NOBANIS – Invasive Alien Species Fact Sheet

Azolla filiculoides

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Species description

Scientific name: *Azolla filiculoides* Lam. 1783, Azollaceae
Synonyms: *Azolla caroliniana* Willd., *Azolla rubra* R.Br., *Azolla japonica* Franch. & Sav., *Azolla arbuscula* Desv., *Azolla filiculoides* var. *rubra* Lam. (R.Br.) Strasb., *Azolla magellanica* Wild., *Azolla squamosa* Molina.
Some scientists consider *A. caroliniana*, *A. japonica* and *A. rubra* as independent species.
Common names: Large mosquito fern (GB), red water fern (GB), Großer Algenfarn (DE), andemadsbregne (DK), Azolla karolinska (PL), šakotoji azolė (LT), Grote kroosvaren (NL), andematbregne (NO), mossbräken (SE), limaskasaniainen (FI).

Fig. 1 and 2. Single plants of *Azolla filiculoides*, photos by A. Hussner.

Fig. 3 and 4. Thin and dense mats of *Azolla filiculoides*, photos by A. Hussner.

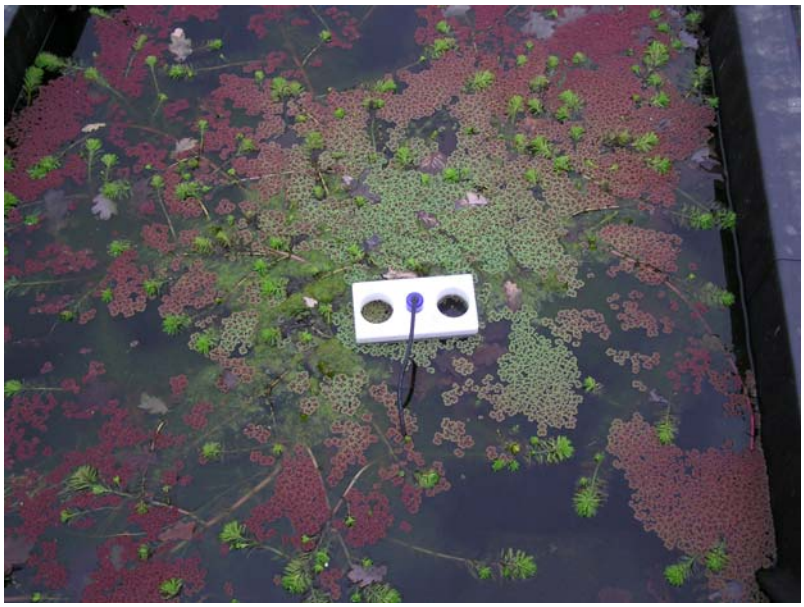

Fig. 5. *Azolla filiculoides* plants in a heated pond in winter; the plants become red with an increasing distance from the heater, photo by A. Hussner.

Species identification
A. filiculoides is a heterosporous, up to 2.5 (10) cm large floating fern (Figs. 1-5). *Azolla* plants are polygonal or triangular in shape (Lumpkin and Plucknett 1980). The sporophytes consist of two-lobed leaves and rhizomes. The lower lobes of the leaves are usually larger than the upper. Svenson (1944) described the lower lobes as so adapted for floating the plant, that only the lower surface of these lower lobes comes in contact with water.

The plants are dark green to reddish and float on the water surface, either individually or in mats, which can reach a thickness of up to 20 cm (McConnachie *et al.* 2004). A characteristic of the genus *Azolla* is the symbiotic relationship with the nitrogen-fixing blue-green alga *Anabaena azollae*. When *A. filiculoides* plants are exposed to strong sunlight they obtain a red colour. The same occurs in wintertime. In shade they always remain green (Moore 1953, Janes 1998a). Janes (1998a) described three different phenotypes of *A. filiculoides* under different habitat and climate conditions.

