EUPHRESCO DeCLAIM Final report

A State-of-the-art June 2011

Ludwigia grandiflora (Michx.) Greuter & Burdet

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

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

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

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

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

The overall project was a joint effort between four partners.

Plant Protection Service

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1. Executive Summary

- **Range:** In its native range, Water Primrose (*Ludwigia grandiflora*) in South America is reported in wetlands in the transition zone-between aquatic and terrestrial environments. In North America, the species has been introduced and is spread across various States, but there are few occurrences reported. In the UK it has been noted as a pest species since the middle of the 1990s (Newman *et al*., 2000). In 2010 there were 13 sites under management (Renals, 2010), but there are likely to be many more occurrences due to extensive planting in garden and ornamental ponds which are classed as unreported. In The Netherlands it is reported throughout the country except in the Waddenzee Islands. The number of sites remains relatively low, and local abundance varies (Luijten & Odé, 2007). The first report of invasive behaviour was in 2000. *L. grandiflora* is widespread in France as well as in Belgium, Germany, Ireland, Italy, the Netherlands, Spain and the UK where invasion is at an early stage.

- **Growth characteristics:** *L. grandiflora* has a highly variable morphology depending on abiotic conditions (Lambert *et al*., 2009), especially the leaf shape and stem size. Three morphological forms are distinguished according to ecological conditions, a prostrate small leaved form; an actively growing creeping form in the first step of development or in static or slow flowing waters and; an erect form at later stages, in favourable ecological conditions, usually in shallow waters. Furthermore it forms two kinds of roots: those for substrate anchorage and nutrient absorption; and adventitious roots, which occur at the stem nodes and can absorb atmospheric oxygen. The adventitious roots allow the plant to tolerate anaerobic sediment conditions.

- **Areas at risk:** We can consider all shallow slow flowing and still waters in the Netherlands to be potentially at risk. For the UK we have indicated a temperature related altitudinal maximum for areas to be at risk, based on current observations plus 100m to account for possible unreported sites. The risk of the northern isles remains to be determined, but it is unlikely to survive conditions in the mainland east coast of Scotland and the northern and western isles.

- **Reproductive strategy:** In the introduced range in Europe, *L. grandiflora* probably relies mainly on vegetative propagation. It overwinters as standing visibly dead vegetation and the main mode of spread is by fragmentation during autumn and winter. Nodal material probably survives longer at colder temperatures and provides numerous viable propagules. Buoyant fragments can be carried over long distances. One single stem node can produce a new plant. Plants may die back considerably as a result of frost but regrow from basal parts.

  The importance of seed production to the overall reproductive strategy of *L. grandiflora* in Northern Europe has not been investigated. However, Ruaux *et al.* (2009) compared various characteristics of seeds of both *L. peploides* and *L. grandiflora* from nine populations. They found that seeds of *L. grandiflora* were buoyant for approximately 12 weeks; that seed populations were approximately 47% viable and that temperatures of 4°C did not affect % seed viability. Freezing of seeds under water reduced viability by about 50%, resulting in a total potential viability of about 25% of all seeds produced under northern |European conditions (freezing temperatures in winter). Dandelot (2004) estimated that seed production in by *L. grandiflora* in western France was approximately 10,000 m^{-2}, giving a potential viable seed number production of close to 2,500 m^{-2} The study thus suggests that sexual reproduction is an important additional mechanism for winter survival and spread of *L. grandiflora*, and given the long buoyancy period, especially over long distances.

- **CHARISMA:** The CHARISMA model is an individual-based and spatially explicit model in which individual plants and overwintering structures are positioned on grid cells (figure 5). This allows modelling spatial ecological processes such as seed or tuber dispersal. CHARISMA allows also to model 3D competition for light and nutrients between two or more aquatic plant species. CHARISMA was run twice to simulate the growth with and without competition from other macrophytes. Model parameters were derived from literature or estimated. In simulations without competition, *L. grandiflora* grows to densities up to 700g m^{-2}. This value is very close to 652g m^{-2}, the averaged biomass (dry weight) measured in the field of *L. peploides* collected from California (Rejmánková 1992). Simulations of the growth of *L. grandiflora* with two competing species, *Chara aspera* and *Potamogeton pectinatus* over a 10 year period. *L. grandiflora* outcompeted the other species and dominated the macrophyte community. This tends to suggest that if left unmanaged, *L. grandiflora* will dominate the macrophyte community after only a few years.

- **Management:** Effective management of this species for eradication is relatively difficult. Mechanical removal tends to create viable fragments which can spread to new areas or recolonise existing managed sites. Even complete removal does not often eradicate the species because of the high propagule pressure created by large numbers of viable overwintering seeds. Chemical control using aquatic approved formulations of glyphosate and the adjuvant TopFilm™ at a rate of 800 mL ha^{-1} were more successful than glyphosate formulations alone (Defra, 2007). 2,4-D amine carries a label recommendation for treatment of *Ludwigia peploides*, but while successful in the USA, no studies have been carried out in Europe using this herbicide. Retreatment and continuous monitoring is recommended for successful management of *Ludwigia* species.

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

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

2. Habitat requirements and areas at risk

2.1. Objectives

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

2.2. Literature Analysis of Growth conditions

In its native range, *Ludwigia grandiflora* is reported growing in wetlands (Rolon *et al*., 2008) and in the transition zone-between aquatic and terrestrial environments (Hernandez & Rangel, 2009). In the introduced range It colonizes static or slow-flowing waters: rivers, shallow ponds and lakes, canals, oxbow lakes, wet margins of ponds and lakes, wetlands, ditch networks. It is also found on sediment bars on river borders and in wet meadows (Laugareil, 2002 ; Zotos *et al*., 2006).

L. grandiflora is tolerant of a wide range of conditions in terms of nutrient levels, types of substrate (gravel banks or sediments), pH and water quality (Matrat *et al*., 2004). It prefers full light but can tolerate shade (biomass production is reduced under shade); it is limited by flow velocity (greater than 0.25 m/s) (Dandelot, 2004), by salinity (up to 6g/L). *Ludwigia* spp. become dominant in nutrient -rich conditions (Rejamánková, 1992). There are few data on temperature ranges.

Water quality

In France conditions may greatly vary depending on the habitat and the infestation:
pH: 5.5 -9.5 (pH values in winter, without the influence of photosynthesis process) (Charbonnier, 1999; Pelotte, 2003). Conductivity between 100 (Charbonnier, 1999; Pelotte, 2003) and 700 µS.cm-1 (Dandelot, 2004) (see salinity experiments below). Orthophosphates: 0.01-1.065 mg/L (Charbonnier, 1999; Pelotte, 2003; Dandelot, 2004). Nitrates are not limiting as the species may grow in water with concentrations from 0.01 mg/L. Total phosphorous: 0.02 – 5.0 mg/L (Charbonnier, 1999; Pelotte, 2003)

Sediments

The species is not very selective with respect to sediment as the species has been observed to grow successfully in mud, sand, gravel, clay, and peat. In France, biomass production was positively correlated with concentration of soil organic matter and nitrogen (Charbonnier, 1999). Nevertheless, there does not appear to be a lower limiting nutrient concentration

(Hussner, 2009). Organic matter at 0.2 - 20 % of dry weight. Kjeldahl nitrogen at 300 - 12500 mg/kg of dry weight, total phosphorous at 200 – 2000 mg/kg of dry weight. (Charbonnier (1999), Pelotte (2003) were all found to be suitable for growth.

Physical characteristics of waterbodies

Ludwigia colonizes lake shores up to 0.8 m above the mean water surface and up to 3 m deep waters (Dutartre, 1986 ; Lambert *et al*., 2009). Optimal conditions for growth in France are however between – 0.7 m and + 0.3 m (Dutartre *et al*., 2009).

Water flow velocity

Growth measurements in different sites colonized by *Ludwigia* showed that maximum values of biomass production are obtained in slow flowing rivers or in static waterbodies (Dandelot, 2004). For a moderate water flow (30 to 40 cm/s), the biomass production was observed to be reduced by up to 85% in a river in the South-West of France (Charbonnier, 1999; Pelotte, 2003). Static or slow-flowing waters are the optimal habitats.

Salinity experiments

L. grandiflora is not usually found in brackish waters, but under controlled conditions, biomass production was greatly reduced at 6g/L of NaCl

Table 1. Environmental variables favourable to *Ludwigia grandiflora*

Environmental variables	**values**	**reference**
Mean depth	-0.7-+0.3m	Dutartre *et al*., 2009
Maximum depth	3m	Dutartre, 1986 ; Lambert *et al*., 2009
pH	5.5 -9.5	Charbonnier, 1999; Pelotte, 2003
substrate	variable	Charbonnier, 1999
Water velocity	< 0.25 m/s	Dandelot, 2004
Nutrient availability	variable	Matrat *et al*., 2004

2.3. Areas at Risk

Databases in the UK and NL could not provide the detailed information we had hoped for. Previous studies in France and the wide distribution in the Netherlands already revealed the wide tolerance of *L. grandiflora* for abiotic factors. Therefore we can consider all shallow slow flowing and still waters in the Netherlands to be potentially at risk. For the UK we have indicated a temperature related altitudinal maximum to be at risk. The presence in the east coast of Scotland and in the northern and western isles indicated by the UK distribution map may be ambitious. It is likely that winter conditions would not favour survival of this species beyond one year. The lack of suitable propagule material may also hinder establishment.

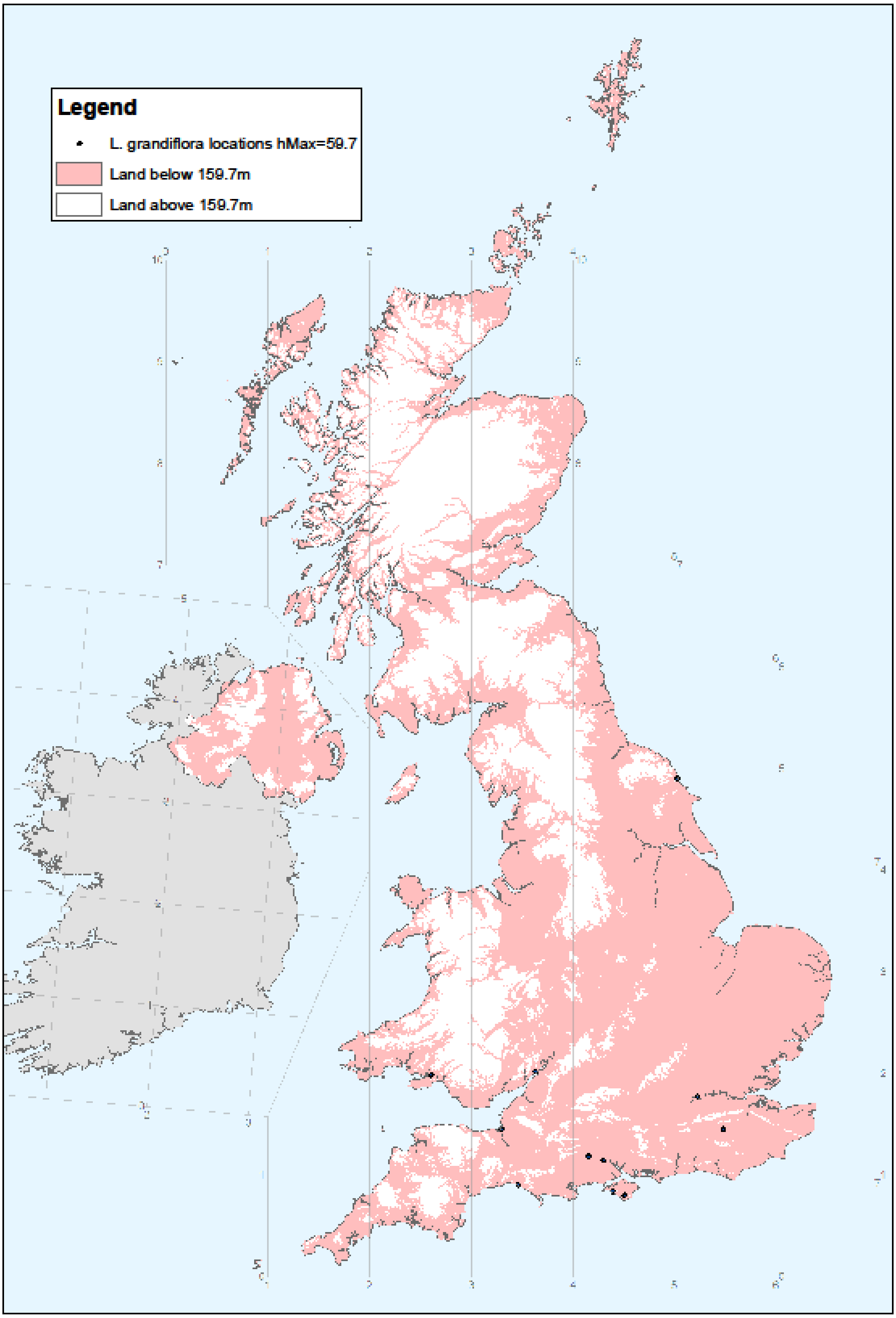


Figure 1. Potential distribution of *Ludwigia grandiflora* in the UK and actual distribution shown by black circles in 2009.

