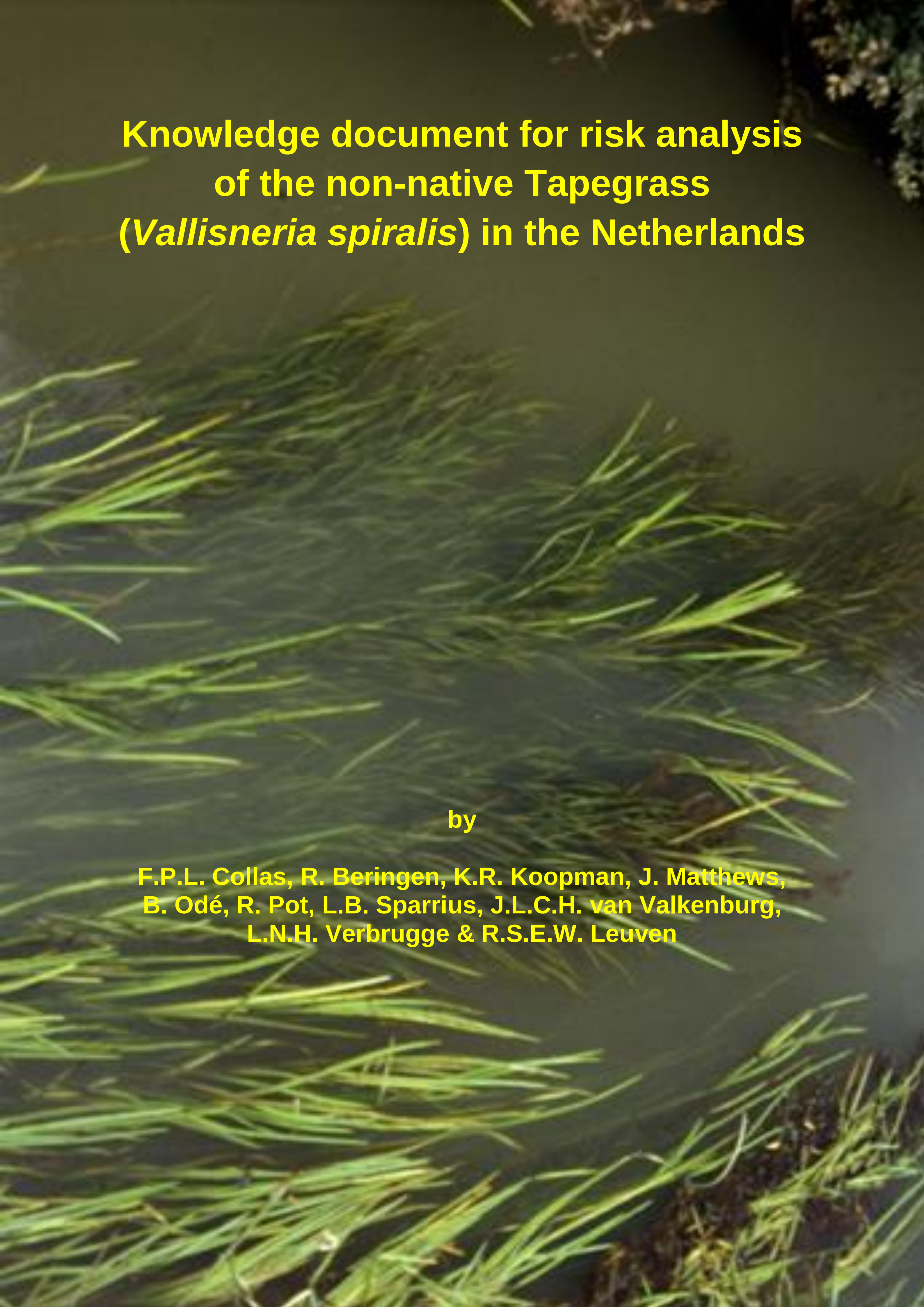

Knowledge document for risk analysis of the non-native Tapegrass (*Vallisneria spiralis*) in the Netherlands

by

F.P.L. Collas, R. Beringen, K.R. Koopman, J. Matthews,
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L.N.H. Verbrugge & R.S.E.W. Leuven

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15 November 2012

Radboud University Nijmegen,
Institute for Water and Wetland Research
Department of Environmental Science,
FLORON & Roelf Pot Research and Consultancy

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

Series of Reports on Environmental Science

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

Reports Environmental Science nr. 416

Title:	Knowledge document for risk analysis of the non-native Tapegrass *(Vallisneria spiralis)* in the Netherlands
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Cover photo:	Tapegrass (*Vallisneria spiralis*) in a side-branch of the river Erft at Kasterer Mühlen, Northrhine-Westphalia, Germany (© Photo A. Hussner).
Project manager:	Dr. R.S.E.W. Leuven, Department of Environmental Science, Institute for Water and Wetland Research, Radboud University Nijmegen, Heyendaalseweg 135, 6525 AJ Nijmegen, the Netherlands, e-mail: r.leuven@science.ru.nl
Project number:	62001590
Client:	Netherlands Food and Consumer Product Safety Authority, Office for Risk Assessment and Research, Invasive Alien Species Team, P.O. Box 43006, 3540 AA Utrecht
Reference client:	TRC/NVWA/2012/2009, order nr. 60400891, formdesk nr. 19460, specification code 6300004
Orders:	Secretariat of the Department of Environmental Science, Faculty of Science, Radboud University Nijmegen, Heyendaalseweg 135, 6525 AJ Nijmegen, the Netherlands, e-mail: secres@science.ru.nl, mentioning Reports Environmental Science nr. 416
Key words:	Dispersal; ecological effects; invasibility; invasiveness; non-indigenous species; weed control

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Content

Summary

Tapegrass (*Vallisneria spiralis*) is a non-native species that was recently observed in the Biesbosch-Merwede area, the Netherlands. To support decision making with regard to the design of measures to prevent ecological, socio-economical and public health effects, the Netherlands Food and Consumer Product Safety Authority, Ministry of Economic Affairs, Agriculture and Innovation has asked us to carry out a risk analysis of *V. spiralis.*

A literature study was carried out to provide an overview of the current knowledge on the distribution and invasion biology of *V. spiralis* 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 with use of university libraries. Various academic and non-academic search engines and websites were used in a systematic search of the Web of Knowledge, Scopus, Google Scholar and in an analysis of information available to the Dutch public, Google.nl.

It was found that the dispersal of the species can occur both through human and natural means, for example transport via wind or water. Besides influencing dispersal, humans also influence the establishment of *V. spiralis* by increasing the water temperature of water bodies. The species has a high invasiveness since it is able to disperse and vegetatively reproduce by fragmentation and colonise new areas. The sites where *V. spiralis* are found in the Netherlands have a high conservation value since the Biesbosch-Merwede is designated as NATURA 2000 site in accordance with the EU Habitats and Bird directives.

In other regions displacements of native submerged macrophytes have been observed, but these effects were limited to heated lakes that are not representative for the Dutch situation.

In its native habitat, the species is known to maintain a high water transparency and inhibition of the growth of blue-green algae. This results in a beneficial effect on the biodiversity of the entire ecosystem. The species is also capable of changing the pore water chemistry towards a more oxidized state and nutrients are retained due to oxygen release. This can result in a decrease of eutrophication in water bodies. Another ecosystem effect of *V. spiralis* is the accumulation of both metals and organic compounds thereby improving the physico-chemical properties of the water. However, the described beneficial effects on the ecosystem are not unique for *V. spiralis,* since the majority of submerged aquatic plants exhibit similar effects.

A number of possible management options were found. Isolation allows the natural disappearance of established populations. However, when more active control is required, leaf biomass should be removed with cutting boats acting at least 20 cm above the bottom to prevent spread of viable fragments with stolons or roots.

Future research should focus on the determination of the dispersal rate of *V. spiralis* and to establish if dispersal is possible through endozoochory. Moreover, it is currently not clear whether both male and female plants are present and capable of producing seeds in the Netherlands.

Finally, the identity of the specimens found in the Netherlands has to be examined further in order to determine whether these plants have a European or non-European origin and whether their establishment is naturally / spontaneous or induced by man.

1. Introduction

1.1. Background and problem statement

The Tapegrass (*Vallisneria spiralis*) is native in Northern Africa, Southern Europe and Asia. This plant species was first recorded in the Netherlands in 1960 in the canal Maastricht-Luik and was recently observed in the Biesbosch area in the Rhine-Meuse estuary (A. Boesveld, unpublished results). 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 *V. spiralis* in the Netherlands.

To support decision making with regard to the design of measures to prevent ecological, socio-economical and public health effects, the Netherlands Food and Consumer Product Safety Authority, Ministry of Economic Affairs, Agriculture and Innovation, has asked us to carry out a risk assessment of *V. spiralis*. 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 *V. spiralis.*
- To describe the global distribution and to analyse the current spread of *V. spiralis* in the Netherlands.
- To identify the key factors for dispersal (pathways, vectors, invasiveness) and successful establishment of *V. spiralis*.
- To assess (potential) ecological, socio-economical and public health effects of *V. spiralis* in the Netherlands, taking into account the impacts of this species in other geographical areas.
- To summarize available risk classifications of *V. spiralis* in other countries.
- To review possible management options for control of spread, establishment and negative effects of *V. spiralis*.

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 *V. spiralis* 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 visually similar species. The habitat characteristics 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. Several 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 species in the Netherlands (Risk analysis).

