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Risk analysis of the Curly Waterweed, *Lagarosiphon major* (Ridley) Moss.

Risk analysis report of non-native organisms in Belgium

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Adopted in date of : 11 March 2013

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Etienne Branquart (Cellule Espèces Invasives, Service Public de Wallonie) developed the risk analysis template that was used for this exercise.

The general process of drafting, reviewing and approval of the risk analysis for selected invasive alien species in Belgium was attended by a steering committee, chaired by the Federal Public Service Health, Food chain safety and Environment. RBINS/KBIN was contracted by the Federal Public Service Health, Food chain safety and Environment to perform PRA's for a batch of species. ULg was contracted by Service Public de Wallonie to perform PRA's for a selection of species. INBO and DEMNA performed risk analysis for a number of species as in-kind contribution.

Steering committee members were:

Tim Adriaens	Research Institute for Nature and Forest (INBO)
Olivier Beck	Brussels Environment (BIM)
Roseline Beudels-Jamar	Royal Belgian Institute of Natural Sciences (RBINS/KBIN)
Etienne Branquart	Département de l'Etude du Milieu Naturel et Agricole (DEMNA)
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Rationale and scope of the Belgian risk analysis scheme

The Convention on Biological Diversity (CBD) emphasises the need for a precautionary approach towards non-native species. It strongly promotes the use of robust and good quality risk assessment to help underpin this approach (COP 6 Decision VI/23). More specifically, when considering trade restrictions for reducing the risk of introduction and spread of a non-native organisms, full and comprehensive risk assessment is required to demonstrate that the proposed measures are adequate and efficient to reduce the risk and that they do not create any disguised barriers to trade. This should be seen in the context of WTO and free trade as a principle in the EU (Baker et al. 2008, Shine et al. 2010, Shrader et al. 2010).

This risk analysis has the specific aim of evaluating whether or not to install trade restrictions for a selection of absent or emerging invasive alien species that may threaten biodiversity in Belgium as a preventive risk management option. It is conducted at the scale of Belgium but results and conclusions could also be relevant for neighbouring areas with similar eco-climatic conditions (e.g. areas included within the Atlantic and the continental biogeographic regions in Europe).

The risk analysis tool that was used here follows a simplified scheme elaborated on the basis of the recommendations provided by the international standard for pest risk analysis for organisms of quarantine concern[1] *produced by the secretariat of the International Plant Protection Convention (FAO 2004). This logical scheme adopted in the plant health domain separates the assessment of entry, establishment, spread and impacts. As proposed in the GB non-native species risk assessment scheme, this IPPC standard can be adapted to assess the risk of intentional introductions of non-native species regardless the taxon that may or not be considered as detrimental (Andersen 2004, Baker et al. 2005, Baker et al. 2008, Schrader et al. 2010).*

The risk analysis follows a process defined by three stages : (1) the <u>initiation process</u> which involves identifying the organism and its introduction pathways that should be considered for risk analysis in relation to Belgium, (2) the <u>risk assessment stage</u> which includes the categorization of emerging non-native species to determine whether the criteria for a quarantine organism are satisfied and an evaluation of the probability of organism entry, establishment, spread, and of their potential environmental, economic and social consequences and (3) the <u>risk management stage</u> which involves identifying management options for reducing the risks identified at stage 2 to an acceptable level. These are evaluated for efficacy, feasibility and impact in order to select the most appropriate. The risk management section in the current risk analysis should however not been regarded as a full-option management plan, which would require an extra feasibility study including legal, technical and financial considerations. Such thorough study is out of the scope of the produced documents, in which the management is largely limited to identifying needed actions separate from trade restrictions and, where possible, to comment on cost-benefit information if easily available in the literature.

This risk analysis is an advisory document and should be used to help support Belgian decision making. It does not in itself determine government policy, nor does it have any legal status. Neither should it reflect stakeholder consensus. Although the document at hand is of public nature, it is important to realise that this risk assessments exercise is carried out by (an) independent expert(s)

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A weed or a pest organism not yet present in the area under assessment, or present but not widely distributed, that is likely to cause economic damages and is proposed for official regulation and control (FAO 2010).

who produces knowledge-based risk assignments sensu Aven (2011). It was completed using a uniform template to ensure that the full range of issues recognised in international standards was addressed.

To address a number of common misconceptions about non-native species risk assessments, the following points should be noted (after Baker et al. 2008):

- *Risk assessments are advisory and therefore part of the suite of information on which policy decisions are based;*
- *The risk assessment deals with potential negative (ecological, economic, social) impacts. It is not meant to consider positive impacts associated with the introduction or presence of a species, nor is the purpose of this assessment to perform a cost-benefit analysis in that respect. The latter elements though would be elements of consideration for any policy decision;*
- *Completed risk assessments are not final and absolute. New scientific evidence may prompt a re-evaluation of the risks and/or a change of policy.*

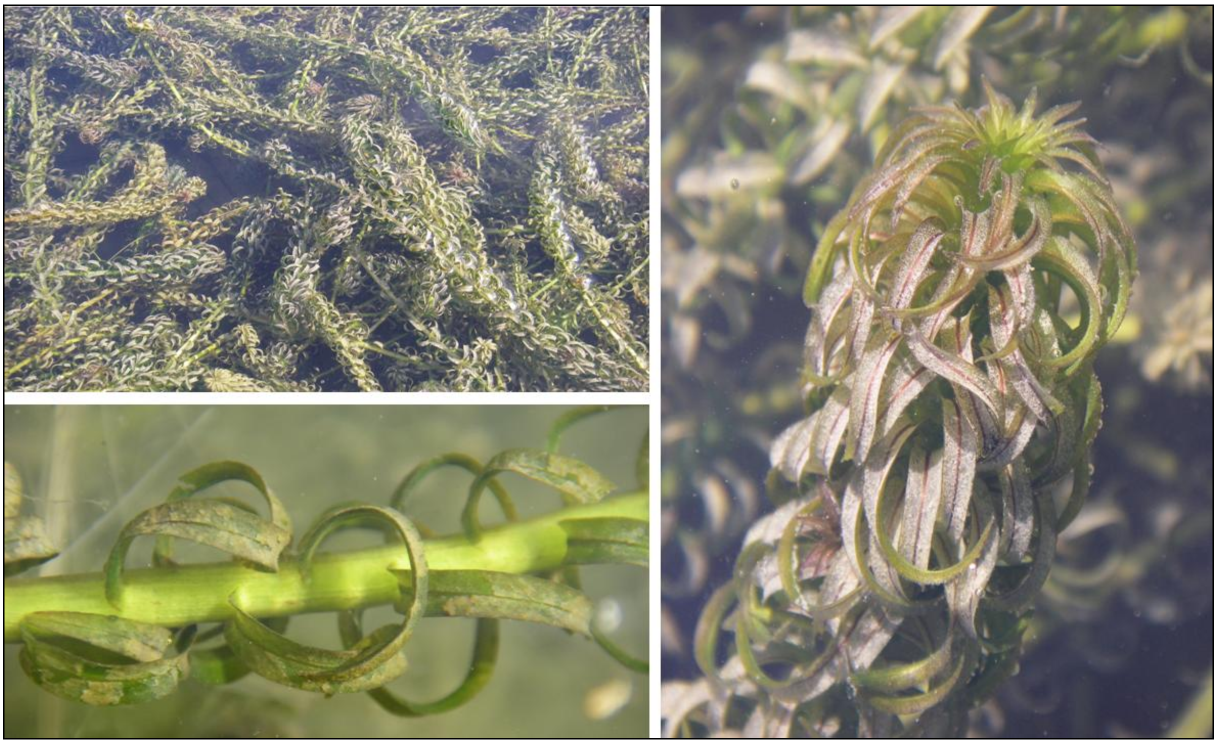


Figure 1: *Lagarosiphon major* (Photos: Tim Adriaens, INBO).

Executive summary

PROBABILITY OF ESTABLISHMENT AND SPREAD (EXPOSURE)

- Entry in Belgium

The species is already present in Belgium with a first observation in the wild dating from 1993. Populations are still isolated but spreading. The species was more than probably introduced initially by horticultural and aquarium trade. Continued (accidental or intentional) introductions through this main pathway are very likely since the species is still imported to Europe and available in the Belgian horticultural trade.

- Establishment capacity

Climatic conditions and habitat characteristics of most Belgian fresh water streams and ponds fit within the ecological requirements of *L. major*. Capacity for establishment in Belgium is therefore high. As the species is aquatic, most wetlands, streams and ponds, including those in sensitive areas, nature reserves and Natura2000 sites are considered highly vulnerable to *L. major* invasion.

- Dispersion capacity

Dispersion in the wild mainly occurs by dissemination of vegetative propagules by water currents. Human activities can greatly enhance dispersal through disposal of cultivated plants, activities that generate plant fragments (such as weed-cutting) or accidental transport with machinery, boats, fishing equipment or live bait. Dispersal by birds or mammals has also been occasionally reported.

EFFECT OF ESTABLISHMENT

- Environmental impacts

L. major forms dense mats near the water surface, outcompeting other native plant species and causing significant shifts in habitat productivity, invertebrate and fish species composition, and food web dynamics. Functions and services of the invaded ecosystems are altered. Dense mats can limit water circulation, cut off light and create severe fluctuations in dissolved oxygen level. *L. major* is also known to increase the water pH (up to a value over 10) and to deplete dissolved inorganic carbon, creating stressful conditions for other aquatic organisms.

RISK MANAGEMENT

The main current pathway of introduction of *Lagarosiphon major* in Belgium remains its sale as an ornamental plant for aquariums and ponds, and its subsequent release in the wild. This pathway is however expected to decrease thanks to education actions carried out in the country (e.g. in the framework of the AlterIAS LIFE project). Once established, vegetative dispersion, mainly human-assisted, occurs. Future invasions from French, Dutch or German populations are very likely.

Legislation at European level to ensure a total ban on import, trade, holding and cultivation of *Lagarosiphon major* and other (potentially) invasive aquatic plants is likely to be most effective. Fortunately, *L. major* is still at an early invasion stage in Belgium and is restricted to small isolated areas. As a result, similar national regulation could effectively prevent its entry, establishment and spread.

Lagarosiphon major is difficult to detect at an early stage of invasion, and therefore control or eradication actions often start when the plant is already well-established.

Since chemical weed control in an aquatic environment is extremely restricted in Belgium and because it could have strong detrimental effects on biodiversity, environment at large and human health, the practical control options should focus on prevention and non-chemical methods. Most efficient methods are mechanical removal or light-exclusion via jute matting. Dredging cannot be advised for control or eradication actions because this technique is often inefficient and may even boost *L. major* growth rate, perhaps because a more mineral soil may facilitate the plant anchoring and hence lead to a more successful growth. New control techniques based on the use of biocontrol agents are currently under development and may provide interesting results in the future.

Résumé

PROBABILITE D'ETABLISSEMENT ET DE DISSEMINATION (EXPOSITION)

- Introduction en Belgique

L'espèce est déjà présente en Belgique, avec une première observation dans la nature en 1993. Ses populations restent isolées mais se disséminent localement. L'espèce a été très probablement introduite initialement via le commerce horticole et de l'aquariophilie. La poursuite de l'introduction (accidentelle ou délibérée) de cette espèce par cette principale voie est fort probable étant donné qu'elle est toujours importée en Europe et encore vendue dans le commerce horticole belge.

- Capacité d'établissement

Les conditions climatiques et les caractéristiques des habitats de la majorité des cours d'eau et des étangs belges répondent aux besoins écologiques de *L. major*. La capacité d'établissement de l'espèce en Belgique est donc élevée. Etant donné que l'espèce est aquatique, la majorité des zones humides, cours d'eau et étangs (y compris les zones sensibles, les réserves naturelles et les sites Natura 2000) sont considérés comme très vulnérables à l'envahissement par *L. major*.

- Capacité de dispersion

La dispersion de la plante dans la nature se fait principalement par la dissémination de propagules végétatives emportées par les courants d'eau. Les activités humaines peuvent largement favoriser la dispersion dans l'environnement, essentiellement lors de l'élimination des résidus de plantes cultivées, lors de la gestion (par arrachage) de zones infestées (générant d'innombrables fragments de plante), mais aussi lors du transport accidentel sur des outils et machines, sur des bateaux ou sur des équipements de pêche et appâts vivants. Des cas de dispersion par les oiseaux ou les mammifères ont aussi été occasionnellement rapportés.

EFFET DE L'ETABLISSEMENT

- Impacts environnementaux

L. major forme des tapis denses à proximité de la surface de l'eau et entre en compétition avec d'autres espèces végétales indigènes ce qui provoque d'importants changements au niveau de la productivité de l'habitat, modifie la composition en espèces d'invertébrés et de poissons et perturbe la dynamique du réseau trophique. Les fonctions et les services des écosystèmes envahis sont modifiés. Ces tapis denses peuvent limiter la circulation de l'eau, empêcher la pénétration de la lumière et générer d'importantes fluctuations des taux d'oxygène dissous. On sait aussi que *L. major* augmente le pH de l'eau (jusqu'à des valeurs supérieures à 10) et épuise le carbone inorganique dissous, ce qui crée des conditions de stress pour les autres organismes aquatiques.

GESTION DES RISQUES

La principale voie actuelle d'introduction de *Lagarosiphon major* en Belgique est sa vente en qualité de plante ornementale pour les aquariums et les étangs et son rejet subséquent dans la nature. On

s'attend toutefois à une diminution des cas d'introduction grâce aux actions éducatives menées dans le pays (p. ex. dans le cadre du projet AlterIAS LIFE). Une fois l'espèce établie, la dispersion s'effectue par dissémination de propagules végétative (principalement par hydrochorie, zoochorie et suite à des actions anthropiques). De futurs envahissements à partir de populations françaises, néerlandaises ou allemandes sont très probables.

L'établissement au niveau européen d'une législation destinée à assurer l'interdiction totale d'importer, de vendre, de détenir ou de cultiver *Lagarosiphon major* (et d'autres plantes aquatiques potentiellement envahissantes) devrait être le moyen le plus efficace pour lutter contre l'introduction et les nuisances causées par cette espèce. Le stade d'envahissement de *L. major* en Belgique est encore très précoce et reste, actuellement, limitée à de petites zones isolées. Par conséquent, une réglementation nationale similaire pourrait efficacement prévenir de nouveaux cas d'introduction (avec établissement et dissémination subséquente).

Lagarosiphon major est difficile à détecter à un stade précoce d'envahissement et pour cette raison, les actions de contrôle ou d'éradication ne sont souvent mises en place que quand la plante est déjà bien établie, ce qui rend le travail beaucoup plus difficile et onéreux.

Etant donné que la lutte chimique contre les espèces envahissantes dans les environnements aquatiques est extrêmement limitée en Belgique et en raison de ses effets délétères importants sur la biodiversité, l'environnement au sens large et la santé humaine, les moyens pratiques de contrôle doivent mettre l'accent sur la prévention et les méthodes d'éradication non chimiques. Pour *L. major*, les méthodes les plus efficaces sont l'arrachage mécanique ou la privation de lumière par l'utilisation de bâches occultantes. Le dragage n'est pas conseillé dans le cadre du contrôle ou de l'éradication de cette espèce du fait que cette technique s'avère souvent inefficace et peut même stimuler le taux de croissance de *L. major* dans certains cas, par le fait qu'un sol plus minéral peut faciliter l'ancrage de la plante et donc favoriser sa croissance. De nouvelles techniques de contrôle basées sur l'utilisation d'agents de biocontrôle sont actuellement en développement et pourraient donner des résultats intéressants à l'avenir.

Samenvatting

WAARSCHIJNLIJKHEID VAN VESTIGING EN VERSPREIDING (BLOOTSTELLING)

- Ingang in België

Lagarosiphon is sinds 1993 in het wild in België waargenomen. Hoewel de groeiplaatsen nog geïsoleerd zijn neemt hun aantal toe. Hoogstwaarschijnlijk werd de soort oorspronkelijk door de vijver- en aquariumsector geïntroduceerd. Dat dit verder (al dan niet opzettelijk) via deze weg zal gebeuren lijdt haast geen twijfel, omdat ze nog steeds in Europa wordt ingevoerd en in de Belgische handel verkrijgbaar is.

- Vestigingsvermogen

De klimaatsomstandigheden en habitatkenmerken van de meeste Belgische zoetwaterlopen en vijvers beantwoorden perfect aan de ecologische vereisten van *L. major*. Daarom is het vestigingsvermogen in België hoog. De meeste waterrijke gebieden natuurgebieden en Natura2000 gebieden met waterlopen en vijvers, als uiterst kwetsbaar beschouwd voor invasie door *L. major*.