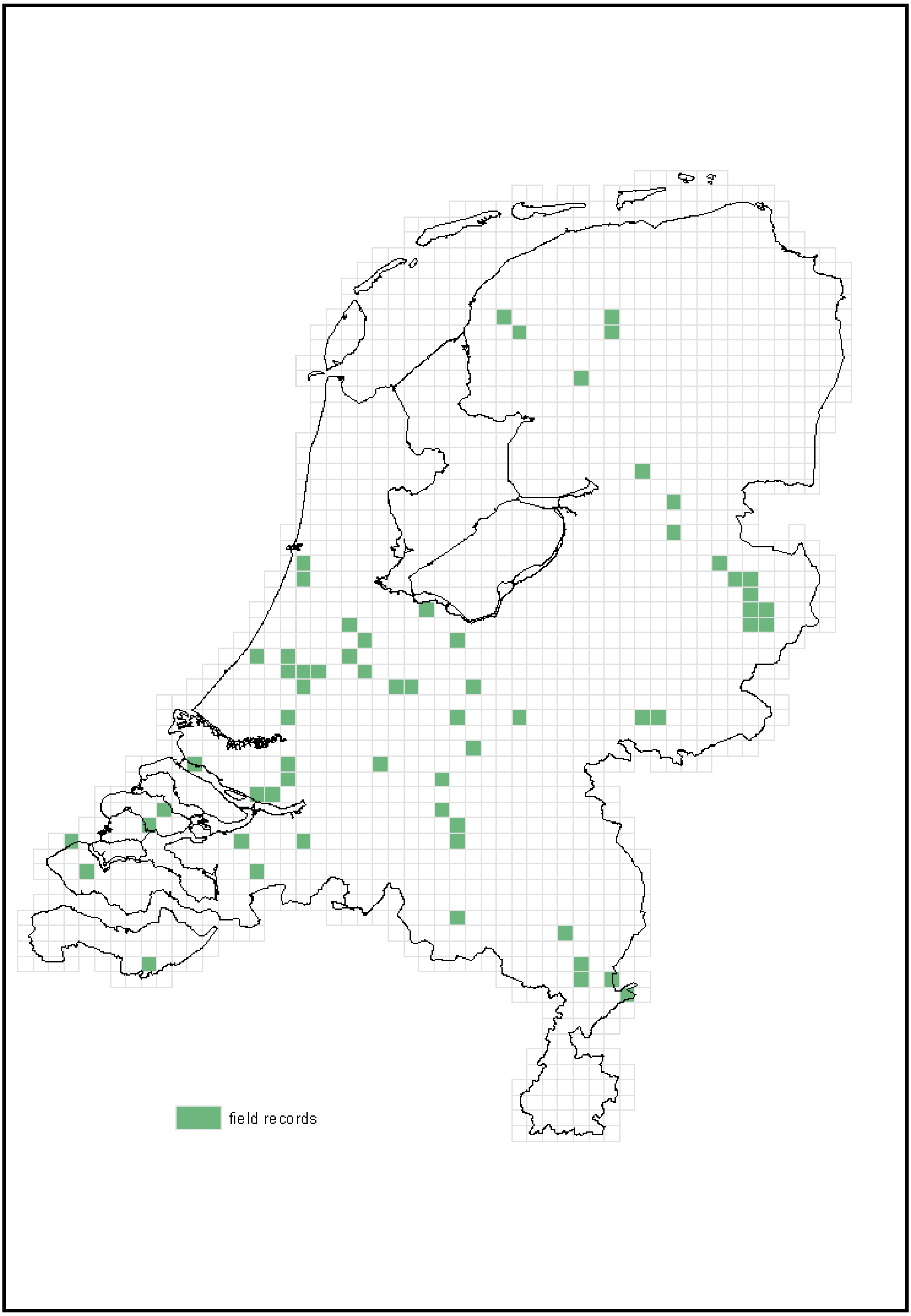


Figure 2. Distribution of *Ludwigia grandiflora* in The Netherlands.

3. Ecology and Growth Modelling using CHARISMA

3.1. Objectives

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

3.2. Life Cycle

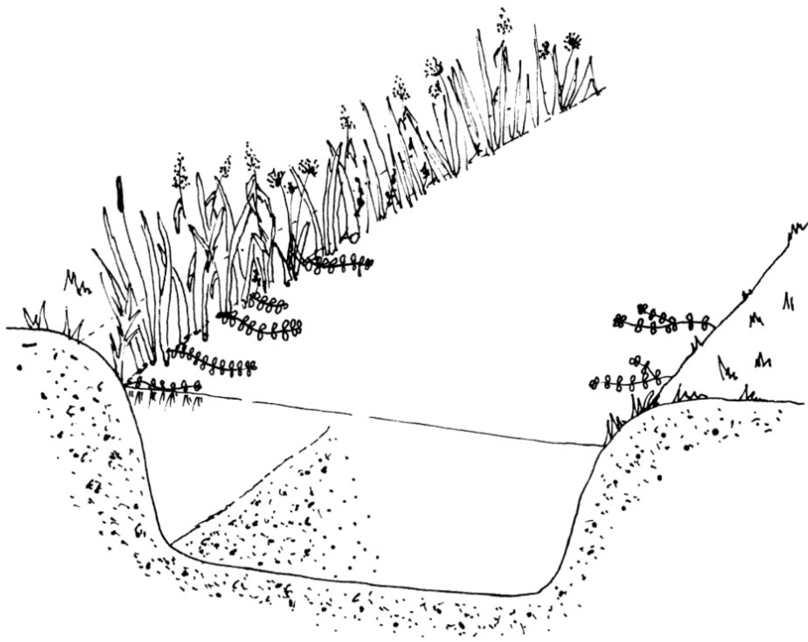
The species reproduces essentially by extensive vegetative reproduction, and easily regrows from any fragments (Dandelot, 2004). Those fragments are buoyant and float away from parent plants. *L. grandiflora* forms new shoots from single nodes (with or without leaves) or single leaves (Hussner, 2009). Biomass production can be very rapid, with standing crop values normally reaching 2 kg of dry matter per square meter (Dutartre, 2004), but in ponds in South-West France, the maximum recorded dry matter reached 3.5 kg per square meter (Pelotte, 2003), although an absolute maximum of 7 kg of dry mater per square meter has been recorded in South-East of France (Dandelot, 2004). This large biomass produces a very large propagule pressure.

L. grandiflora is an out-crossing plant, pollinated by insects, with seed germination requiring cold stratification. In populations that produced many fruits, Dandelot (2004) estimated that *L. grandiflora* has a high potential seed output with around 10,000 seeds per m^2., germination rates vary greatly between various regions in France between 10 and 90% (Ruaux, 2008; Ruaux *et al*. 2009: Dutartre *et al*., 2007).

The adventitious roots are capable of absorbing atmospheric oxygen, allowing the plant to tolerate anaerobic sediment conditions (Rejmankova, 1992).

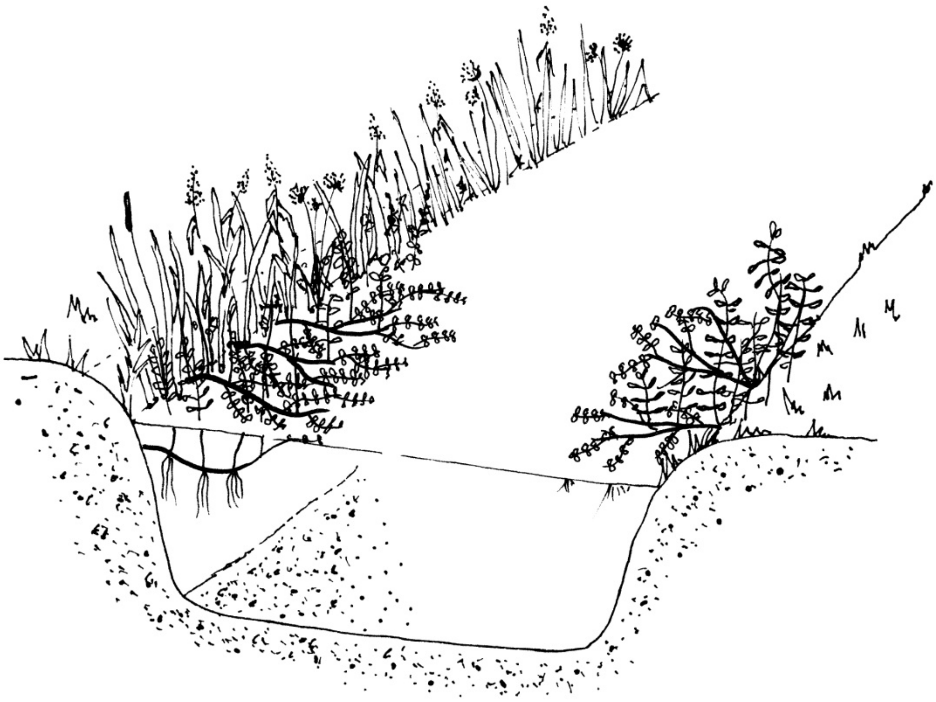
3.2.1. Life cycle diagrams

The following diagrams illustrate the growth form through the seasons



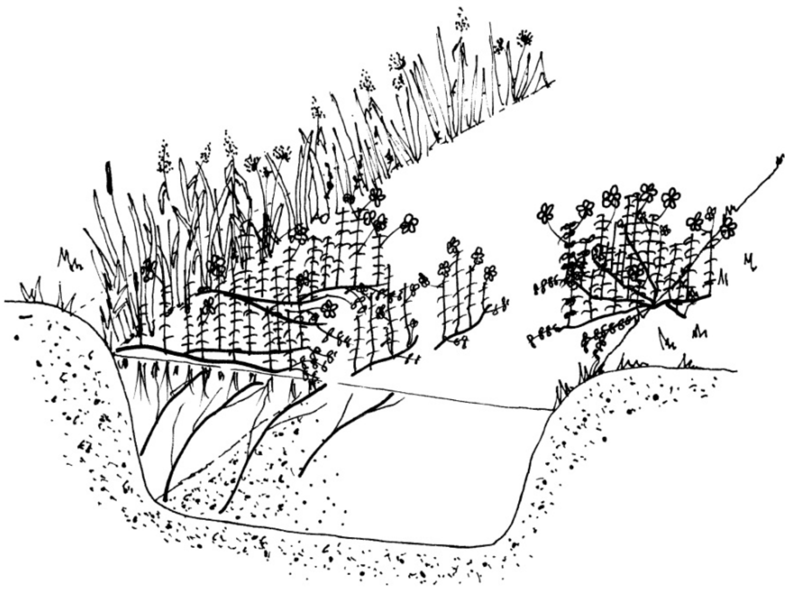
Ludwigia in Spring

In spring, single stems grow from overwintering shoots. Leaves are usually flat on the water surface and obovate in shape. Small rosettes form at the stem apices. Some new growth may form from underwater root material in stable flooded conditions.



