 1977). Further records exist from the Doorn area till 1991 after which no further records were made at this location. After the year 2000, recordings of *E. densa* in the Netherlands have been made nearly every year. The number of kilometre squares wherein the species is recorded varied from 0 to 8 per year. In 2008 and 2014, seven *new* kilometre squares were recorded for *E. densa* where the plant had not been earlier observed. Since 1944, *E. densa* has been recorded in 54 kilometre square grids in the Netherlands.

Although its non-native range is extensive there are conflicting reports regarding *E. densa's* ability to colonise countries neighbouring the Netherlands. It was first recorded in the United Kingdom in Ashton Canal, Droylesden in 1953 but it has not become invasive and there is no evidence of spread from naturalised populations. Until recently it was only found in a few canals and mill-lodges, but has spread rapidly over the last few years (Dadds & Bell, undated). An increasing number of population complexes may have resulted from fragment spread. There are fewer than twenty 10 km squares recordings of *E. densa* in the United Kingdom (GB Non-native Species Secretariat, 2014). *E. densa* was first recorded on the island of Ireland in 1988 and to date only two records exist (Millane & Caffrey, 2014).

E. densa was first recorded in Belgium in 1999 in a small pond in Ezemaal (Robijns *et al.,* 2002). At present the species does not show very effective natural dispersal (Lafontaine *et al.,* 2013). The number of records has increased subsequently and the species is naturalised in a few locations in Flanders (Denys *et al.,* 2004), and could locally become invasive (Branquart, 2013). *E. densa* has been recorded in isolated populations (1 to 5 localities) in Kempen, Northern Belgium, bordering the Netherlands (Lafontaine *et al.,* 2013).

In Germany, *E. densa* was first recorded in 1910 in the Elster-Saale Canal near Leipzig. The plant was removed and has never since been recorded at this location. In 1914 it was recorded in the River Niers but did not survive. From 1932 until the 1950's *E. densa* grew in a thermally polluted canal at Karlsruhe. From 1974 to 1976 it was recorded in a pit at Birkenfeld, Pfalz. The species is now present in six Länder and established in the river Erft, North Rhine-Westphalia, bordering the Netherlands, and Baden-Würtenberg (Hussner, 2010). However, since 2003, the abundance of *E. densa* in the river Erft has declined while the abundance of other non-native plants e.g. water lettuce (*Pistia stratiotes* L.) and tape grass (*Vallisneria spiralis* L.) have either remained stable or significantly increased in the river. Moreover, the river Erft is not representative of the German climate as it is a thermally polluted river whose temperature does not dip below 10°C in winter (Hussner, 2014).

A study of Wells & Clayton (1991) on Lake Rotorua, New Zealand, showed that *E. densa* was able to arrive and spread to 96% of sampled sites in less than six years. At the initial site of entry coverage increased from 10% to 100% in the near shore area (1.5-3 m) within two years. The plant was the most abundant aquatic plant in the 81 km^2 lake five years after its initial establishment (Wells & Clayton, 1991). Lake Rotorua is located in an area with geothermal activity. The lake is fed by thermally polluted river water and the water temperature fluctuates between 9 and 24°C (Hamilton & McBride, 2013).

In the United States, *E. densa* was able to completely cover a 8.5 km^2 lake within two years in ideal growing conditions (Washington State Department of Ecology, 2014). However, according to the Koppen-Geiger climate classification, both these locations are dissimilar to the Netherlands climatologically (Rubel & Kottek, 2010).

According to CABI (2014), Brazilian waterweed (*E. densa*) has dispersed to 27 countries outside of its native range and is recorded as an invasive species in 12 (44%) of these countries. According to the Koppen-Geiger climate classification, parts of five countries climatically match with the Netherlands (France, Germany Italy, Switzerland and the United Kingdom).

6. Impacts

Impacts related to Brazilian waterweed (*Egeria densa*) are related to its abundance. To date in the Netherlands, no positive or negative impacts relating to *E .densa* have been reported. However, if the plant were to become abundant then impacts may be expected. *E. densa* has, to date, not become invasive in neighbouring countries despite being present for decades in a number of cases (Section 5.4). For example, in the United Kingdom no major negative ecological or socio-economic impacts have been observed since it was first recorded in 1953 (except in Cornwall in south-west England; Plantlife, 2010), and are unlikely to occur unless populations increase significantly (Lansdown, 2011). However, other closely related species such as curly waterweed (*Lagarosiphon major*) and nuttall's waterweed (*Elodea nuttallii* (Planchon) St. John) have caused ecological and socio-economic impacts in Ireland (Caffrey *et al.*, 2006; Caffrey *et al.*, 2011). Therefore, it is suggested that *E. densa* may have the potential to emulate this (Millane & Caffrey, 2014).

The following paragraphs describe impacts resulting from *E. densa* colonization seen in countries experiencing high abundances of this waterweed. Similar impacts will occur in the Netherlands only if the plant becomes at least locally abundant.

6.1. Ecological effects

6.1.1 Impacts on native species

Adverse effects

Macrophytes
The major adverse impacts of *E. densa* on native species are related to interference and exploitation competition. Under favourable conditions, *E. densa* can grow up to 0.4 cm per day and form a dense surface reaching canopy, even in low light, that can quickly out-compete native macrophyte species (De Winton & Clayton 1996; Champion & Clayton, 2000; Carrillo, 2006; Washington State Department of Ecology, 2014; Yarrow *et al.,* 2009; Branquart, 2013; Lafontaine *et al.,* 2013; GB Non-native Species Secretariat, 2014). *E. densa* possesses a canopy that is denser than other non-native species such as *L. major*, favouring mono-specific stands which often colonise entire water bodies (Hofstra *et al.,* 1999; Roberts *et al.,* 1999; Branquart, 2013). Moreover, a tolerance of low light may allow *E. densa* to establish in deeper water than some native species giving it an additional competitive advantage (Wells *et al.,* 1997). On the other hand, in clear waters *E. densa* forms a canopy sometimes 2-3 m below the surface avoiding the near-surface high-light habitat (Wells *et al.,* 1997). Therefore, other less light sensitive plants may be able to overgrow and eventually exclude *E. densa* in water bodies featuring high transparency (Hofstra *et al.,* 1999).