- Verspreidingsvermogen

Verbreiding in het wild gebeurt hoofdzakelijk door de verspreiding van vegetatieve propagulen in waterlopen. Menselijke activiteiten kunnen de verspreiding sterk in de hand werken door het wegwerpen van gekweekte planten, werkzaamheden waarbij planten worden gefragmenteerd (zoals het maaien van waterplanten), of onopzettelijk transport met machines, boten, visgerei of levend aas. Occasioneel wordt ook verspreiding door vogels of zoogdieren gemeld.

EFFECTEN VAN DE VESTIGING

- Milieu-impact

L. major vormt zeer dichte begroeiingen vlakbij het wateroppervlak, verdringt inheemse plantensoorten en veroorzaakt ingrijpende verschuivingen in de productiviteit van de habitat, de levensgemeenschap van ongewervelde dieren en vissen en het voedselweb. De dichte vegetaties beperken de watercirculatie, verminderen het doordringende licht weg en veroorzaken sterke schommelingen in het zuurstofgehalte. Door de fotosynthese kan de zuurgraad van het water aanzienlijk stijgen en opgeloste anorganische koolstof beperkt worden, waardoor andere aquatische organismen aan hoge stress worden blootgesteld.

RISICOBEHEER

De verkoop als sierplant voor aquaria en vijvers en het aansluitend wegwerpen ervan in het wild zijn de voornaamste actuele introductiewegen van *Lagarosiphon major* in België . Vermoedt wordt dat dit dankzij nationale educatieve acties (bv. in het kader van het AlterIAS LIFE project) over zijn hoogtepunt heen is. Eens gevestigd gebeurt de vegetatieve verbreiding overwegend door menselijke tussenkomst. Invasies door Franse, Nederlandse of Duitse populaties zijn in de toekomst hoogst waarschijnlijk.

De meest efficiëntie beperking wordt verwacht van wetgeving op Europees niveau die de invoer, handel, bezit en het cultiveren van de *Lagarosiphon major* en andere (potentieel) invasieve waterplanten zal verbieden. Gelukkig is de invasie van *L. major* in België nog in een pril stadium en nog beperkt tot kleine, geïsoleerde gebieden. Dit betekent dat gelijkaardige regelgeving op nationaal niveau de introductie, vestiging en verspreiding doeltreffend kan verhinderen.

Lagarosiphon major is in een vroeg invasiestadium moeilijk op te sporen; daarom starten de controle- of uitroeiingsacties vaak pas als de plant al goed is gevestigd.

Omdat chemische onkruidbestrijding in een aquatisch milieu in België aan verregaande beperkingen is onderworpen en omwille van de erg schadelijke effecten ervan op de biodiversiteit, het milieu in ruime betekenis en op de volksgezondheid, zijn preventie en niet-chemische methoden in de praktijk de meest voor de hand liggende controleopties. De meest doeltreffende bestrijdingsmethoden zijn mechanische verwijdering, of het afschermen van licht door het aanbrengen van jute matten. Baggeren is doorgaans niet efficiënt en kan het groeitempo van *L. major* nog opdrijven, mogelijk doordat de plant beter kan groeien op een minerale bodem. Momenteel worden beloftevolle biologische controletechnieken ontwikkeld.

STAGE 1: INITIATION

1.1 ORGANISM IDENTITY

Scientific name :	*Lagarosiphon major* (Ridley) Moss ex V.A. Wager
Synonyms:	*Anacharis crispa* hort. *Elodea crispa* hort. *Lagarosiphon muscoides* Harvey var. *major* Ridl.
Common names :	African Elodea, Lagarosiphon major, Curly Waterweed, Pib-flodyn Crych (Welsh), Oxygen Weed, Curly Water Thyme, Curly Waterweed, South African Oxygen Weed, Submerged Onocotyledon (Eng.); Élodée crépue, Lagarosiphon majeur, Lagarosiphon élevé, Grand Lagarosiphon (Fr); Verspreidbladige Waterpest (Nl); Große Wechselblatt, Wasserpest, Schmalrohr, Wassergirlande (Ge); Peste d'acqua arcuata (It).
Taxonomic position:	Domain: Eukaryota / Kingdom: Plantae / Phylum: Spermatophyta / Subphylum: Angiospermae / Class: Liliopsida / Order: Hydrocharitales / Family: Hydrocharitaceae / Genus: *Lagarosiphon* / Species: *Lagarosiphon major.*

1.2 SHORT DESCRIPTION

Lagarosiphon major is a rhizomatous, perennial, submerged aquatic plant (Figure 1). It has numerous threadlike roots, which are branching from the stem and, along with rhizomes (horizontal stems in the sediment), anchor it to the bottom (ISSG, 2006; Caffrey & Acevedo, 2007). Stems, which can reach the surface, are brittle and sparsely branched, 3-5 mm in diameter and curved towards the base (J-shaped) (ISSG, 2006; Caffrey & Acevedo, 2007). The leaves are generally 5-20 mm long and 2-3 mm wide, and occur in alternate spirals along the stem. They generally have tapered tips curving downwards towards the stem, except in low alkalinity water where they are straight (ISSG, 2006). The leaves rapidly become encrusted with calcium carbonate on the upper surface; a consequence of the way in which carbon is taken up by the plant (CAPM, 2004; Kalff, 2002 in Stiers et al., 2011).

The species is dioecious, meaning that male and female flowers are on different plants (Symoens & Triest, 1983, Haynes, 1988; Figure 2). The male flowers break from the plant and float towards the female flowers which remain attached to the stem by a long, thin filament-like tube, the hypanthium (Symoens & Triest, 1983, Haynes, 1988; DAFF, 2013). The three-petalled female flowers are very small, clear-white on the surface, and grow on very thin white to almost translucent filament-like stalks. Neither the male flower, nor fruits or seeds have been recorded outside of its native range (Symoens & Triest, 1983; Levy et al., 2011; DAFF, 2013).

The species is sometimes rather reminiscent of *Elodea nuttallii* (native to North America but sold as an aquarium plant outside its native range) and is possibly still confused with it. Both often share the strongly recurved leaves, but *Lagarosiphon major* is usually more robust with leaves commonly wider and longer and obviously spirally arranged in the lower parts and very densely crowded in the upper part of the stems (Verloove, 2006; http://alienplantsbelgium.be/content/lagarosiphon-major-0).

Chromosome number is 2n = 22 (Symoens & Triest, 1983).

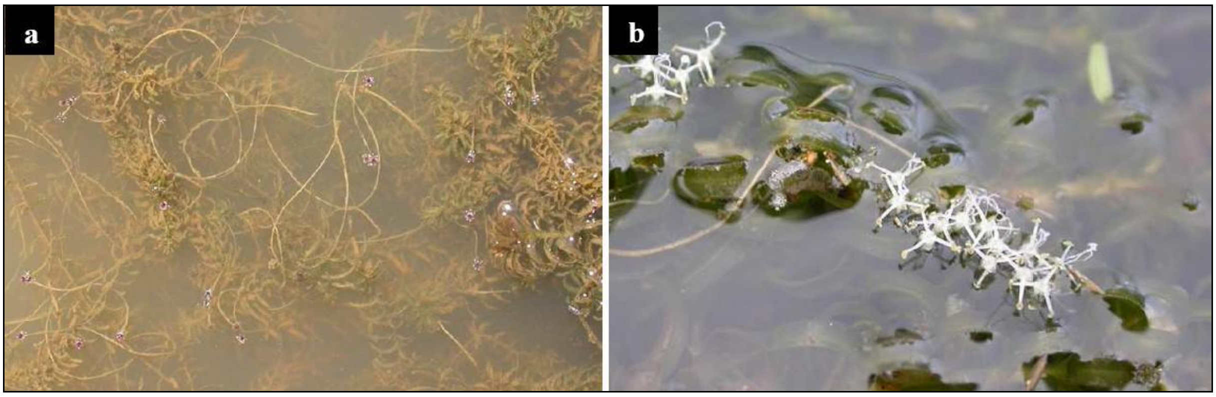


Figure 2: Female (a) and male (b, ca 1 mm) reproductive structures of *Lagarosiphon major* as they can be observed in its native range [only female flowers are recorded in the introduced range so far]. Male structures floating on the water surface are attracted to the depressions formed by the female flower, which facilitates pollination (Source: Caffrey et al., 2009a).

1.3 ORGANISM DISTRIBUTION

Native range

Lagarosiphon major is native to central and southern Africa (i.e. Zambia, Zimbabwe, Botswana, Lesotho and South Africa; Figure 3), where it may sometimes constitute a nuisance for commercial navigation and water-based recreation (Symoens & Triest, 1983; CAPM, 2004; Caffrey et al., 2011; GB Non-Native Species Secretariat, 2011).

Introduced range

- Belgium:

Lagarosiphon major is an increasing, locally naturalised alien plant in fishponds and canals. Its first report in the wild in Belgium dates from 1993, when a population was discovered in an old branch of the Meuse River at Lives-sur-Meuse (Bouxin & Lambinon, 1996).

- Rest of Europe (Figure 3):

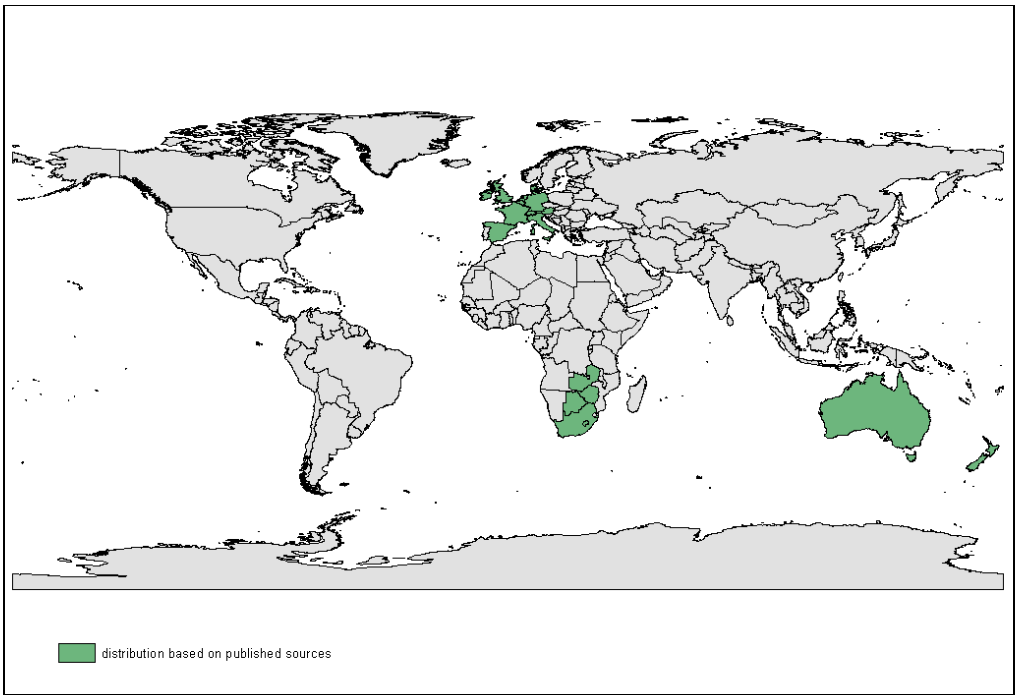
Lagarosiphon major was first recorded in Britain in 1944 and in Germany and Ireland in 1966. The species is now present and well established in Germany, France [including Reunion Island in the Indian Ocean; CBNM (2010)], Italy, Portugal, Spain, Switzerland and the United Kingdom. It is also present in Austria, Ireland and the Netherlands where it appears to be spreading (Adams et al., 1978; Symoens & Triest, 1983; ISSG, 2006; GB Non-Native Species Secretariat, 2011 and references there-in).

- <u>Other continents:</u>

The species is naturalised in parts of the Australasian-Pacific region <u>(Figure 3)</u>:

Australia: In Tasmania, *Lagarosiphon major* is regarded as an emerging environmental, and, in many parts of southern Australia, as a potential environmental weed or "sleeper weed" (Csurhes & Edwards, 1998; The University of Queensland, 2011; DAFF, 2013). It is also on the "Alert List for Environmental Weeds", a list of 28 non-native plants that have the potential to seriously degrade Australia's ecosystems which are currently in the early stages of establishment (The University of Queensland, 2011).

New Zealand: The species was first noted in this country in 1950 and it rapidly became an important nuisance (Howard-Williams & Davies, 1988; de Winton et al., 2009; Riss et al., 2010, 2012; Figure 4). Early naturalised records frequently came from widely distributed population centres, suggesting colonization through aquarium liberations (de Winton et al., 2009).



<u>Figure 3:</u> Countries where *Lagarosiphon major* is currently recorded (Source: Q-bank ; http://www.q-bank.eu/Plants/Factsheets/Lagarosiphon%20major%20NL.pdf).

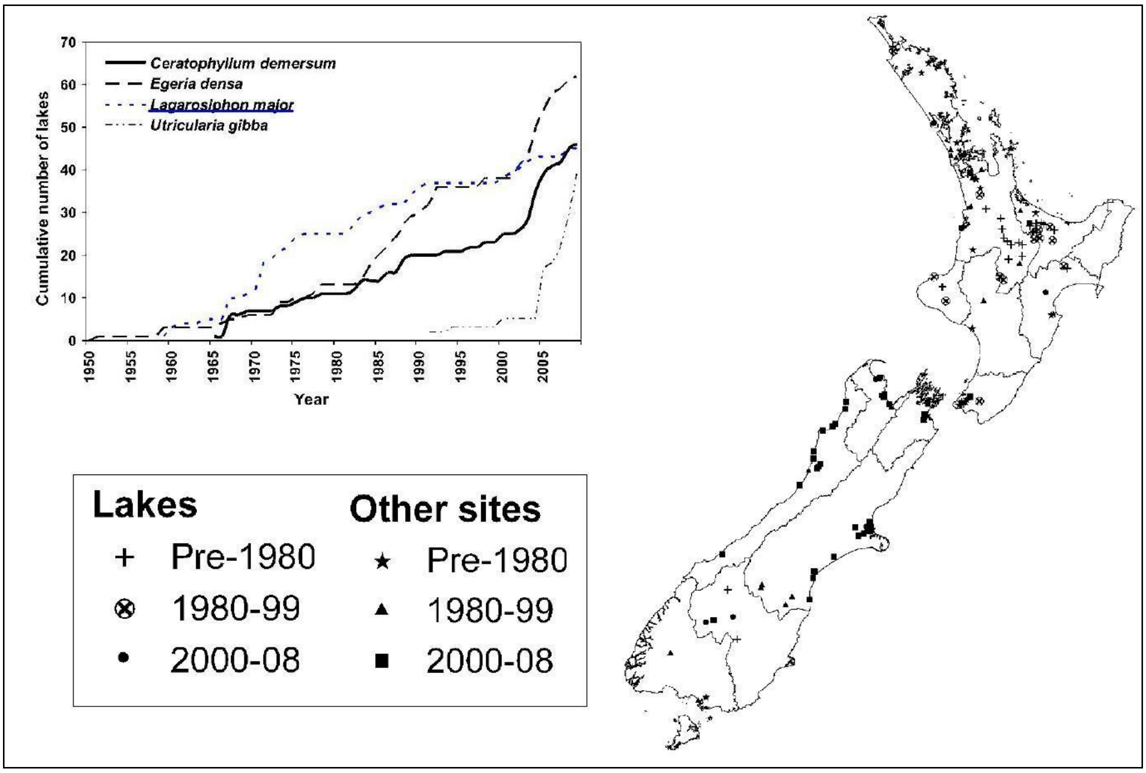


Figure 4: Distribution of *Lagarosiphon major* in New Zealand based on the date of first record and differentiating lakes from other sites. Regional boundaries are indicated. The graph on the upper left corner shows the cumulative records of *L. major* and of three other pest plants over time for New Zealand lakes based on the year of first record. The high dispersion and establishment capacities of *L. major* are evident (Modified from de Winton et al., 2009).

1.4 REASONS FOR PERFORMING RISK ANALYSIS

Weber, in 1997, noted : "Some plant species are present in the introduced flora of Europe which are considered as serious plant invaders elsewhere, e.g. *Lagarosiphon major* [...]. These species do not appear to be invasive in Europe and are considered a threat to intact communities, but their presence in the introduced flora indicates that potentially harmful non-indigenous plant species are present in Europe. Since introduced plant species can stay within a restricted area for a certain time before they start to spread, these species should be monitored carefully."