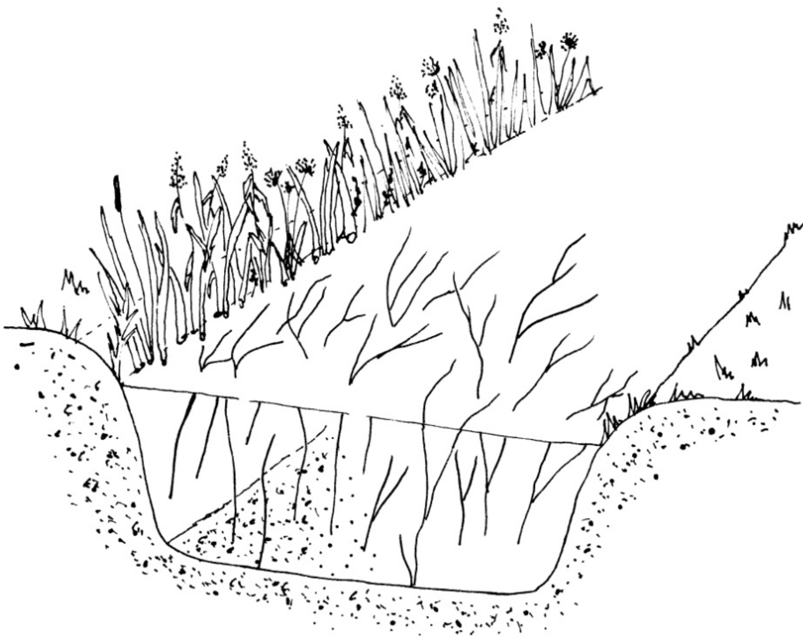
Ludwigia in Early Summer

In early summer, the plant is usually well established and emergent stems start to grow form prostrate creeping stems. They carry the flowers and some occasional flower bud formation may be observed. The stems usually have many branches by now, with creeping prostrate leaves at the edge of the mat, and emergent stems growing from further back for the stem tips. This growth form occurs on terrestrial and in aquatic situations



Ludwigia in Summer

The majority of creeping stems will have emergent erect stems and characteristic large yellow flowers with 5 or 6 petals will be visible.



Ludwigia in Winter

After flowering from early autumn onwards, leaves on emersed stems drop off after the first night frost the plant leaving mostly bare woody stems which remain standing over winter. This is useful for identifying areas for mechanical removal in winter.

3.3. CHARISMA Model Development

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

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

We used the literature review to parameterize the CHARISMA model. The model has been optimised for *Potamogeton pectinatus, P. perfoliatus* and *Chara aspera* (Van Nes *et al*. 2002, 2003; Coops *et al*. 2002) These parameter sets will be used as a general basis for species responses to environmental conditions. In discussion with partners we obtained data and achieved a preliminary parameterization of the model. For *Ludwigia*, that has a different growth form similar to *Hydrocotyle*, the aim will be to come to an appropriate design of the model.

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

3.3.1. The CHARISMA model

The CHARISMA model is an individual-based and spatially explicit model in which individual plants and overwintering structures are positioned on grid cells (figure 5). This allows modelling spatial ecological processes such as seed or tuber dispersal. CHARISMA allows to modelling of 3D competition for light and nutrients between two or more aquatic plant species.

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

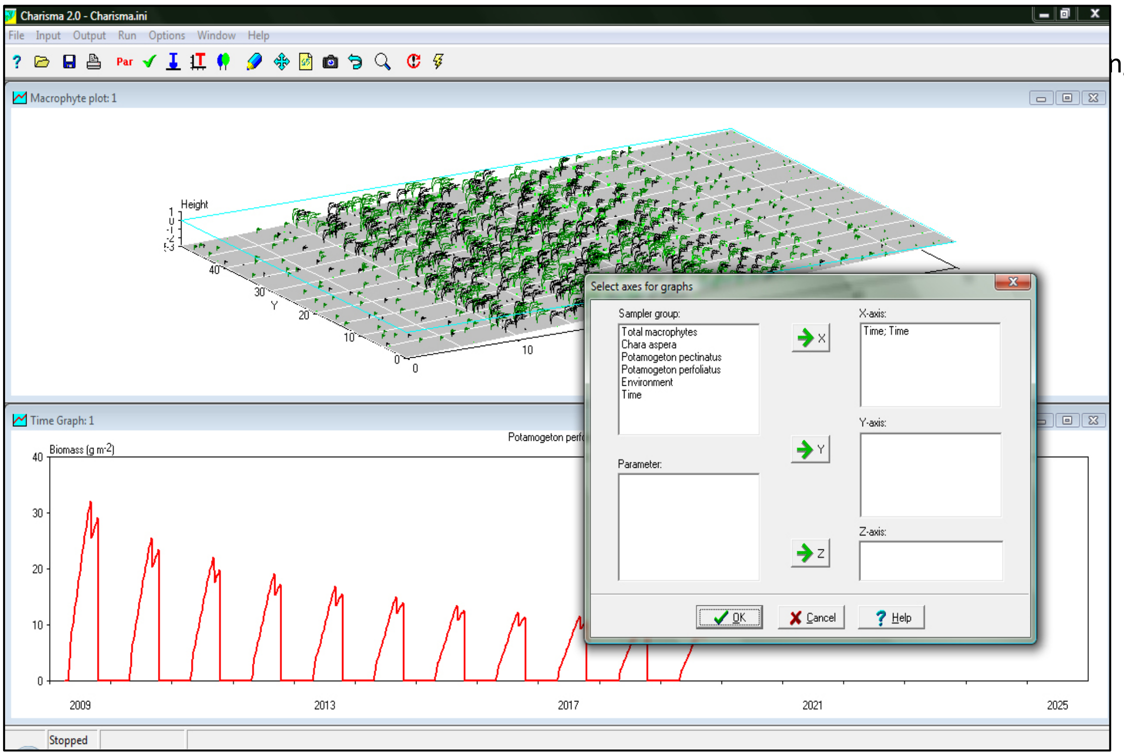


Figure 3. The CHARISMA model.

3.3.1.1. Growth form

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

3.3.1.2. Growth rate and mortality

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

3.3.1.3. Environmental variables

The CHARISMA model allows you to modify a wide array of environmental variables such as light levels, temperature, turbidity, bicarbonate concentrations in the water and water levels (figure 3).Model parameters, including comments on significant gaps. An exhaustive list of all the parameters that can be adjusted In CHARISMA is presented in the annex 1.

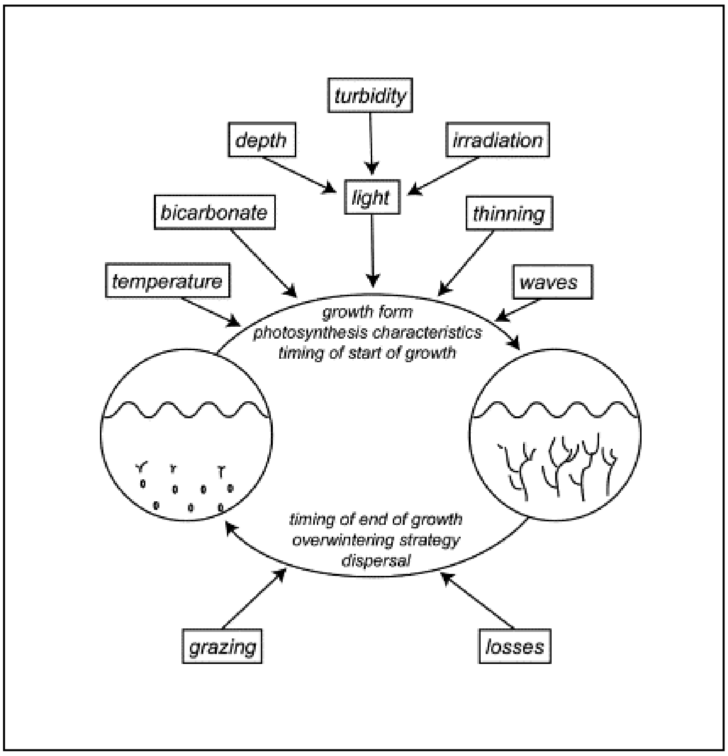


Figure 4. Seasonal cycle and environmental variables in the CHARISMA model

3.3.2. Summary of available data for CHARISMA variable

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

The P_{Max}, the maximal gross photosynthetic rate at the plant top at 20°C in the absence of light limitation, has been adjusted for *L. grandiflora* to 0.055/h, based on measurements of 2,200 µmol of $CO_2h^{-1}g^{-1}$dry weight (Hussner 2009). The light compensation point (hPhotoLight) was fixed at the default value (52 µE/m^2/s), as well as the plant K (0.02 m^2/g). The respiration rate was fixed at 0.0025/day (calibrated).

The average root/shoot ratio, 0.756, has been determined from Hussner (2009), although this is limited to one morphology predominating on mud and in very shallow water.

L. grandiflora can produce viable seeds. The seed biomass was estimated from the length of 1.6 mm (Ruaux *et al*. 2009). The seed width was estimated from a picture (digital seed atlas of the Netherlands) to be approximately half the length, 0.8 mm. The estimated biomass is equal to 0.00168g. The fraction of biomass allocated to seeds has been calculated from the following information. The number of seeds produced is estimated to be approximately 10,000 seeds m^{-2} (Dandelot *et al*. 2005); 47% of seeds are viable (Ruaux *et al.* 2009) which will be the SeedGermination parameter in CHARISMA. Seed production (10000 x 0.00168 =16.8g) represents 0.84% of 2 kg m^{-2} (dry weight) maximal biomass observed for *L. peploides* (Rejmánková 1992).

The flowering and fruiting period has been fixed to between June 15th – October 31st (Dandelot *et al.* 2005) which is entered in the model as Age 75 for SeedsStartAge, the beginning of seed production. Age 75 represents June 15th since the plants of L. grandiflora start to grow on April 1st.

The seed production ends on October 31st, 4.5 months later, when the plants are at age 210 (SeedEndAge).

From calculations for *Hydrocotyle ranunculoides*, we fixed at 0.18g the average weight of segments of one node (including leaf-petiole-shoot-root weight). In CHARISMA, regeneration fragments (any vegetative wintering structure) will be considered as a tuber. Thus 0.18g will be considered the average TuberBiomass in the model. 0.18g will also be considered as the ''frond weight'' (WeightFond) as *L. grandiflora* is modeled as a floating plant in CHARISMA, which was based on Lemna species (default floating species). This may be a significant source of error as *L. grandiflora* is a woody species.

The fraction of biomass allocated to tuber has been fixed at 90% (TuberFraction).This percentage has been estimated from the % of biomass allocated only to root and shoot (NOT to leaves) from Dutartre *et al*. 2004. This represents conditions where in the winter, most of the leaves died after the first night frosts.

The germination day of the overwintering fragments (TuberGerminationDay) has been fixed to April 1st, while the seeds germinate two weeks later on April 15th (SeedGerminationDay). As described for *Hydrocotyle ranunculoides*, this germination delay is to represent the advantage that overwintering structures have on seeds: an earlier germination because overwintering structures are already photosynthetic structures. One hundred percent of the biomass of the overwintering fragments (cTuber=1) turns into photosynthetic shoots on April 1st, the germination day – the fragments are not storing any resources as opposed to tubers which release only a proportion of their biomass everyday for the production of shoots. Because the overwintering structures of *L. grandiflora* are fragments of stems, we decided to set the age of the plant when it starts to make overwintering structures on October 1st (at age 180 days). The end of the production of fragments, October 31st (at age 210 days), is also the end of the growing season (reproDay) which represents the day when seeds and tubers are dispersed.

We also decided for the duration of the simulations not to have any import of new seeds (seed import=0) nor fragments (tuber import=0).