Native range
A. filiculoides is native to warm temperate and subtropical America through Western North America (including Alaska). West (1953) described *A. filiculoides* furthermore as a species which in former times was native to Europe (Ekman 1998, 1999, O`Brien and Jones 2003), but died out during the last Ice Ages.

Alien distribution

History of introduction and geographical spread
A. filiculoides has actually become a cosmopolitan plant, with occurrences in South Africa (Hill and Cilliers 1999, Gratwicke and Marshall 2001, McConnachie *et al.* 2003, 2004), Asia (Ahmad 1941, 1943, Kitoh *et al.* 1993), Australia, South-, Central- and North America (Svenson 1944), South-, West-, Central- and North Europe (West 1953, Birkenbeil 1974, Bernhardt 1991, Kohler 1995, Ferreira *et al*. 1998, Janes 1998a, b, Hussner and Lösch 2005) and Scandinavia (Rune and Jørgensen 1997). The species was introduced to Europe in 1880 near Bordeaux (West 1953). First plants were reported from France, and since then the species spread to nearly the whole of Europe with a main occurrence in Atlantic-Mediterranean regions.

Pathways of introduction
A. filiculoides is able to reach new regions by waterfowls, in ballast tanks of ships, or by human influence (intentionally or unintentionally). Discharge by aquarium keepers may play an important role in spread of this species. Rune and Jørgensen (1997) described two examples of intentional releases of *A. filiculoides* plants in Denmark.

Alien status in region
A. filiculoides is an alien plant to Europe and Scandinavia (see table 1). In Germany *A. filiculoides* is common (Birkenbeil 1974, Bernhardt 1991, Kohler 1995, Jaeger and Werner 2002, Kowarik 2003, Hussner and Lösch 2005), but there are no reports on such thick mats as they are reported from other countries (McConnachie *et al.* 2003). Rune and Jørgensen (1997) described *A. filiculoides* from 11 different sites in Denmark. *A.filiculoides* is found in a few localities in Southern Sweden. It is uncertain if *A. filiculoides* is established or if occurrences are incidental.
In Poland the species is known from some ephemeral locations in the SW and NE regions (Rostański and Sowa 1986-1987, Wokowycki 1999). In Lithuania *A. filiculoides* was recorded abundantly growing in an exploited peatbog in 1946, later became extinct (Gudžinskas 2000). In

Norway it has been recorded from three different locations; Oslo (1927 and later), Klepp in the SW (1995) and Stokke in the SE (2001). The species is so far apparently not able to survive the winters in Norway.

Country	Not found	Not established	Rare	Local	Common	Very common	Not known
Austria		X					
Belgium				X			
Czech republic							X
Denmark			X				
Estonia	X						
European part of Russia	X						
Finland	X						
Faroe Islands	X						
Germany					X		
Greenland	X						
Iceland	X						
Ireland				X			
Latvia	X						
Lithuania		X					
Netherlands					X		
Norway		X					
Poland		X					
Slovakia							X
Sweden			X				

Table 1. The frequency and establishment of *Azolla filiculoides*, please refer also to the information provided for this species at www.nobanis.org/search.asp. Legend for this table: **Not found** - The species is not found in the country; **Not established** - The species has not formed self-reproducing populations (but is found as a casual or incidental species); **Rare** - Few sites where it is found in the country; **Local** - Locally abundant, many individuals in some areas of the country; **Common** - Many sites in the country; **Very common** - Many sites and many individuals; **Not known** - No information was available.