Evidences are now obtained that *Lagarosiphon major* is invasive in several European countries, in which the species may cause severe ecological and economic damages (Levy et al., 2011; Caffrey et al., 2011). As Branquart et al. (2010) explain:
"As observed for most non-native *Hydrocharitaceae* species, this [*Lagarosiphon major*] submerged perennial aquatic plant makes dense mono-specific populations which often colonise all of water bodies, restrict water movement, cut off light, produce anoxic conditions and trap sediments in the system (siltation increase). The curly waterweed is known to take the water pH up to value over 10 and to deplete dissolved CO_2 concentrations [it is also a very efficient bicarbonate user (Stiers et al., 2011)], creating stressful conditions for other aquatic organisms. It has been reported to outcompete native aquatic plants (e.g. charophytes, *Myriophyllum* spp., *Potamogeton* spp.) and to affect associated populations of aquatic invertebrates and vertebrates, especially in alkaline waters. Dense beds provide a poor habitat for aquatic animals and the plants are not consumed by fish. They interfere with recreation activities and increase the risk of adjacent land flooding."

Several traits allow *L. major* to be an efficient invader such as its vegetative growth habit, its broad environmental tolerance linked with a high phenotypic plasticity, and its high relative growth rate (Riis et al., 2010; Stiers et al., 2011).

The species is a relatively new invasive in Belgium. However, it is sold in several European countries, including Belgium (Brunel et al., 2009; Halford et al., 2011). In 2006, nearly 25.000 *L. major* plants were imported for trade in 10 European and Mediterranean countries (namely, Austria, Czech Republic, Estonia, France, Germany, Hungary, the Netherlands, Latvia, Switzerland and Turkey) (Brunel, 2009). Most important importers were the Netherlands (ca. 20.000 units) and Germany (5200 units). As a result, establishment of new introduced populations in European countries, including Belgium, is high.

STAGE 2 : RISK ASSESSMENT

2.1 PROBABILITY OF ESTABLISHMENT AND SPREAD (EXPOSURE)

Evidence should be available to support the conclusion that the non-native organism could enter, become established in the wild and spread in Belgium and neighboring areas. An analysis of each associated pathways from its origin to its establishment in Belgium is required. Organisms intentionally imported maybe maintained in a number of intended sites for an indeterminate period. In this specific case, the risk may arise because of the probability to spread and establish in unintended habitats nearby intended introduction sites.

2.1.1 Present status in Belgium

Specify if the species already occurs in Belgium and if it makes self-sustaining populations in the wild (establishment). Give detail about species abundance and distribution within Belgium when establishment is confirmed together with the size of area suitable for further spread within Belgium.

Lagarosiphon major appears to be well naturalised in Belgium by now, especially in Flanders, where the species is spreading (Verloove, 2006). Habitats favourable at the species are mostly fishponds, canals and slow flowing streams.

The first record for the country was done in 1993, in Lives-sur-Meuse, in an old branch of the Meuse River but the population soon disappeared after its discovery (Bouxin & Lambinon, 1996). The species was subsequently found in abundance in a small canal in Ieper in 2004, and later also near Stene, Vosselaar, Nieuwpoort, Herselt and doubtlessly elsewhere (Verloove, 2006; http://alienplantsbelgium.be/content/lagarosiphon-major-0). In the Walloon region, the species was discovered in 2009 in a pond near Trooz, and in 2010 at Niverlée (DEMNA - "Département de l'Etude du Milieu Naturel et Agricole", pers. comm.; Figure 5). The species is, however, perhaps under-noticed. Indeed, no observations of the species were reported in Belgium on the website "observations.be" (http://observations.be/soort/maps/85443), although the species is present in the country. This suggests that Belgian naturalists may misidentify or do not notice the species. It is likely that a better understanding of the identification criteria of *Lagarosiphon major*, through public education and information, would yield additional records in Belgium.

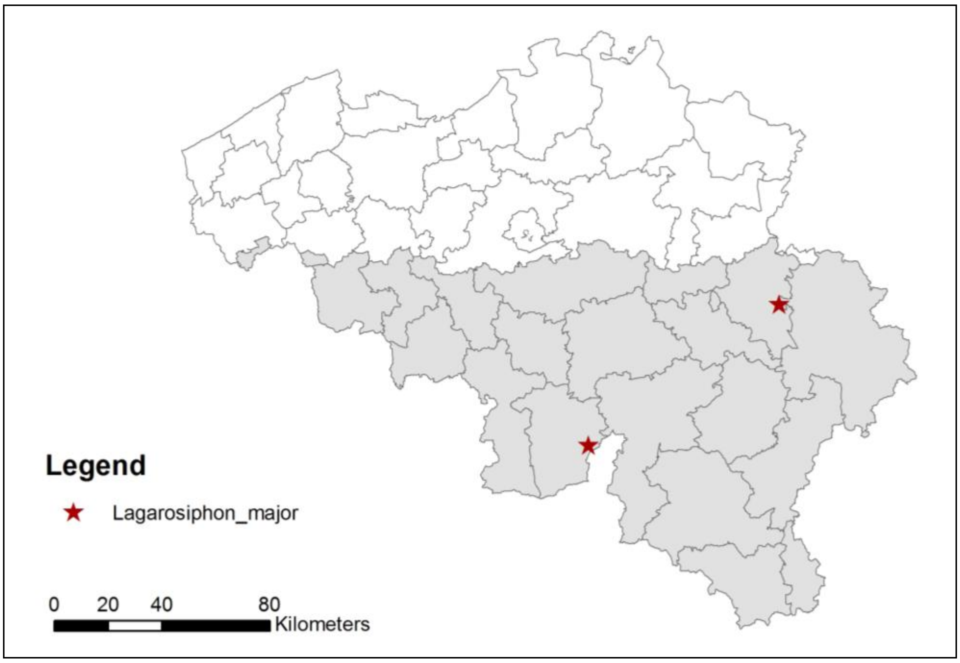


Figure 5: Geographic localizations of *Lagarosiphon major* sightings in Wallonia (Data from DEMNA [Département de l'Etude du Milieu Naturel et Agricole], 2000-2012; Map by Yaëlle Bouyer, RBINS).

2.1.2 Present status in neighbouring countries

Mention here the status of the non-native organism in the neighbouring countries.

- **The Netherlands:**

L. major was first recorded in the Netherlands in Soest around 2003 (Van Valkenburg & Pot, 2008). Over the past decade, this plant species was also recorded at locations, isolated from each other, in the southern and northern provinces (Matthews et al., 2012b ; Figure 6). The species still has a relatively limited distribution in the Netherlands (Figures 6 & 7) but it is expanding its range **(**Van Valkenburg & Pot, 2008, Matthews et al. 2012a, 2012b). In their Risk Analysis of *L. major* in the Netherlands, Matthews et al. (2012b) advice for a total ban of sale and an increase of general public awareness about the ecological and economic risks linked to this plant.

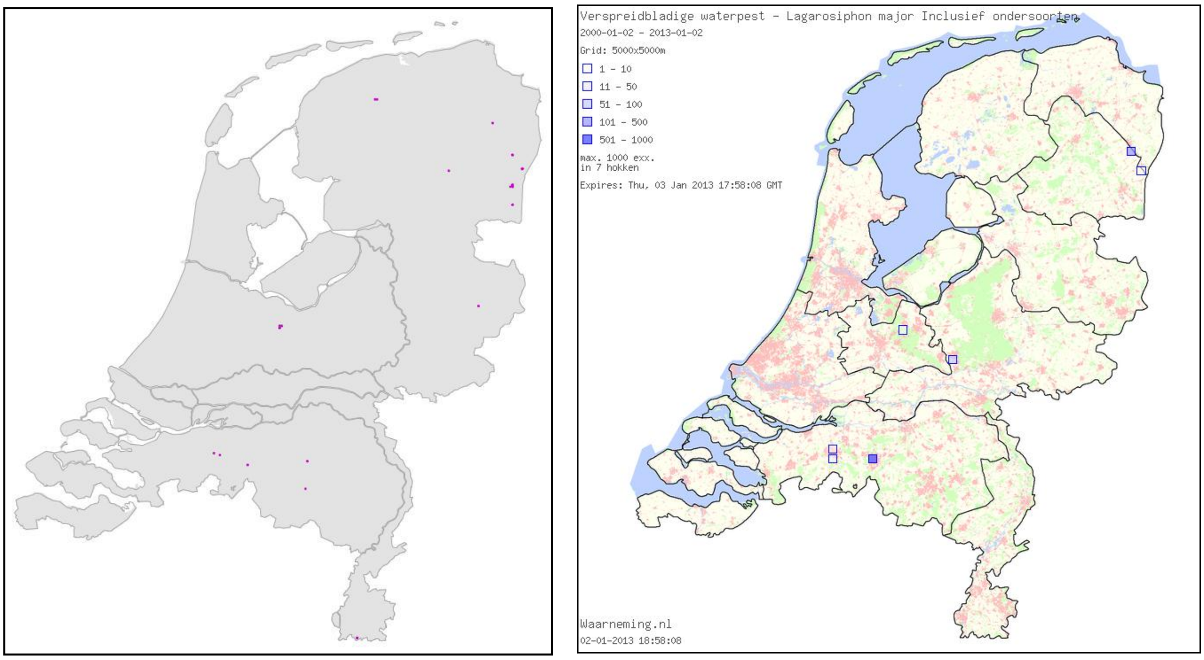


Figure 6: Distribution of *Lagarosiphon major* in the Netherlands since its first introduction in 2003, according to two different sources (Left: Matthews et al. (2012); Right: excerpt 02/01/2013 from waarneming.nl).

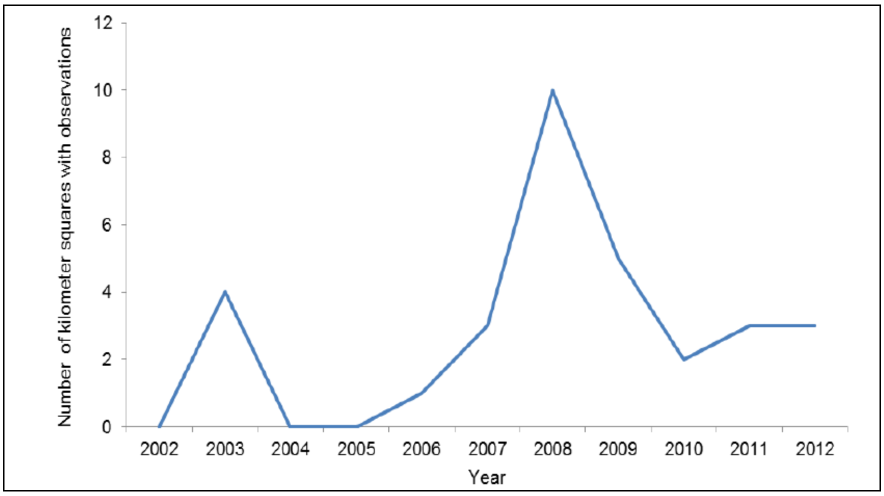


Figure 7: Annual number of kilometre squares with *Lagarosiphon major* in the Netherlands (Source: Matthews et al., 2012a).

- **France:**

In France, the species is mostly present in the western part but it is also recorded in some departments in the South-East (Figure 8). The first population was found around 1935 (Symoens & Triest, 1983; Levy et al., 2011), and was likely the result of an aquarium release (Toussaint & Bedouet, 2005). The species is currently spreading in the Nord-Pas de Calais region, where known populations are found in four sites around Lille (Roubaix Canal), one in the Scarpe River and another one in the Avesnois (Levy et al. 2011; Figure 9).

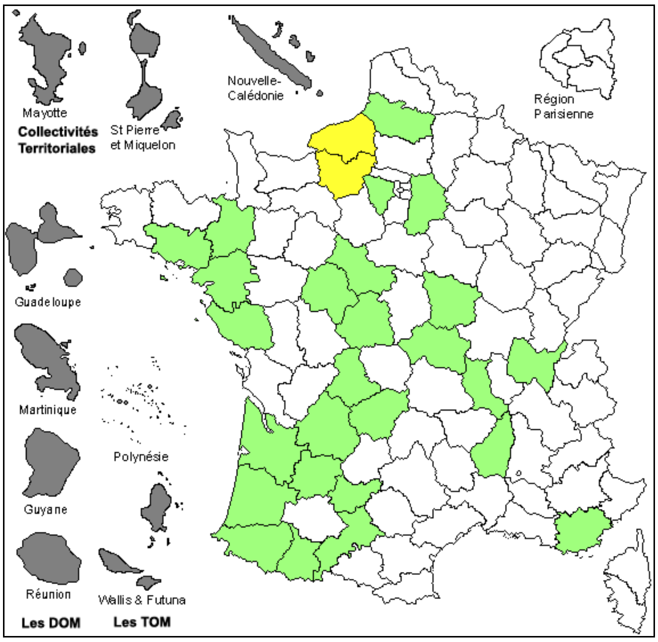


Figure 8: Distribution of *Lagarosiphon major* by department in France (until 2009), green = present, yellow = to be confirmed, white no mention. [TelaBotanica; http://www.tela-botanica.org/page:chorologie_taxons?format=html&module=chorologie&action=carte_presence&pr=25&nt=6071&langue=en]

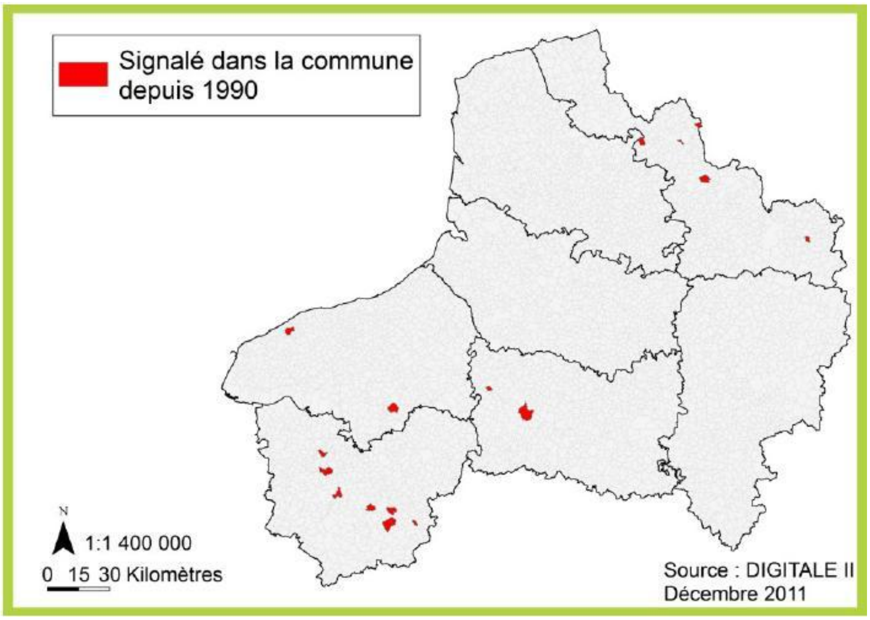


Figure 9: Detailed distribution of *Lagarosiphon major* for the French North-West region (until 2011). Modified from Levy et al. (2011).

- **Germany:**

In Germany the species was first recorded in 1966 in Allgäu (Wolff, 1980 ; Hussner et al., 2010), since then the species became established in five Länder in the south-western part of the country (Hussner, 2010; Figure 10).