Table 2. Values of the parameters adjusted for modelling the growth of *Ludwigia grandiflora.*

Parameter	**value**	**remarks**
PMax	0.055/h	
hPhotoLight	52 microE/m2/s	default
half saturation light intensity (PAR)		
PlantK	0.02 m2/g	default
Resp20	0.01375 /day	calibrated
ReproDay	Day#304	#day of dispersal (seeds and tubers): October 31st
SeedGerminationDay	Day#105	April 14th
Seed Germination	0.47	
Seed Mortality	1	
Seed fraction	0.0084	
Seed Biomass	0.00168 g	
SeedsStartAge	75	
SeedsEndAge	210	
SeedImport	0	
tuberfraction	0.90	
TuberGerminationDay	Day#92	April 1st
Tuberbiomass	0.18g	weight of one fragment
TuberImport	0	
cTuber	1	
TuberStartAge	180	
TuberEndAge	210	
maxWeightLen ratio	n	
RootShootRatio	0.756	

MaxLenght	N
Weight Fond	0.18g

3.3.3. Results

After adjusting in the model all the required parameters, we ran simulations of the growth of *Ludwigia grandiflora* without other competing species (*Chara aspera, Potamogeton pectinatus*).

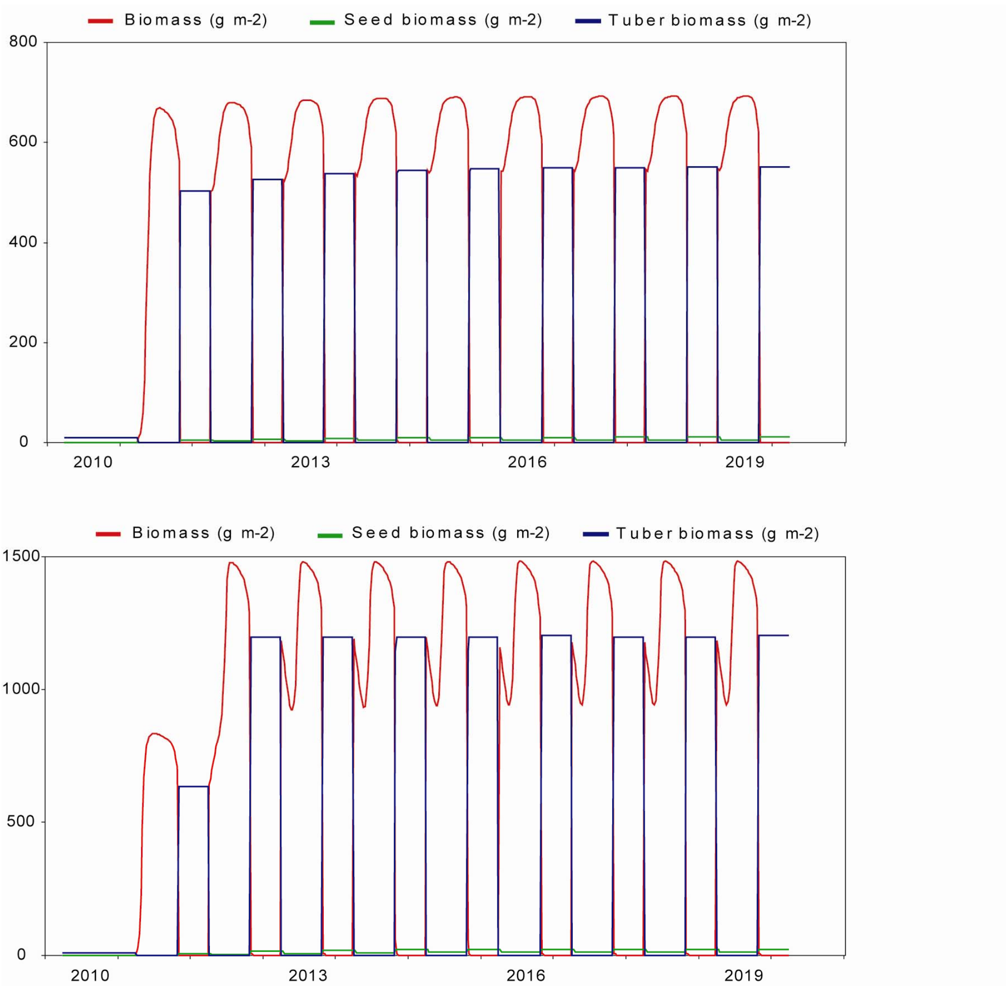


Figure 5. Simulations of the growth of *L. grandiflora* without competition. a) with a root:shoot ratio of 0.9. b) with a root:shoot ratio of 0.1. The blue line is the shoot biomass and the blue line is the wintering biomass ('tuber biomass' in CHARISMA).

The aim of the first set of simulations was to understand better the growth patterns of *L. grandiflora* alone without competition. We first used the parameters from table 2. The species grows to densities up to 700g/m^2 (figure 5a). This biomass is very close to 652g m^{-2}, the averaged biomass (dry weight) measured in the field of *L. peploides* collected from California (Rejmánková 1992). Under natural conditions, with enough space to grow, the biomass ranges between 500-700 g m^{-2}. Under controlled conditions, growth is vertical, limited by physical space and overcrowding; the observed carrying capacity of around 2000g m^{-2} (Rejmánková 1992) is thus underestimated by the model.. We were only able to approach such high values by lowering the root:shoot ratio from 0.9 to 0.1 (figure 5b). The values then rise up to 1500g m^{-2} (figure 5b). This ratio is extremely unlikely to occur in this species.

We then performed simulations of the growth of *L. grandiflora* with two competing species, *Chara aspera* and *Potamogeton pectinatus* on a 10 years period. We can see that *L. grandiflora* outcompetes the other species and dominates the macrophyte community. This leads to extinction of *Chara aspera* and *Potamogeton pectinatus* (figure 6). Figure 6a represents a root:shoot ratio for *L. grandiflora* of 0.9 and figure 6b, a root:shoot ratio of 0.1.

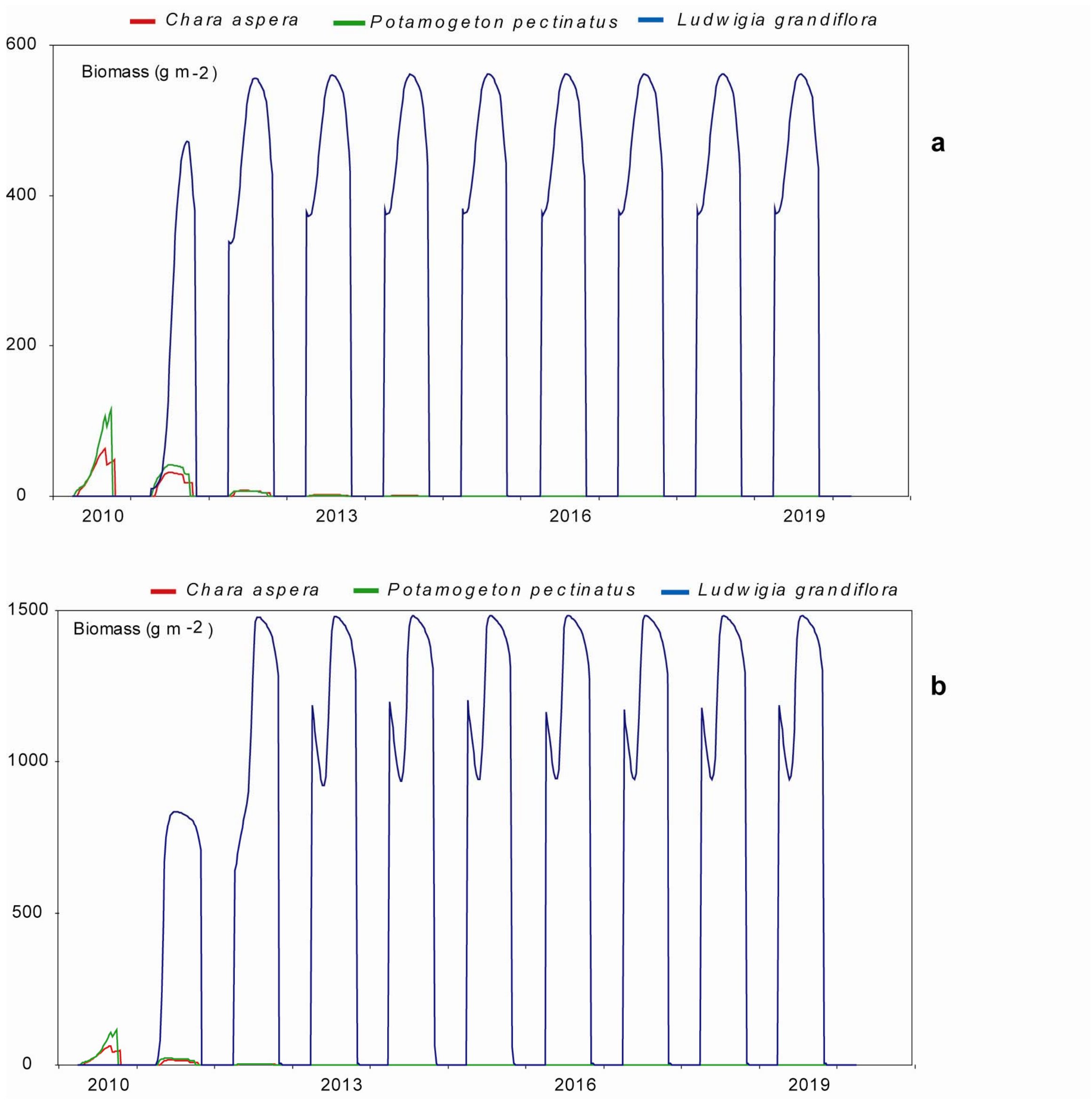


Figure 6. Simulations of the growth of *Ludwigia grandiflora* with competition by *Chara aspera* and *Potamogeton pectinatus* over ten years. (a) *L. grandiflora* with a root:shoot ratio of 0.9 (b) *L. grandiflora* with a root:shoot ratio of 0.1.

3.4. Discussion

Information on *L. grandiflora* biology is currently very limited, and its taxonomy is confused, making it difficult to determine optimal control strategies. Understanding the basic ecology of dispersal mechanisms, taxonomy and ecosystem function and its potential ecological interactions is essential to develop optimal control strategies.

It is unlikely that even in seemingly monospecific dominant conditions there will be a complete absence of other plant species, so some competition will always be present. Figure 6a seems to be a better representation of actual field data, both in Europe and the USA. This implies that even though the reproductive pressure and photosynthetic capacity should result in biomass of approximately double that noted in the field, there are limiting factors which could be exploited. Factors accounting for this could be the variability of fragment viability or dispersal, the % germination in different environments, growth conditions following germination in different years, colonisation by native pathogens and insects, or that performance in field conditions may not exactly match that determined by laboratory experiments. However, the simulation of biomass in Figure 6a is accurate and should be used as the basis for further modelling of this species.

4. Management

4.1. Objectives

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

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

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

4.2. Introduction

L. grandiflora is adapted to submersed or temporarily exposed soils, achieving high biomass values under normal conditions. In addition, the species grows well in low-oxygen (anaerobic) conditions, due to the possession of two distinct specialized root structures that may extract oxygen and nutrients from the water column and sediment (Rejmankova, 1992). Along with the ability to tolerate low oxygen, increased nitrogen and phosphorous concentrations result in greater plant biomass.

Roots and rooting stem fragments, embedded in soil or mud, send out lateral shoots that root from nodes into submersed or seasonally exposed soils. Continued growth develops dense mats of emergent vegetation, covering shallow water areas and transitional margins. The amphibious character of this species allows for limited upland survival; dry soils appear to decrease survival and reproductive ability, making it a poor competitor with other riparian and plant species on dry soils. On moist soils, the species tends to dominate most other species after a few years.

Water level and flow-rate appear to be central drivers of *Ludwigia* distribution patterns and reproductive success. Thus, water-level management is a potentially powerful tool for invasive *Ludwigia* control, manipulating levels by strategically draining or deepening areas.