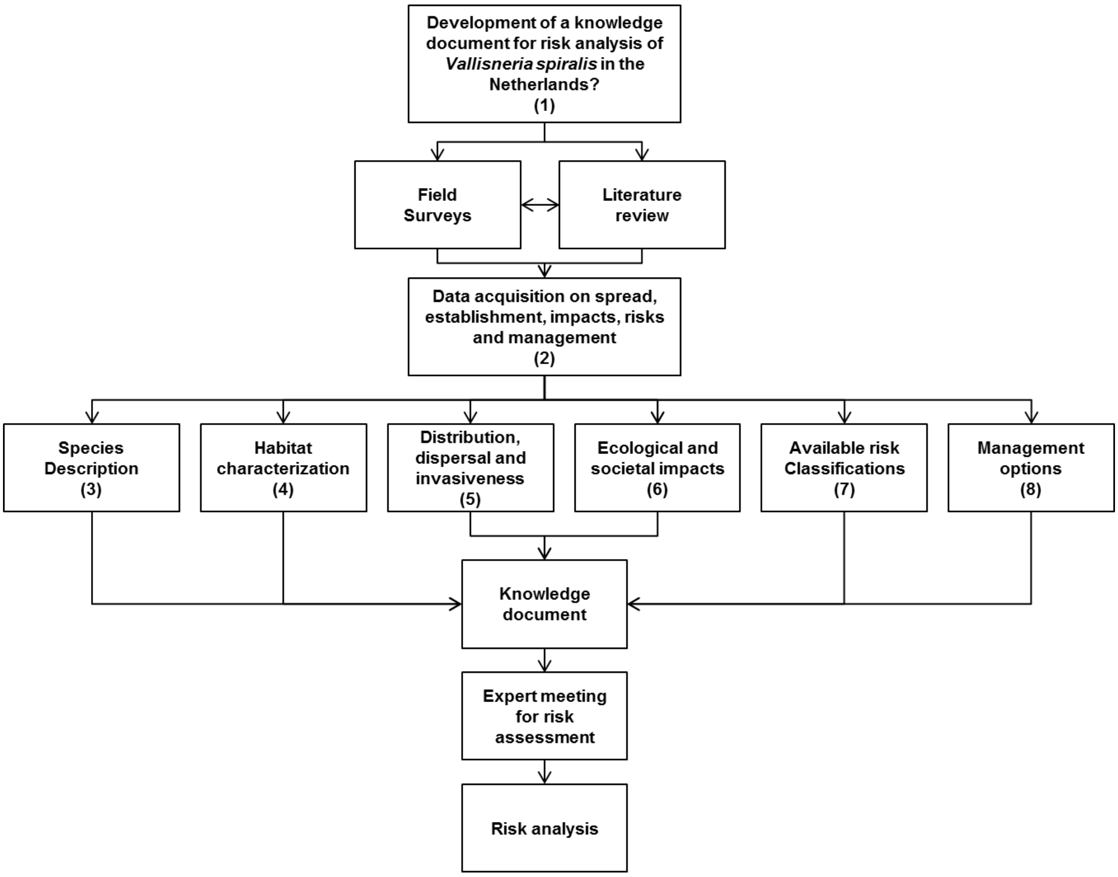

Figure 1.2: Flow chart visualising the coherence of various research activities in order to develop a knowledge document for risk analysis of Tapegrass (*Vallisneria spiralis*) in the Netherlands. Chapter numbers are given in brackets.

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 Tapegrass (*Vallisneria spiralis*). 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. Our study was largely internet based and used university libraries. The literature research was conducted with the use of three different search engines: ISI Web of Knowledge, Scopus and Google Scholar. The first two engines were used with the search term *V. spiralis*. In Google Scholar the following six search terms in combination with the Latin species name were used: control, dispersal, distribution, impact, management and vectors. The first fifty hits in Google Scholar were examined and added to a database of available literature. The first fifty hits certainly covered the most relevant articles.

All the articles found during the literature search were assessed and, when relevant, added to a database. The database consisted of the first author followed by the year and the title of the article. The search engine and search term used to find the specific article were also added. Two keywords for the specific article were added to the database, this gave the possibility to specifically search for certain subjects. A short description of the content of each article was given, as well as a scientific status (peer reviewed, grey or anecdotic paper). The availability of each article was also analyzed since not all articles were available in the libraries of Dutch universities or in the public domain on internet. Finally, the date of the search was indicated. The excel-file is available on request and contains all the articles acquired through the literate search.

To analyze the perception that the general public has on *V. spiralis* and give an insight into its availability from retailers an analysis of search engine hits via Google.nl was performed. The first 50 websites found via Google.nl search were categorized according to their content. Categories comprised regulatory, educational, retail and hobbyist websites and the number of websites contained within each category was recorded. Google.nl was searched using the term *V. spiralis*, and the Dutch common names 'Vallisneria'. Websites that contained names not referring directly to a species were omitted.

2.2. Data acquisition on current distribution

The distribution data originated from the National Database Flora & Fauna (NDFF). These data were complemented with data of A. Boesveld, who discovered the species in the Biesbosch-Merwede area in 2001, and with recent recordings on the website www.waarneming.nl.

2.3. Additional field surveys

On July 2, 2012 field surveys at three locations (Nieuwe Merwede: Spieringsluis and Lage Hof, Dordtsche Biesbosch: Zuid Maartensgat) were performed (Appendix 1). At each site plants were collected for herbarium specimens and DNA bar-coding. Species, location, date of field search, coordinates, water depth (cm), transparency / secchi depth (cm), width of water body (m), water flow, water type, surface area covered by non-native species (m^2), number of individuals/shoots and phenology were recorded.

A Tansley survey was performed at each site using the following abundance codes (DAFOR): d: dominant; a: abundant; f: frequent; o: occasional; r: rare. The growth form of each species was described using the following codes: d: floating; e: emergent and s: submerged.

At each site water samples were taken and at the laboratory the pH and alkalinity of the water was measured, using a ABU901 Autoburette in combination with TitraLabtm 80 (Radiometer, Copenhagen). Samples of both sediment and water were stored in a refrigerator for further analysis.

3. Species description

3.1. Nomenclature and taxonomical status

Tapegrass (*Vallisneria spiralis*) is one species in a genus that has recently been revised, especially regarding the Australian and Eastern Asian specimens (Les *et al*., 2008). The original definition of the species is valid in Europe, Northern Africa and Asia and presumably all specimens found in the wild and trade are of this species.

Table 3.1: Nomenclature and taxonomical status of Tapegrass (*Vallisneria spiralis*).

<table>
<tr><td colspan="2">Scientific name:

Vallisneria spiralis Linnaeus, 1753</td></tr>
<tr><td colspan="2">Synonyms:

Vallisneria jacquini Savi
Vallisneria jacquiniana Sprengel
Vallisneria micheliana Sprengel
Vallisneria michellii Savi
Vallisneria pusilla Barbieri ex Bertoloni</td></tr>
<tr><td colspan="2">Taxonomic tree</td></tr>
<tr><td>According to CABI (2012):
Domain: Eukaryota
Kingdom: Plantae
Phylum: Spermatophyta
Class: Monocotyledonae
Order: Hydrocharitales
Family: Hydrocharitaceae
Genus: Vallisneria
Species: Vallisneria spiralis</td><td>According to Mabberley (2008):
Domain: Eukaryota
Kingdom: Plantae
Phylum: Tracheophyta
Class: Spermatopsida
Order: Alismatales
Family: Hydrocharitaceae
Genus: Vallisneria
Species: Vallisneria spiralis</td></tr>
<tr><td colspan="2">Preferred Dutch name:

Vallisneria</td></tr>
<tr><td colspan="2">Other Dutch names:

No other names are used</td></tr>
<tr><td colspan="2">Preferred English name:

Tapegrass</td></tr>
<tr><td colspan="2">Other English names:

Eelgrass, Eel Grass, Eelweed, Tape Grass, Tapeweed Channel Grass, Coiled Vallisneria</td></tr>
<tr><td colspan="2">Native range:

Asia, Southern Europe and Northern Africa</td></tr>
<tr><td colspan="2">Visually similar species:

Vallisneria americana, Sagittaria sagittifolia, Sparganum emersum</td></tr>
</table>

References: CABI (2012), Mabberley (2008), Naturalis Biodiversity Center (2012).

The preferred English name is derived from Preston & Croft (1997). Though the name Eelgrass is found more often in literature it is also in use for *Zostera* and for the genus *Vallisneria*. In the USA the name Eelgrass is also used for *Vallisneria americana*. The official Dutch name is the same as the scientific genus name (Naturalis Biodiversity Center, 2011). The Scientific name is generally accepted as the legal scientific name. Due to recent revisions on the taxonomy of *V. spiralis* (Les *et al*., 2008), there is a debate if the specimens described in China, India and Australia are *V. spiralis* or other species.

3.2. Species characteristics

According to Hussner (2010) *V. spiralis* is a member of the Family Hydrocharitaceae and native to Southern Europe, Northern Africa and Asia. It is a rhizomatous, perennial, submerged aquatic plant with fibrous roots, featuring a short stem and horizontal runners. The plant features narrow, linear leaves, numbering between 5 and 20 displayed in radical rosettes, up to 1-2 m long and up to 10 mm wide. The leaves range in colour from a pale-green to reddish and usually feature unicellular spines. More clearly visible near the obtuse apex, the leaves incorporate 3-9 veins. Lateral veins join a more distinct central vein below the apex. The leaves have either entire toothed margins or finely toothed margins (Lowden, 1982; Figure 3.1b and i). The plants are dioecious and have axillary inflorescence.

Hussner (2010) describes that male inflorescence develop on a short, up to 7 cm, stalk. The tiny male flowers (diameter <1 mm) are numerous (>100) and enclosed in a 6-9 mm long spathe. This spathe breaks away from the plant and float on the water surface. The flowers have three sepals (Lowden, 1982). Besides three sepals, one minute petal rudiment is present as well as one staminodium and two stamens. The scapes are 1 - 1.3 mm wide and 10 - 30 mm long (Lowden, 1982; Figure 3.1h). The flowers are slightly zygomorphic and have obliquely extended stamens (Lowden, 1982; Figure 3.1f and g). No hairs are present at the base of the androecium. The staminodia adnate near the apex of the fused stigmatic lobes. The lobes are conspicuously fringed and shallowly cleft.