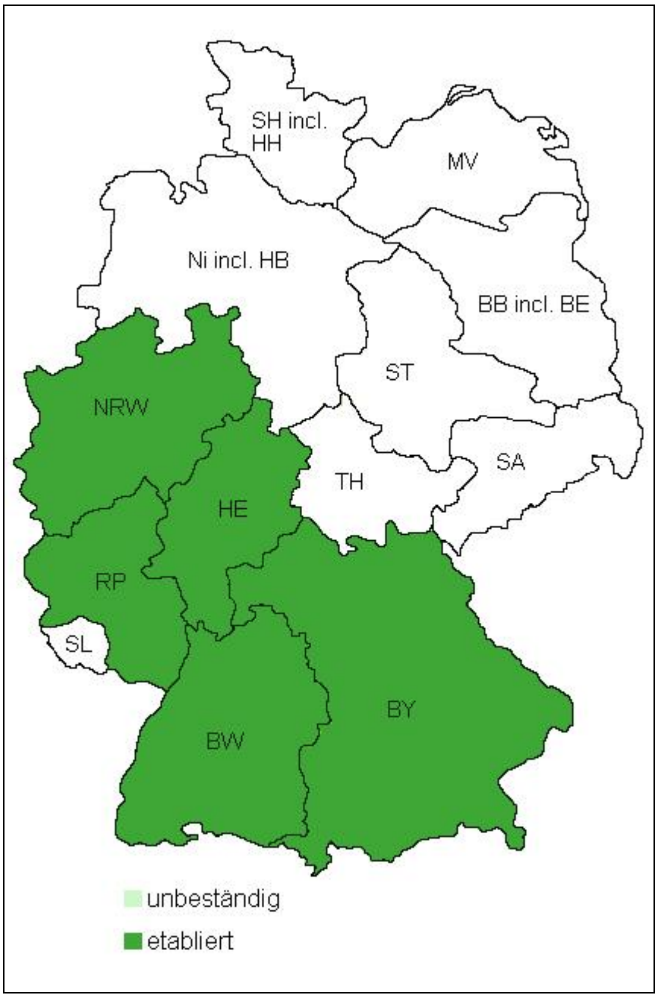


Figure 10: Distribution map of *Lagarosiphon major* in Germany, with Länder where the species is established (Source: Hussner, 2010).

- **United Kingdom and Ireland:**

First recorded in a chalk pit in 1944 (Symoens & Triest, 1983; CAPM, 2004), the species is now widespread and abundant throughout most of England and Wales, particularly in the south, as well as in scattered localities in the Isle of Man, Scotland and Ireland (National Biodiversity Data Centre, 2012; National Biodiversity Network's Gateway, 2013). The species is now present in 476 of the 2810 10 km squares in the UK (Figure 11).

In Ireland, the species was first noted in 1966 (Symoens & Triest, 1983) but apparently the population did not persist. In 2005, the species was found in a large sheltered bay on upper Lough Corrib (Caffrey & Acevedo, 2007) but was probably already present in the mid- to late 1990s (Caffrey, 2009). As the species is sold in Ireland, populations found in the wild are likely the result of aquarium or garden pond escapes (Caffrey et al., 2009a). The species is spreading and new populations are regularly discovered (Caffrey et al., 2009b; National Biodiversity Data Centre, 2012; Figure 12).

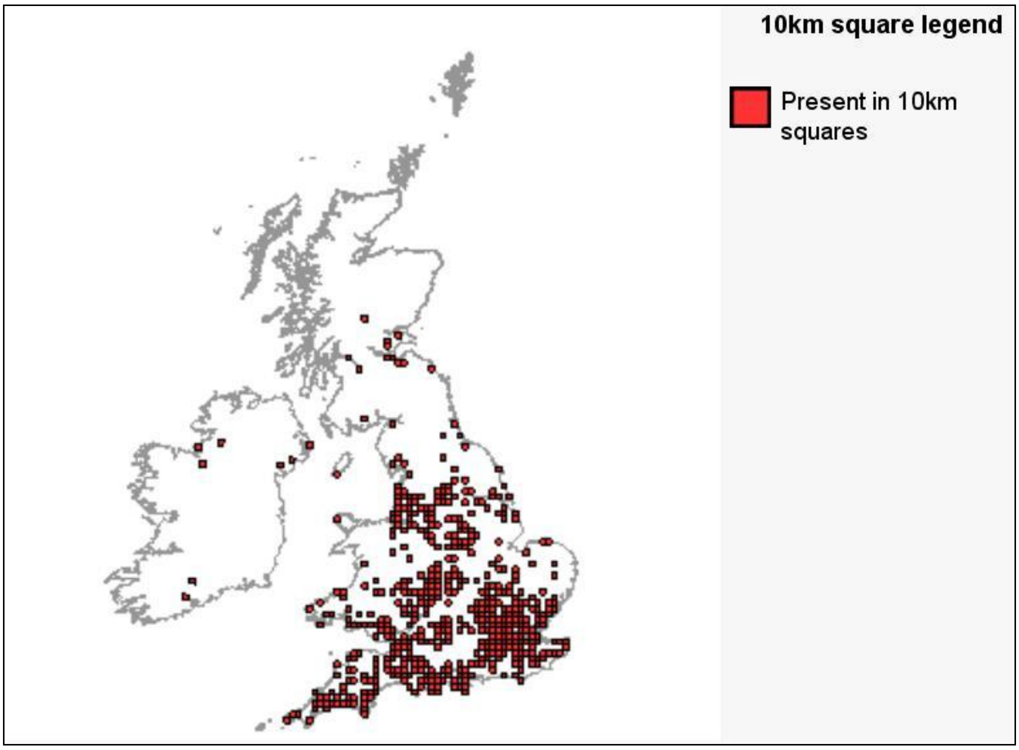


Figure 11: Distribution map of *Lagarosiphon major* in United-Kingdom and Ireland. (Source: National Biodiversity Network's Gateway, 2013; http://data.nbn.org.uk/gridMap/gridMap.jsp?allDs=1&srchSpKey=NHMSYS0000460065).

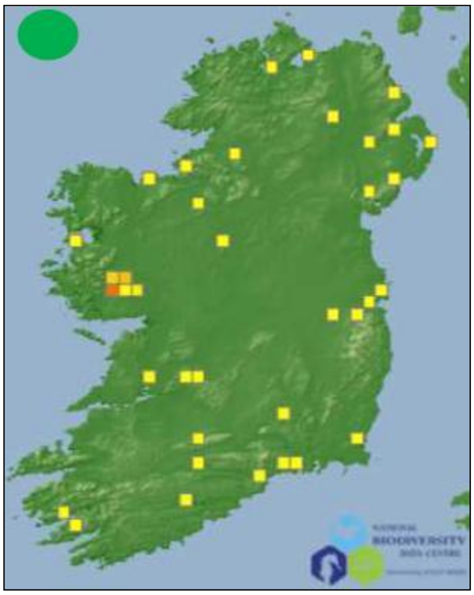


Figure 12: Geographic distribution of *L. major* in Ireland. The green dot on the upper left corner means that all known records are displayed. The colour intensity of the record square from yellow to red reflects the increase in the number of records for each 10 km² (Source: National Biodiversity Data Centre, 2012).

2.1.3 Introduction in Belgium

Specify what are the potential international introduction pathways mediated by human, the frequency of introduction and the number of individuals that are likely to be released in Europe and in Belgium. Consider potential for natural colonisation from neighbouring areas where the species is established and compare with the risk of introduction by the human-mediated pathways. In case of plant or animal species kept in captivity, assess risk for organism escape to the wild (unintended habitats).

Human-mediated pathways are the main risk of introduction in Belgium, and in other European countries and elsewhere as well (Johnstone et al., 1985; Brunel, 2009; Caffrey et al., 2009a, 2011; de Winton et al., 2009; Hussner et al., 2010; Compton et al., 2012). In fact, the only pathway mentioned in the scientific literature for long distance dispersal of *Lagarosiphon major* is horticultural and aquarium trade (e.g. Thiébaut, 2007). The species is sold as an aquarium oxygenating plant and garden pond plant in Belgium (Halford et al., 2011) and in neighbouring countries, including France, the Netherlands and Germany (Brunel, 2009; Levy et al., 2011; Matthews et al., 2012a, 2012b)[2]. In all these countries, introductions into the wild were probably the result of discarded plants.

A recent study suggested that Belgian horticulture professionals had, until recently, a poor understanding of ecological issues caused by invasive plants, resulting from a lack of information and awareness (Vanderhoeven et al., 2011). Fortunately, progress has been made and it becomes well known that *L. major,* and other plants as well, may become invasive in Belgium. The species is now black listed (Branquart et al., 2010) and several professional and non-professional horticulturists and gardeners have agreed with a code of conduct on invasive plants in Belgium (Halford et al., 2011), developed by the AlterIAS LIFE project (Alternatives for invasive plants, http://www.alterias.be/). As a result, the species progressively disappears from catalogues of aquatic nurseries (Luc Denys, pers. comm.).

Once established, subsequent occurrences at new locations may result from (non-)deliberate spreading through human activity (e.g. fishing, diving, boating) or natural water transport of plant fragments (hydrochory); animal transport, by large birds for instance (ornithochory), has also been suggested but this pathway is poorly supported so far (Johnstone et al., 1985; de Winton et al., 2009; CAPM, 2004; Compton et al., 2012).

[2] Confusingly, it may be sold under the name *Elodea densa, Elodea crispa* or African Elodea (CAPM, 2004; GB Non-Native Species Secretariat, 2011).

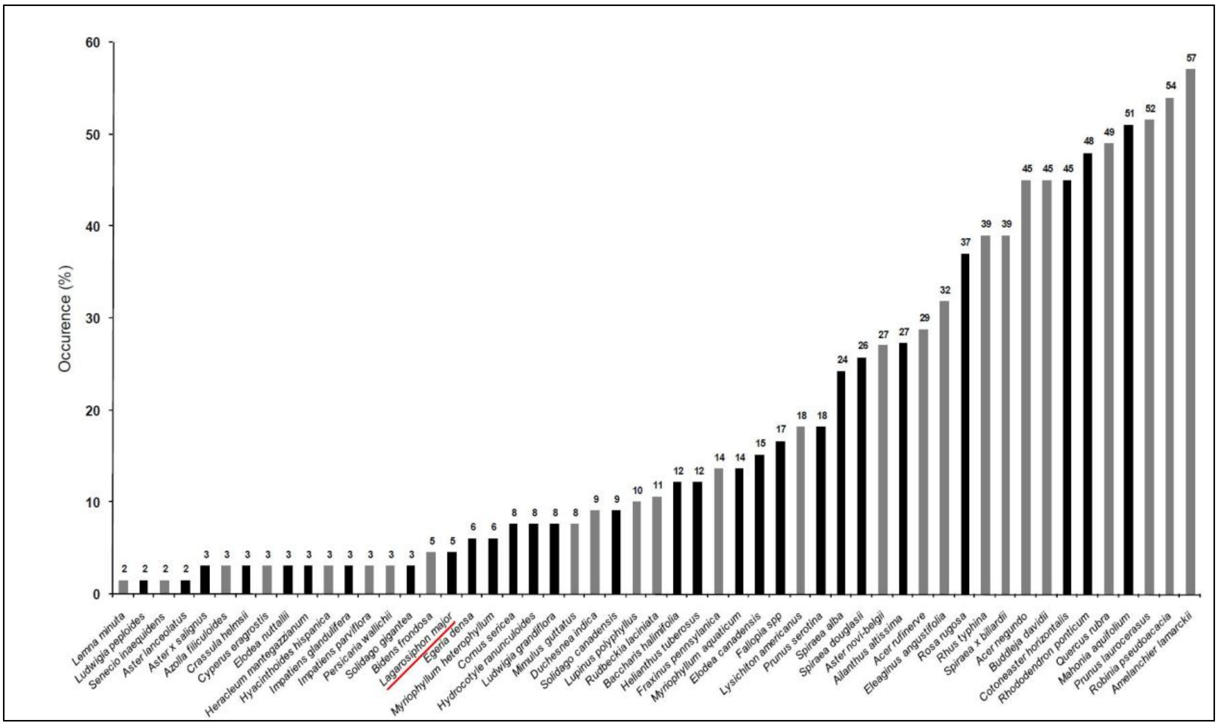


Figure 13: Occurrence of invasive plants (terrestrial and aquatic) sold in nurseries in Belgium (n = 67). Black bars: black listed species. Grey bars: watch listed species. *Lagarosiphon major* (underlined in red) is present in 5% of the Belgian nurseries studied (modified from Halford et al., 2011).

ENTRY IN BELGIUM
The species is already present in Belgium and in the neighbouring countries. Belgian populations are still isolated but spreading. The species was more than probably introduced initially by horticultural and aquarium trade. Continued (accidental or not) introductions are very likely since the species is still imported to Europe and available in the horticultural trade.

2.1.4 Establishment capacity and endangered area

Provide a short description of life-history and reproduction traits of the organism that should be compared with those of their closest native relatives (A). Specify which are the optimal and limiting climatic (B), habitat (C) and food (D) requirements for organism survival, growth and reproduction both in its native and introduced ranges. When present in Belgium, specify agents (predators, parasites, diseases, etc.) that are likely to control population development (E). For species absent from Belgium, identify the probability for future establishment (F) and the area most suitable for species establishment (endangered area) (G) depending if climatic, habitat and food conditions found in Belgium are considered as optimal, suboptimal or inadequate for the establishment of a reproductively viable population. The endangered area may be the whole country or part of it where ecological factors favour the establishment of the organism (consider the spatial distribution of preferred habitats). For non-native species already established, mention if they are well adapted to the eco-climatic conditions found in Belgium (F), where they easily form self-sustaining populations, and which areas in Belgium are still available for future colonisation (G).

A/ Life-cycle and reproduction

All *L. major* reproduction in regions outside its native range is asexual, primarily by fragmentation or local growth by rhizomatous spread (Symoens & Triest, 1983; Levy et al., 2011).

In its native range (and in most of its introduced range) *L. major* grows in the spring, producing large masses of interwoven stems in the summer. It starts flowering in the summer and concludes in early autumn. Curiously, *L. major* exhibits a different life cycle in Lough Corrib (Ireland). There, the plant grows vigorously in winter and collapses during the summer months (Caffrey et al., 2011). The authors consider that this growth cycle confers a competitive advantage on *L. major* over the indigenous macrophytes present in the lake by presenting tall, light-excluding stands during the spring season when most species emerge from the substrate to commence active growth. Results from studies conducted in the lake have revealed the success of this strategy and the virtual exclusion of native macrophyte communities in *L. major* dominated areas (Caffrey & Acevedo 2008; Caffrey et al. 2009a, 2009b). This observation shows that adaptability of *L. major* is high. This plasticity certainly contributes to its invasion success (Riis et al., 2010).

B/ Climatic requirements[3]

The species best grows in temperate waters (Branquart et al., 2010), although it may grow at slightly higher temperatures than other north temperate aquatic macrophytes in its native range. It becomes dormant as light intensity, temperature and day-length decrease. Maximum growth rate is achieved at 18-25°C (McKee et al., 2002; Caffrey & Acevedo, 2007; Riis et al., 2012). In fact, *L. major* greatly declined at 30°C both in growth rate and photosynthetic rate, indicating stress responses to mean temperatures above 25°C (Riis et al., 2012).

Winter cold temperatures do not prohibit the invasion of *L. major*, as observed in the UK for instance (GB Non-Native Species Secretariat, 2011; Figure 11). Indeed, *Lagarosiphon major* is perennial in this country and winter conditions do not kill the plant. Because climatic conditions in Belgium are similar to those observed in the UK, the species is not expected to be limited anywhere in Belgium, except possibly in the highest (or the most continental) part of the country (Ardennes).

With the help of freshwater microcosm experiments that mimicked north temperate shallow lake and pond environments, McKee et al. (2002) have demonstrated that a temperature increase due to climate change (up to 3°C above ambient year-round temperature) would probably positively impact *L. major* growth.

C/ Habitat preferences[4]

Although genetic diversity within *L. major* populations is generally low in its introduced range (e.g. in New Zealand; Lambertini et al., 2010; Riis et al., 2010), the species presents a broad range of morphological variations (Riis et al., 2010). This high phenotypic plasticity explains its tolerance to a broad range of environmental conditions, and contributes to its invasion success (Riis et al., 2010).

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[3] Organism's capacity to establish a self-sustaining population under Atlantic temperate conditions (Cfb Köppen-Geiger climate type) should be considered, with a focus on its potential to survive cold periods during the wintertime (e.g. plant hardiness) and to reproduce taking into account the limited amount of heat available during the summertime.

[4] Including host plant, soil conditions and other abiotic factors where appropriate.

Sheltered waters: *Lagarosiphon major* prefers sheltered habitats or reed beds, which are well protected from wind, waves and currents (ISSG, 2006; Caffrey & Acevedo, 2007).