4.3. Environmental Control

The worst infestations appear to be associated with symptoms of wetland degradation: thick sediments in shallow, slow-moving, nutrient-rich waters in full sun. Thus, long-term control of *Ludwigia* could benefit from restoration of riparian areas; improved water quality by reducing nutrient loads and sedimentation; and possible channel modifications (potentially including sediment removal) to encourage higher-quality habitat development.

L. grandiflora is resistant to extended drawdown or drying periods. However, it may be susceptible to flooding if water levels are increased substantially early in the year for an extended period of time, resulting in prolonged periods of very low oxygen concentration at the growing points. This observation is supported by dramatic reductions in infestation levels in the Camargue after prolonged winter submersion of *Ludwigia* species and is also mentioned as a successful method of control in rice fields by Naples (2005).

4.4. Non Chemical Control

Above-ground biomass removal is possible using manual or mechanical methods. However, *L. grandiflora* is a perennial that forms new shoots readily from root and stem fragments. For this reason, removal of biomass that do not completely eliminate the root system, or that are not done in conjunction with an herbicide treatment to kill the roots, can result in re-growth. Without killing the entire plant, at best these methods have limited effectiveness, and at worst they produce fragments that can spread to other parts of the system.

A study performed on behalf of the State Water Resources Control Board by the San Francisco Estuary Institute (in Meisler, 2008) found that shredding plant material in stagnant water bodies (without removing shredded biomass) led to decreased dissolved oxygen, increases in nutrients, and an increased biochemical oxygen demand. Mechanical removal of above-ground plant material from shallow wetlands can also create substantial disturbance, and ideally should be minimized.

Meisler (2008) further reports that in 2005, 5,388 tons of *Ludwigia* were removed from 44 acres at two sites. Researchers in France found that in the field, plants of *Ludwigia* can double in mass in 15-90 days, depending on conditions (Dutartre, pers comm.).

In California, the production of *L. grandiflora* has been estimated at between 135 and 148 tons of biomass per hectare in open lake systems and at up to 427 tons/hectare in narrow shallow channels, although the contribution of increased sediment removal to this value cannot be accurately quantified. These massive quantities of biomass in the worst-infested areas make manual removal difficult and expensive to sustain as a long-term control strategy. *Ludwigia* can be managed by hand-pulling and raking in the worst infested areas for 2-6 person hours/week, but this rate is likely only to just keep up with its growth. However, hand pulling is likely to be a good option for less dense or isolated infestations.

Mechanical excavation and dredging is a more comprehensive removal of invasive *Ludwigia* plants and roots, and would have better success in eliminating *Ludwigia* from waterways, especially if dredged channels are made too deep for *Ludwigia* to successfully re-establish. However, concerns remain about re-growth and fragmentation spreading the plant to other areas.

Disposal of Cut Vegetation
Vegetation disposal has been successfully achieved through drying, shredding and disking in nearby upland fields on dry soils.

Other methods
Shading may be effective for killing *Ludwigia* plants, although this has not been assessed for fabric choice, timing or length of shade required for eradication.

4.5. Chemical Control

Ludwigia is a perennial species that regenerates readily from root and stem fragments. Therefore, systemic herbicides are required to effectively eliminate infestations. The compounds that have had the greatest success in controlling *Ludwigia* species are glyphosate, diquat, 2,4-D, imazapyr and triclopyr as approved aquatic products (in the USA).

Chemical control is possible with several herbicides (IPAMS website at http://www.gri.msstate.edu/ipams). The auxinic herbicides 2,4-D and triclopyr both provide good control and are selective for broadleaf species, minimizing damage to native grasses and other monocots. The broad-spectrum systemic herbicides glyphosate and imazapyr provide good control on emergent and floating-leaved species. Diquat may be used to control newer infestations, particularly in spot applications, but regrowth may require re-treatment. All of these herbicides should be used in combination with a surfactant that is appropriate for aquatic use (e.g. Defra , 2007)

The discussion below has been limited to the availability of herbicides approved for aquatic use under the Plant Protection Products Directive EU 91/414/EEC, which may not always provide adequate control in certain circumstances

Results of EU Aquatic Approved Herbicide Application

Glyphosate
In Sonoma County trials (Meisler, 2008) the kill rate achieved by the herbicide glyphosate was approximately 75%. This was likely due to a combination of limited efficacy of both the herbicide and

surfactant, method of application, density of existing plants, and timing. The density of the canopy is an important factor in limiting the success of glyphosate application, and herbicides should be applied before June or July to get the best canopy penetration leading to more effective control. Although glyphosate provides a desirable balance between reasonably high efficacy and low mobility and toxicity, it is possible that it did not have the strength to kill the plant entirely. This is supported by work of Defra (2007) where an effective adjuvant was required to give much better control than using glyphosate formulations without adjuvants.

The recommended treatment is to use an aquatic approved formulation of glyphosate at a rate of 2.28 Kg active ingredient per hectare, with the adjuvant TopFilm at a rate of 1 L/ha

2,4-D amine

At an early growth stage, the plants are easily killed by 2,4-D or a foliar spraying with 2,4-D amine (480 g/L). *L. octovalvis* (Jacq.) Raven*, L. hyssopifollia* (G. Don) Exell *& L. perennis* L.*:* 2 applications of 0.45 kg of 2,4-D in 91 L of water at 4-week intervals, with spot-spraying later. Application of 2,4-D amine to *Ludwigia* has also been successful in the USA (McGregor *et al.*, 1996).

Discussion

Effective control of *Ludwigia* is possible using approved aquatic herbicides. However, timing and the use of adjuvants are critical in determining success. The use of Triclopyr products in the USA has achieved much more rapid and effective control and consideration could be given to obtaining off label approval for similar products in Europe (e.g. Garlon 4), depending on the spatial scale and level of infestation

4.6. Biological control

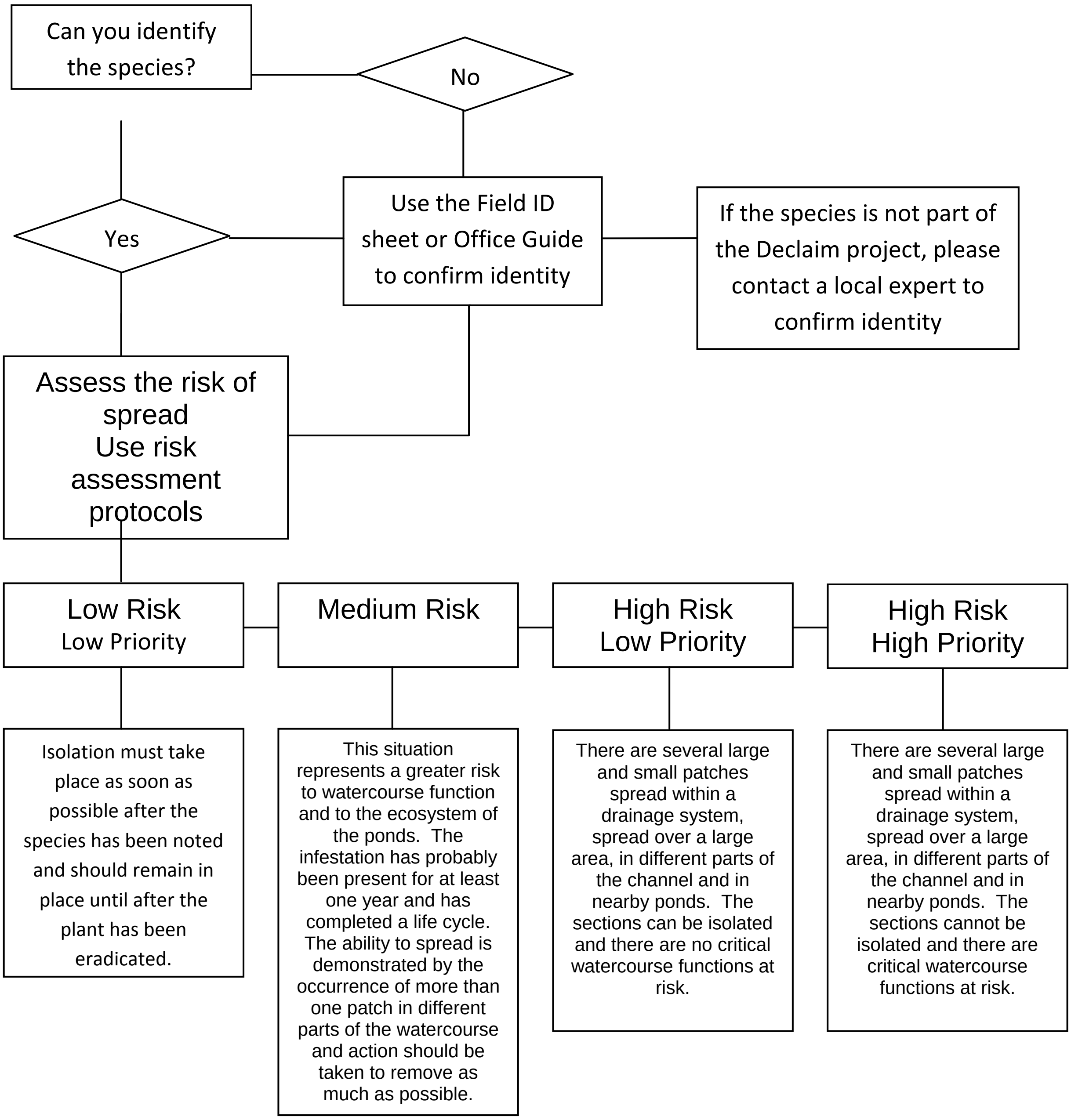
Several species of flea beetles of the genus *Lysathia* have been identified that eat *L. grandiflora* (*L. flavipes* (Cordo & DeLoach, 1982), *L. ludoviciana* (McGregor *et al.,* 1996), although the latter also completes its lifecycle on *Myriophyllum aquaticum* (Habek & Wilkerson, 1980). It is not clear how host specific these agents would be under European conditions, although they are recommended for further assessment (Gassman *et al.,* 2006). Other potential agents include *Ochetina bruchi*, *Auleutes bosqi*, and some *Onychylis* and *Tyloderma* species (Wood, 2006, Sheppard *et al.* 2006)

5. Decision Support System

5.1. Objectives

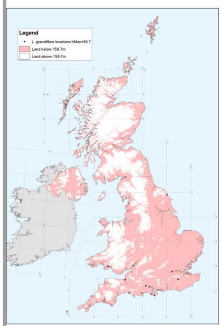
The objective of this work package is to derive from the current practices in aquatic weed management and from the results of Work packages 2, 3 and 4 a prototype DSS. This DSS will be disseminated amongst bodies involved in water management for review.

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



5.2. Information for use in the Field

5.2.1. Identification



Areas at Risk of Colonisation in the UK. *L. grandiflora* has been found in low lying ponds adjacent to the coast. However, there are several sites where it has been deliberately planted as an ornamental. It is tolerant of British winter tempe-ratures and its occurrence is predicted to be widespread in ponds anywhere at low altitudes.

Ludwigia grandiflora

(Water Primrose)

Field Recognition Guide

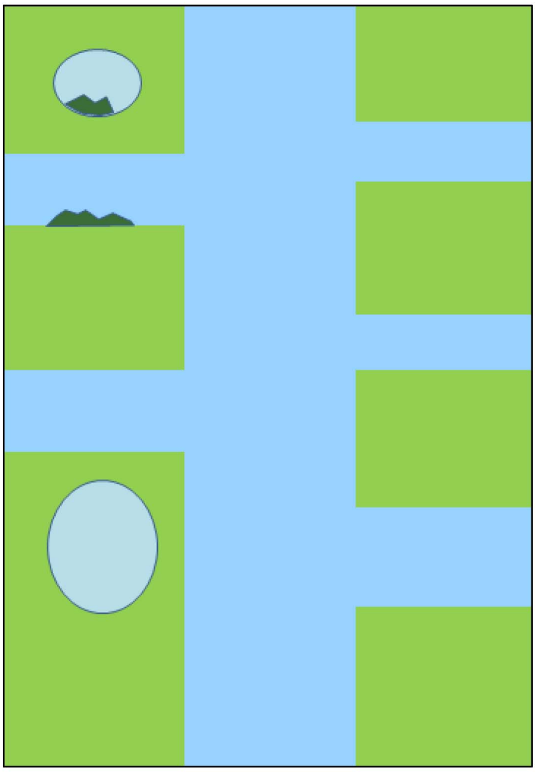
Preferred habitat: static shallow water-courses, ponds, ditches, with gently sloping muddy margins. Dead stems are visible in winter with green growth starting in March or early April. Flowers from July onwards.