There are few examples of the competitiveness of *E. densa*. However, these cases are not representative for the temperature regime of water bodies in the Netherlands under current climatic circumstances (section 5.4). In the river Erft, North Rhine-Westphalia, Germany, *E. densa* suppressed the formerly widely distributed native broad leaved pondweed (*Potamogeton natans*) and fennel pondweed (*Potamogeton pectinatus*) and potentially

displaced Canadian waterweed (*Elodea canadensis*) and *E. nuttallii* (Friedrich, 1973; Diekjobst & Wolff, 1995; Hussner & Losch, 2005). Since 2003, the abundance of *E. densa* in the river Erft has declined while the abundance of other native and non-native plants has remained stable or significantly increased (Hussner, 2014). In New Zealand, *E. densa* became widespread and locally displaced assemblages of native macrophytes (Champion & Tanner, 2000). *E. densa* was able to grow deeper and denser than either *L. major* and *E. canadensis*, resulting in displacement of these species (Champion & Clayton, 2000). In Kotukutuku Bay, New Zealand, *E. densa* dominated to 10 m depth (Wells *et al.,* 1997). Moreover, seed number and seed species richness were significantly lower at sites where the macrophyte vegetation was dominated by *E. densa* and other adventive weeds, compared with a predominantly New Zealand native vegetation (De Winton & Clayton, 1996). *E. densa* is also stated to out-compete *E. canadensis* in North America (Mony *et al.,* 2007).

E. densa has no known natural pathogens and genetic effects are not expected as no European congeneric species exist (Darrin, 2009; Lafontaine et *al.,* 2013).

Macroinvertebrates and plankton
Changes in light and nutrients levels resulting from the establishment of dense *E. densa* beds may impact plankton communities (Darrin, 2009). A study comparing open water with *E. densa* beds in a lake in Uruguay showed that chlorophyll *a* was significantly lower and the zooplankton community significantly different in *E. densa* beds (Mazzeo *et al.,* 2003). Canopy forming aquatic plants such as *E. densa* tend to shade out phytoplankton lower in the water column (Yarrow *et al.,* 2009). *E. densa* may affect local ecosystem functioning for plankton species. Plant beds may act as a refuge, and also as a feeding zone for zooplankton, dependent on the abundance of planktivorous fish and density of macrophyte stands (Mazzeo *et al.,* 2003). Moreover, in New Zealand, greater rotifer abundances were generally found on *E. densa* beds compared with two other aquatic plant species, the tall spike rush (*Eleocharis sphacelata* R. Br.) and the spiked water milfoil (*Myriophyllum propinquum* A. Cunn.) (Duggan *et al.,* 2001). In an Argentinian study, *E. densa* was found to have a relatively low mean fractal dimension, a measurement of complexity, compared to other aquatic plants. This was related to a lower abundance of macro-invertebrates present on *E. densa* than other plant species. Fractal dimension increased in the following sequence: *E. densa* → broad leaf pondweed (*Stuckenia striata* (Ruiz & Pavon) Holub) → South American waterweed (*Elodea callitrichoides* (L.C. Richard) Caspary) → Hornwort (*Ceratophyllum demersum*). However, fractal dimension was not related to macroinvertebrate biomass, richness, and diversity (Ferreiro *et al.,* 2011).

Fish
The presence of invasive aquatic plant species impacts on fish populations. Heavy infestations confer no oxygen benefit to fish or other animals (Ramey, 2001). *E. densa* has been reported to negatively affect fish communities. Dense *E. densa* beds are a poor habitat for aquatic animals and are less palatable to fish species than other aquatic macrophytes (State of Indiana, undated; Branquart, 2013). As a result, selective herbivory of native macrophytes may occur (Lake *et al.,* 2002). When present in high abundance, *E. densa* can cause imbalances in the fish population (State of Indiana, undated). Growns *et al.* (2003) state that *E. densa* stands are likely to feature a different fish assemblage than those of native macrophytes. Moreover, large fish species could have more difficulty migrating

through dense stands of *E. densa,* and dense beds of invasive exotic macrophytes have been linked with reduced foraging efficiency and success in fish (Engle, 1995; Johnson *et al.,* 2006). A Californian study reported higher catches of centrarchid fish due to the presence of *E. densa* in a river delta (Brown & Michniuk, 2007). The centrarchidae are all native to North America, however, pumpkinseed (*Lepomis gibbosus*) has been introduced to the Netherlands (Van Kleef *et al.,* 2008). Increases in *E. densa* abundance in the Netherlands may provide habitat and increase the spread of non-native fish species such as *L. gibbosus.*

Positive effects

Despite potentially altering community structure, *E. densa* appears to promote relatively diverse communities of phytoplankton, zooplankton and fish (Mazzeo *et al.,* 2003, Pelicice & Agostinho, 2006). In general, macrophytes can exercise a positive influence on epiphytic macroinvertebrates and many benthic macroinvertebrates (Yarrow *et al.,* 2009). Large *E. densa* beds provide protection and a feeding ground for various zooplankton species (Darrin, 2009)

Certain fish species benefit from the protection and extra food provided by *E. densa* beds. *E. densa* is eaten by a number of herbivorous species (Osborne & Sassic, 1981; Pelicice *et al.,* 2005). *E. densa* beds provide protection for juveniles as well some small adult fish (Darrin, 2009). In a study of *E. densa* in a Brazilian reservoir, macrophyte biomass, volume and proportional volume were strongly correlated with fish density and species richness (Pelicice *et al.,* 2008). The reservoir was colonized by smaller fish species that used the macrophyte beds as shelter against predators. However, open water species may become more vulnerable to predators due to reduced turbidity following *E. densa* invasion (Ferrari *et al.,* 2014).

Bird species that forage in dense macrophyte beds may benefit from the presence of *E. densa*. A study from Florida, USA, showed that native birds utilized *E. densa* mats primarily as foraging sites but comparisons with native macrophyte beds were not made (Bartodziej & Weymouth, 1995; Yarrow *et al.,* 2009).

E. densa has been demonstrated to have a species-specific inhibitory effect on three species of blue-green algae during laboratory experiments (Nakai *et al.,* 1999).