Ecology

Habitat description

A. filiculoides settles in ponds, ditches, water reservoirs, wetlands, channels and slow flowing rivers. *A. filiculoides* can be found in sunny to shady parts of the water bodies. Through its symbiotic association with *Anabaena azollae*, the floating fern is able to grow in nitrogen-deficient waters. Kitoh *et al.* (1993) observed that less phosphorous can limit the growth of the species. The species grows at best at 15-20°C and high irradiance (Tung and Watanabe 1983, Watanabe and Berja 1983, Janes 1998a). Wong *et al.* (1987) stated that optimum temperature for both nitrogen fixation and oxygen evolution is 25°C. Janes (1998a) reported that plants die under laboratory conditions at temperatures below – 4°C. Janes (1998a) described *A. filiculoides* as the most frost tolerant of the *Azolla* species. Wong *et al.* (1987) reported that *A. filiculoides* withstands field temperatures of – 10 to – 15°C. Janes (1998a) observed successfully overwintered vegetative plants

in Worcester (UK) where the minimum air temperature reached – 10°C. Janes (1998a) described that plants are able to survive encasement in ice for at least one week, but those parts of the plants which protruded above the ice, were killed.

Reproduction and life cycle
A. filiculoides has a surface-area doubling time of 7-10 days under favourable conditions. Kitoh *et al.* (1993) observed a doubling of the biomass every 2.2 – 3.4 days under laboratory conditions. The growth rate of *A. filiculoides* increased with increased photoperiod. Janes (1998a, b) investigated the sporulation and germination of *A. filiculoides* and showed that the species sporulates regularly at many sites in Britain, most often between May and November. From Germany sporulating plants are known too (pers. obs.). It seems that sporulation of this species is regulated by the interacting effects of light intensity, photoperiod, temperature, pH and nutrient availability. Janes (1998b) suggested that a thick mat of 8 kg m^{-2} fresh biomass may produce 85 000 megasporocarps and 380 000 microsporocarps. In laboratory experiments a maximum of germination was reached at 20°C, but at a constant temperature of 5°C no germination was observed (Janes 1998b). For germination a temperature above 10°C and light are necessary. Temperatures of about – 10°C for at least 18 days had no influence on further germination of the sporocarps. The heterosporous life cycle of the genus *Azolla* is illustrated in Fig. 6.

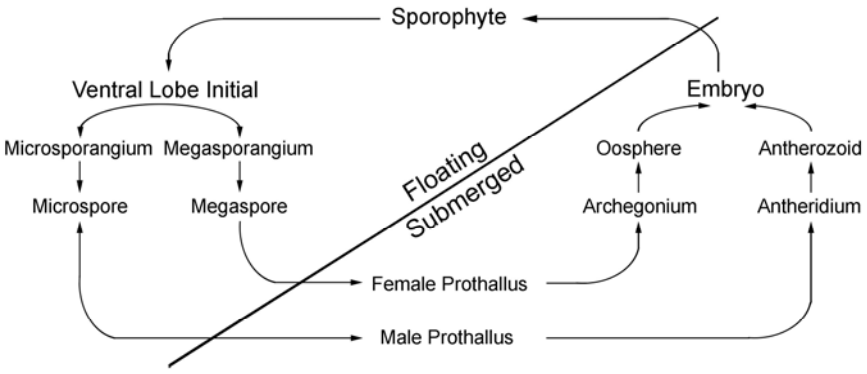

Fig. 6. Heterosporous life cycle of *Azolla* (redrawn from Lumpkin and Plucknett 1980)

Dispersal and spread
A. filiculoides can spread locally by waterfowls, water sport tackle (diving, fishing, water skiing etc.) or by discharge from aquarium keepers.

Impact

Affected habitats and indigenous organisms
A. filiculoides settles in ponds, ditches, water reservoirs, channels and slow flowing rivers. In some cases the species can be found together with *Lemna minuta*, *Lemna minor* and *Spirodela polyrhiza.* In other cases *A. filiculoides* forms dense monospecific mats. These mats of floating plants can affect the water by eliminating submerged plants and algae (Janes *et al.* 1996), preventing their photosynthesis and blocking oxygen diffusion. Also populations of animals are reduced in the water beneath the mats (Gratwicke and Marshall 2001).