Key features: Deltoid (triangular) bracteoles at base of petiole. Prostrate form: leaves alternate on stem, oval in shape with distinct petiole and obvious opposite veins. Adventitious roots at nodes. Upright form: Leaves alternate on stem, elongated with obvious opposite veins. Flowers bright yellow 5 with petals.

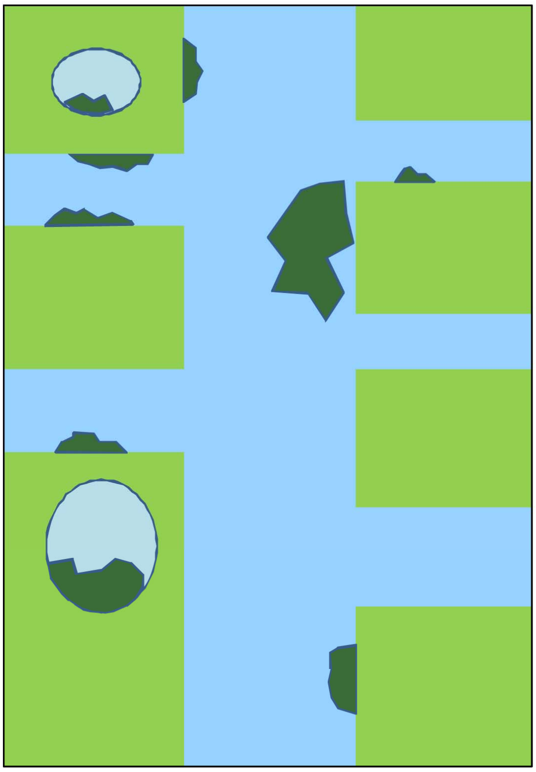
Reporting: please inform the Non Native Species Secretariat at www.nonnnative species.org giving grid reference, extent of infestation, photograph and date of observation, and the Biological records centre at http://www.brc.ac.uk/contact.htm

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

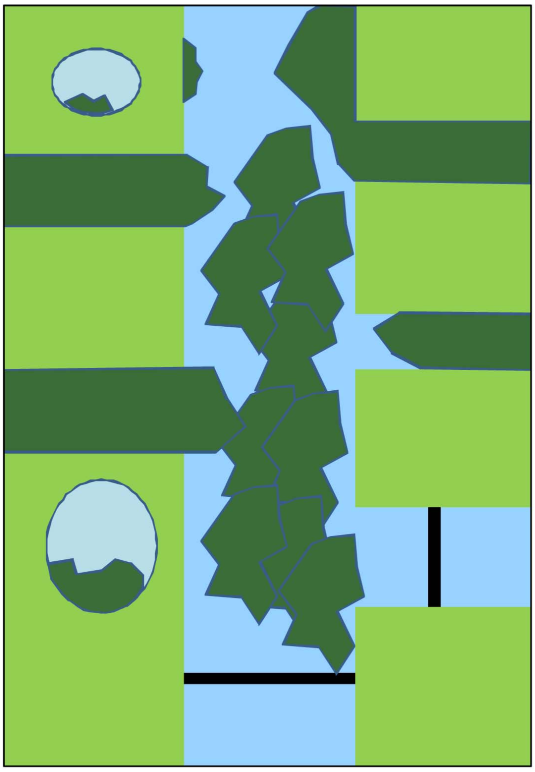
5.2.2. Risk assessment



LOW RISK
The occurrence is limited to a few square metres at one location.
ACTION:
1. Inform appropriate manager, authority, national organisation
2. Arrange for removal by manual / hand picking.
3. Ensure no fragments get out of the side channel into the main river, or spread to nearby ponds.



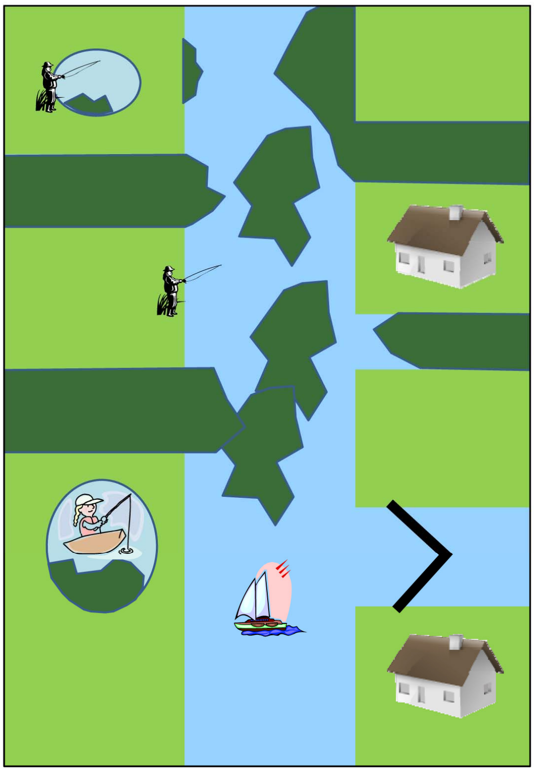
MEDIUM RISK
There are several small patches of less than ten square meters spread within a short distance, but in different parts of the channel and in nearby ponds.
ACTION:
1. Inform appropriate manager, authority, national organisation
2. Arrange for removal by manual / hand picking.
3. Ensure no fragments spread form the small patches by isolating side channels or retaining patches in large channels by using floating barriers etc.
4. Monitor for regrowth at 4 week intervals



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

ACTION:

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



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

ACTION:

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

5.3. Information for use in the Office

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

Ludwigia grandiflora (Michx.) Greuter & Burdet

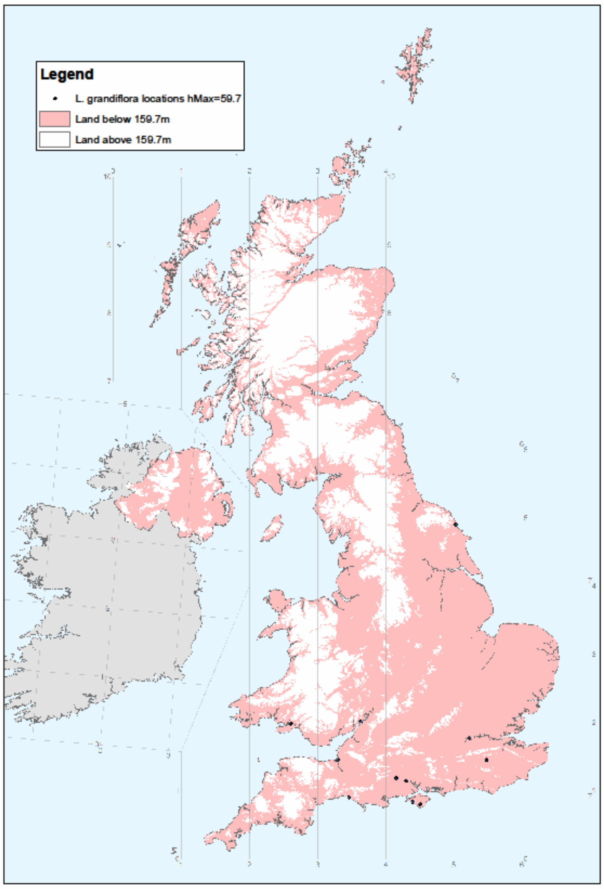
A guide to Identification, Risk Assessment and Management

© S. Hathaway

Background and Ecology

What is it?

Ludwigia grandiflora (Michaux) Greuter & Burdet (Raven, 1963) is a herbaceous, perennial, wetland obligate plant, which can be categorized as a creeping macrophyte (Rejmánková, 1992), meaning that it is an emergent macrophyte with stems that grow prostrate on the mud or float on the water surface. Stems are fleshy and reach a length between 20- 300 cm long and slightly to densely covered with long soft hairs. Leaves are alternately arranged and variable in hairiness, shape and size. They can be lanceolate (longer than wide and usually tapering at both ends), oblanceolate (broader above the middle of the leaf, than tapering at base), or obovate (egg-shaped, wider at leaf tip), although leaves are typically round during the early growth period. Petiole lengths are up to 4 cm and the leaf blade ranges in length between 1 – 9 cm. On erect shoots bright yellow flowers appear from July onwards. *Ludwigia* is a genus of some 80 species of herbaceous and floating to woody and erect water plants with a cosmopolitan distribution, centred in the Americas with one species indigenous to Europe. There is still debate on the delimitation of various tribes within the genus and especially with respect to the nomenclature of the naturalised ornamental plants, belonging to the section Oligospermum, posing problems in Europe, making the genus taxonomically difficult. In addition it can be confused with several other aquatic species, including *Ludwigia peploides, Mentha aquatica* and *Persicaria amphibia.*



L. grandiflora is adapted to submersed or temporarily exposed soils as well as low-oxygen (anaerobic) conditions, through the presence of two distinct specialized root structures that extract oxygen and nutrients from the water column. Porous, upward growing aerenchymous roots provide a conduit for atmospheric gases to transfer throughout the plant in anaerobic conditions. Tightly packed cells of downward-growing adventitious roots (arising from the stem) absorb nutrients in the water column, often without contact with the substrate. Along with the ability to tolerate low oxygen, increased nitrogen and phosphorous concentrations result in greater plant biomass.

Where does it grow? This species grows on muddy banks or rooted in the mud of stagnant to slow flowing water, including, lakes, ponds, canals, and ditches. The species was introduced to natural watercourses in the Netherlands and the UK via discarded or deliberately planted pond plants. The map shows known sites in the UK, and the pink area shows the areas where *L. grandiflora* growth is possible, based on altitude and historical temperature data. These areas change when climate change scenarios are used to amend the factors, but almost all simulations predict a greater possible distribution range in future.

Ludwigia grandiflora is very morphologically variable, with leaf form switching from the prostrate form to the emergent form very quickly. The leaf forms for particular situations are not exclusive as you can see from the figure below, where it appears that the lanceolate leaf form occurs on the prostrate morphotype on the right hand side, but the more oval form occurs under the same environmental conditions on the left hand side. Leaf shape changes within days when plants are moved from water to damp mud. The presence of emergent type leaves in the figure below may be an artefact caused by an increase in water level, where a previously emergent growth form has become submerged below the water surface.

© Jonathan Newman

Characteristic features: deltoid (triangular) bracteoles and large (2 – 5 cm diameter) yellow flowers with 5 petals

© Trevor Renals

Picture Left: Detail of seed capsule of *L. grandiflora*. Note the length is normally similar to leaf length

Identification:

The identification of *Ludwigia* species of the section Oligospermum *s.l.* has always been very difficult and resulted in unending taxonomic changes and inextricable synonymy (Dandelot et *al.*, 2005a). The *L. uruguayensis* complex comprising a decaploid entity (2n = 80) and a hexaploid (2n = 48), differing by quantitative, intergrading morphological features, is known to produce hybrids of intermediary morphology in regions of sympatry. (Nesom & Kartesz, 2000)

L. grandiflora has an inherent highly variable morphology depending on abiotic conditions (Lambert et al., 2009), especially the leave shape and stem size. Three morphological forms are distinguished according to ecological conditions:

- a prostrate small leaved form;
- an actively growing creeping form in the first step of development or in static or slow flowing waters;
- An erect form at later stages, in favourable ecological conditions, on damp mud or in shallow waters.

L. grandiflora forms two kinds of roots: those for substrate anchorage and nutrient absorption; and adventitious roots, which occur at the stem nodes and can absorb atmospheric oxygen. The adventitious roots allow the plant to tolerate anaerobic conditions (Rejmankova, 1992).