6.1.2. Alterations to ecosystem functioning

Adverse effects

Non-native *E. densa* affects light, nutrient availability and sedimentation, drastically altering native environments and in doing so, meeting the definition of an autogenic ecosystem engineer (Jones *et al.,* 1994). The mechanism by which *E. densa* works as an ecosystem engineer is illustrated in figure 6.2. A high density of *E. densa* decreases water turbulence, leading to a reduction in sediment re-suspension and an increase in sedimentation (Fig. 6.3). Reduced sediment re-suspension increases light penetration, maintaining the clear water ecosystem state. Nutrients are sequestered into the sediments reducing the standing stock of phytoplankton. Zooplankton abundance increases since *E. densa* stands act as a refuge

from predation. However, in the long term these feedback mechanisms may generate adverse conditions for macrophyte development due to increases in sediment depth (Adapted from Jones *et al.,* 1994; Yarrow *et al.,* 2009; Lafontaine *et al.,* 2013).
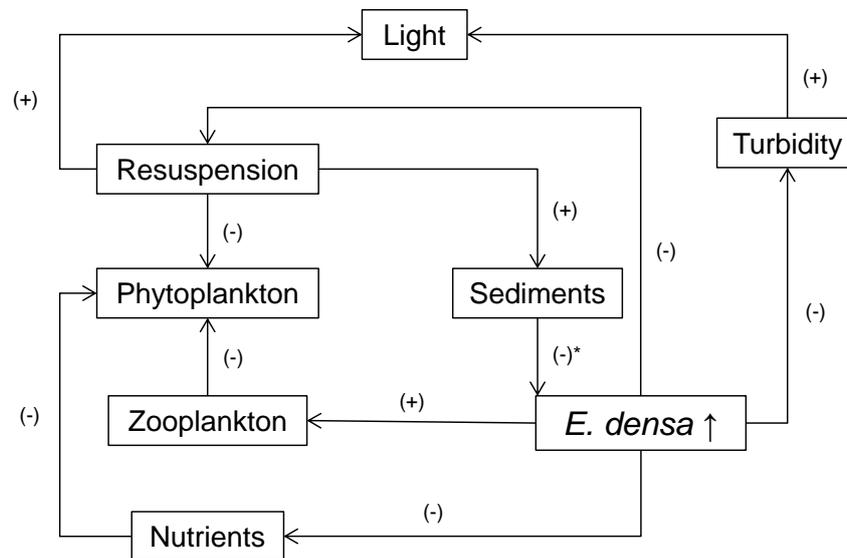
Figure 6.2: Brazilian waterweed (*Egeria densa*) as an ecosystem engineer (Adapted from Jones *et al.,* 1994; Yarrow *et al.,* 2009; Lafontaine *et al.,* 2013). -: decrease; +: increase.

In high densities, *E. densa* may cut off light, deplete oxygen, increase water temperature, alter nutrient cycles and alter the morphology and hydrology of rivers and lakes by restricting water movement and trapping sediments (Mazzeo *et al.,* 2003; Branquart, 2013; CABI, 2014; GB Non-native Species Secretariat, 2014). Moreover, in a New Zealand study, *E. densa* was the only aquatic plant in a group containing *E. canadensis*, *C. demersum*, *L. major* and curled pondweed (*Potamogeton crispus* L.) to be significantly correlated with lakes moving between a clear water state and turbid state (Schallenberg & Sorrel, 2009).
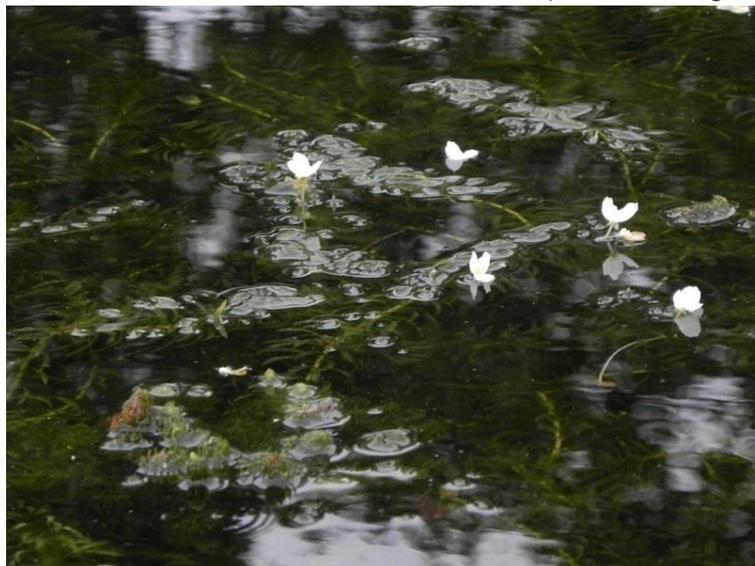
Figure 6.3: Dense vegetation of Brazilian waterweed (*Egeria densa*) at Hoogeveen, the Netherlands (Photo: J. van Valkenburg).

Sediments

In areas of significant infestation (such as the USA, Australia and New Zealand), *E. densa* traps suspended particles and nutrients, and prevents wind mixing (Darrin, 2009; GB Non-native Species Secretariat, 2014). Yarrow *et al.* (2009) states that the trapping of sediment and reduction in current velocity associated with dense *E. densa* beds increases light attenuation and promotes plant growth. However, in New Zealand, *E. densa* has been implicated in contributing to the collapse and decline of vegetation as a result of modification to sediments in many Waikato shallow lakes (Champion & Clayton, 2000). Increased sedimentation due to changes in water velocity and anaerobic processes in the sediment layer may result from dense *E. densa* colonization (Yarrow *et al.,* 2009; G. van der Velde, pers. comm.).

Dissolved oxygen

The growth of aquatic macrophytes may lead to local changes in dissolved oxygen concentration. In a study of dissolved oxygen in *E. densa* beds in a lake in Uruguay, oxygen levels were significantly higher in the *E. densa* beds compared to the open water zone during April and May. In summer, higher dissolved oxygen levels were detected in open waters when the phytoplankton biomass increased (Mazzeo *et al.,* 2003). Changes in stratification may occur due to more dissolved oxygen near to the bottom of *E. densa* stands and less at the surface (Darrin, 2009).