Depth, Flow & Light: *Lagarosiphon major* is a submerged plant, permanently or almost constantly growing under water. It preferably develops in clear still and slow-flowing water systems, where it can grow down to 0.1 – 6.6 meters (Riis & Biggs, 2003; Caffrey & Acevedo, 2007; Branquart et al., 2010; DAFF, 2013). In murky water, it may only grow to 1 m. Research conducted in New Zealand has determined that, even at sites with sufficient light and substrate for growth, *Lagarosiphon major* is unable to survive at pressures greater than 7 bar, which equates to a depth of ca. 7 m (Coffey & Wah, 1988). It does not grow in fast flowing water, although it will grow in canals, drainage ditches and slow-flowing rivers (CAPM, 2004; Branquart et al., 2010; Levy et al., 2011). Overall, the species does not seem particularly sensible to extreme light exposure and also occurs in partial shade (ISSG, 2006; Levy et al., 2011). Nevertheless, Riis et al. (2012) have demonstrated that light availability had an overall stronger effect on growth rate and plant morphology than temperature in *Lagarosiphon major* (Figure 14). In their experiment, growth rate increased three-fold from low to high light (25% and 50 % of incident light available, respectively).

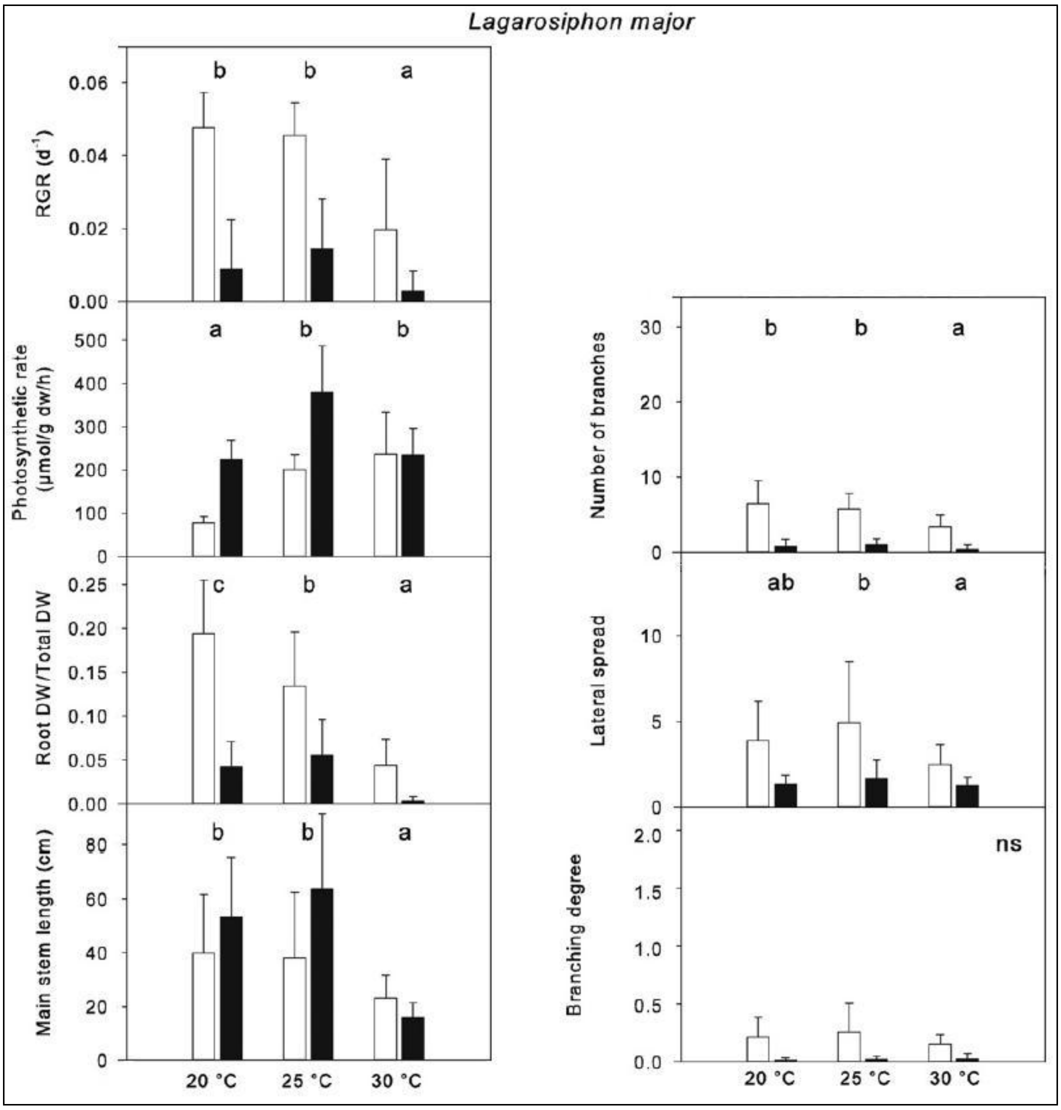

Figure 14: Results of an experiment testing the effect of temperature (20°C, 25°C and 30°C) and light (white bars: 50% incident light; black bars: 25% incident light ; Mean ± SD; n = 30) on morphological and physiological traits of *Lagarosiphon major* after six weeks in outdoor growth tanks. Letters indicate significant differences between the three temperatures given by a two-way ANOVA analysis; ns indicates no significance; RGR and DW mean Relative Growth Rate and Dry Weight, respectively. It clearly appears that *Lagarosiphon major* performs best (*i*) under cold water conditions (20°C) and (*ii*) under higher light availability (50% incident light). Modified from Riis et al. (2012).

Soil texture: In New Zealand, *Lagarosiphon major* has its maximum height and biomass in sites with fine sediment and steep slope (> 70 from horizontal; Howard-Williams & Davies, 1988) but this may be linked with idiosyncrasies of Lake Taupo, the study site. More generally, *L. major* displays a definite preference for a deep and organically rich substrate, and is not observed in rocky locations (Caffrey & Acevedo, 2007). Nevertheless, *L. major* is highly plastic and the species can live in a wide range of trophic conditions and altitude providing that mineral bottom (either silty or sandy soils), rich in nutrients, is available (ISSG, 2006; Caffrey & Acevedo, 2007; de Winton et al., 2009; Branquart et al., 2010). In addition, *L. major* modifies the environment to its advantage. Indeed, the tall, dense vegetation produced by the plant reduces water flow and thus accumulates deep deposits of organic mud at the base of the stand, which provides the plant with sufficient nutrient for growth, even in relatively oligotrophic water (Caffrey & Acevedo, 2007).

pH: *Lagarosiphon major*, as other Hydrocharitaceae (e.g. *Elodea* spp. or *Egeria* spp.; Prins et al., 1979; James et al., 1999; Cavalli et al., 2012), is able to efficiently utilize bicarbonate ions as a dissolved inorganic carbon source for photosynthetic activity (James et al., 1999; Stiers et al., 2011). It is a great advantage in alkaline waters compared to plants depending on dissolved carbon dioxide for photosynthesis, since concentration of the latter decreases with pH. As a result, *L. major* is found in weakly acid to alkaline waters but never in very acid waters (Adams et al., 1978; Branquart et al., 2010; Matthews, 2012d; Stiers et al., 2011). Moreover, the photosynthetic activity of *L. major* increases pH value of the water (up to 10.4, the limit of bicarbonate uptake [Stiers et al., 2011]), which, in turns, improves *L. major* competitiveness. This key feature is one of the reasons of its ecological success as few submerged macrophytes can photosynthesise effectively at such high pH (CAPM, 2004; Stiers et al., 2011).

Salinity & nutrients: *L. major* is absent from saline sites, and if in coastal situations, it is presence is only accidental and non-persistent when subjected to saline spray or water. The species has a medium stress tolerance to nitrogen (Grime et al*.,* 1997). *L. major* growth is often limited by phosphorus availability, especially in oligotrophic water (Rattray et al., 1991). In this direction, Riis et al. (2010) have experimentally demonstrated that both inorganic carbon (as free CO_2) and dissolved phosphorous are key factors in the control of plant size. For instance, shoot diameter and leaf width of *L. major* decrease with decreasing phosphorus availability (Riss et al., 2010). Moreover, Rattray et al. (1991) have demonstrated that the plant may use the phosphorus available from both the sediment and the water.

Toussaint et al. (2008) offer a simplified summary of the needs of *L. major* along a scale from 1 to 5 (Table below; for clarity the scale meaning is namely explained within the cells).

Factor	1	2	3	4	5
Water					**Aquatic plant**
pH			**Neutrophilous to calciphilous**		
Nutrients				**Prefers eutrophic to hypertrophic conditions**	
Organic Matter			**Prefers soil with medium to high organic matter quantity**		
Granulometry					**Prefers silt soils; supports anoxic conditions**
Light				**Helophyte**	
Salt	**Not halophile**				

D/ Food habits[5]

NA

E/ Control agents

To our knowledge, no control agents are known in *L. major* introduced range.

However, a survey for natural enemies in its native range indicated that several phytophagous species feed on the plant. At least three show notable promise as candidate agents for biocontrol. Amongst these, a leaf-mining fly, *Hydrellia lagarosiphon* (Diptera: Ephydridae) that occurred over a wide distribution causes significant leaf damage despite high levels of parasitism by braconid wasps. Another yet unidentified fly was recorded mining the stem of *L. major*. Two leaf feeding and shoot boring weevils, cf. *Bagous* sp. (Coleoptera: Curculionidae) were recorded damaging the shoot tips and stunting the growth of the stem. Several leaf feeding lepidopteran species (Lepidoptera: Nymphulinae) were frequently recorded, but are expected to feed on a wide range of plant species and are not considered for importation before other candidates are assessed (McGregor & Gourlay, 2002; Caffrey et al., 2009a; Baars et al., 2010; Mangan & Baars, 2013). In addition, the nematode *Aphelenchoides fragariae* has also been recorded attacking the apical tips of *L. major* causing shoot dwarfing (McGregor & Gourlay,2002).

At last, the possibility of the use of the Grass Carp (*Ctenopharyngodon idella*), a fish native from Asia and invasive in numerous parts of the world, as biological control agent of *L. major* in New Zealand has been suggested (Chapman & Coffey, 1971). Trials showed that the fish would indeed eat the problematic plant. Nevertheless, this option cannot be recommended because of the negative impact that the fish may have on native ecosystems (ISSG, 2005).

F/ Establishment capacity in Belgium

Considerable. The large distribution and continuous spreading of *L. major* in the UK show that the species is well adapted to eco-climatic conditions occurring in Belgium. Establishment capacity is

[5] For animal species only.

considered high in most geographic districts of the country, except in parts of Ardennes where winter conditions are probably too harsh for survival. Human-mediated introduction (accidental or not) and subsequent dissemination by humans or by natural means (e.g. water currents displacing propagules or, to a lesser extent, transport by birds and other animals) may occur with a high probability and most of our aquatic ecosystems (especially slow-flowing alkaline waters) provide suitable ecological conditions for effective population growth. Even polder and dune waters are often very well suited for the plant establishment and several occurrences are already reported in these habitats (Luc Denys, pers. comm.).

G/ Endangered areas in Belgium

Most freshwater bodies and slow flowing streams of the territory, especially those with alkaline water, and including endangered and sensitive areas, are to be considered as suitable for *Lagarosiphon major* establishment (Figure 15). For instance, the species is already present in some Flemish natural reserves (e.g. Stiers et al., 2011).

Nowadays climatic conditions (linked with altitude) may play a role in keeping the species from invading harsher climatic parts of Wallonia (Ardennes) but, with predicted increasing temperatures due to climate change, the species could extend its range (McKee et al., 2002) and spread further south.

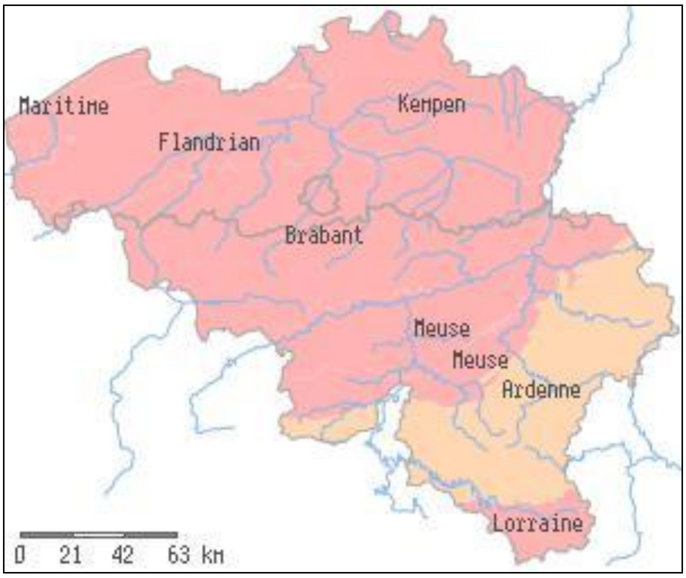

Figure 15: Threat from *Lagarosiphon major* on Belgian areas (orange: medium risk; pink: high risk). Based on the species climatic requirement in the UK and pH of surface water (Source: http://ias.biodiversity.be).

Establishment capacity in the Belgian geographic districts:

Districts in Belgium	Environmental conditions for species establishment[6]	Environmental conditions for species establishment under increasing temperature due to climate change
Maritime	Optimal	Optimal
Flandrian	Optimal	Optimal
Brabant	Optimal	Optimal
Kempen	Optimal	Optimal
Meuse	Optimal	Optimal
Ardenne	Suboptimal	Optimal
Lorraine	Optimal	Optimal

ESTABLISHMENT CAPACITY AND ENDANGERED AREAS IN BELGIUM
Climatic conditions and habitat characteristics of most Belgian fresh water streams and ponds fit within the ecological requirements of *L. major*. Belgium is therefore a country where the species shows a potentially high establishment capacity. As the species is aquatic and closely associated to freshwater, most wetlands, streams and ponds (including sensitive areas, nature reserves and Natura2000 sites) are considered highly vulnerable to *L. major* invasion.

2.1.5 Dispersion capacity

Specify what is the rate of dispersal once the species is released or disperses into a new area. When available, data on mean expansion rate in introduced territories can be specified. For natural dispersion, provide information about frequency and range of long-distance movements (i.e. species capacity to colonise remote areas) and potential barriers for spread, both in native and in introduced areas, and specify if the species is considered as rather sedentary or mobile. For human-assisted dispersion, specify the likelihood and the frequency of intentional and accidental movements, considering especially the transport to areas from which the species may easily colonise unintended habitats with a high conservation value.

A/ Natural spread

Only female plants are known outside of the native range of this species (Symoens & Triest, 1983; Levy et al., 2011). All reproduction in introduced regions is therefore asexual, primarily by fragmentation or local growth by rhizomatous spread (Symoens & Triest, 1983). Dispersion is mainly downstream directed (de Winton et al., 2009). Strong winds and flooding may increase plant fragmentation and facilitate its dispersion (Levy et al., 2011). Transport by animals (birds, mammals) is not well-documented but plausible. Animal foraging may also result in the fragmentation of the plant, which may facilitate its dispersion, and eventually results in the production of new populations (Levy et al., 2011). It is, however, unlikely that colonization of new isolated ponds results from natural dispersion.

[6] For each district, choose one of the following options : optimal, suboptimal or inadequate.

Once established, *Lagarosiphon major* may rapidly increase in cover and biomass. For instance, in Lough Corrib (Ireland), an increase of around 1,028 tonnes of fresh weight biomass of *L. major* was observed between 2005 and 2007 (Caffrey et al., 2011).

B/ Human assistance

The general assumption is that this species has entered in all non-native areas as an aquarium plant (Johnstone et al., 1985; CAPM, 2004; ISSG, 2006; Thiébaut, 2007; Brunel, 2009; Caffrey et al., 2009a, 2011; de Winton et al., 2009; Hussner et al., 2010; Compton et al., 2012). Human activities greatly enhance dispersal by lack of precautions during disposal of horticultural residues or accidental transport on clothes, footwear, machinery, boats or fishing equipment. Mechanical management seems to enhance fragmentation which in turns increases dispersal within and between water systems (Levy et al., 2011).

In New Zealand, dispersal of aquatic pest plants, including *L. major*, is supposed to be mainly related to boating and fishing activities or equipment rather than to natural vectors such as birds and wind (Johnstone et al., 1985; de Winton et al., 2009; Compton et al., 2012). Mathematical models have supported this assumption (Johnstone et al., 1985; Compton et al., 2012). This is likely to be true elsewhere as well, because human-mediated dispersal is often a key process in the range expansion of non-native plant species (Kowarik, 2003; Kowarik & von der Lippe, 2007).