V. spiralis has female flowers carried on extended or spirally coiled stalks of up to 60 cm or more when fruiting. Female flowers are singular and enclosed in a 5-15 mm long bivalve spathe (Hussner, 2010). The flowers are solitary and slightly zygomorphic with three 2 - 3.5 mm long sepals (Lowden, 1982; Figure 3.1a, d and e). Besides the sepals three minute transparent petal rudiments, three staminodia and three bifid stigmas are present. These bifid stigmas are borne on short or highly reduced styles. The staminodia are small and inconspicuous. The staminodia are also adnate to fused discordant stigmatic fringed lobes. The floral incision is the deepest between matching stigmatic lobes. The ovary is formed inferior and unilocular. The fruit is elongated and approximately between 9.5 and 10 cm long. The fruits have an ellipsoid shape and are indehiscent. The placentation is parietal and numerous ellipsoid and striate seeds are formed. These seeds vary in length between 1.3 and 2 mm. No endosperm is formed (Lowden, 1982).

Seeds have not been observed germinating in aquaria (J.L.C.H. van Valkenburg, unpublished observation). Instead, plants most often propagate using runners which can lead to dense stands.

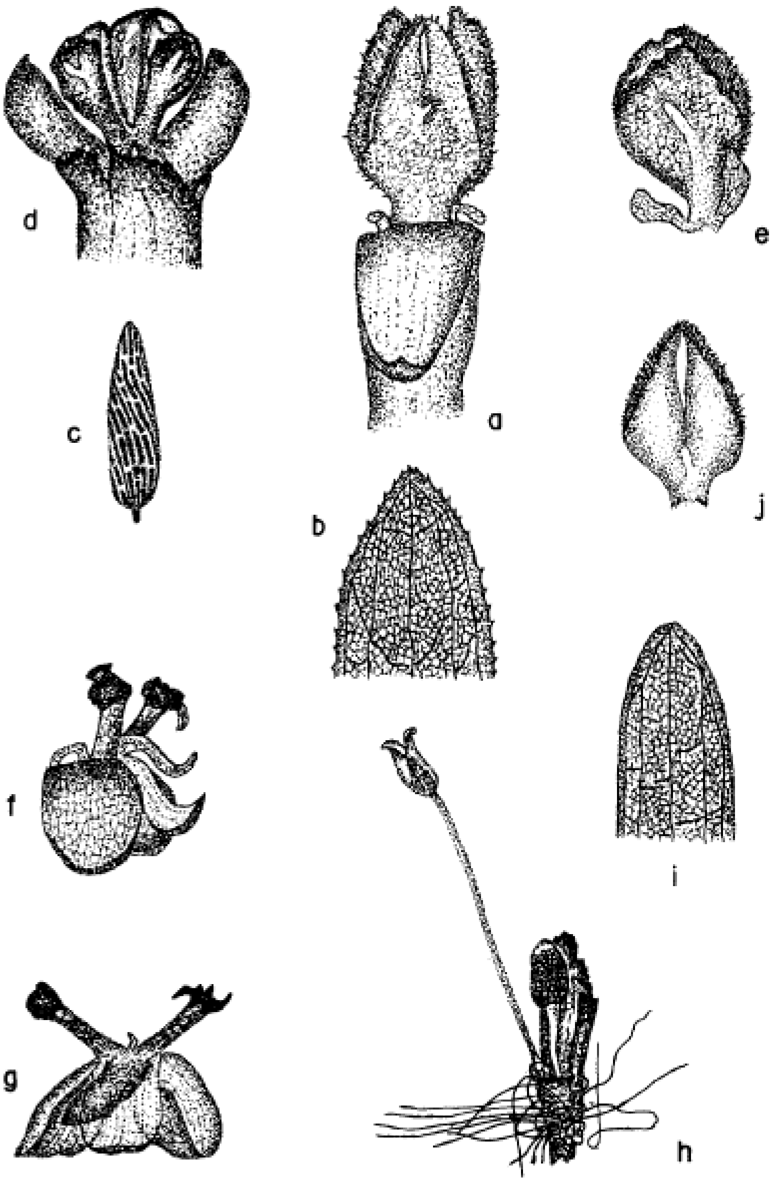

Figure 3.1: Identification of Tapegrass (*Vallisneria spiralis*). (a) and (d): female flowers; (c): mature seed; (b) and (i): finely and entire toothed margins, respectively; (e): fused staminodium; (f) and (g): freely extended stamens of the staminate flowers, and (h): male plant which is partly dissected. Source: Lowden (1982).

3.3. Differences with visually similar species

Vallisneria americana can only be distinguished by their male flowers: spathes are longer (10-23 mm, 6-9 mm in *V. spiralis*), and wider (8-10 mm (dried), 3-4 mm (dried) in *V. spiralis*). *Sagittaria sagittifolia* and *Sparganum emersum* can be easily distinguished when they form floating or emerging leaves. Submerged leaves are highly similar but can be distinguished by their veins. *S. sagittifolia:* veins are more or less equal and the outermost lateral veins deflect sideways into a margin below the apex. *S. emersum*: secondary veins are very regular, perpendicular to the main veins and form a ‘brick wall’ pattern (Pot, 2003).

3.4. Reproduction

V. spiralis spreads asexually through runners (Figure 3.2) (Hutorowicz & Hutorowicz 2008). Xiao *et al.* (2007) found that clonal integration by *V. spiralis* enables the species to grow under a canopy of neighbouring plants thereby improving its competitive ability and clonal expansion. Thus clonal growth through runners enables *V. spiralis* to spread into vegetated areas (Xiao *et al.*, 2007; Xiao *et al.*, 2011). However, Xiao *et al.* (2006b) found no clonal integration between interconnected ramets, due to the uniform nutrient concentration in water which compensates for the nutrient heterogeneity of the soil. In its native range, the plant shows clonal growth from April to September. Flowering takes place in autumn and the plant overwinters with the use of tubers. At the end of autumn the leaves die (Fox *et al.*, 2011; Xiao *et al.*, 2011). The plant is also able to colonise new areas through the spread of plant fragments (CABI, 2012).

The species can also spread by seeds. The staminate flowers of *V. spiralis* detach completely from the male plants. The flowers then rise to the surface and open. They are then dispersed through the wind and currents as free floating rafts. The anthers and the pollen remain dry within the perianth of the pistillate flower. The pistillate flowers are attached to the plant by long flexuous peduncles. The flowers orientate their opening at the water’s surface. Pollination occurs when anthers of the floating staminate flowers come into contact the stigmas of the pistillate flowers. When fertilization has occurred the peduncle coils into a spiral which results in the retraction of the developing fruit under water where it matures (Al Asadi *et al.*, 2007; Les *et al.*, 2008).

Figure 3.2: Growth form of Tapegrass *Vallisneria spiralis* (Photo: J.L.C.H. van Valkenburg).

4. Habitat characteristics

4.1. Habitat description

Table 4.1 gives an overview of the physiological tolerances of Tapegrass (*Vallisneria spiralis*). The species has been recorded in water bodies with a wide variety of temperatures (18.1-39 ^oC) and does not tolerate water temperatures below 5 ^oC. Besides the water temperature the species can tolerate slightly acidic to slightly alkaline conditions (Table 4.1). The plant is present to a maximum depth of 6.5 m and prefers clear water. *V. spiralis* can be found in both still and flowing waters and has a high tolerance to wave stress (Ali *et al.*, 1999; Hussner & Lösch, 2005; Al-Asadi *et al.*, 2007). The species occurs on muddy, sandy and gravelly sediment and can tolerate low light conditions due to a low light compensation point (Hussner & Lösch, 2005; Mukhopadhyay & Dewanji, 2005; Ye *et al.*, 2009). In Egypt, the species is not found at polluted sites that directly receive effluent from factories (Ali & Soltan, 1996). The species can form thick beds in the littoral zone of ponds and lakes (e.g. see figure 4.1) and has a maximum biomass of 3632 gram dry weight per m^{-2} (Royle & King, 1991; Mukhopadhyay *et al.*, 2007).

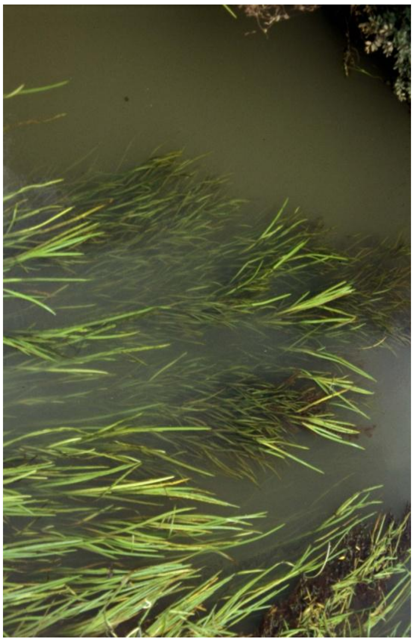

Figure 4.1: Tapegrass (*Vallisneria spiralis*) in a side-branch of the river Erft at Kasterer Mühlen, Northrhine-Westphalia, Germany (Photo: A. Hussner).

Several studies describe the effects of environmental factors on the growth of *V. spiralis*. According to Ye *et al.* (2009), *V. spiralis* achieves the highest growth rate on fertile sediments. The growth rate itself was found to vary during the year. Pinardi *et al.* (2009) calculated that the net growth rate (NGR) of leaves was 0.001 d^{-1} during the winter and 0.08 d^{-1} during the summer. The leaf NGR was calculated using an exponential growth model and measurements of leaf length and width. Gao *et al.* (2009) found a relative growth rate of 0.1, calculated as the ratio of dry weight difference between dry weight at the end of 30 days of incubation and dry weight at the beginning of the experiment.