Oxygen depletion results from plant decomposition following mass plant die-offs. Mass mortality of *E. densa* may lead to higher levels of decomposing material, which increases nutrient loads, decreases oxygen concentration and alters the redox potential particularly where there is little water flow (Rose & Crumpton, 1996; Washington State Department of Ecology, 2014; Yarrow *et al.,* 2009; Bianchini *et al.,* 2010; GB Non-native Species Secretariat, 2014).

Nutrients

E. densa efficiently absorbs nutrients such as ammonium, nitrate and phosphorus from the sediment and water column, thus changing the composition of the water as well as the sediment in macrophyte beds (Mazzeo *et al.,* 2003). Studies show that nitrogen and phosphorus levels in sediment are lower near *E. densa* beds than in areas without *E. densa* (Barko & James, 1998; Mazzeo *et al.,* 2003). As an example of the degree of nutrient sequestration, Søndergaard & Moss (1998) cite an instance where *Elodea* (originating from the same family as *E. densa*) contained over 60 % of nitrogen and phosphorus in a shallow lake system (excluding sediment). Strong competition for nutrients may be an additional reason why *E. densa* may be able to out-compete native plant species.

Changes in redox potential as a result of oxygen depletion due to *E. densa* increase the potential for phosphorus release from sediment. The presence of iron-bound and redox-sensitive phosphorus in the sediment increase the likelihood of this occurring (Søndergaard & Moss, 1998).

Mass plant mortality may result in changes in biogeochemical cycles, a reduction of plant diversity (Meyerson *et al.,* 2000), an increase in primary productivity (Jordan *et al.,* 1990) and changes to trophic relationships (Batzer, 1998).

Temperature
E. densa absorbs sunlight which may lead to an increase in local water temperature (GB Non-native Species Secretariat, 2014). The results of a Uruguayan study indicated that lake temperature was higher in *E. densa* beds compared to open water, but the difference was generally lower than 1°C (Mazzeo *et al.,* 2003).

pH
A study comparing open water and *E. densa* beds in a lake in Uruguay indicated that the photosynthetic activity of plants and microalgae influenced the spatial pattern of pH. Lake water was more alkaline within the zones with plants in spring, and more alkaline in the zone without plants during summer (Mazzeo *et al.,* 2003).

Positive effects

In a New Zealand study, *E. densa* played an important role in promoting habitat heterogeneity by inducing a greater variation in flow velocity, and providing large stable low flow areas (Champion & Tanner, 2000).

It is probable that structural changes to habitat resulting from mature *E. densa* stands will better suit cyprinid, perch and pike populations than salmonid species. Salmonids have a preference for open water conditions while the cyprinids, perch and pike commonly seek the cover provided by dense weed beds (Caffrey & Acavedo, 2007). Moreover, the height and complexity of the plant canopy in beds of non-native species result in a physical change in habitat that appears to provide more habitat for zoobenthic prey, more resting areas for benthic fish such as bullies, and greater refuge from top predators than in native beds (Gilinsky, 1984; Keast, 1984; Gotceitas, 1990; Schriver *et al.*, 1995; Valley & Bremigan, 2002).

6.2. Socio-economic effects

Adverse effects

In high densities, *E. densa* disrupts navigation and hinders water-sports, fishing, and swimming (GB Non-native Species Secretariat, 2014). It may also clog agricultural irrigation intakes, negatively affect the exploitation of commercial fish stocks, impede water flow increasing the risk of adjacent flooding, trap sediment, clog municipal water intakes and the unsightly mats may diminish property values (State of Indiana, undated; Branquart, 2013; GB Non-native Species Secretariat, 2014). In southeast Brazil and New Zealand, *E. densa* growth results in financial losses to hydroelectric companies due to interruptions to electricity generation and damage to grids and equipment (Barreto *et al.*, 2000; Csurhes *et al.,* 2008).

E. densa is very expensive to control when it reaches nuisance levels (State of Indiana, undated). The cost of removal of *E. densa* from lakes and reservoirs to some USA states is several million dollars per year (CABI, 2014). Between 1994 and 2000, 530,300 dollars (420,100 euros; Date of exchange rate 1 October 2014) was spent on the management of *E. densa* in various lakes in Washington, USA. This constituted over 15% of the total budget for the management of invasive water plants in the state (Washington State Department of Ecology, 2014). Large-scale management projects in the United States have cost up to three

million dollars (2.38 million euros; Date of exchange rate 1 October 2014) (Johnson *et al.,* 2006).

The banning of *E. densa* from sale may have significant impact on the aquatic plant trade. *E. densa* is one of the most frequently imported aquatic plant species to the Netherlands and is a popular aquarium plant. Attempts at banning the plant may result in resistance from the retail sector (Verbrugge *et al.,* 2013). However, resistance may be moderated by the provision of alternative aquatic plants that may be sold in place of *E. densa* (See section 8.1).

Positive effects

It has been reported that harvested *E. densa* could be used to feed broiler chicks. When dried the plant can constitute 5% of the diets of human bred waterfowl without any impact on health (Dillon *et al.,* 1988). Boyd & McGinty (1981) found that *E. densa* had the second highest percentage of digestible material and protein of eight submerged aquatic weed species. Investigations have been carried to assess the growth of the oyster mushroom (*Pleurotus ostreatus* (Jacq.) P. Kumm)) on *E. densa* in order to evaluate the possible use of spent biomass and fruiting bodies in the production of human and animal foods (Martinez-Nieto *et al.,* 2014).

In studies examining biosorbents, *E. densa* was observed to have a good metal removal potential that could possibly be applied in effluent treatment systems (Juliana *et al.,* 2009).

Weeds may also be composted and the resulting fertilizer applied to land (Dorahy *et al.,* 2009).

6.3. Public health effects

Adverse effects

Dense mats of *E. densa* may have contributed to the drowning of a doctor who was trying to rescue a swimmer struggling in the water (Johnson *et al.,* 2006; Lansdown, 2011). Reports from the USA and Australia state that in high densities *E. densa* creates mosquito breeding areas (GB Non-native Species Secretariat, 2014).

Positive effects

No information regarding positive public health effects of *E. densa* was found in the literature.