DISPERSAL CAPACITY
High. Main dispersion in the wild occurs by vegetative propagules disseminated by water currents. Human activities can greatly enhance dispersal by lack of precautions during disposal of horticultural residues or accidental transport on clothes and footwear, machinery, boats or fishing equipment. Dispersal can also possibly take place through bird or mammal movements.

2.2 EFFECTS OF ESTABLISHMENT

Consider the potential of the non-native organism to cause direct and indirect environmental, economic and social damages as a result of establishment. Information should be obtained from areas where the pest occurs naturally or has been introduced, preferably within Belgium and neighboring areas or in other areas with similar eco-climatic conditions. Compare this information with the situation in the risk analysis area. Invasion histories concerning comparable organisms can usefully be considered. The magnitude of those effects should be also compared with those caused by their closest native relatives.

2.2.1 Environmental impacts

Specify if competition, predation (or herbivory), pathogen pollution and genetic effects is likely to cause a strong, widespread and persistent decline of the populations of native species and if those mechanisms are likely to affect common or threatened species. Document also the effects (intensity, frequency and persistency) the non-native species may have on habitat peculiarities and ecosystem functions, including physical modification of the habitat, change to nutrient cycling and availability, alteration of natural successions and disruption of trophic and mutualistic interactions. Specify what kind of ecosystems are especially at risk.

A/ Competition [HIGH]

Lagarosiphon major has been reported to outcompete native submerged aquatic plants, including charophytes, *Myriophyllum* spp., *Potamogeton* spp., *Ceratophyllum demersum* (Rattray et al., 1994;

Howard-Williams & Davies, 1998; Keenan et al., 2009; Stiers et al., 2011). As a consequence, monospecific beds of *L. major* may develop, as observed in Lough Corrib (Ireland) for instance (Caffrey et al., 2009; 2011; Figure 16).

Riis et al. (2012) have experimentally demonstrated that *L. major* is more competitive in cold water (20°C) than in warm water (≥ 25°C), whereas the opposite pattern is present for *Egeria densa*, another invasive aquatic plant in Europe. These authors also noted that *L. major* is a superior competitor of *Elodea canadensis* (also invasive in Europe), except perhaps at early colonization stage. James et al. (1999) also showed that *Lagarosiphon major* is able to actively displace *Elodea* species in some lentic British waters.

Several traits or reasons explain the competitive success of *L. major:*

- In its introduced range, no natural control agents (herbivores, parasites) occur (Baars et al., 2010).

- *L. major* is able to photosynthesize and consequently grow under very stressful conditions of high pH and low free CO_2, perhaps through more efficient bicarbonate utilization than the other aquatic plant species (CAPM, 2004; James et al., 1999; Stiers et al., 2011).

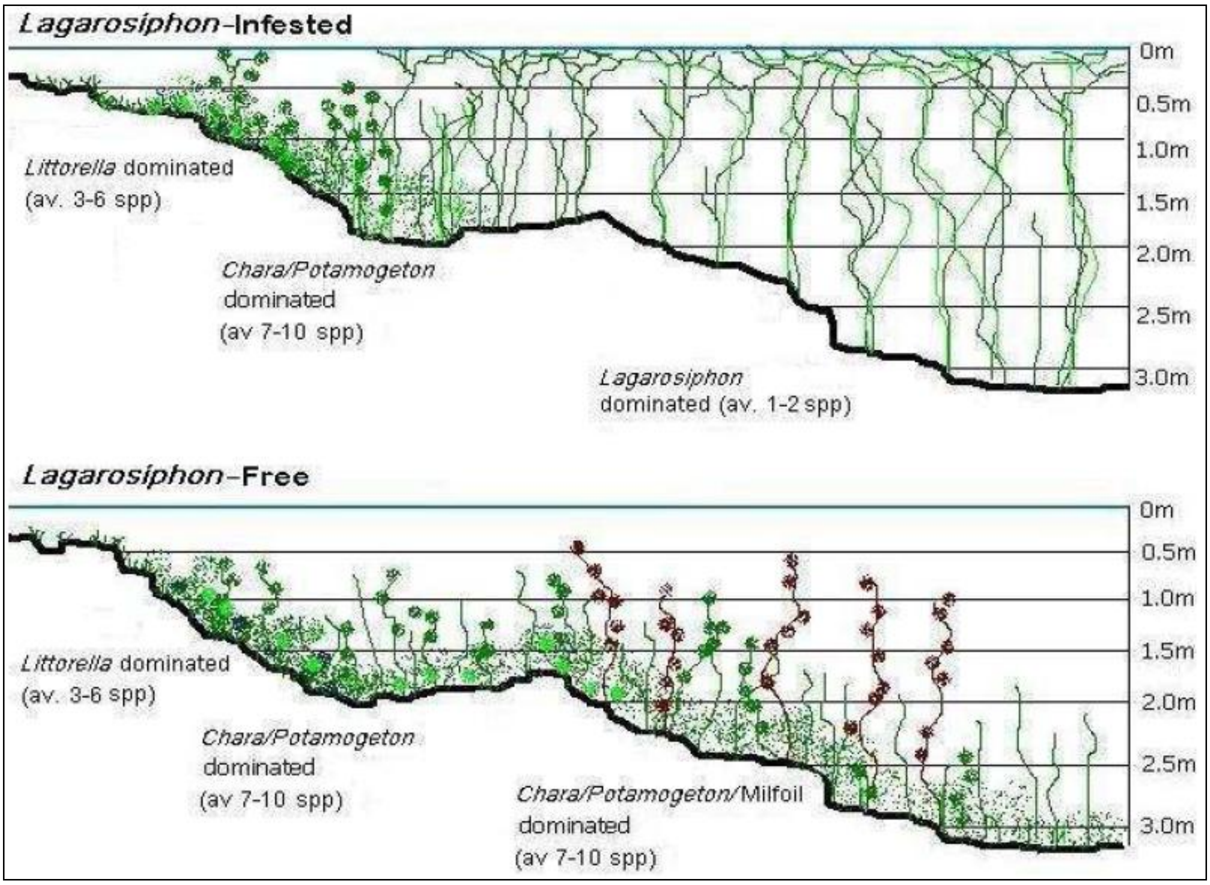

Figure 16: A typical depth profile of Lough Corrib (Ireland) showing the typical macrophyte species pattern in both *Lagarosiphon*-infested and *Lagarosiphon*-free sites. Sites at which *Lagarosiphon* is established demonstrate a significant reduction in macrophyte species diversity. (Source: Caffrey et al. 2009).

- By its photosynthetic activity, *L. major* creates progressively stressful conditions of high pH and low CO_2 content for other plants (James et al., 1999; Stiers et al., 2011). Similarly, the tall, dense vegetation produced by the plant accumulates deep deposits of organic mud at the base of the stand (= siltation increase), which provide the plant with sufficient nutrient for growth, even in relatively oligotrophic water (Caffrey & Acevedo, 2007; Branquart et al., 2010).

- Higher performance of *L. major* may also be due to its high plasticity (Riis et al., 2010) and capacity of adaptation to local environmental conditions by modifying its life history traits (as noted for instance by Caffrey et al. (2011) in Ireland; see § 2.1.4.A). As a result of this plasticity, *L. major* presents a broad tolerance to several environmental factors (light, pH, etc.; see § 2.1.4.B and 2.1.4.C).

- One of the plant's greatest competitive features is its ability to produce a dense surface canopy. This effectively blocks sunlight from penetrating to native plants present in the understorey beneath the canopy (Caffrey & Acevedo, 2007; Caffrey et al., 2009; 2010a, 2011; Figure 17). For instance, it has been demonstrated that as little as 1% sunlight can penetrate a canopy of 0.5 m deep of *L. major* (Schwartz & Howard-Williams, 1993).

- In addition to the competitive advantage conferred on *Lagarosiphon major* by its growth form, research has demonstrated the competitive ability of *L. major* fragments over those produced by other tall aquatic plant species. Shoot fragments possess the ability to absorb nutrients from the water as well as using stored nutrients. Where nutrients are plentiful in the water, *L. major* channels its growth resources into shoot extension rather than into root development. This is particularly advantageous, particularly in aquatic situations where light may be limiting. Other species appear to require the development of an extensive root system before manifesting shoot growth (Rattray et al., 1991, 1994; Caffrey & Acevedo, 2007).

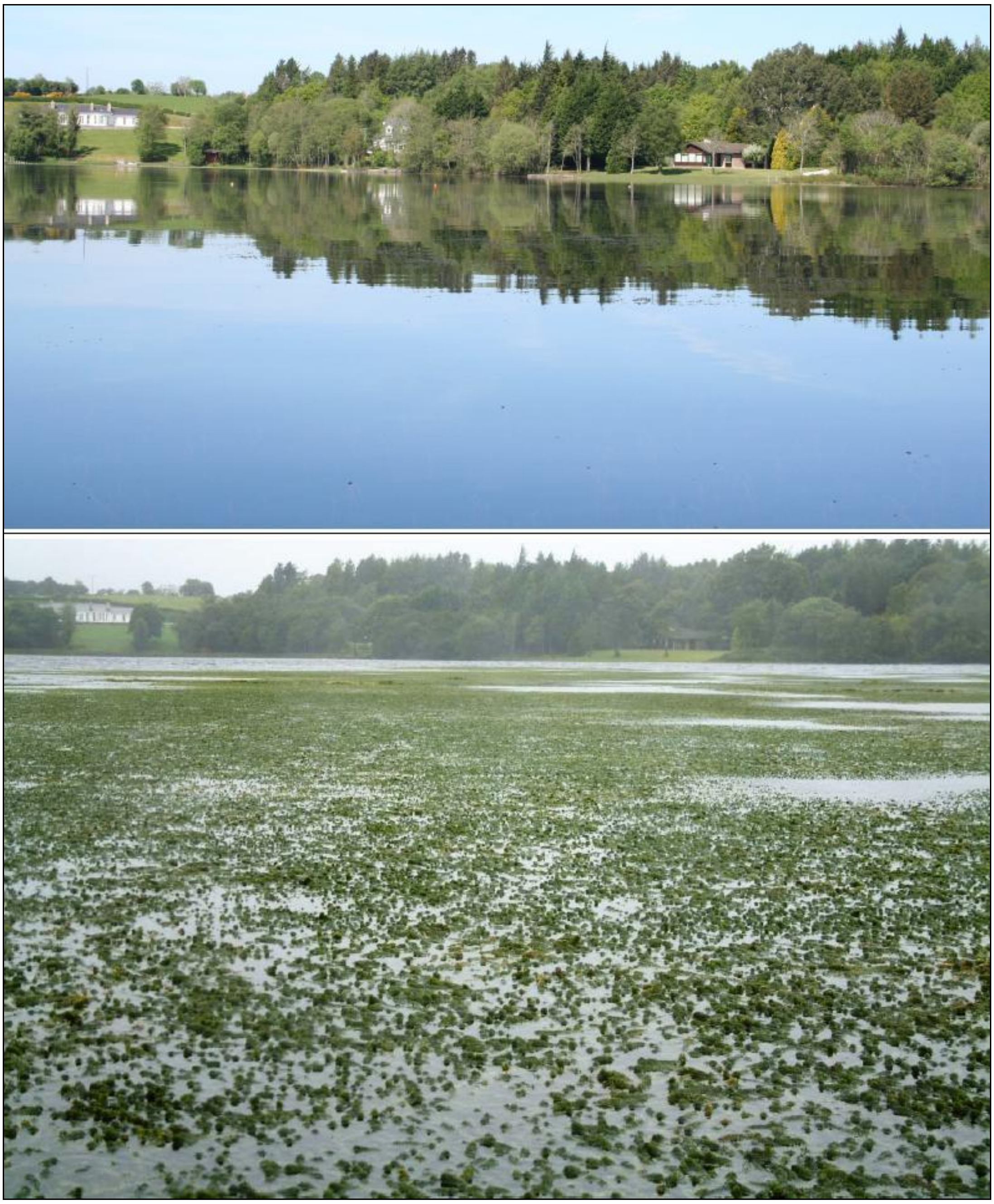

Figure 17: View of Rinerroon Bay, Lough Corrib (Ireland), before (top) and after (bottom) the establishment of a dense population of *Lagarosiphon major*. Such dense mats highly alter ecosystem diversity, functions and services, increase flood hazards (decreasing lake discharge), reduce amenity value of the waterbody (decline in local tourism may be observed), and negatively impact various recreational and economic activities. (Source : Caffrey et al. 2010a).

B/ Predation/herbivory (NA)

NA

C/ Genetic effects and hybridization [LOW]

None known and not to be expected (there is no congeneric or close relative species in Europe).

D/ Pathogen pollution [LOW]

Pathogen pollution is not likely to cause any decline of native species populations and this mechanism is certainly not likely to affect any threatened native species in Belgium.

E/ Effects on ecosystem functions [HIGH]

Dense stands and mats of *Lagarosiphon major* (e.g. Figure 17) can increase siltation and nitrogen concentration, decrease light availability for other organisms, and change water hydrology and quality (e.g. water pH can increase over 10, dissolved inorganic carbon be depleted, and oxygen levels decrease because of its photosynthetic activity and of a decrease of water circulation) (CAPM, 2004; James et al., 1999; Caffrey & Acevedo, 2007; Branquart et al., 2010; Stiers et al., 2011). In addition, rotting plants may degrade water quality (Sullivan & Hutchison, 2010).

All these habitat changes may alter ecosystems functions and services and create stressful conditions for other aquatic organisms. In this direction, *Lagarosiphon major* has been reported to affect associated assemblages of aquatic invertebrates and vertebrates (fish, waterbirds), especially where the growth has become dense and restrictive (Rattray et al., 1994; Keenan et al., 2009, DAFF, 2013).

For invertebrates, if biomass and species diversity are sometimes not affected by *L. major* establishment (in fact, they may even increase [Kelly & Hawes, 2005]), changes in taxon composition were always observed (Kelly & Hawes, 2005; Caffrey & Acevedo, 2007; Baars et al., 2009; Bickel & Closs, 2009; Caffrey et al., 2009a, 2010a). For instance, in Lough Corrib (Ireland), establishment of dense beds of *L. major* increase the abundance of some macroinvertebrate species or groups, notably Chironomidae (Diptera) and some invasive species such as the Amphipoda *Crangonyx pseudogracilis* and the Zebra Mussel, *Dreissena polymorpha* (Caffrey & Acevedo, 2007; Caffrey et al., 2010a). The fact that *L. major* introduction may promote the establishment and spread of other invasive species (= facilitation process), may lead to an invasional meltdown (*sensu* Simberloff and von Holle, 1999). Also, an invasive species may facilitate the establishment and/or spread of *L. major*. For instance, in New Zealand, Lake et al. (2002) state that Rudd (*Scardinius erythrophtalmus*), an invasive fish native from Europe and Asia, selectively feeds on native plants, and therefore facilitates the invasion of *Lagarosiphon major* and of other exotic oxygen weeds.

The establishment of *L. major* may modify fish assemblages. For instance, in Lough Corrib, *L. major* creates habitats favoured by some fish such as Pike, *Esox lucius*, Perch, *Perca fluviatilis*, Roach, *Rutilus rutilus,* and other cyprinid species, to the detriment of Wild Brown Trout (*Salmo trutta*) and Atlantic Salmon (*Salmo salar*). *L. major* mats provide for favoured fish a spawning medium (Figure 18), a relatively predator-free sanctuary, and a zone rich in some invertebrates (e.g. Chironomidae larvae) used as food by young fish (Caffrey et al., 2011). Positive impact of *L. major* invasion on some fish species has also been observed in New Zealand (Bickel & Closs, 2008).

To conclude, *Lagarosiphon major* invasion can cause significant shifts in habitat productivity, species composition, and food web dynamics (Kelly & Hawes, 2005).

Figure 18: Perch, *Perca fluviatilis*, spawn deposited on *Lagarosiphon major* in Lough Corrib, Ireland (Source: Caffrey et al. 2010a).

ENVIRONMENTAL IMPACTS

L. major **forms dense mats over the surface, outcompeting other native plant species and causing significant shifts in habitat productivity, invertebrate and fish species composition, and food web dynamics. Functions and services of the invaded habitat are altered. Indeed, dense mats limit water circulation, cut off light and create severe fluctuations in dissolved oxygen level.** ***L. major*** **is also known to increase the water pH (up to a value over 10) and to deplete dissolved inorganic carbon, creating stressful conditions for other aquatic organisms.**

2.2.2 Other impacts

A/ Economic impacts

Describe the expected or observed direct costs of the introduced species on sectorial activities (e.g. damages to crops, forests, livestock, aquaculture, tourism or infrastructures).