Table 4.1: Physiological tolerances of Tapegrass (*Vallisneria spiralis*) recorded in the Netherlands (referred to as this study) and abroad.

Parameter	Published data	References
Water Temperature (^oC)	18.1 – 39	Ejsmont-Karabin & Hutorowicz (2011); Ali *et al.* (2011); Rachetti *et al.* (2010); Rai & Tripathi (2009); Al-Asadi *et al.* (2007); Mukhopadhyay & Dewanji (2004); Jana & Choudhuri (1984)
Minimum Temperature (^oC)	5	Kasselmann (2009)
pH	4.3 – 8.8[a] 2.9[b] 7.96 – 8.48	Ali *et al.* (2011); Rachetti *et al.* (2010); Rai & Tripathi (2009); Ye *et al.* (2007); Al-Asadi *et al.* (2007); Mukhopadhyay & Dewanji (2005); Hussner & Lösch (2005) This study
Alkalinity (mg l^{-1})	63 – 290 113.11 – 123.12	Rai & Tripathi (2009) This study
Nitrate (mg l^{-1})	0.84 – 391	Rai & Tripathi (2009); Ye *et al.* (2007); Mukhopadhyay & Dewanji (2005); Hussner & Lösch (2005); Mukhopadhyay & Dewanji (2004)
Phosphate (mg l^{-1})	0.02 – 10.4	Rai & Tripathi (2009); Ye *et al.* (2007); Mukhopadhyay & Dewanji (2005); Hussner & Lösch (2005); Mukhopadhyay & Dewanji (2004)
Depth (cm^{-1})	10 – 650	Ali *et al.* (2011)
Secchi disk visibility (cm^{-1})	63 – 167 55-75	Ye *et al.* (2007); Mukhopadhyay & Dewanji (2005); Mukhopadhyay & Dewanji (2004) This study
Dissolved oxygen (mg l^{-1})	0.96 – 20.3	Ejsmont-Karabin & Hutorowicz (2011); Ali *et al.* (2011); Rachetti *et al.* (2010); Ye *et al.* (2007); Al-Asadi *et al.*(2007)
Flow velocity (m s^{-1})	0 – 0.8	Hussner & Lösch (2005)
Conductivity (µS cm^{-1})	104.17 – 1990	Ali *et al.* (2011); Rachetti *et al.* (2010); Hussner & Lösch (2005)

[a] Generic range found for the pH; [b] Incidental pH value.

V. spiralis can experience different types of stress in its habitat. In the case that the species is exposed to habitat with heterogeneous nutrient availability and light conditions it produces more ramets in favourable patches, thereby enabling escape from low nutrient and low light patches (Xiao *et al.*, 2006a; Xiao *et al.*, 2006b; Wang & Yu, 2007; Xiao *et al.*, 2007; Zhao *et al.*, 2012). Ali *et al.* (2011) found *V. spiralis* only in the unshaded areas along the littoral zone since the growth and spread of the plant is limited by the light availability. Another type of stress the plants experience is sedimentation stress, which occurs in turbid waters (Hussner & Lösch, 2005). A decrease in relative growth was found when the species was exposed to high sedimentation levels (i.e. sedimentation of eight cm sand; Li & Xie, 2009). However, at lower sedimentation levels *V. spiralis* showed two escape mechanisms to avoid the negative effects of sedimentation: the runners were developed in a decreased angle and the runner was elongated thereby placing the ramets closer to the sediment surface. A high water turbulence between 1.61 and 2.86 cm s^{-1} was also found to decrease the growth of the species (Ellawala *et al.*, 2011).

4.2. Associations with other species

In the Netherlands *V. spiralis* was found accompanied by a number of aquatic plants e.g. *Myriophyllum spicatum*, *Alisma gramineum, Potamogeton pectinatus*, *Potamogeton crispus*, *Potamogeton pusillus*, *Ceratophyllum demersum* and *Potamogeton lucens*. *V. spiralis* was absent when *Potamogeton pectinatus* was abundant. The species and the coverage of the plant species at each site surveyed are shown in appendix 1. Some of the sites in the Biesbosch (Zuid-Maartensgat) are visited by large numbers of migrating birds like Tufted duck (*Aythya fuligula*), Common Pochard (*Aythya ferina*), Gadwell (*Anas strepera*), Eurasian Wigeon (*Anas penelope*) en Northern Pintail (*Anas acuta*) (T. Muusse, personal communication).

A number of plant species are known to occur with *V. spiralis* in its native range. Mukhopadhyay *et al.* (2007) found a correlation between *Nymphoides hydrophylla*, *Alternanthera philoxeroides* and *V. spiralis* in India. This correlation might be explained through the difference in habitat: floating, emergent and submerged. In China *V. spiralis* is often found with *Myriophyllum spicatum*, another submerged macrophyte. When the two species live together, *V. spiralis* inhabits the horizontal space through clonal growth, whereas *M. spicatum* inhabits the vertical space through shoot branching (Xiao *et al.*, 2011).

Besides associations with other plant species, *V. spiralis* is known to have interactions with animals as well. The plant serves as an important food source for water feeding birds in China. These birds feed on the highly energetic tubers of *V. spiralis* (Fox *et al.*, 2011). The periphyton on the leaves of *V. spiralis* also serves as a food source for other species. One of these species is the gastropod *Radix swimhoei*. The growth of *V. spiralis* was enhanced at low snail densities and decreased at high densities (Li *et al.*, 2009). Gastropods are also known to consume *V. spiralis* (Li *et al.*, 2009). The species is able to compensate for the removal of leaves explaining its coexistence with herbivores (Li *et al.*, 2010). The interaction between *V. spiralis* and the snails is required to achieve and maintain a clear water state (Li *et al.*, 2008). In China the beds formed by *V. spiralis* are known to serve as a refuge for fishes (Xie *et al.*, 2000). Copeland *et al.* (2012) found an associations in Burundi between Chironomid species and *V. spiralis*. On the contrary, Krecker (1939) found low numbers of animals and species living on *V. spiralis*. It has to be noted that the *V. spiralis* species used by Krecker are now classified as a new species: *V. americana*.

5. Distribution, dispersal and invasiveness

5.1. Global distribution

Tapegrass (*Vallisneria spiralis*) is most likely native to Asia, Southern Europe and Northern Africa. The species occurs in both tropical and subtropical areas (Hussner & Lösch, 2005; Les *et al.*, 2008; Hussner, 2012), as shown in figure 5.1. The figure can give a distorted image as one sighting results in the highlighting of an entire country or state (e.g. in central Africa the species has been recorded in one lake that is located in two countries). An overview of countries where *V. spiralis* occurs is given in table 5.1, although its presence at some locations is currently under debate. According to Les *et al.* (2008) the presence of *V. spiralis* in China and India remains unclear due to recent taxonomic revisions.

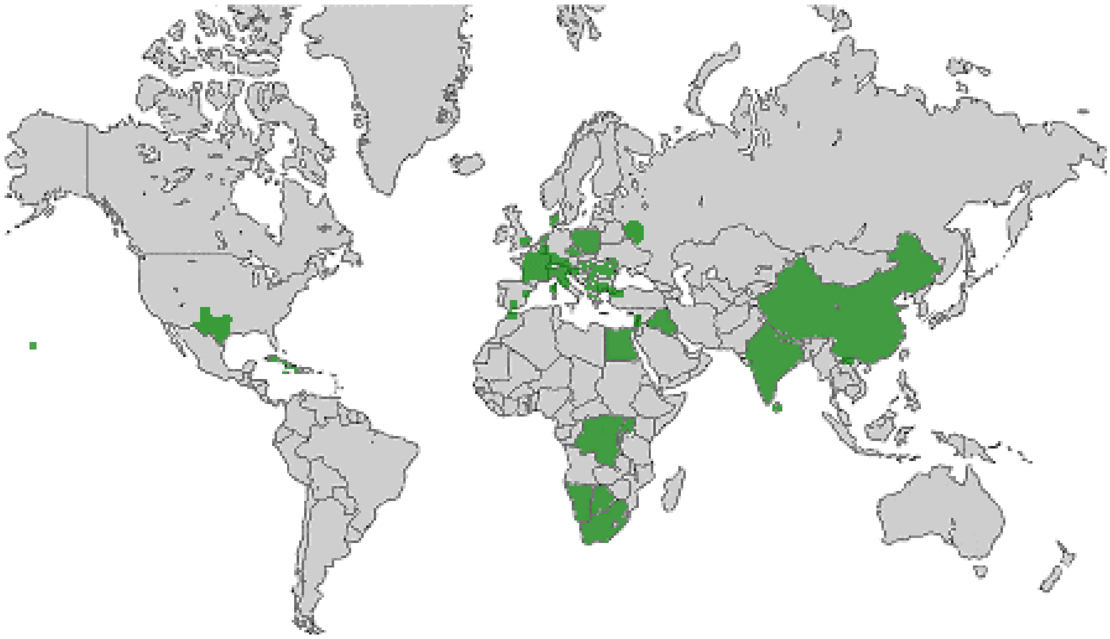

Figure 5.1: The worldwide distribution of Tapegrass (*Vallisneria spiralis*) (modified from Dijkstra, 2012; Data on geographical distribution: table 5.1).

The global distribution of *V. spiralis* is changing due to climate change. The higher temperature of the water results in an increase of potential habitat in the colder regions of Europe. Because of the increase in potential habitat the plant can become an invasive species (Hussner & Lösch, 2005; Willby, 2007).

Table 5.1: An overview of countries where Tapegrass (*Vallisneria spiralis*) is known to occur.