7. Available risk classifications

7.1 Formal risk assessments

Risk classifications are available for a number of European countries and Australia (Table 7.1). Full formal risk assessments have been carried out in Belgium, Ireland and Australia.

Table 7.1: Overview of risk classifications previously performed for Brazilian waterweed (*Egeria densa*).

	Belgium	Luxembourg	Ireland	Switzerland	Europe	Australia	United States
Scope	Ecological risk assessment	Risk prioritisation method	Ecological risk assessment	Risk prioritisation method	Risk prioritisation method	Ecological risk assessment	Risk prioritisation method
Method	ISEIA	ISEIA	Non-native species application based risk analysis (NAPRA) tool (version 2.66)	Swiss risk assessment scheme	The Aquatic Weed Risk Assessment Model (AWRAM)	Australian aquatic weed risk assessment model (AWRAM)	Expert judgement method
Year	2007	2013	2013	2004	2010	2008	2002
Risk classification	**High (12)**	**High (11)**	**Moderate**	**High risk (33)**	**Banned species (64)**	**High risk (82)**	**Lesser threat (Rank 3)**
Source	http://ias.biodiversity.be/species/show/54; Lafontaine *et al.* (2013)	Ries *et al.* (2013)	Millane & Caffrey (2014)	Weber & Gut (2004)	Champion *et al.* (2010)	Csurhes *et al.* (2008)	Bowen *et al.* (2002)

In Belgium, Brazilian waterweed (*Egeria densa*) scored 12 out of a possible 12 using the ISEIA protocol. Following this, the Belgium Forum on Invasive Species (BFIS) categorised *E. densa* as an A1 species defining it as exhibiting isolated populations in Belgium and displaying high environmental hazard (Branquart *et al.*, 2013). As a result, *E. densa* was placed on a black list for exotic species present in Belgium including species that are highly detrimental to biodiversity. In Ireland, *E. densa* was judged to pose a moderate risk to Irish biodiversity. This result was allocated a medium confidence level and was based on knowledge of the negative impacts that similar non-native aquatic plant species have had in Ireland (Millane & Caffrey, 2014). In Australia, an assessment carried out in 2008 using the Australian aquatic weed risk assessment model scored *E. densa* 82 out of 130 for ecological risk (Csurhes *et al.,* 2008).

7.2 Other risk classifications

In Luxembourg, *E. densa* scored 11 out of a possible 12 using the ISEIA protocol. Following this, *E. densa* received an A0 classification, defining the species as absent from Luxembourg but displaying high environmental hazard (Ries *et al.,* 2013). In Switzerland, *E. densa* scored 33 out of a possible 39 (high risk) in a trial of the Swiss risk assessment scheme (Weber & Gut, 2004). In an assessment using the Aquatic Weed Risk Assessment Model (AWRAM) applied to a number of European and Mediterranean Plant Protection

Organization (EPPO) quarantine list, alert list and priority species, *E. densa* was defined as a banned species. In this assessment *E. densa* scores 64 out of a theoretical 100 (Champion *et al.,* 2010). Species scoring over 50 are managed either by banning their sale or by statutory control. Finally, a ranking method using expert judgement was applied in the state of Tennessee, the United States to risk prioritise a number of non-native plant species. *E. densa* was classified in a lesser threat group (Rank 3). Rank 3 species spread in or near disturbed areas, but are not, at the time of the assessment, considered a threat to native plant communities (Bowen *et al.,* 2002).

8. Management options

8.1. Prevention

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

In the Dutch code of conduct for aquatic plants (2010), Brazilian waterweed (*E. densa*) has been declared a list 2 species. This means that it should only be sold when accompanied with a warning about its invasiveness. This should help stop the release of plants into open water by hobbyists who are unaware of the plants invasive nature or how to properly dispose of it. The results of a survey of stakeholder groups including aquarists, water gardeners and plant retailers in 2012 into the effectiveness of the Dutch code of conduct revealed that *E. densa* was included in a group of species that were most often named by respondents as non-native (Verbrugge *et al.,* 2014). However, *E. densa* is often sold in bunches containing several species. In 2012, 40 out of a total of 44 Dutch retailer sites sampled were offering *E. densa* for sale as part of oxygenating plant bunches. Of these, around 18 percent were correctly labeled in line with the guidelines of the code of conduct (Verbrugge *et al.,* 2014).

In an assessment of a voluntary code of conduct in North America, Burt *et al.* (2007) found that factors such as awareness of invasive plants and involvement in trade associations significantly predict increased participation in preventive measures. Moreover, the authors identified incentives and obstacles to participating in preventive behaviours including concern for the environment and a lack of information.

The selling of alternative, similar aquatic plants in place of *E. densa* may also be considered. The following alternative aquatic plant species are suggested for use in cold water aquaria and garden ponds:

- Canadian pondweed (*Elodea canadensis*). This plant is easy to maintain and relatively cheap to produce. *E. canadensis* is a non-native species, but became established in the Netherlands long ago.
- Nuttall's waterweed (*Elodea nuttallii*). Similarly to *E. canadensis*, *E. nuttallii* is easy to maintain and relatively cheap to produce. *E. nuttallii* is also a non-native species, but has been established in the Netherlands for a long period.

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

Education of anglers and boaters may be especially useful as they can assist in reporting sightings of the plant. Moreover, instruction on the cleaning of boating and angling equipment is necessary to prevent dispersal of *E. densa* facilitated by these vectors. In the Netherlands, a simple photographic aid to the identification of a number of invasive species was produced in conjunction with the 'Code of conduct for aquatic plants' by van Valkenburg (2014). Its aim is to create awareness and assist in the monitoring of non-native aquatic plants.

The early detection of non-native plants before they become widespread will contribute to their efficient eradication (European Commission, 2013). However, little attention is focused on submerged water plants in general, even by conservationists, and preventative methods may have to be actively applied (e.g. raking, diving and repeated observations) to detect less visible, low abundant species (Lafontaine *et al.,* 2013). Management in the United States is increasingly focused on surveying for early detection, associated with education of the public (Darrin, 2009).

8.2. Eradication and control measures

In infested water-bodies, the banning of propeller driven boats prior to management intervention may minimise fragment spread. However, this policy was applied at Loosdrecht in the Netherlands following invasion of another invasive plant, Fanwort (*Cabomba caroliniana* A. Gray), and was difficult to implement and regulate.