Negative impacts:

Large and dense mats of *Lagarosiphon major* may increase flood hazards (decreasing lake discharge), reduce amenity value of the waterbody (decline in local tourism may be observed), and negatively impact various recreational or economic activities such as boat navigation, fishing, angling, diving and swimming (McGregor & Gourlay, 2002; Caffrey, 2009; Caffrey et al. 2010a; Levy et al., 2011; GB Non-Native Species Secretariat, 2011).

In the United Kingdom Risk Assessment Analysis (GB Non-Native Species Secretariat, 2011), the cost of mechanical control is estimated at approximately £1000 (ca. 1200€) per hectare. Assuming that each 10 km² where the species has been recorded contains at least 1 hectare with *L. major*, country-wide control would cost at least £500,000 (ca. 600,000€) each year. Oreska & Aldbridge (2011) estimate this might cost even up to £1,955,000/year (2,400,000€). Moreover, Williams et al. (2011) estimate that *L. major* in the UK may cost £1,365,084/year (ca. 1,644,700€) to the angling industry, £3,000,000/year (ca. 3,614,450€) for the waterway management, and £5,230,000/year (ca. 6,301,200€) to power companies [for this latter cost, the impact of other invasive species are also included] since the plant can block the intakes of hydroelectric systems (GB Non-Native Species Secretariat, 2011). These costs are likely underestimated since *L. major* is often identified as *Elodea densa* or *Elodea crispa* (CAPM, 2004; GB Non-Native Species Secretariat, 2011).

Other intangible or unquantifiable costs include the consequences of dense growth of *Lagarosiphon major* on biodiversity of native water plants and associated aquatic invertebrates.

Positive impacts:

Lagarosiphon major can grow in waters having relatively high concentrations of pesticides (de Carvalho et al., 2007) or heavy metals such as Cadmium (Cd) or Arsenic (As) (Reay, 1972; Chandra & Kulshreshtha, 2004). The plant accumulates these contaminants in its tissues. *L. major* has thus been proposed for phytoremediation actions aiming at the removal of pesticides from contaminated waters for instance (de Carvalho et al., 2007). However, in regard to its ecological and economic impacts, a such use cannot be encouraged.

B/ Social impacts

Describe the expected or observed effects of the introduced species on human health and well-being, recreation activities and aesthetic values.

As explained in the preceding paragraph, large beds of *Lagarosiphon major* can restrict boating and recreational activities such as swimming and angling (McGregor & Gourlay, 2002; Caffrey, 2009; Caffrey et al. 2010a; Levy et al., 2011; GB Non-Native Species Secretariat, 2011).

Human health: In New Zealand, large beds of *L. major* may support more snails which host the waterborne schistosome cercariae larvae that cause "swimmers itch" (Sullivan & Hutchison, 2010). To our knowldege, no other direct or indirect impact of *L. major* on human health is documented.

STAGE 3 : RISK MANAGEMENT

The decision to be made in the risk management process will be based on the information collected during the two preceding stages, e.g. reason for initiating the process, estimation of probability of introduction and evaluation of potential consequences of introduction in Belgium. If the risk is found to be unacceptable, then possible preventive and control actions should be identified to mitigate the impact of the non-native organism and reduce the risk below an acceptable level. Specify the efficiency of potential measures for risk reduction.

3.1 RELATIVE IMPORTANCE OF PATHWAYS FOR INVASIVE SPECIES ENTRY IN BELGIUM

The main current pathway of introductions in the wild of *Lagarosiphon major* in Europe, including Belgium, is the release (accidental or not) of plants or plant fragments from aquariums and ponds. Subsequent dispersion by humans (accidental or not) may also exist (e.g. when plant fragments are hitchhiked by boats or angler equipment from one pond to another). Indeed, although natural dispersal capacity of *L. major* is high, it can hardly alone explain the rapid spreading of the species (as observed in New Zealand or Ireland, for instance) or its appearance in sites highly distant from established populations. Nevertheless, natural colonisation from neighbouring countries (France, Germany and the Netherlands) can soon become regular because populations of the species are now close to the Belgian border and spread rapidly in these territories (especially in the French Nord department). Moreover, the species is still imported and sold in these countries and in Belgium as well. Fortunately, progress has been made and it becomes well known that *L. major*, and other plants as well, may become invasive in Belgium (and in other European countries). As a result, the species progressively disappears from catalogues of aquatic plant nurseries. (For complementary information and references on introduction pathways in Belgium, see § 2.1.3).

3.2 PREVENTIVE ACTIONS

Which preventive measures have been identified to reduce the risk of introduction of the organism? Do they reduce the risk to an acceptable level and are they considered as cost-effective? Specify if the proposed measures have undesirable social or environmental consequences. Consider especially (i) the restrictions on importation and trade and (ii) the use of specific holding conditions and effect of prohibition of organism introduction into the wild.

Lagarosiphon major is still not well established in Belgium. It would be therefore very timely to undertake actions preventing its introduction in the country. These actions are:

- **Action 1: Amend existing legislation.**
  Legislation should be strengthened to ensure a total ban on import and possession of potential invasive plants such as *L. major* and closely related species (i.e. other non-native Hydrocharitaceae, such as *Egeria densa*, *Elodea canadensis*, or *Elodea nuttallii*).

- **Action 2: Highlight, support and promote Invasive Species Codes of Practice.**
  A priority action to prevent the spread and release of invasive species such as *L. major* is to promote wide use and implementation of the Invasive Species Codes of Practice (ISCP; Table below), recently developed in Belgium through the AlterIAS LIFE project (http://www.alterias.be/),

and to support these with literature and information leaflets for both the horticultural sector and the general public.

Table: Invasive Species Codes of Practice for the industry and the general public. Source: http://www.alterias.be/fr/que-pouvons-nous-fairen/les-codes-de-conduite-sur-les-plantes-invasives

ISCP for horticultural professionals	ISCP for the general public
1.Be informed about the Belgian alien species list	1.Be informed about the Belgian alien species list
2.Stop selling and/or planting invasive alien species	2.Avoid buying and planting alien species
3.Spread information about invasive alien species to customers and the general public	3.Choose non-invasive native plants as an alternative to alien species
4. Promote the use of alternative, non-invasive plants	4.Do not dump vegetal residues in nature
5. Take part in early invasive alien species detection actions	5. Share your knowledge and awareness about invasive plants and issues related to their introduction

Indeed, *L. major* is valued as an ornamental plant, therefore educational programs must be directed to educate the public about the dangers this plant poses outside its native range. Teaching water managers how to clean equipment in a way that decreases the chance of transmission is one way to lessen the prevalence of human-mediated transport. Additionally, information should be disseminated regarding responsible propagation and cultivation of this species if it remains to be sold (which is an undesired scenario).

In Belgium, a large information campaign was already promoted by AlterIAS. Such initiatives enhance awareness of the risks caused by invasive species such as *L. major,* facilitate early warning and correct identification and provide valuable measures for careful culture and manipulation, as well as trade reduction, by proposing alternative garden plants (Figure 19) through detailed Invasive Species Codes of Practice, targeting the public at large as well as retailers. As the species is still easily available in Belgium, there is an opportunity for education at various points along the horticultural trade pathway from distributor to introduction. Fortunately, as explained in §2.1.3, several nurseries of aquatic plants have already agreed with the Invasive Species Codes of Practice.

- **Action 3: Public sector bodies adopt Invasive Species Codes of Practice**

All public sector organizations should lead by example and adopt the Invasive Species Codes of Practice in their relevant work areas. This is key to the success of both existing codes (for professionals in horticulture and for general public). Government agencies should also incorporate the philosophy of the codes into tenders and procurement procedures and ensure that suppliers and contractors for public works are abiding the codes.

- **Action 4: Biosecurity measures**

As Caffrey et al. (2011) explain: "The implementation of rigorous and informed biosecurity measures by all water users and stakeholders will be essential if the spread of *L. major* within the country is to be stopped. This will involve the proper disinfection of all angling equipment, boats, trailers, outboard motors and associated equipment after each fishing, shooting or boating trip. It may even be necessary to consider restricting the unauthorised movement of boats from one catchment to another".

To sum up, the main distribution channel or vector is trade of plants for aquariums and garden ponds. 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 species of crossing countries' borders. The second stage is to prevent release of the plant to the freshwater system from isolated locations such as greenhouses, aquariums or garden ponds through accidental or deliberate release. The third stage is prevention of further dispersal through connected waterways and overland via vectors from site of initial introduction.

Figure 19: Extract from a leaflet produced by AlterIAS. Its aim is to encourage both horticultural professionals and amateur gardeners to plant native species rather than invasive ones. Here are presented the plants proposed as alternatives to *Lagarosiphon major* and other invasive aquatic plants. The entire document is available at: http://www.alterias.be/images/stories/downloads/folder_brochures/folder_aquatic_final_fr.pdf.

(i) Prohibition of organism importation, trade and holding

Being sold as an aquarium plant in Europe, and also as an outdoor pond plant, it is likely that, without the introduction of restrictive legislation and enforcement, further spread of *L. major* will occur.

Similar patterns of introduction are noted for other aquatic plants in most countries with an aquatic horticultural trade (http://www.cabi.org/).

Hussner et al. (2010) consider that the increase in species number and abundance of aquatic plants is probably caused by enhanced trading and increased invasibility by water eutrophication / re-oligotrophication and climate change. They made proposal of a trading ban for highly invasive non-indigenous aquatic plants with which we agree. This will not stop their natural spread where they are already established, but should reduce the risk of further unintended entry and thus can be a major control factor.

In Belgium, *Lagarosiphon major* figures on the national black list of invasive species (Branquart et al., 2010). In addition, as explained above, representatives of the horticultural sector approved a code of conduct for invasive plants and most wholesalers voluntarily removed *L. major* from their catalogue.

(ii) Use of specific holding conditions and effect of prohibition of organism introduction into the wild

A large campaign of information with proposed alternatives for limiting invasive species introduction has been promoted by AlterIAS (Figure 19). Such initiatives enhance awareness of the risks caused by invasive species such as *L. major* and provide valuable measures for careful holding/manipulations, reduce trade, accurately identify specimens and propose alternative plants for gardens through detailed Invasive Species Codes of Practice targeting the public at large as well as garden plants retailers. In Belgium, Garden Centres are still selling this plant under the name *L. major*, and possibly also *Elodea densa* or *Elodea crispa* as observed in the UK (CAPM, 2004; GB Non-Native Species Secretariat, 2011) but some centres have been asked to withdraw the species from trade from 2009 onwards by the Belgian Forum on Invasive Alien Species (Branquart, 2008). As *L. major* is not one of the plants with the highest income value (Figure 13), professionals generally rapidly accept to remove the plant from their catalogue, once they have been correctly informed about the potential economic and environmental impacts of this invasive plant (Vanderhoeven et al., 2011; Halford et al., 2011).

3.3 CONTROL AND ERADICATION ACTIONS

Which management measures have been identified to reduce the risk of introduction of the organism? Do they reduce the risk to an acceptable level and are they considered as cost-effective? Specify if the proposed measures have undesirable social or environmental consequences. Consider especially the following questions.

(i) Can the species be easily detected at early stages of invasion (early detection)?

As most submerged aquatic plants, *Lagarosiphon major* is difficult to detect at early stages of invasion. Moreover, *L. major* may spread and disseminate by way of small, but viable, plant fragments. Detection at an early stage of invasion is therefore very unlikely, however due to its extremely high growth rate it is often detected when already well established. Unfortunately, control is then extremely difficult (as for most submerged aquatic plants) (Csurhes and Edwards, 1998).

(ii) Are there some best practices available for organism local eradication?

The side effect of chemicals and even biological control methods can often be as detrimental or even worse for the environment, native species and human health. The precautionary principle should be applied as a general rule.

The removal of aquatic macrophytes from a water body should be done after careful consideration. Under certain environmental conditions, removal of non-native macrophytes can lead to the proliferation of algae and turbid conditions rather than recolonisation by native macrophytes (Perrow et al., 1997; Donabaum et al., 1999). Methods used to attempt the control or the eradication of *Lagarosiphon major* in invaded habitats are described below.

Mechanical methods: As Caffrey et al. (2011) explain: "Mechanical cutting provides a method for rapidly removing obstructive vegetation from a watercourse. The results tend be short term, however, as weed regrowth can again present obstructive stands within weeks of the initial cut (Caffrey, 1993a). Regrowth among *L. major* plants is significantly reduced where the plant is cut at root level." Mechanical removal can be achieved with the use of weed cutting boats or manual removal by scuba divers. The last approach is slow and labour intensive, but it is acknowledged to be an effective long-term strategy for the control or eradication of *L. major* at sites where the plant has recently invaded and/or where the level of vegetative abundance is low (Clayton, 2003). Care should be taken to remove as much cut material as possible because of the problem of vegetative reproduction from fragments (CAPM, 2004; Clayton, 2006; Caffrey et al., 2009b; Levy et al., 2011). To be effective follow-up surveys after 8 weeks and repeated management 3-4 months following initial removal are necessary (Clayton, 2006).

Chemical methods: *Lagarosiphon major* is susceptible to herbicides containing terbutryn (e.g. Clarosan) or dichlobenil (CAPM, 2004; Caffrey et al., 2011). Clarosan will however kill most submerged vegetation. The severe consequent decline in photosynthesis will, in turn, drastically reduce oxygen concentration, and will eventually cause the death of fish and other organisms (CAPM, 2004). To the contrary, dichlobenil is supposed to have minimal adverse impact on water quality, non-target plants, macroinvertebrates or fish (Caffrey, 1993a, 1993b). The herbicide is used to best effect in discrete areas that are inaccessible to boats, such as in the vicinity of small marinas or harbours or to target localised plant stands that regrow following mechanical weed cutting operations (Caffrey et al., 2011). In the UK, the herbicide is applied in March-April (CAPM, 2004). In Irish small ponds, dichlobenil granules were applied at the rate of 200 kg/ha in order to provide effective control of infestations (Caffrey et al., 2009b). Trials using dichlobenil on *L. major* in Lough Corrib and in Shannonhill Lake (both in Ireland) have demonstrated the susceptibility of this plant to the activity of the herbicide and, in suitable habitats, a 100% plant kill has been normally achieved (Caffrey et al., 2011). However, only transient growth effects were observed in trials carried out in New Zealand (Hofstra & Clayton, 2001). These authors also tested the effect of other herbicides, namely diquat, endothall, and triclopyr. They demonstrated that (i) diquat can be ineffective under some environmental conditions, (ii) only transient growth effects can be observed with triclopyr, but (iii) endothall can kill *Lagarosiphon major.* At last, Davies et al. (2003) tested the effect of sulfosulfuron, a selective post-emergence, sulfonylurea herbicide, on *L. major*. Results revealed that *L. major* was poorly sensitive, showing no consistent adverse responses in dry weight data following exposure to concentrations of 0.11–10 mg/litre for periods up to 70 days. Instead, treatment with sulfosulfuron at any concentration stimulated biomass accumulation.

Environmental control: **Increasing water flow** may reduce the growth of *L. major* but may also facilitate its spread (CAPM, 2004).

Excavation to depths of over 4 m will also prevent growth but it is almost impractical (CAPM, 2004) and may dramatically alter the native ecosystem. Clayton (2003) recorded the re-establishment of native vegetation cover following suction dredging and hand removal of *Lagarosiphon major* beds. He found that no recolonisation of indigenous species occurred in the eight months that followed weed cutting in the 50 x 50 m trial plot. The reason for this reduce ability of native plants to recolonize the habitat is unclear but may relate to the fact that the seed reserve in the substrate has been exhausted or that the anoxic conditions present in the mud have impacted the indigenous seed bank (Caffrey & Acevedo, 2007). Moreover, Stiers et al. (2011) have experimentally demonstrated that sediment dredging will not lead to decline of *L. major* in Belgium. In fact, this technique may even boost *L. major* growth rate, perhaps because a more mineral soil may facilitate the plant anchoring and hence lead to a more successful growth.

To **drain out** the invaded habitat can be an effective option (Levy et al., 2011) but it is again almost impractical for large water bodies and may impact other organisms.