Country	Origin	Reference
Albania	Introduced	Hussner (2012)
Austria	Introduced	Les *et al.* (2008); Hussner (2012)
Belgium	Introduced	Hussner (2012)
Botswana	Unknown	Cook (2004)
Bulgaria	Introduced	Hussner (2012)
Burundi	Unknown	Copeland *et al.* (2012)
China	Unknown	Li & Xie (2009)
Congo Democratic Republic	Native	Les *et al.* (2008)
Croatia	Introduced	Hussner (2012)
Cuba	Introduced	Lowden (1982)
Czech Republic	Introduced	Hussner (2012)
Denmark (incl. Faeroes, Greenland)	Introduced	Hussner (2012)
Egypt	Native	Ali *et al.* (1999)
England	Introduced	Hussner (2012)
France (incl. Corsica)	Introduced [a]	Lowden (1982); Dutrarte (1997); Hussner (2012)
Germany	Introduced	Hussner & Lösch (2005); Les *et al.* (2008); Hussner (2012)
Greece	Introduced	Hussner (2012)
Hungary	Native	Lowden (1982); Hussner (2012)
Iraq	Native	Lowden (1982)
India	Native	Lowden (1982)
Italy	Native	Lowden (1982)
Israel	Native / re-introduced	Flora of Israel Online (2006)
Jamaica	Introduced	Lowden (1982)
Luxembourg	Introduced	Hussner (2012)
Macedonia	Introduced	Hussner (2012)
Moldova	Introduced	Hussner (2012)
Montenegro	Introduced	Hussner (2012)
Morocco	Unknown	Dijkstra (2012)
Namibia	Unknown	Cook (2004)
Netherlands	Introduced	Van Ooststroom & Reichelt (1961); Hussner (2012); this study
Nepal	Unknown	Shrestha & Janauer (2001)
Poland	Introduced	Hutorowicz & Hutorowicz (2008); Hussner (2012)
Romania	Introduced [b]	Hussner (2012)
Russia	Introduced	Katsman & Kuchkina (2010)
Serbia	Introduced	Hussner (2012)
South Africa	Unknown	Cook (2004)
Spain (incl. Baleares, Canary Islands)	Introduced	Hussner (2012)
Sri Lanka	Unknown	CABI (2012)
Switzerland	Native/ Introduced [c]	Schratt (1978); Hussner (2012)
Uganda	Native	Les *et al.* (2008)
United States of America (Hawaii and Texas)	Introduced	Staples *et al.* (2003); Les *et al.* (2008)
Vietnam	Unknown	Neve *et al.* (2009)

[a] The status of *V. spiralis* in France remains unclear, it differs per author (Thiébaut, 2007); [b] It is unsure if the species is native in Romania or introduced; [c] Status is still unclear: Schratt (1978) describes that the species is native to Switzerland, whereas Hussner (2012) classifies it as a non-native species; Info Flora - Centre National de Données et D'informations sur la Flore de Suisse (2012) also regards the species as non-native / naturalized, but in neighbouring parts of Italy the species is classified as native (Lowden, 1982).

5.2. Current distribution in the Netherlands

5.2.1 Geographical distribution and trends in range extension

In the Netherlands *V. spiralis* was first recorded in 1960 in the Maastricht-Luik canal in Maastricht (Figure 5.2). A year later, another large site was discovered nearby (southern part of the spillway Bosscherveld). These recordings coincided with the expansion of *Vallisneria* along the river Meuse in Belgium around 1955 (Van Ooststroom & Reichelt, 1961; Van Ooststroom & Reichelt, 1963). In 2005 an escaped population in a brook near Eijsden was observed. No later recordings of *V. spiralis* in the municipality of Maastricht and near Eijsden are known. Therefore, it is uncertain whether the species is still present or extinct in this area. Two records of *V. spiralis* were available for the Northern part of the Netherlands (i.e. 1976 and 1987). However, no later recordings of these locations are available.

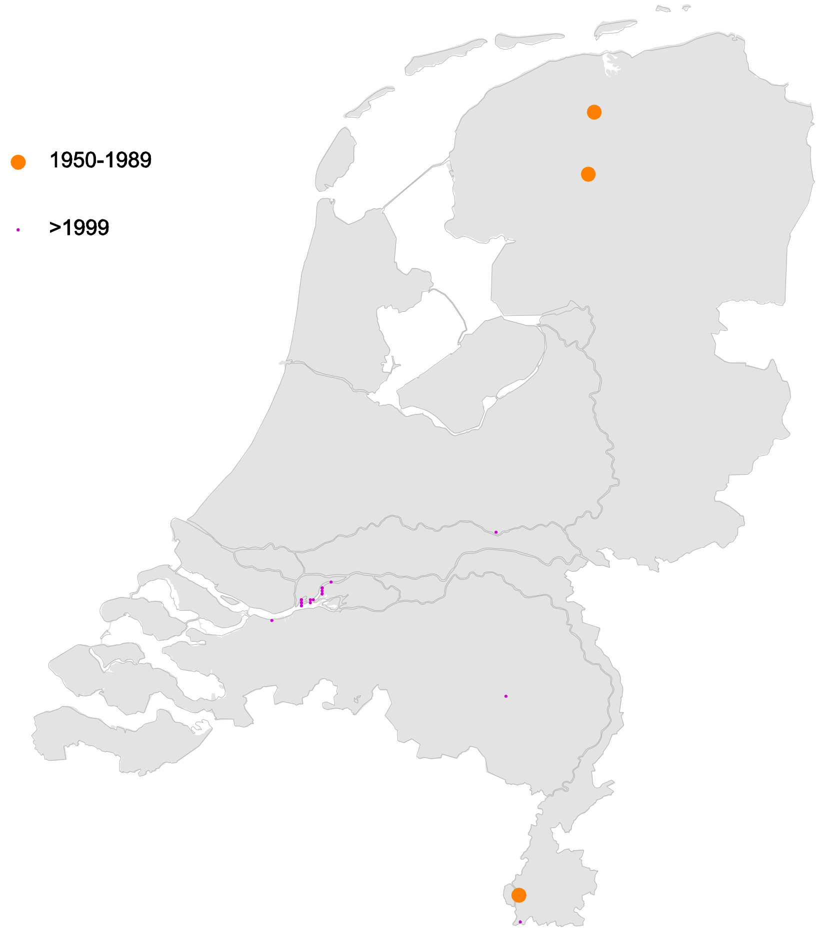

Figure 5.2: The distribution of Tapegrass (*Vallisneria spiralis*) in the Netherlands (Data: National Database Flora en Fauna, complemented with data sources mentioned in section 2.2 and Beringen, 2012).

In the Biesbosch-Merwede area *V. spiralis* was at first discovered in 2001 during an aquatic macrophyte survey and by divers in search of molluscs (A. Boesveld, personal communication). In this area *V. spiralis* is a very inconspicuous species. *V. spiralis* has been recorded within at least 8 square-kilometres at this location. Most sites are almost invisible from on shore or from a boat. Figure 5.3 shows the habitat of two locations where *V. spiralis* was found. The real extent of its presence became clear in 2011 when, at low tide and in a period of low river discharge, leaves protruded above the water surface (Van der Neut & Muusse, 2011). Recent surveys revealed that *V. spiralis* since 2001 has expanded rapidly in the Merwede area (A. Boesveld, personal communication).).

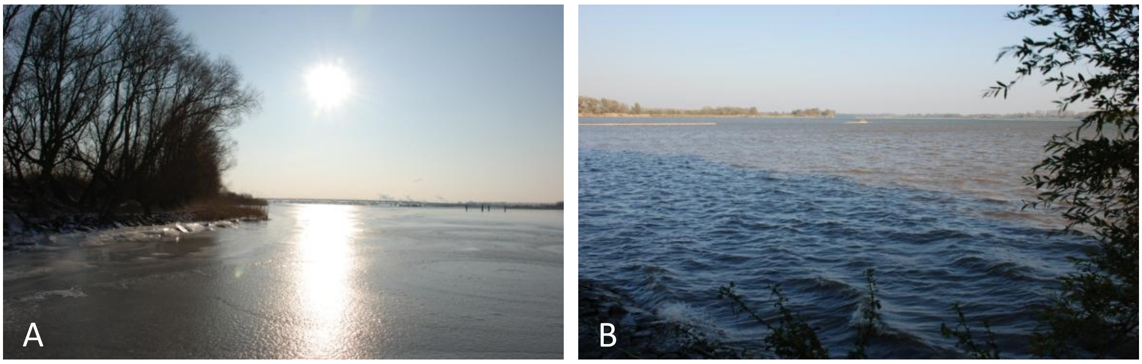

Figure 5.3: (A) The habitat of Tapegrass (*Vallisneria spiralis*) near the Zuid-Maartengat during winter; (B) The habitat of *V. spiralis* near the Dam van England (Photos: A. Boesveld).

Most recent evidence shows that the species has been recorded from within at least 11 square-kilometre plots in the Biesbosch – Merwede - Hollandsch Diep area. (figure 5.2). In a number of these square kilometre plots, *V. spiralis* has been present for a period of at least 11 years (2001-2012). In the Zuid Maartensgat, the plant grows over a large area (Appendix 1). The species grows to a depth of 40-100 cm in water bodies with tidal fluctuations of about 30 cm. Along the Merwede, *V. spiralis* seems to prefer the lower reaches of tidal creeks. Until now only flowering female plants have been collected. The presence of male plants has not yet been proven. At some sites in the Dordtsche Biesbosch, native unionid mussels and non-native Asiatic clams (*Corbicula* spec.; e.g. Figure 5.4) and dreissenid mussels (*Dreissena* spec.) were abundant.

Figure 5.4: Tapegrass (*Vallisneria spiralis*) collected at water depth 50 cm in the Dordtsche Biesbosch, Zuid Maartengat, The Netherlands. At this site shells of the invasive Asiatic Clam (*Corbicula fluminea*) and Zebra Mussel (*Dreissena polymorpha*) were also present (Photo: J.L.C.H. van Valkenburg).