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

8.2.1. Manual and mechanical control

Manual and mechanical management techniques involve the direct cutting and/or removal of unwanted plant material from the affected area (Wilson *et al.,* 2007). Interventions such as these will only be successful if the cutting of large populations on a large scale is followed by continued management intervention on a smaller scale. This has been widely demonstrated during the management of floating pennywort (*Hydrocotyle ranunculoides* L. fil.) in the Netherlands (R. Pot, unpublished).

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

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

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

- Harvesting boats. Small boats with a hydraulic controlled rack on the front that can collect floating plants and transport them to the banks (Figure 8.2). This method allows only partial collection of plant biomass and further spread is not prevented completely. Larger boats that cut and collect in one action are much more efficient but expensive and not practical in small water bodies.

- Mowing basket. A steel bucket with cutter bar attached to the hydraulic arm of a tractor or excavator that can be lowered into drainage channels, small rivers and ponds, and cut and collect plant material. Loss of plant material may be relatively low if the machinery is operated with care. Mowing baskets can therefore be effective in preventing the spread of unwanted plant species.

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

Mechanical methods aimed at the control of established infestations such as mechanical harvesting, hydroraking and rotovation, may result in the breakup of branching plant stems resulting in the dispersal of plants to new areas (Bowmer *et al.*, 1995; Massachusetts Department of Conservation and Recreation, 2005; EPPO, 2007; Wilson *et al.,* 2007). Mechanical removal may only result in control over the short- to medium-term and will probably not achieve eradication (Millane & Caffrey, 2014). Experience in countries such as the U.S.A. and Australia shows mechanical removal of *E. densa* only exacerbates the problem due to the accidental dispersal of cut fragments, particularly in flowing river systems (Coetzee *et al.,* 2011). Moreover, the mechanical removal of *E. densa* from plots in the shallows of a Brazilian reservoir was ineffective as the plant regained its original biomass within approximately three months, even though removal was repeated five times during this period (Oliveira *et al.,* 2005). In France mechanical methods were applied to *E. densa* that had established in the river Vendée associated with retaining nets designed to catch drifting fragments. Monitoring indicated that there were significant reductions in plant biomass approximately a month following mowing interventions (Le Syndicat Mixte du Marais Poitevin, 2014). Management interventions of *E. densa* in La Rochelle Marans canal, France began as early as 2001 using weed cutting boats and chemical treatment. However, the plant recovered completely within 3 months after each intervention. Recently, dredging has been initiated in an attempt to control the plant (Conseil général de Charente-Maritime, 2014). Due to the possibility of further spread, mechanical methods should only be used when all available niches have been filled and attention should be paid to the fragmentation of plants when employing cutting machinery (Csurhes *et al.,* 2008; Lafontaine *et al.,* 2013). Cleaning of machinery prior to their movement between sites, isolating the sites with nets that trap floating fragments, and visual checks for new colonisations in the near surroundings a few weeks after cutting may prevent further spread resulting from the escape of cut fragments (DiTomaso & Kyser, 2013). Cuttings may be composted to prevent them from re-entering the freshwater system.

The eradication of low density infestations over a limited area can be achieved via careful manual removal that avoids plant fragmentation (Lansdown, 2011; Millane & Caffrey, 2014). Whole plants, including roots, can be gathered with a rake. The use of divers to manually remove plants is easy and straightforward, with minimal environmental impacts, however, it is also labour intensive and therefore generally only cost-effective for small, localized infestations (Wilson *et al.,* 2007).

8.2.2. Biological control

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

An experimental bio-herbicide inoculum, based on *Fusarium graminearum* (Schwein.) Petch cultures, was studied with promising results when used as a co-adjuvant with herbicides against *E. densa* (Borges Neto & Pitelli, 2004). After exposure to the inoculum in the laboratory, *E. densa* developed progressive chlorosis, followed by necrosis and complete

tissue disintegration. No information is available on the effectivity of this bio-agent in the field or its possible suitability (including effects on native species), it has not yet been developed for commercial field use (Lafontaine *et al.,* 2013; Walsh *et al.,* 2013). However, *F. graminearum* is most effective as a biological agent at temperatures of 25 $^{\circ}$C and above and therefore appears less suitable for conditions found in the Netherlands (Borges Neto *et al.,* 2005; Kempenaar *et al.,* 2009). The addition of adjuvants such as ground rice to the *F. graminearum* solution can increase its effectiveness (Borges Neto & Pitelli, 2004; Kempenaar *et al.,* 2009).

E. densa has relatively few native predators so possibilities for bio-control are fairly limited (Darrin, 2009). In studies on the ecology of *E. densa* and its associated fauna in its native range of Argentina, Walsh *et al.* (2013) found an abundant undescribed species of *Hydrellia* (Diptera: Ephydridae) feeding on *E. densa*. This species was shown to be quite promising as a future biological control agent due to its specificity, high damage rates even in the native range, adaptability to adverse climatic and physical conditions, and a high level of specific mortality which suggests that larval densities could be higher in environments where specific natural enemies are absent (Diaz *et al.,* 2009; Walsh *et al.,* 2013). In the laboratory, a single female can produce enough offspring to cause the defoliation of a whole *E. densa* stem (Coetzee *et al.*, 2011). Climate matching and potential field impact studies have begun to further assess this species effectiveness against *E. densa* in its non-native range, but its distribution in Argentina suggests that it could adapt to the areas in the world most heavily infested by the plant (Diaz *et al.,* 2009; Walsh *et al.,* 2013). A Pakistani beetle species, *Bagous affinis* Hustache, has been shown to cause significant damage by feeding on *E. densa* and could possibly be used as a bio-agent against *E. densa* in Europe (Buckingham & Bennett, 1998; Kempenaar *et al.,* 2009).

In a small private pond in Spain, pekin ducks (*Anas platyrhynchos* L.) were observed to be very effective grazers on *E. densa*. The plants were not eradicated but kept at a reasonable growth level (Curt *et al.,* 2010).