The **exclusion of incident light** from submerged vegetation will inhibit photosynthesis and result in the death of targeted plants. **Increasing shade**, by planting trees around invaded ponds for instance, will prevent *L. major* growth and may thus control (rather than eradicate) the population. However this approach is difficult to apply for large water bodies (CAPM, 2004). **Installing black plastic** at the bottom of the water body to exclude light from *L. major* is difficult (e.g. it is necessary to secure the material to the pond or lake bed) and only a modest level of plant control is generally achieved (Caffrey et al., 2011). After trials in Lough Corrib (Ireland), it was considered that the method would prove too onerous and costly to implement in the longer term (Caffrey et al., 2011). In addition, the ballooning of the plastic towards the water surface as the weed decayed beneath presented a hazard to anglers and boaters.

In contrast, light-exclusion **thanks to biodegradable material** made of natural fibre (jute) is a promising method, recently implemented in Lough Corrib (Caffrey et al., 2010b, 2011; Figure 20). At all seven test sites the *L. major* beneath the matting was killed, even where the matting was in place for only four months (Caffrey et al., 2010b, 2011). At each site where seven or more months had elapsed from the time the jute matting was put in place, native macrophyte species grew through the weave of the material. Percentage cover with charophyte species varied between 37% and 85% at these sites within seven months of jute placement (Caffrey et al., 2010b). A number of indigenous or naturalised angiosperm species were also recorded growing through the weave of the jute matting. These included *Myriophyllum alterniflorum*, *M. spicatum* and *Elodea canadensis*.

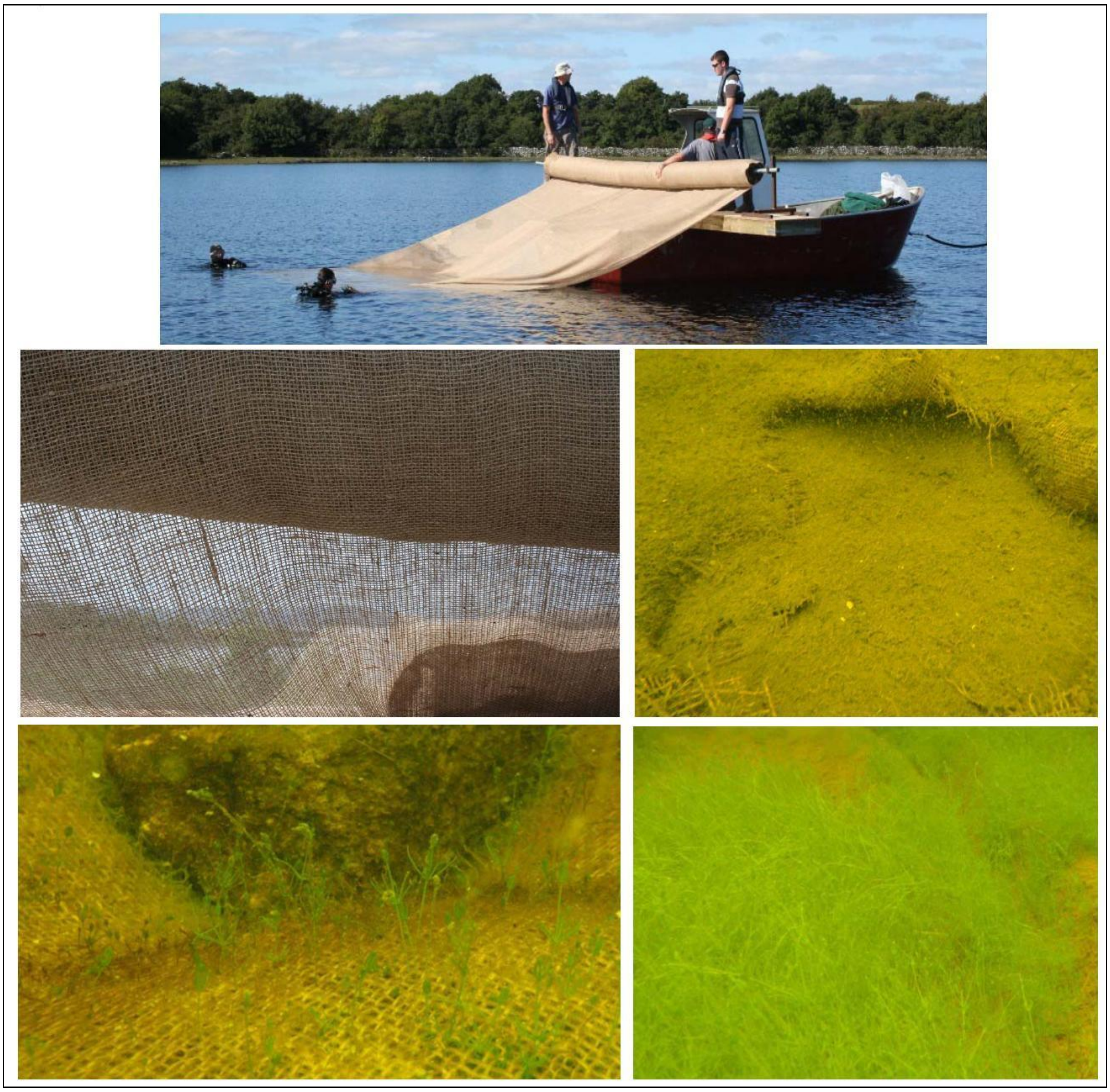

Figure 20: Light-exclusion control of *Lagarosiphon major* using jute matting. (Top) Rolls of jute matting (100 x 5 m; cost: 150 Euro for 100 m²) are deposited during a calm weather day at the waterbody bottom from a modified boat and with the help of experienced divers. (Middle left) Jute is a highly durable, natural and biodegradable fibre, which is easy to use since it is rapidly saturated by water and sinks. (Middle right) Jute remains intact during at least one year (under environmental conditions occurring at Lough Corrib, Ireland), and disintegrates on contact at 17 months. *Lagarosiphon major* dies and decays within 4 months and aerobic conditions are maintained beneath jute matting.

(Bottom left) Charophytes are able to grew through the jute weave in less than 6 months. (Bottom right) Dense and species-rich meadows establish within 10 months. *Lagarosiphon major* was never observed growing through the jute matting. (Modified from Caffrey et al., 2010b).

Biological control: As explained in §2.1.4.E, no control agents are currently known in *L. major* introduced range. However, a survey for natural enemies in its native range indicated that several phytophagous species feed on the plant (Baars et al., 2010; Mangan & Baars, 2013). At least three show notable promise as candidate agents for biocontrol. Amongst these, a leaf-mining fly, *Hydrellia lagarosiphon* (Diptera: Ephydridae) that occurred over a wide distribution causes significant leaf damage (Figure 21) despite high levels of parasitism by braconid wasps. The potential of *H. lagarosiphon* to become a biocontrol agent in Europe is currently under study. Its host specificity, life history, and ecological needs are particularly under investigation in order to avoid the release of an additional invasive species! Recently, it has been shown that the species can tolerate climatic conditions found in Europe and could therefore establish viable populations, except perhaps at higher latitudes due to colder temperatures (Mangan & Baars, 2013).

Along with *H. lagarosiphon*, another yet unidentified fly was recorded mining the stem of *L. major,* and two leaf feeding and shoot boring weevils, cf. *Bagous* sp. (Coleoptera: Curculionidae) were recorded damaging the shoot tips and stunting the growth of the stem (Figure 22). Several leaf feeding lepidopteran species (Lepidoptera: Nymphulinae) were also frequently recorded, but are expected to feed on a wide range of plant species and are not considered for importation before other candidates are assessed (McGregor & Gourlay, 2002; Caffrey et al., 2009a; Baars et al., 2010; Mangan & Baars, 2013).

In addition, the nematode *Aphelenchoides fragariae* has also been recorded attacking the apical tips of *L. major* causing shoot dwarfing (McGregor & Gourlay,2002), but the possibility to use it as biocontrol agent was apparently not assessed.

At last, the possibility of the use of the Grass Carp (*Ctenopharyngodon idella*), a fish native from Asia and invasive in numerous parts of the world, as biological control agent of *L. major* in New Zealand has been suggested (Chapman & Coffey, 1971). Trials showed that the fish would indeed eat the problematic plant. Nevertheless, this option cannot be recommended because of the negative impact that the fish may have on native ecosystems (ISSG, 2005).

Figure 21: *Hydrellia lagarosiphon* (Diptera: Ephydridae) as potential biocontrol agent of *Lagarosiphon major*. (a) Typical damage induced by the leaf-mining fly on the plant. (b) Fly larva feeding within the leaf tissue. (c) Fly larva pupating within the leaf. (d) Eggs laid on emergent material. (e) Adult fly. (Source: Baars et al., 2010).

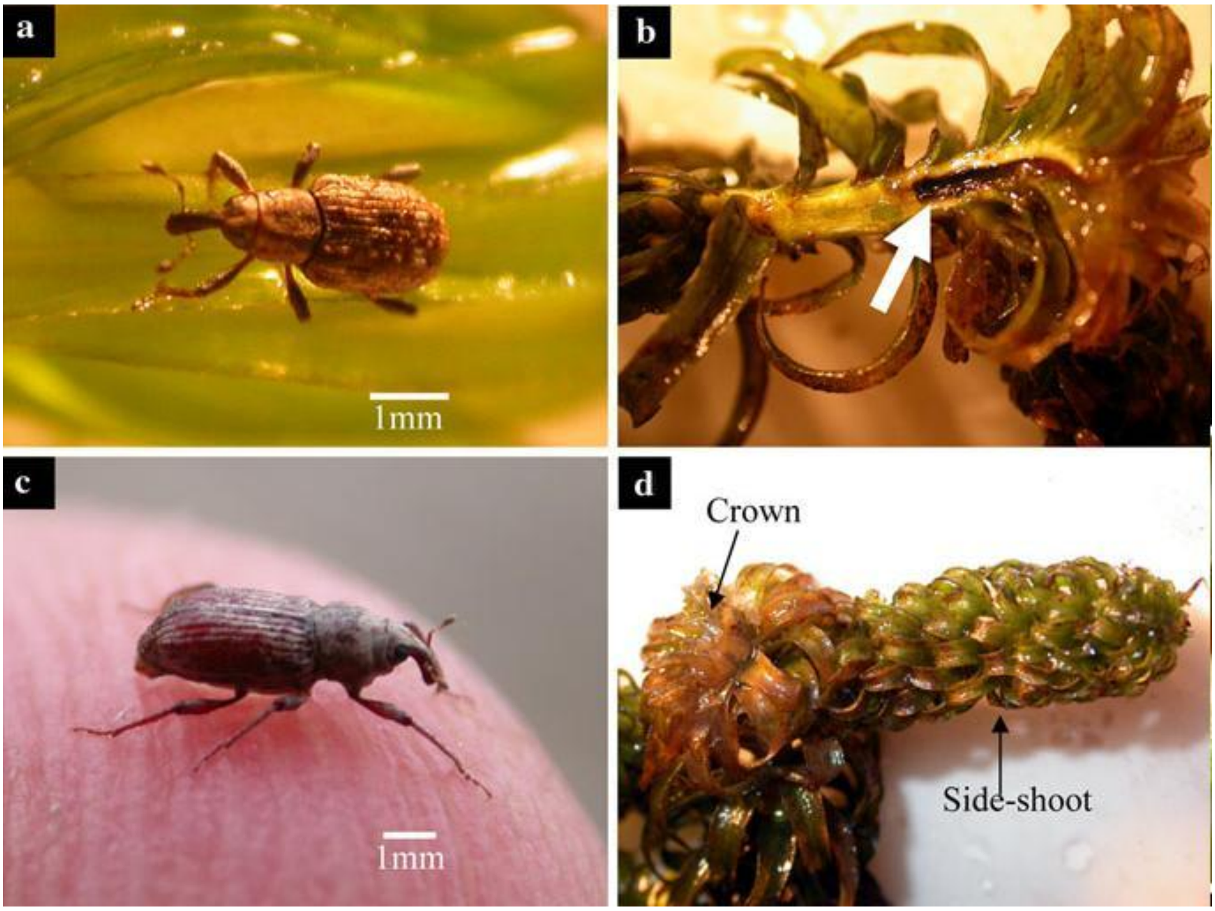

Figure 22: *Bagous* weevils as potential biocontrol agent of *Lagarosiphon major*. (a) Crown and stem mining weevils collected on *L. major* in South Africa. Smaller of the two adult weevils, cf. *Bagous* sp. A. (b) Crown damage probably due to larval feeding. (c) Larger of the two adult weevils, cf. *Bagous* sp. B. (d) Sideshoot stimulated by crown damage on the main stem. (Source: Baars et al., 2010).

(iii) Do eradication and control actions cause undesirable consequences on non-target species and on ecosystem services ?

Yes, they do! Every eradication and control actions can have undesirable consequences on non-target species and on ecosystem functions and services. These impacts are already detailed for each method in the preceding point. Most adverse approaches are chemicals and dredging.

Moreover, as already stated, the removal of aquatic macrophytes from a water body should only be done after careful consideration. Under certain environmental conditions, removal of non-native macrophytes can lead to the proliferation of algae and turbid conditions rather than recolonisation by native macrophytes (Perrow et al., 1997; Donabaum et al., 1999).

It is also important that future management plans include the complexity of interactions between invasive species and the entire native community, as well as interactions among invasive species to avoid, for instance, the explosive growth of another invasive plant species after the eradication of *L. major*. For instance, in Lough Corrib (Ireland), *Elodea canadensis* was observed to be favoured by the eradication of *L. major* (Caffrey et al., 2010b, 2011).

(iv) Could the species be effectively eradicated at early stage of invasion?

Eradication of the species is possible at small spatial scale and at very early stage of invasion (Caffrey et al., 2009b, 2011). For instance, the eradication of *L. major* in Shannonhill Lake (Ireland), an artificial lake of 0.4 ha, was obtained using the broad-spectrum herbicide, dichlobenil at the rate of 200 kg/ha to the whole lake area (no fish or native plant species that required protection were present; Caffrey et al., 2009b). Prior to applying the granular herbicide, a large fraction of the dense canopy vegetation was removed using a long-reach excavator. The excavated plant was retained on site. It was covered with black polythene and sealed with earth. A vegetation survey conducted in March 2008 revealed that the lake contained 64.4 tonnes of *Lagarosiphon major*. This occupied the full water column and created a dense canopy on the water surface. In August 2008, practically all of the species was dying or dead. Very little green tissue remained. A subsequent survey in January 2009 could not detect any live *Lagarosiphon major* plant. Even the roots were in the process of rotting (Caffrey et al., 2009b). This result demonstrates that herbicidal products have the capacity to provide effective control of *L. major* infestations, at least under certain environmental (climatic, physical and biological) conditions and in small water bodies.

In larger lakes, the use of jute matting (Figure 20) is a recent and promising method, which apparently provides the eradication of *L. major* even in places where the plant was well-established (Caffrey et al., 2010b, 2011).

Mechanical control may also allow water managers to obtain good results, when cutting is repeated along the season and when care has been taken to avoid dispersion of plant fragments (CAPM, 2004; Clayton, 2006; Caffrey et al., 2009b, 2011; Levy et al., 2011).

(v) If widely widespread, can the species be easily contained in a given area or limited under an acceptable population level?

The connectivity of freshwater habitats makes containment very difficult. Moreover, dispersion capacity of *L. major* is high. The plant may vegetatively disperse either through natural means (water flood and current, and perhaps also transport by birds and mammals) or through human-assisted movements (accidental or not).

RISK MANAGEMENT

The main current pathway of introductions of *Lagarosiphon major* in Belgium remains its sale as an ornamental plant for aquariums and ponds, and its subsequent release in the wild. This pathway is however decreasing thanks to education actions carried out in the country (e.g. in the framework of the AlterIAS LIFE project). Once established, vegetative dispersion occurs (mainly human-assisted). Future invasions within the country, but also from French, Dutch or German populations, are very likely.

A unified, strengthened legislation should be established <u>in Europe</u> to ensure a total ban on import, trade and holding of *Lagarosiphon major* and other (potentially) invasive aquatic plants. Fortunately, for *L. major*, populations are still at an early invasion stage in Belgium and populations

are restricted to small isolated areas. As a result, prohibition of importation, trade and holding in Belgium could effectively prevent its entry, establishment and spread.

Lagarosiphon major **is difficult to detect at early stages of invasion, and therefore control or eradication actions often start when the plant is already well-established.**

Since chemical weed control in an aquatic environment is extremely restricted in Belgium and its different regions and because the results should be of practical use, the practical control options should focus on prevention and non-chemical methods (mechanical removal or light-exclusion via jute matting for *L. major*). It is also important to note that dredging cannot be advise for control or eradication actions of *L. major.*

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