Since humans are nearly absent in the Biesbosch and considering the extent of the plant population in this area, *V. spiralis* could have been established here without human intervention. Establishment might be due to the transport of seeds and fragments through the Rhine and Meuse. Another option is the transport of seeds through waterfowl which are abundant in the Biesbosch. The seeds could be transported by migrating birds from France where *V. spiralis* is known to occur.

Only two squares are located outside the Biesbosch – Merwede - Hollandsch Diep area; one in the Eindhovens canal and a second one in a sand excavation pit near Grebbeberg. In August 2003 plants with female flowers were collected in the Eindhovens canal between Mierlo and Helmond (Observation by J. Bruinsma). These plants were growing along the North bank covering an area of around 20x2 m. Plants were still present in 2012, meaning a population was present here for at least 9 years. During a flora course of Wageningen University in Spring 2009 a second new growing site was discovered in a sand excavation pit near Grebbeberg (observation by J. Wieringa). The plants can not been seen from the banks and can be only observed when diving. The plants showed a sparse coverage with a total area of circa 10x1 m. In Spring 2012 plants still occurred, however in limited abundance.

The trends in the yearly number of kilometre squares containing new records of *V. spiralis* are shown in figure 5.5. This figure is based on non-systematic distribution data of the species. The graph shows that the first known records of *V. spiralis* were in the 1960s. Throughout the 20th century the records of *V. spiralis* varied between 1 and 2 kilometre squares. During the 21th century the kilometre squares containing *V. spiralis* increased, with a maximum of thirteen in 2011.

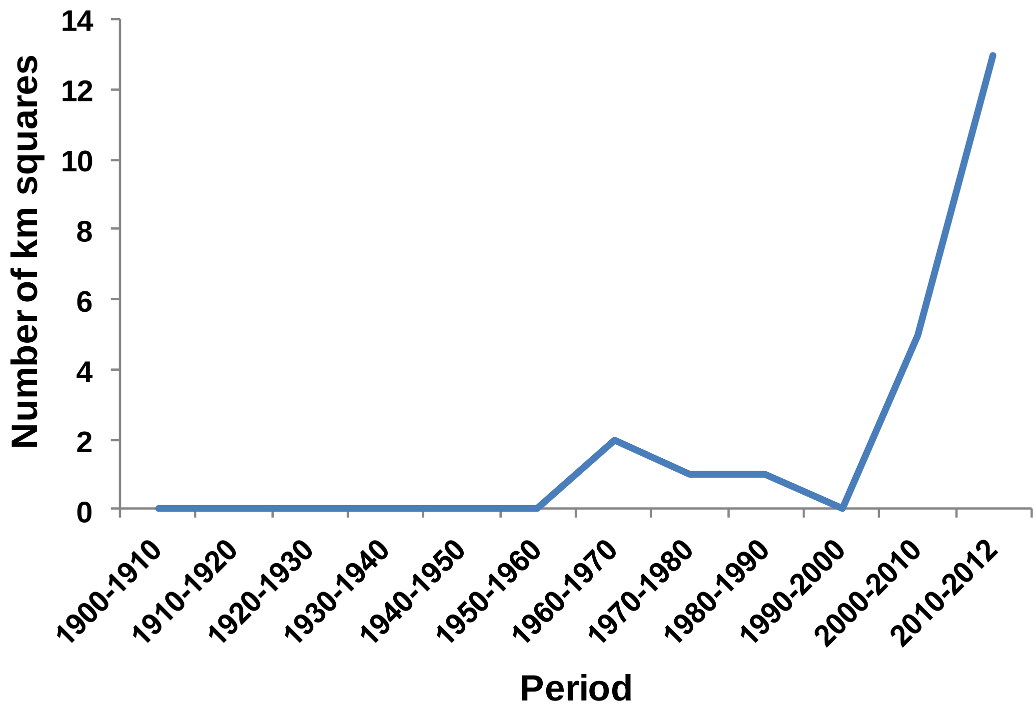

Figure 5.5: The number of km squares where Tapegrass (*Vallisneria spiralis*) has been observed in the Netherlands.

5.2.2. Colonisation of high conservation value habitats

The only recent known areas of high conservation habitats colonized by V. spiralis in the Netherlands are the freshwater tidal area of the Biesbosch-Merwede and a sand excavation pit in the floodplains along the Nederrijn River near Grebbeberg (both sites are located in a Natura 2000 area according to the European Habitats Directive and Birds Directive). The habitats in which the species grows within the Biesbosch-Merwede area are more or less comparable to Habitat type H3260 Water courses of plain to mountain levels (Ranunculion fluitantis and Callitricho-Batrachion).

5.3. Pathways and vectors for dispersal

5.3.1. Dispersal potential by natural means

One possible vector is the transport of seeds through waterfowl (Hussner & Lösch, 2005; Van Leeuwen, 2012). Endozoochory of the order Alismatales is reported by Van Leeuwen (2012), but data on internal transport of *V. spiralis* by birds are not available. Washed up plants of *V. spiralis* were found on banks in the Biesbosch and along the Hollandsch Diep (A. Boesveld, personal communication). These plants might have been uprooted by waterfowl and been transported by currents afterwards. Table 5.2 gives an overview of various vectors, both human and natural.

Table 5.2: An overview of the vectors for dispersal of Tapegrass (*Vallisneria spiralis*).

Vector/Mechanism	Mode of transport	References
Aquarium trade	Emptying aquaria in nature, humans	Hussner & Lösch (2005); Thiébaut (2007); Martin & Coetzee (2011); Hussner (2012)
Dispersal through species	Waterfowl, aerial transport, water flow	Hussner & Lösch (2005); Van Leeuwen (2012)

5.3.2. Dispersal potential with human assistance

Since *V. spiralis* is a widely used aquarium plant, the main route of introduction is most likely the ornamental trade (Hussner & Lösch, 2005; Thiébaut, 2007; Martin & Coetzee, 2011; Hussner, 2012). The only method to stop the introduction of aquatic species like *V. spiralis* is to ban the trading of the species (Hussner, 2012). Besides the ornamental trade, humans also influence the temperature of rivers (Hussner & Lösch, 2005; Willby, 2007). River water temperature is increased due to discharge of cooling water. The higher river temperature enables *V. spiralis* to spread into new habitats.

A Google.nl search was conducted to assess the availability of *V. spiralis* for sale. The species was advertised by both commercial and hobbyist websites (Figure 5.6 and 5.7). No commercial websites were found for the Dutch name: Vallisneria. However, for both the search term *V. spiralis* and Vallisneria numerous hobbyists were found that were selling the species (Figure 5.6). The main providers of *V. spiralis* are hobbyist with spare plants on discussion forums.

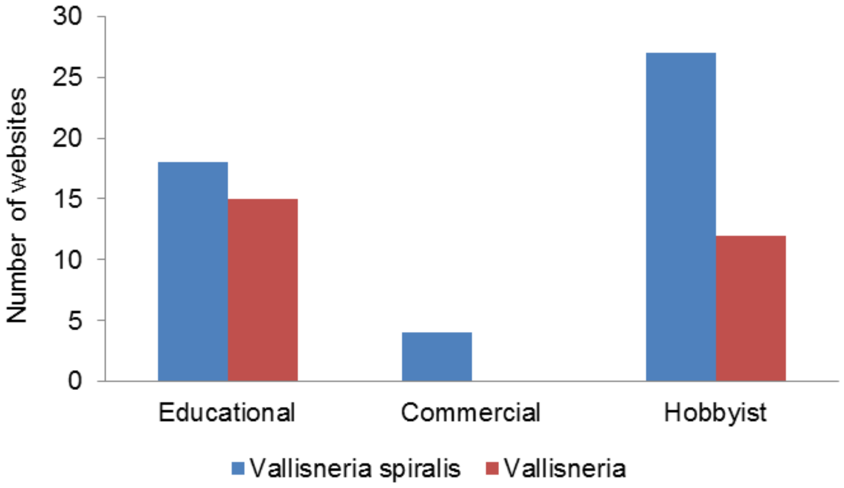

Figure 5.6: The different types of websites with different search terms in Google.nl.

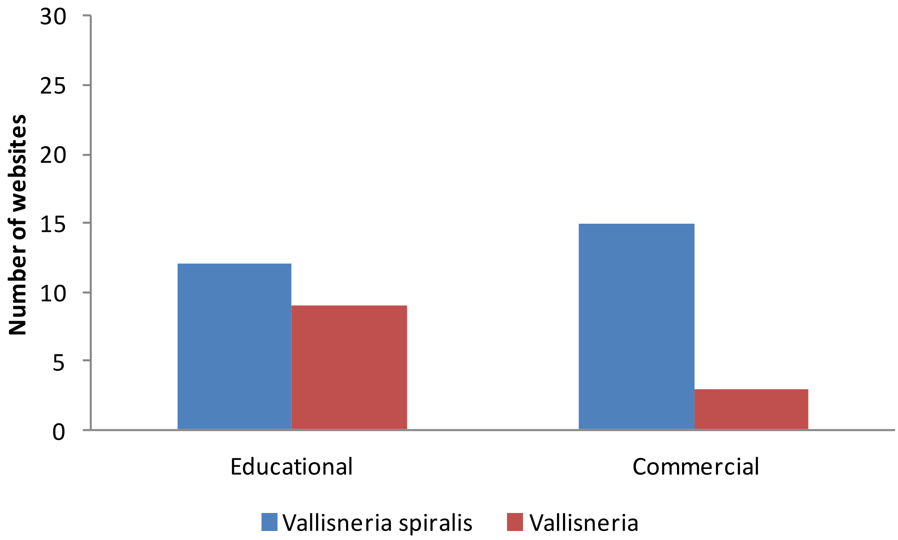

Figure 5.7: Types of disscussion performed on the hobbyist discussion forums found using Google.nl.