Triploid grass carp (*Ctenopharyngodon idella* Valenciennes) find *E. densa* highly palatable and have been used to manage *E. densa* in Devil's Lake, Oregon and Silver Lake, Cowlitz County in the United States (Washington State Department of Ecology, 2014). However, due to their lack of feeding preference, *C. idella* can remove the entire submersed aquatic community, hence introduction should be undertaken with care (Mitchell, 1980; Lafontaine *et al.,* 2013). There is one example in literature of biological control using *C. idella* where native macrophyte species were first to return to a lake after stocking, *E. densa* did not return at all in the following growing season after removal (Tanner *et al.,* 1990).

The feeding preference of *C. idella* may be influenced by stock density. At low densities, *C. idella* has been observed to preferentially select species other than *E. densa* while at higher densities, all vegetation is removed (Mitchell, 1980). Moreover, fish size may influence the consumption of aquatic waterweeds by *C. idella.* In Florida, *C. idella* fed preferentially on hydrilla (*Hydrilla verticillata* (L. fil.) Royle) rather than other non-native species such as *E. densa* (Cuda *et al.,* 2008). In a second study, feeding experiments showed that *E. densa* was the least preferred species of small (200-300 g) grass carp compared to Eurasion watermilfoil (*Myriophyllum spicatum*) and hornwort (*Ceratophyllum demersum*). However, as

fish grew (up to 927 g) *E. densa* shifted from least preferred to most preferred species (Bonar *et al.,* 1993).

C. idella is already widespread in the Netherlands as a result of multiple introductions for the management of aquatic weeds, but the species is present in low density and not able to reproduce. *C. idella* may pose a high risk to ecosystem functions when present in high densities due to impacts relating to modification of nutrient cycling or resource pools, physical modifications of the habitat, modifications of natural succession and disruptions of food webs (Schiphouwer *et al.,* 2014).

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

8.2.3. Chemical control

Several sources (CABI, 2014; Global Invasive species database, 2014; Parsons *et al.,* 2007; Skogerboe *et al.,* 2006) state that diquat and fluridone are effective herbicides against *E. densa*. However, since the withdrawal of all herbicides for use in aquatic environments there is no appropriate chemical method for the control of *E. densa* in the Netherlands.

8.3. Ecosystem based management

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

Lake drawdown may facilitate the removal of *E. densa.* The plants shoots and leaf tissues are vulnerable to drying and freezing when left out of the water for a minimum of 1 to 5 hours, while prolonged drawdown readily kills roots (Hauenstein Barra, 2012; Darrin, 2009). Multiple drawdowns in colder temperatures have been most effective in promoting larger decreases in *E. densa* populations (Goldsby & Sanders, 1977). Drawdown may be an effective measure in areas of low ecological value such as artificial channels and reservoirs.

However, evidence relating to this management technique is conflicting. Lake drawdown was not very successful in an experiment by Dugdale *et al.* (2012). After 34 days, 12% of stems and 32% of crowns collected from the bottom of weed mounds were still viable. The authors concluded that regeneration from in situ stem fragments and crowns following refilling are an important potential source of re-establishment for *E. densa*. Draining for sufficient time is not always feasible, especially in larger canals (Bowmer *et al.*, 1995). Moreover, this control technique will destroy fish, aquatic organism populations, possibly reptiles and amphibians, and may alter downstream conditions (Commonwealth of Massachusetts, 2002).

Light-excluding benthic barriers, such as jute matting, may be an effective control in the event of localised *E. densa* colonisation (Millane & Caffrey, 2014). The use of jute matting, was effective against Curly waterweed (*Lagarosiphon major*) in Ireland (Caffrey *et al.,* 2010) and is likely to be similarly effective against *E. densa* as both species are morphologically similar and do not produce seeds (Millane & Caffrey, 2014).

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

Increasing water turbidity as a measure against *E. densa* provides no realistic basis for management (Marin, 2014; Schallenberg & Sorrell, 2009).

9. Conclusions and recommendations

9.1. Conclusions

Habitat description
- *E. densa* thrives in various types of freshwater habitats. In its native range, *E. densa* is found in slow flowing, shallow waters. Outside its native range it is also found in lakes, ponds, quarry pools and sluggish rivers, streams and canals.

- The species may be vulnerable to harsh winters found in the Netherlands and mortality occurs at water temperatures below 3°C, but it can survive under ice. Growth occurs between 10 and 30°C, however over 30°C tissue damage has been reported. *E. densa* may tolerate water temperatures up to a maximum of 35°C.

- *E. densa* tolerates pH from 5.5 to 7.9, low to moderate current velocities of 0 to 1 m s^{-1}, features a light compensation point of 7.5 to 16.2 mmol m^{-2} s, and is usually found at a water depth between 0.15 and 3 m. *E. densa* has been recorded at a conductivity between 715 and 802 μs cm^{-1}. The species grows on sapropelium and other organic, fine in-organic and sandy substrates.

Distribution, dispersal and invasiveness
- According to CABI (2014), Brazilian waterweed (*Egeria densa*) has dispersed to 27 countries outside of its native range and is recorded as an invasive species in 12 (44%) of these countries.

- In 2006, the Netherlands imported almost 1,7 million *E. densa* plants for use in aquaria and garden ponds (approximately 34% of all aquatic plant imports). The plant is sold freely at garden centres and aquarium shops.

- A google.nl search using the terms 'Braziliaanse waterpest' and 'Argentijnse waterpest' revealed 11 online retailers offering *E. densa* for sale in the Netherlands. The species is also sold under the Latin names *Egeria densa*, *Elodea densa*, *Anacharis densa* or *Philotria densa.* None of the retailer's websites visited gave information regarding the invasive nature of E. densa or the importance of avoiding introductions of this species to the freshwater network on the retail page of any of the sites visited.

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

- Global introductions of *E. densa* have been attributed to the discarding or deliberate planting of aquarium plants in natural waterways.

- Humans appear to be the main vector of secondary dispersal of *E. densa* away from initial points of introduction. Examples of vectors found in literature are: boats, fishing equipment, weed harvesters, clothes and footwear.

- *E. densa* was first recorded in Dutch nature near Dordrecht in 1944. Since then the species has been recorded in 54 kilometre square grids in the Netherlands. The plant was recorded in 1951, in a pond in Bussum, and in 1976 and 1977 in the municipality of Doorn. After the year 2000, recordings of *E. densa* have been made nearly every year.