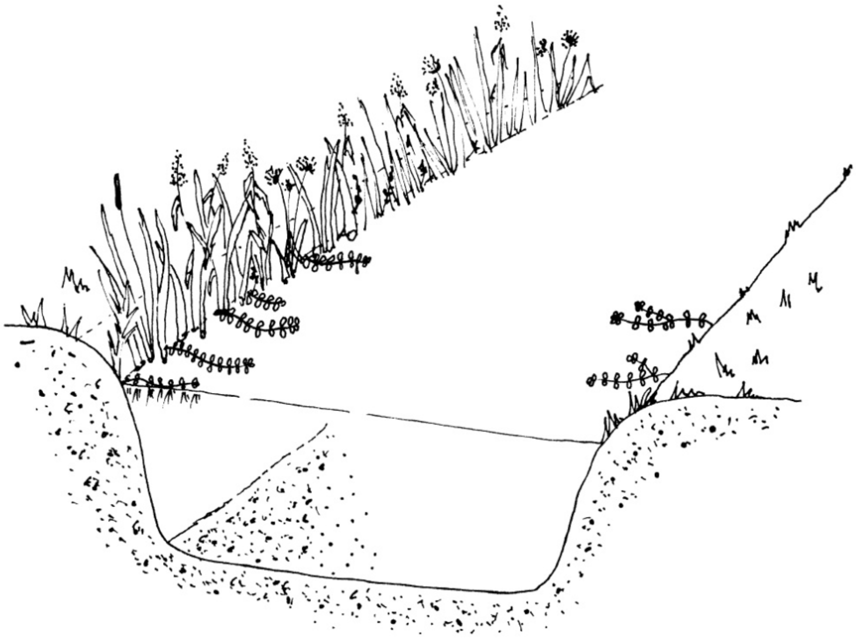
Morphological description

Amphibious plant. Stems up to several meters long, usually ascendant to procumbent on water. Leaves arranged alternately on stem, lanceolate to obovate, leaf blade decurrent on the petiole. Leaves shining on prostrate and floating stems, dull green and hairy on erect stems. No flowers until erect stems formed. Yellow flowers up to 5 cm in diameter with 5 (or 6) petals and yellow stamens and stigmas. Deltoid bracteoles at base of petiole and on the fruit.

Not to be confused with:

Persicaria amphibia	*Myosotis scorpiodes*	*Ludwigia peploides*
		
General Appearance Leaves always lanceolate with petiole, pink upright flowers	General Appearance Upright single stems, blue flowers	General Appearance Normally prostrate with flowers borne on erect stems
		
Leaf insertion Red stems, frequent branching	Leaf insertion Hairy stems	Leaf insertion And see below
		
Inflorescence detail Cylindrical with densely packed flowers	Inflorescence detail Flowers in a terminal spiralled cyme	Inflorescence detail Flowers solitary in the leaf-axils

Life Cycle



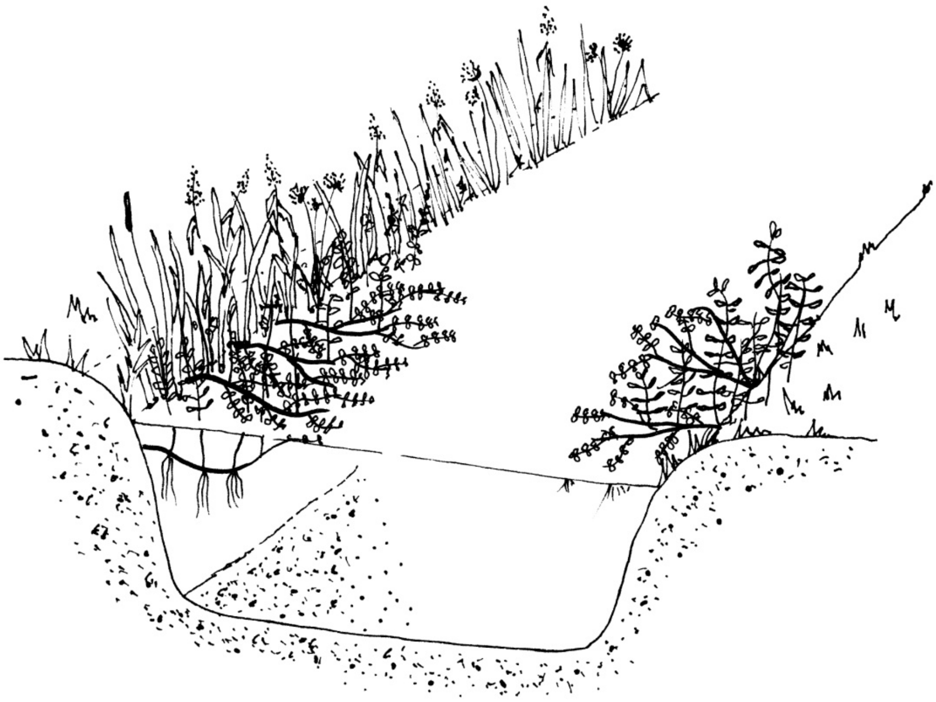
***Ludwigia* in Spring**

In spring, single stems grow from overwintering shoots. Leaves are usually flat on the water surface and obovate in shape. Small rosette form at the stem apices

Management Weak Point: Manual removal of small colonies is possible at this stage, but mechanical control using excavators to remove plant material and topsoil is also possible.

Management Restrictions: None applicable for the recommended action.

Action: Chemical treatment using 2,4-D amine or glyphosate mixed with TopFilm is possible at this stage, but retreatment will be necessary. See chemical control section later in this document.



***Ludwigia* in Early Summer**

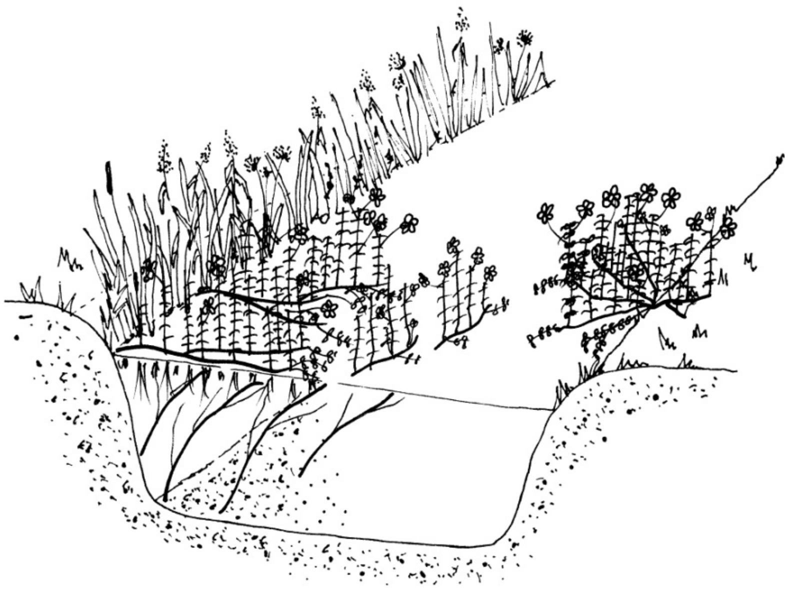
In early summer, the plant is usually well established and emergent stems start to grow form prostrate creeping stems. They carry the flowers and some occasional flower bud formation may be observed. The stems usually have many branches by now, with creeping prostrate leaves at the edge of the mat, and emergent stems growing from further back for the stem tips.

Action: Manual removal of small colonies is still just possible at this stage, but mechanical control using excavators to remove plant material and topsoil is recommended.

Cutting the plant just encourages more rapid growth and does not appear to weaken the plant.

Chemical treatment using 2,4-D amine or glyphosate mixed with TopFilm is possible at this stage, but retreatment will be necessary. Chemical treatment now is usually more effective than earlier treatment, although is earlier spray have been applied, a retreatment will usually be necessary again. See chemical control section later in this document.

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



***Ludwigia* in Summer**

The majority of creeping stems will have emergent erect stems and characteristic large yellow flowers with 5 or 6 petals will be visible.

Action: Manual removal of small colonies is still just possible at this stage, but mechanical control using excavators to remove plant material and topsoil is recommended.

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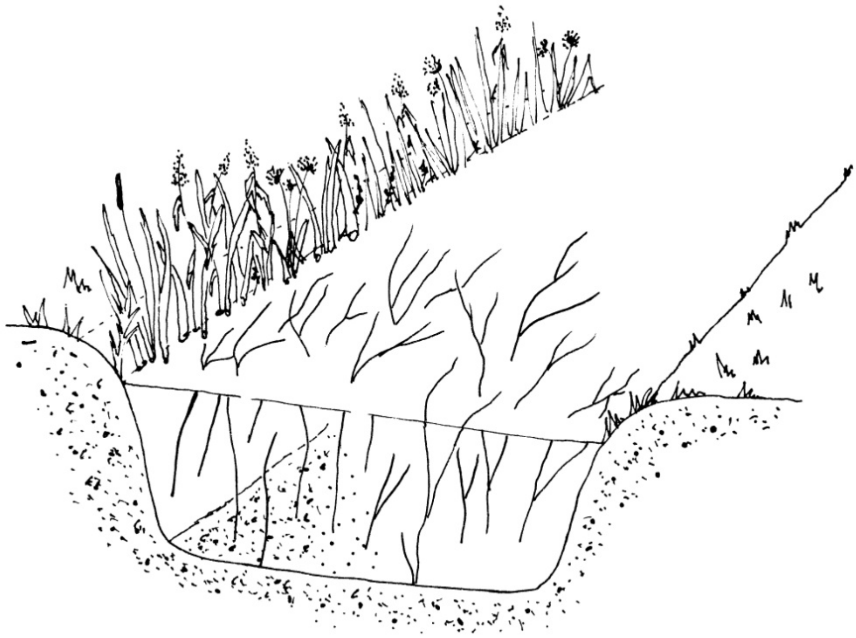
Management Restrictions: There are no restrictions on mowing, dredging re-profiling and cutting should only be undertaken after the middle of July.



***Ludwigia* in Winter**

After flowering from early autumn onwards, leaves on emergent stems drop off after the first night frost the plant leaving mostly bare woody stems which remain standing over winter. This is useful for identifying areas for mechanical removal in winter.

Management

Mechanical Control

Out of the Water and in Shallow water: *L. grandiflora* is relatively shallow rooted and mechanical excavation of the top 10 cm or so of the soil surface removes the majority of plant material. Reproduction via fragments is possible, so regular inspection and monitoring of a treated site is advisable for several years after eradication.

Case Study

	A small population of *Ludwigia peploides* was found upstream from Rotterdam. Immediate action was taken to prevent the spread to other areas of the wetland restoration site. Although this case study is for *L. peploides*, the same methods should be used for small infestations of *L. grandiflora*
	The topsoil was scraped off to a depth of 10 – 30 cm and stockpiled
	The extent of emergent creeping vegetation was marked and the soil excavated to a depth of 30 cm.

	Holes were dug at the site in areas where no *L. peploides* was present, and contaminated topsoil with fragments and plants was buried at least 1 m deep.
	
	Small patches in shallow water were buried in holes in uncontaminated areas adjacent to the plant patches.
	The holes were filled in with clean soil

	Drainage of the excavated area was necessary to ensure all plants could be seen before excavation. Care was taken to avoid any fragments being pumped out of the area.
	The channel and shallow margin was reprofiled, carefully burying any small fragments
	The stockpile of contaminated material from reprofiling was buried on site

Mechanical Control

Above-ground biomass removal is possible using manual or mechanical methods. However, *L. grandiflora* is a perennial that re-sprouts readily from root and stem fragments. For this reason, biomass removals that do not completely eliminate the root system, or that are not done in conjunction with an herbicide treatment to kill the roots, can result in re-growth. Without killing the entire plant, at best these methods have limited effectiveness, and at worst they produce fragments that can spread to other parts of the system.