5.4. Invasiveness

The species can easily disperse through wind, water and humans, and likely by birds. The potential habitat area of *V. spiralis* will increase due to climate change and the discharge of cooling water. The species is able to reproduce vegetatively by rhizomes. Uprooted plants by waterfowl can be transported by water flow and may be capable of colonizing new areas.

6. Impacts

6.1. Ecological effects

6.1.1 Impacts on native species

Adverse effects
Ejsmont-Karabin & Hutorowicz (2011) found that Tapegrass (*Vallisneria spiralis*) completely displaced native submerged macrophytes in heated lakes in Poland. These lakes were heated by the cooling water of an energy plant in Poland. A similar displacement in the same lakes was found by Bakbo *et al.* (2010), where the presence of the species resulted in the disappearance of most native submerged macrophytes except *Nuphar*. The plant formed a dense mono-species meadow at a depth of up to 2.5 m (Bakbo *et al.*, 2010). The planktonic algae also decreased due to the increase in epiphyte algae habitat on the leaves of *V. spiralis* (Socha & Hutorowicz, 2009). No information is available on the transmission of parasites and diseases by *V. spiralis*.

Currently, there are no signs that indigenous aquatic plant species are displaced by *V. spiralis* in the Biesbosch-Merwede area.

Positive effects
In the heated lakes in Poland Ejsmont-Karabin & Hutorowicz (2011) found no decrease in rotifer diversity despite the fact that *V. spiralis* completely displaced native submerged macrophytes. In the same lakes the ciliate diversity did not decrease despite the replacement of native submerged macrophytes. There were even more ciliate species on *V. spiralis* than on native submerged macrophytes as *Potamogeton* or *Najas* (Bakbo *et al.*, 2010). This high diversity is contrary to what is expected with a simple plant structure like *V. spiralis*. This may be explained by the dense patches of the species that create a horizontal and vertical heterogeneity resulting in complex structures (Ejsmont-Karabin & Hutorowicz, 2011). The high rotifer diversity could also be explained by the presence of periphyton on the leaves of *V. spiralis*. The periphyton is released due to wave action thereby increasing the phytoplankton community (Ejsmont-Karabin & Hutorowicz, 2011). However, the increase in both rotifers and ciliate diversity can also be caused by the increase in water temperature in the lakes. In Germany in the River Erft, a river also heated (e.g. by cooling water of a power plant and deep ground water discharged from brown coal mines), *V. spiralis* is in competition with *Sparganium emersum* without replacing the species (Hussner & Lösch, 2005).

In its native habitat the species is known to maintain a high water transparency in the water. This inhibits the growth and blooms of blue- green algae. Thereby having a beneficial effect on the biodiversity of the entire system (Mukhopadhyay & Dewanji, 2004; Mukhopadhyay *et al.*, 2007; Al-Asadi *et al*., 2007). There are indications that *V. spiralis* is able to secrete allelochemicals which are capable of inhibiting algal growth (Xian *et al.*, 2006; Gao *et al.*, 2011).

6.1.2. Alterations to ecosystem functioning

Adverse effects
No adverse effects of *V. spiralis* where found.

Positive effects
The transparency of the different water types is increased through the presence of *V. spiralis*. Mukhopadhyay & Dewanji (2004) found a positive correlation between the coverage of *V. spiralis* and the Secchi disk transparency. When *V. spiralis* covered 90% of a pond the Secchi disk transparency was 3.5m. The maximum coverage percentage in this pond was 98% during 39 months and the mean coverage during this entire period was 61.7% with a standard deviation of 27.08% (Mukhopadhyay *et al*., 2007). *V. spiralis* affects pore water chemistry. When *V. spiralis* colonised a new area the chemistry changed to a more oxidized state and nutrients where retained within the sediment due to the release of oxygen by the roots and the uptake capacity of *V. spiralis* (Rachetti *et al.*, 2010; Ribaudo *et al.*, 2011). The species is also known to use the nitrogen from Microcystis detritus for growth. This decreases the availability of nutrients for the growth of Microcystis, enhancing water clarity (Zhang *et al.*, 2010). *V. spiralis* may improve nutrient conditions through changing the pore water chemistry thereby decreasing the eutrophication of water bodies (Al-Asadi *et al.*, 2007).

V. spiralis can be used to remove heavy metals and organic compounds from effluents thereby improving the physico-chemical properties (Shukla *et al*., 2009; Du *et al.*, 2007; Di Marzio *et al.*, 2005; Yan *et al.*, 2011). However, Rai *et al.* (1995) concluded that the accumulation within *V. spiralis* is not as high as found in other species. Accumulation of metals and organic compounds in *V. spiralis* can result in higher concentrations throughout the food web since *V. spiralis* is a carbon and energy source for higher trophic levels (Gupta & Chandra, 1998). Besides treating the effluent, *V. spiralis* can also be used as an active biomonitor (Kumar *et al.*, 2008). An overview of the accumulation potentials for different metals is given in appendix 2.

The positive effects described above are not unique for *V. spiralis*, the majority of submerged aquatic plants have the same effect.

6.2. Socio-economic effects

V. spiralis is known to affect the drainage of different water bodies as well as impede recreational use (CABI, 2012). The bioaccumulation potential of *V. spiralis* has a positive economic effect.

6.3. Public health effects

No effects on the public health are known for *V. spiralis*.

7. Available risk classifications

7.1. Formal risk assessments

In the United Kingdom a risk assessment for Tapegrass (*Vallisneria spiralis*) was carried out using a rapid screening process (Horizon scanning) to classify a large number of non-native plants (Natural England, 2011). This screening was based on the Australian Weed Risk Assessment (WRA; Pheloung, 1995).

V. spiralis was classified as an urgent species with a score of 22 out of 28 (Natural England, 2011). The score was based on the characteristics of *V. spiralis* and the spread of the species. The scoring of *V. spiralis* was based on the following characteristics: a history of repeated cultivations and naturalization in new areas around the world; occasional occurrence in valued habitats; naturalization beyond its (subtropical) native range; the formation of moderately dense thickets although the species is not able to produce seeds in the United Kingdom; vegetative reproduction; propagules are spread by water and wind, and as contaminant; benefits from mutilation/cultivation; intentional and unintentional human introductions (Natural England, 2011).

7.2. Other risk assessments

Another risk assessment was performed in New Zealand and used the aquatic weed risk assessment model (AWRAM) with a minimum and maximum value of 4 and 100, respectively (Champion & Clayton, 2000). *V. spiralis* scored 51 and was listed as a surveillance pest plant. However, the species assessed is currently reported as *Vallisneria australis* (Paul Champion, personal communication, July 23, 2012).

8. Management options

Combating the introduction of invasive plant species involves a number of stages that should be applied in order. The first stage is to prevent the spread of the species crossing borders. The second stage is the prevention of release to the freshwater system from isolated locations such as aquaria or garden ponds, by accident or deliberately. The third stage is prevention of dispersal through connected waterways and overland via vectors from the site of introduction. There is very limited information available on management measures designed specifically for Tapegrass (*Vallisneria spiralis*)*,* however, the following general management strategies maybe applied.

8.1. Prevention

The main distribution channel or vector for the spread of *V. spiralis* is trade of plants for aquaria and garden pools. The species may be replaced by *Sparganium emersum*, a more benign species, in the plant trade. Plants are sold under the name *Vallisneria americana* and *Vallisneria gigantea* but the taxonomic status of this alternative is unclear. The plants may be a more potable strain of *V. spiralis*, which makes them an even more risky alternative. In New Zealand *V. spiralis* has been prohibited from trade since 2007 (De Winton *et al.*, 2009). The species is listed as a surveillance pest plant and has a score of 51 on the aquatic weed risk assessment model (AWRAM) (De Winton *et al.*, 2009; CABI, 2012). However, the species assessed is now known as *Vallisneria australis* (Paul Champion, personal communication, July 23, 2012). The strategy in New Zealand is to prevent the propagation, distribution and exhibition of *V. spiralis* (CABI, 2012). To prevent escape from aquaria, the plant can be kept in isolation with the cooperation of the owners of the aquaria and pools. However, there is no option to prevent dispersal out of the area once the plants are released. There is no feasible option for preventing spread of species after establishing in the open field. *V. spiralis* cannot be stopped from autonomously dispersing through fragmentation or through the deployment of runners.

8.2. Eradication and control measures

Eradication
Once the plants have established eradication is very difficult. However, locally isolated populations near Eijsden, in Maastricht and at some locations in the northern part of the Netherlands naturally disappeared. Therefore, isolation of the local populations and waiting for natural disappearance might be an option for eradication.

Mechanical control
The density of *V. spiralis* can be assessed with the use of a spectroradiometer in the lab and in large constructed lakes. This technique might enable the assessment of *V. spiralis* density in the future (Yuan & Zhang, 2006; 2007). Once the scale of the problem has been established, several machine types are available for cutting and collecting the plant material (Wade, 1990; Wijnhoven & Niemeijer, 1995).

- Passive cutting boats. Boats with a V-shaped knife pulled along the bottom behind the boat. Plants are only dislodged and broken and float partly to the surface.

Obstruction to water flow is reduced temporarily but the plants are not removed, collecting plant biomass is only partially possible and spread is stimulated.

- Active cutting boats. Boats with cutter bars coupled to hydraulic control of the depth and angle of the cutter bar in the water. Plants are cut more efficiently than with passive cutting boats, they have the same disadvantage in relation to collecting plant biomass and spread (Figure 8.1).

- Harvesting boats. Small boats with a hydraulic controlled rack on the front that can collect floating plants and transport them to the banks. Collecting plant biomass is only possible partially and 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 a hydraulic arm of a tractor or excavator that can be lowered in drainage channels, small rivers and ponds, and cut and collect plant material very efficiently. Loss of plants rarely occurs and the machine is very effective in preventing the spread of unwanted species.