Genetic effects
Janes (1998b) reported that there is some evidence that *A. filiculoides* might have adapted to the British climate since its introduction. Similar adaptations are possible for the population in other countries.

Human health effects
There are no human health effects known.

Economic and societal effects (positive/negative)
The genus *Azolla* is useful in rice fields, because it can assimilate atmospheric nitrogen gas owing to the nitrogen fixation by cyanobacteria (blue green alga) living in the cavities located at the lower side of upper (dorsal) lobes of leaf. By this, *Azolla* is used as a green manure in rice fields in Asia since several decennia (Moore 1969, Mandal *et al.* 1999, Choudhury and Kennedy 2004, De Macale and Vlek 2004, Nayak *et al.* 2004, Kimura 2005). Aside from this fertilizing effect in cultivation of rice, *Azolla* may influence the pH of the water (Vlek *et al.* 2002). Shiomi and Kitoh (2001), Parthasarathy *et al.* (2002) and Reyes and Fermin (2003) described the use of *Azolla* as a feed for animals, particularly for fishes.

In the last years the genus *Azolla* has become more and more important in wastewater treatments to eradicate different metals or to remove nitrogenous compounds from the water (Ghobrial and Siam 1998, Sanyahumi *et al.* 1998, Zhao and Duncan 1998, Costa *et al*. 1999, Zhao *et al.* 1999 a, b, Allison *et al.* 2000, Forni *et al.* 2001a, b, 2002, Cohen-Shoel *et al.* 2002, Oren Benaroya *et al.* 2004, Shiny *et al.* 2004, Gardea *et al.* 2005, Stepniewska *et al.* 2005).

On the other hand, *Azolla* can form such dense and thick mats, that it may be impossible to row a boat through it (Moore 1969). *Azolla* mats can reduce the population of different animals from water beneath the mats (Gratwicke and Marshall 2001), and furthermore submerged plants can be eradicated by shading (Janes *et al.* 1996).

Management approaches

Prevention methods
Prevention methods are not known.

Eradication, control and monitoring efforts
Control options for *A. filiculoides* are limited. Due to a surface-area doubling time of 7-10 days, mechanical control is impractical. Hill and Cilliers (1999) considered manual, mechanical and herbicidal control as undesirable and only small infestations of *Azolla* can be removed manually using fine meshed nets. Barreto *et al.* (2000) described the biological control of *Azolla* with fungi. Hill (1998), Hill and Cilliers (1999) and McConnachie *et al.* (2003, 2004) described a successful biological control of bigger occurrences by the frond-feeding weevil *Stenopelmus rufinasus* in South Africa, where *A. filiculoides* covered dams and water reservoirs.

Education and awareness
No information available.

Knowledge and research

There is a broad knowledge about the biology and physiology of *A. filiculoides*. Since several decennia scientists around the world have investigated the genus *Azolla*. Moore (1969) and Lumpkin and Plucknett (1980) have made excellent reviews of literature. In the last years the control of *A. filiculoides* has gained more and more importance (McConnachie *et al.* 2003, 2004). In addition the research about bioaccumulation and phytoremediation has received high interest in the science of wastewater treatment (Ghobrial and Siam 1998, Sanyahumi *et al.* 1998, Zhao and Duncan 1998, Zhao *et al.* 1999 a, b, Forni *et al.* 2001, 2002, Cohen-Shoel *et al.* 2002, Oren Benaroya *et al.* 2004, Shiny *et al.* 2004, Gardea *et al.* 2005, Stepniewska *et al.* 2005).

Recommendations or comments from experts and local communities
A comprehensive investigation of actual distribution and involved water bodies will be helpful for an estimation of the further spread of this species in our region.

References and other resources

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Links

Aquatic neophytes – in German

Flora of Northern Ireland – fact sheet on *Azolla filiculoides*

Canadas Plant Species – *Azolla filiculoides* incl. distribution map

Biological Control of Red Water Fern in South Africa - report

Azolla in USA

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