- *E. densa* was first recorded in the United Kingdom in Ashton Canal, Droylesden in 1953 but there is no evidence of spread from naturalised populations. There are fewer than twenty recordings of *E. densa* at 10 km square grid scale in the United Kingdom. *E. densa* was first recorded in Belgium in 1999 in a small pond in Ezemaal. At present the species does not show very effective natural dispersal. However, the number of records has increased substantially and the plant is now naturalised in a few locations in Flanders. *E. densa* was first recorded in Germany in 1910 in the Elster-Saale Canal near Leipzig. the species is now present in six Länder and established in the river Erft, North Rhine-Westphalia, bordering the Netherlands, and Baden-Würtenberg. However, since 2003, the abundance of *E. densa* in the river Erft has declined. Moreover, the river Erft is not representative of the German climate as it is a thermally polluted river whose temperature does not dip below 10°C in winter.

Ecological and socio-economic impacts
- To date, ecological or socio-economic impacts have not been reported for the Netherlands.

- Neighbouring countries have experienced few impacts relating to *E. densa*. The lack of major negative ecological or socio-economic impacts in the United Kingdom is attributed to *E. densa*'s low abundance there. In Ireland, other closely related species such as curly waterweed (*Lagarosiphon major*) and Nuttall's waterweed (*Elodea nuttallii*) have caused ecological and socio-economic impacts and it is suggested that *E. densa* might be able to emulate this if it becomes more abundant. In Germany, *E. densa* suppressed the formerly widely distributed native broad leaved pondweed (*Potamogeton natans*) and fennel pondweed (*Potamogeton pectinatus*) in the river Erft, North Rhine-Westphalia. In Belgium, despite *E. densa* becoming more abundant, it has not yet become invasive.

- In countries where *E. densa* has become highly abundant such as Australia, the United States and New Zealand, significant ecological and socio-economic impacts have resulted. At high abundances *E. densa* has been described as an ecosystem engineer whose presence leads to alterations in aquatic habitats and local species composition. Other impacts include restrictions to recreational activity, reduced visual amenity, increased potential for local flooding, obstruction of industrial water intakes and the high cost of remedial management.

Available risk classifications
- Out of five European risk classifications, three classified *E. densa* as a high risk species (Belgium, Luxembourg, Switzerland). In an assessment applied to EPPO quarantine list, alert list and priority species using the New Zealand AWRAM system, *E. densa* was defined as a banned species. In Ireland, *E. densa* was classified as a medium risk species. Out of the two classifications obtained from outside Europe, the Australian

47

assessment classified *E. densa* as a high risk species and the USA assessment classified *E. densa* as posing a lesser threat.

9.2. Effective management options

- The following alternative aquatic plant species are suggested for use in cold water aquaria and garden ponds: Canadian pondweed (*Elodea canadensis*) or Nuttall's waterweed (*Elodea nuttallii*). These plants are easy to maintain and relatively cheap to produce; both are alien species, but established in the Netherlands long ago.

- Improvements to labelling of (potential) invasive aquatic plants by garden centres, pet shops and online retailers and continuous dissemination of information about potential invasiveness of non-native species to create awareness of water gardeners and aquarium hobbyists may help prevent the disposal of *E. densa* to water bodies. Moreover, awareness campaigns for specific actors (e.g., fisherman, boat owners) may reduce human spread of invasive in the Netherlands.

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

- Limiting standard management intervention appears to be the best method of limiting the spread of the species. A high level of fragment spread occurs when cutting machinery is used without the immediate collection of plant material.

- If control of *E. densa* is required, it is best to focus on the prevention of fragment spread. Mowing baskets or harvesting boats may be the best options for this, but only when the removal of all plant material from the water body is assured, preferably including the root system. Retaining nets stretched from bank to bank that catch fragments and stop them floating away during cutting may be required. Cuttings may be composted to prevent them from re-entering the freshwater system.

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

9.3. Recommendations for further research

The reasons given for the limited distribution and dispersal capacity of *E. densa* at the majority of locations in the Netherlands are based on expert knowledge. Further research is required to support or reject these expert opinions. Establishing the specific conditions that allow the plant to become invasive will allow nature managers to better predict the likelihood that *E. densa* will colonise and become invasive at locations in the Netherlands. This will also offer insight into key factors for cost effective management in the future.

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Appendices

Appendix 1: Results of field survey 2014.

Location	Hoogeveen
Date of field search	26-08-2014
Latitude (dd mm,mmm)	52 42.827
Longitude (dd mm,mmm)	6 29.658
Amersfoort coordinates (RD, m)	229812 525728
Water depth (cm)	50 - 100
Transparency	>80
Width water (m)	20
Width emergent zone (m)	0 - 0.5
Water flow cm . s^{-1}	0.5
Water type	Standing, urban pond in sandy soil
Surface area covered by *Egeria*	20%
Surface area covered by all submerged plants	40%
Surface area covered by all floating plants	2%
Surface area covered by all emerged plants	<1%
Number of individuals/shoots	>1000
Phenology	Vegetative
Tansley survey	
Water zone	
Egeria densa 1)	a
Ceratophyllum demersum	a
Persicaria amphibia	o
Sparganium erectum	o
Lemna minor	f
Lemna minuta 1)	r
Nymphaea alba-hybrid 1)	lo
unidentified, cf. *Ludwigia* spec. 1)	r
Limnobium leavigatum 1)	o
Emergent zone only	
Glyceria maxima	f
Convolvulus sepium	f
Lotus pedunculatus	o
Vicia cracca	o
Sparganium erectum	la
Bidens frondosa	o
Persicaria amphibia	o
Holcus lanatus	lf
Juncus effusus	la
Poa trivialis	o
Alnus glutinosa	lf
Lysimachia vulgaris	o
Agrostis stolonifera	lf
Fraxinus excelsior	r
Iris pseudacorus	o
Plantago lanceolata	f
Carex pseudocyperus	f
Lycopus europaeus	o
Galium palustre	o
Ranunculus repens	o
Carex hirta	lf
Urtica dioica	o
Cerastium fontanum	o

Tansley / DAFOR score a: abundant; d: dominant; f: frequent; o: occasional; r: rare (note: prefix l was used for local); 1) = non-native.