- Manual collecting of plants is the most primitive physical control method, but also the most precise. Additional to large scale mechanical harvesting, manual handpicking the remaining fragments of the target species may be very effective in attempts to eradicate pest species, at least locally, and prevent spread. In New Zealand populations of *V. spiralis*, now known as *V. australis* (Paul Champion, personal communication, July 23, 2012) were kept under control through hand-pulling. However, this can result in the spreading of vegetative fragments (CABI, 2012).

Figure 8.1: A weed cutting boat with mowing gear (Photo: R. Pot).

Regular cutting of the above ground biomass of *V. spiralis* was discussed as a management option by Shrestha & Janauer (2001). One advantage of this method is that biomass can be easily and rapidly turned into Biogas (Singhal & Rai, 2003). A further option is to use the biomass as a fertilizer. This method has been applied in Vietnam, where it has been found that *V. spiralis* makes a good quality fertilizer (Neve *et al.*, 2009).

Biological control

There are also a few biological control options available. The herbivorous Chinese Grass Carp (*Ctenopharyngodon idella*) is the best known biological control agent for submersed aquatic plants. It has no specific preference and is therefore only practical to control superfluous vegetation. Classical biological control agents act specifically and are usually recruited from the area where the target species is native. The lungfish *Neoceratodus forsteri* is known to feed on *V. spiralis* (Kemp *et al.*, 1981). However, this fish species is vulnerable, nationally protected and listed under CITES, making it impossible to use as a biological control agent. Introduction of such agents is also a potential pest risk in itself and are only suitable after thorough testing and risk assessment.

Chemical control

Since the withdrawal of all herbicides for use in aquatic environments in The Netherlands there is no appropriate chemical method of control for these plants. Nevertheless, experiences in other countries are reported in this document.

Swezey (1953) investigated the use of a chemical, hexachlorocyclohexane (Lindane), as a pesticide for *V. spiralis*. Plants were exposed for one hour to 250 ppm of hexachlorocyclohexane and after 42 days 100% of the specimens died.

8.3. Ecosystem based management

Another option to control *V. spiralis* is through the environment. Environmental control usually limits the availability of natural resources such as light, water or nutrients. For submersed aquatic plants shading is a well-known and often applied way to intervene in light availability. Drying down temporarily, sometime in combination with freezing, when applied in winter, is an effective method but often unpractical.

9. Conclusions and recommendations

9.1. Conclusions

- Tapegrass (*Vallisneria spiralis*) is able to reproduce vegetatively and plant fragments are capable of colonizing new areas. The species can spread through wind, water, humans and birds.

- In the Netherlands the species is mainly for sale through hobbyist sites.

- Human activities may influence the (potential) habitat of *V. spiralis* through increasing the water temperature (e.g. thermal discharges and climate change).

- In the Netherlands *V. spiralis* currently occurs in the Biesbosch-Merwede area which is a designated NATURA 2000 site in accordance with the EU Habitats Directive and Bird Directive. The habitats in which the species grows in this area is more or less comparable to Habitat type H3260 Water courses of plain to mountainous levels (Ranunculion fluitantis and Callitricho-Batrachion).

- Negative effects on native submerged macrophytes have been recorded in heated lakes in Poland. The species formed a dense mono-species meadow and the planktonic algae decreased due to the increase in ephiphyte algae habitat on the leaves of *V. spiralis.* However, ciliate and rotifer diversity did not decrease despite the replacement of native submerged macrophytes. In a heated river in Germany *V. spiralis* competed with *S. emersum* without species replacements.

- Within the Netherlands there are no signs that aquatic plant species are replaced by *V. spiralis*.

- For its native habitat positive effects of *V. spiralis* on ecosystem functioning are documented (e.g., maintaining a high water transparency in the water thereby inhibiting the growth and blooms of blue-green algae; nutrient retention in sediments; high ability to accumulate heavy metals and organic compounds). However, these effects are not unique for this species since the majority of submerged aquatic plants show similar effects.

- Dense mono-species beds formed by *V. spiralis* may decrease the drainage capacity of streams and negatively affect recreation.

- A risk assessment in the United Kingdom classified *V. spiralis* as an urgent species.

9.2. Effective management options

Eradication

Once the plants have established eradication is very difficult. Best option is isolation of the local populations and wait for disappearance in a natural way.

Management

There is no experience with species-specific control measures. If control is inevitable best method is removing leaf biomass by cutting boats acting at least 20 cm above the bottom to prevent spread of viable fragments with stolons or roots.

9.3. Recommendations for further research

Further research should focus on future spread of *V. spiralis* in the Netherlands and elucidate if dispersal is possible through endozoochory.

Currently, it is still unknown whether both male and female plants are present and *V. spiralis* is capable of producing viable seeds in the Netherlands. Furthermore, the species identity of the specimens found in the Netherlands has to be examined further to better determine their modes of dispersal.

Finally, additional field surveys along the banks of the rivers Rhine and Meuse are recommended to identify whether or not populations of *V. spiralis* have been established upstream of the Biesbosch-Merwede area.

Acknowledgements

We thank the Netherlands Food and Consumer Product Safety Authority of the Ministry of Economic Affairs, Agriculture and Innovation for financial support of this study. Dr. Trix Rietveld-Piepers of the Netherlands Food and Consumer Product Safety Authority (Office for Risk Assessment and Research, Invasive Alien Species Team) delivered constructive comments on an earlier draft of this report. We thank Arno Boesveld for delivering distribution data on *V. spiralis* in Biesbosch-Merwede area and putting his photo's at our disposal for the report. Several other volunteers delivered their data to national databases. The authors also thank Theo Muusse (SBB) for sailing us to *V. spiralis* sites, Andreas Hussner (Heinrich Heine University, Dusseldorf, Germany) for allowing us to use his photos of *V. spiralis* in the river Erft, Germa Verheggen for technical advises and assistance with physico-chemical analyses, and Marije Orbons for delivering monitoring devices.

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Appendices

Appendix 1: Results of field surveys 2012.

	1	2	3	
Species	***Vallisneria***	***Vallisneria***	***Vallisneria***	
Location	**Nieuwe Merwede, Spieringsluis**	**Nieuwe Merwede, Lage Hof**	**Dordtsche Biesbosch, Zuid Maartensgat**	
Date of field search	**02-07-2012**	**02-07-2012**	**02-07-2012**	
Amersfoort coordinates	111.436-421.041	111.156-419.633	104.516-415.809	
Water depth (cm)	70-100	40-75	55-65	
pH	7.96	8.48	8.15	
Alkalinity (meq l^{-1})	2.46	2.26	2.35	
Transparency (cm)	65	Up to bottom	55	
Width (m)	20	30	Not applicable	
Water flow	Tidal flow	Tidal flow	Tidal flow	
Water type	Creek mouth	Edge of creek mouth	Large water body, behind longitudinal dam	
Surface area covered (m^2)	?	?	> 50 x 100	
Number of individuals/shoots	?	?		
Phenology	Vegetative	Vegetative	Vegetative	
Code water sample	VW1	VW2	VW3	
Code sediment sample	VS1	VS2	VS3	
Code barcoding	24L2	24S8	245K	
		Tansley survey		
	Score	Score	Score	Frequency of occurrence
Species (growth form)				
Vallisneria spiralis **(s)**	o	o	f	3
Filamentous algae on sediment	+	+	+	3
Potamogeton pusillus **(s)**	r	r		2
Elodea nuttallii **(s)**	r	r		2
Ceratophyllum demersum **(s)**	r	r		2
Potamogeton pectinatus **(s)**		r	o	2
Alisma gramineum **(s)**		r	r	2
Potamogeton crispus **(s)**			o	1
Potamogeton lucens **(s)**		r		1
Myriophyllum spicatum **(s)**			a	1
Zannichellia palustris **(s)**			r	1
Remarks	Growths in the middle of the upstream part of the creek Sediment black	At the edge of the creek, between filamentous algae on sediment Sediment black	At open areas between *Myriophyllum* Sediment not blackzwart Many Asiatic clams (*Corbicula*) Plants less sturdy than at other locations	

Tansley / DAFOR score d: dominant; a: abundant; f: frequent; o: occasional; r: rare.
Growth form code d: floating; e: emergent; s: submerged.

Appendix 2: Metal accumulation potential of Tapegrass (*Vallisneria spiralis*).

Metal	Accumulation	Effect	Reference
Chromium µg g^{-1} dry weight	385.6 1758	Negative	Gupta *et al.* (2011); Shukla *et al.* (2009); Rai & Tripathi (2009); Vajpayee *et al.* (2001) and Sinha *et al.* (2002)
Copper µg g^{-1} dry weight	Roots: 396 Shoot: 114	Negative	Sing *et al.* (2010); Jana & Choudhuri (1984); Jana & Choudhuri (1982); Vajpayee *et al.* (2005); Sinha *et al.* (1994); Wang *et al.* (2010)
Cadmium µg g^{-1} dry weight	Roots: 63.8 Shoot: 48 Total: 836	Negative	Sing *et al.* (2010); Rai & Tripathi (2009)
Lead µg g^{-1} dry weight	319	Negative	Rai & Tripathi (2009); Jana & Choudhuri (1982); Jana & Choudhuri (1984)
Zinc µg g^{-1} dry weight	53		Rai & Tripathi (2009)
Mercury	Roots: 1.12 mmol g^{-1} dry weight Shoot: 0.25 mmol g^{-1} dry weight 1071 µg g^{-1} dry weight	Negative	Rai & Tripathi (2009); Gupta & Chandra (1998); Jana & Choudhuri (1984); Kumar *et al.* (2008)
Manganese µg g^{-1} dry weight	836	Negative	Rai & Tripathi (2009); Mukhopadhyay & Sharma (1990)
Nickel µg g^{-1} dry weight	1630		Rai & Tripathi (2009)
Cobalt	3.09 – 0.16 ppm		Kumar *et al.* (2008)
Lead	82.40 – 53.16 ppm		Kumar *et al.* (2008)