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At an early growth stage, the plants are easily killed by 2,4-D or MCPA or a foliar spraying with 2,4-D ester or amine (480 g/L). *L. octovalvis* (Jacq.) Raven*, L. hyssopifollia* (G. Don) Exell *& L. perennis* L.*:* 2 applications of 0.45 kg of 2,4-D in 91 L of water at 4-week intervals, with spot-spraying later. Application of 2,4-D amine to *Ludwigia* has also been successful in the USA (McGregor *et al.*, 1996).

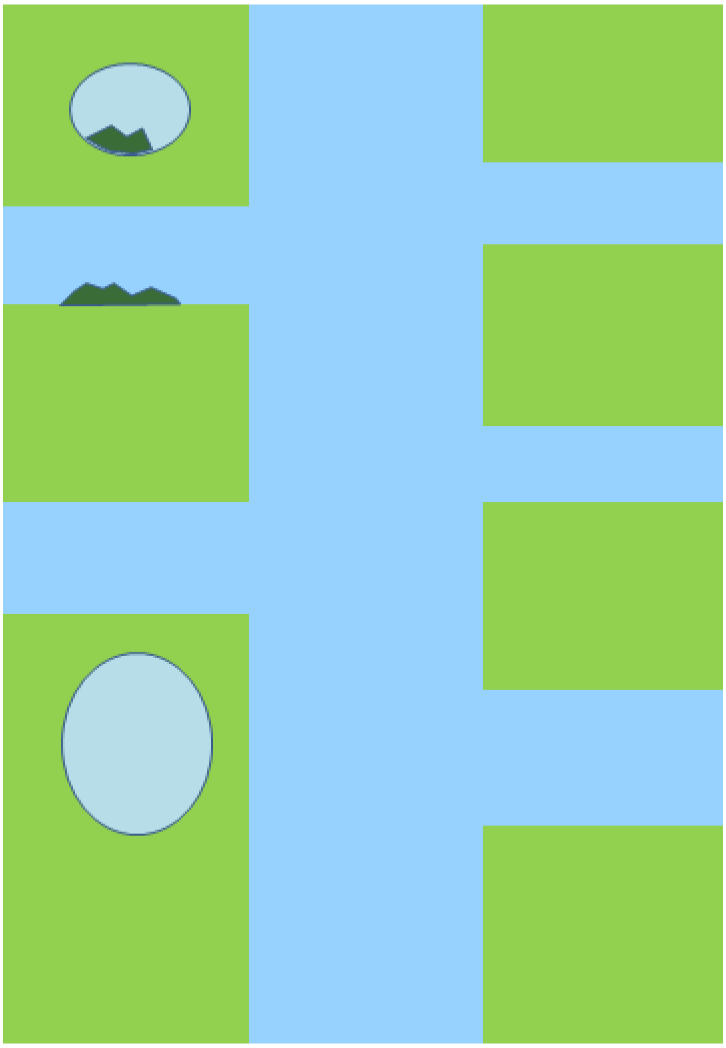
Biological Control

Several species of flea beetles of the genus *Lysathia* have been identified that eat *L. grandiflora* (*L. flavipes* (Cordo & DeLoach, 1982), *L. ludoviciana* (McGregor et al., 1996), although the latter also completes its lifecycle on *M. aquaticum* (Habek & Wilkerson, 1980). It is not clear how host specific these agents would be under European conditions, although they are recommended for further assessment (Gassman et al., 2006). Other potential agents include *Ochetina bruchi*, *Auleutes bosqi*, and some *Onychylis* and *Tyloderma* species (Wood, 2006, Sheppard *et al*. 2006).

Environmental Control

Shading may be effective for killing *Ludwigia* plants, although this has not been assessed for fabric choice, timing or length of shade required for eradication. The worst infestations appear to be associated with symptoms of wetland degradation: thick sediments in shallow, slow-moving, nutrient-rich waters in full sun. Thus, long-term control of *Ludwigia* could benefit from restoration of riparian areas; improved water quality by reducing nutrient loads and sedimentation; and possible channel modifications (potentially including sediment removal) to encourage higher-quality habitat development.

L. grandiflora is resistant to extended drawdown or drying periods. However, it may be susceptible to flooding if water levels are increased substantially early in the year for an extended period of time, resulting in prolonged periods of very low oxygen concentration at the growing points. This observation is supported by dramatic reductions in infestaqtion levels in the Camargue after prolonged winter submersion of *Ludwigia* species and is also mentioned as a successful method of control in rice field by Naples (2005)

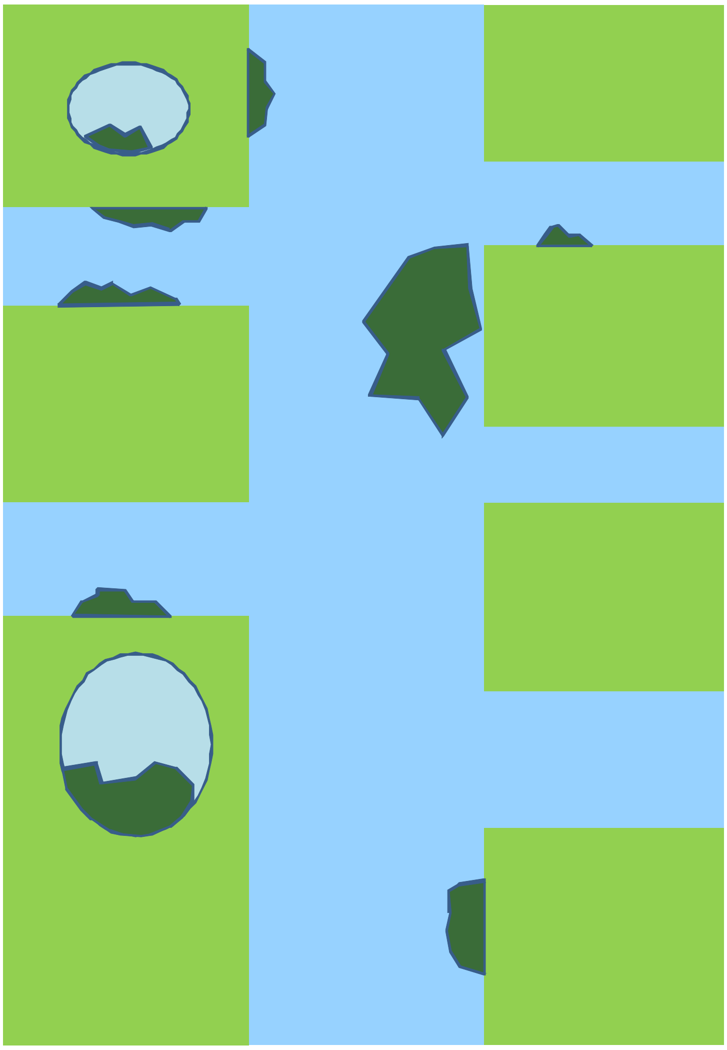


Low Risk High Priority

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

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

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

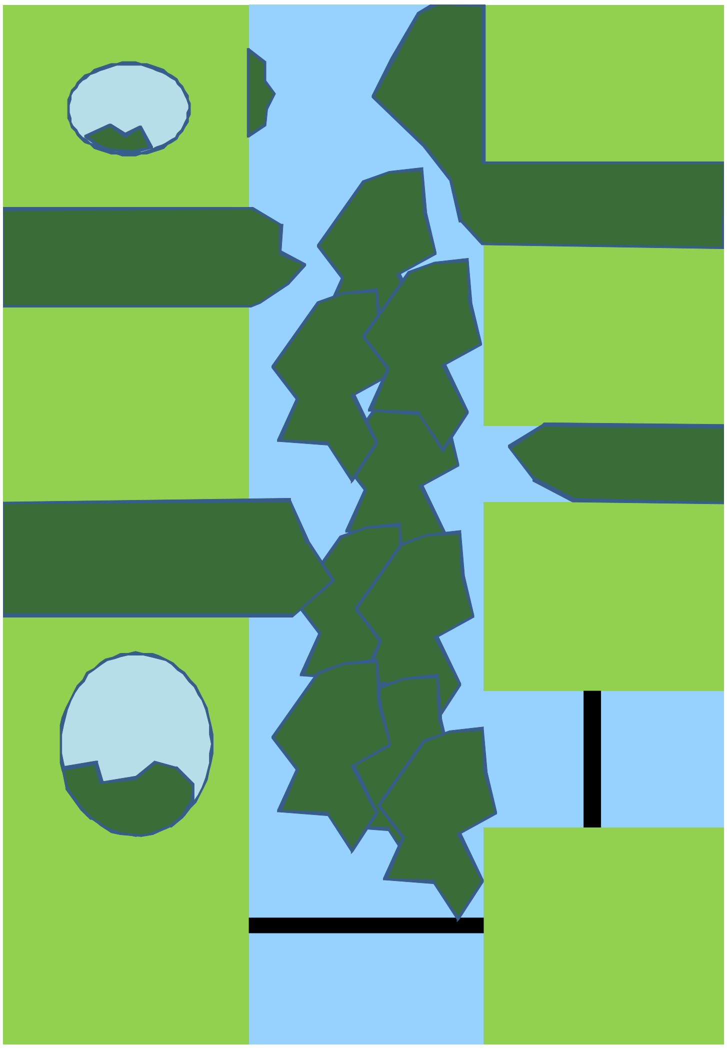


Medium Risk

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

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

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



High Risk – Low Priority

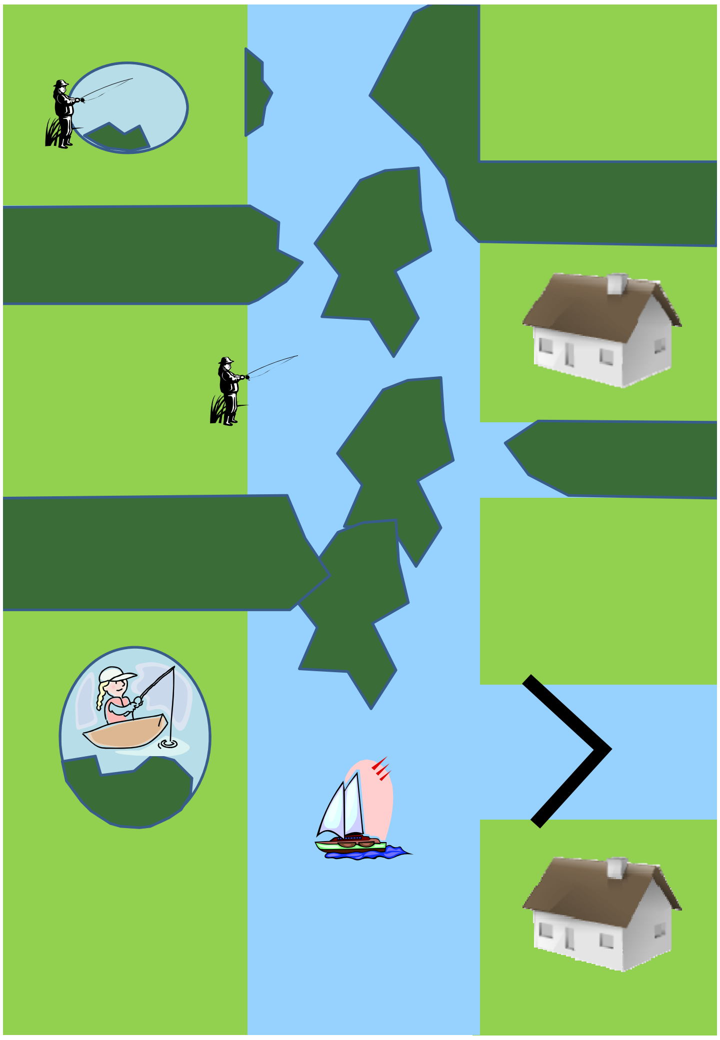
There are several large and small patches spread within a drainage system, spread over a large area, in different parts of the channel and in nearby ponds. The sections can be isolated and there are no critical watercourse functions at risk.

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

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

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

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



High Risk and High Priority

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

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

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

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

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

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

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

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