Ephemeral Occurrence of the Mosquito Fern, *Azolla caroliniana*, at Ottawa, Ontario

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Mosquito fern, *Azolla caroliniana*, is known in Canada only from records at Hamilton (1862) and Gananoque (1981), where it did not persist. In 1997 it was found in a pond in a residential area of central Ottawa. In 1998 is was not detected at this pond, but was found in the Rideau River through central Ottawa and into the Ottawa River on both the Ontario and Quebec shores. The enormous populations which had spread in the rivers in 1998 were completely absent in 1999.

Key Words: *Azolla caroliniana*, Mosquito Fern, invasive plants, weeds, rare plants, plant dispersal.

The fern family Azollaceae contains one genus, *Azolla*, with about five to seven extant species and a number of others known from fossil material. Commonly called mosquito ferns, they are small free-floating aquatic plants distributed in tropical and warm temperate regions throughout the world. Morphological reduction is exhibited along with various adaptations to its aquatic habitat. Copiously branched short stems bear alternate and (usually) closely imbricate leaves and a few pendulous roots. The leaves are divided into two lobes, a slightly larger, thin and translucent submersed lobe and a green or reddish emersed lobe covered with minute papillae.

Three species are native to North America with two reported in Canada, *Azolla mexicana* C. Presl in British Columbia, and *A. caroliniana* Willd. in Ontario (Cody and Britton 1989). Another species, *A. filiculoides* Lam. has been reported for southern Alaska (Svenson 1944; Lumpkin 1993) and may possibly be found in British Columbia. The distribution maps for *A. mexicana* and *A. caroliniana* in Cody and Britton (1989) have the captions inadvertently switched.

Widespread in the eastern United States, south through Central America and the West Indies to South America, *A. caroliniana* has also been introduced to Europe and Asia (Lumpkin 1993). In spite of its wide distribution, Lellinger (1985) considered it a "rare" plant. Other authors report it as common or even abundant, but, because of its rapid growth under suitable conditions, large populations can cover connected water bodies quickly, giving an illusion of widespread abundance. Although known from northern New York State (see overview in Cody and Schueler 1988), it has been found only twice in Ontario (Cody and Schueler 1988). The first collection in Canada is of plants taken at Burlington Beach (near Hamilton) in 1862. The plant does not seem to have persisted there, and has not been seen since the original collection. An extensive population found at Knights Creek (near Gananoque) in 1981 also did not persist to the following year (Cody and Schueler 1988).

Azolla caroliniana is a plant of slow-moving or stagnant water in ponds, lakes, marshes, swamps, streams, rivers, ditches, etc. (Lumpkin 1993). It is the most cold resistant species in the genus (Lumpkin 1993), and Redman (1995) reported that populations successfully over-wintered in Maryland and Washington, D.C. Studies on physiology and responses to environmental conditions have mostly been conducted on the economically important, tropical and subtropical species *A. pinnata* R. Br. and are summarized by Wagner (1997).

Species of *Azolla* are heterosporic, but reproduction in *A. caroliniana* seems to be entirely vegetative. Megaspores are unknown, although microspores are sometimes detected and are produced under conditions of crowding (Lellinger 1985).

A symbiotic relationship has formed between species of *Azolla* and the cyanobacterium (blue-green alga) *Anabaena azollae* Strasb. (and possibly other bacteria) much like the relationship between the Fabaceae (Leguminosae) and *Rhizobium* (Wagner 1997). The cyanobacterium is able to fix atmospheric nitrogen, thus providing a source of this nutrient normally unavailable to plants (Wagner 1997). Although nitrogen is not a limiting nutrient, phosphorus availability can be a major constraint on *Azolla* growth (Kushari and Watanabe 1991; Wagner 1997). Reports of minimal phosphorous concentrations required for maximum growth vary between studies as well as between species. Concentrations ranging from 400 $\mu g\ l^{-1}$ to 20,000 $\mu g\ l^{-1}$ have been reported as minimum requirements for maximum growth rates. Under optimal conditions some *Azolla* species can double their biomass in 3–5 days (Lumpkin and Plunknett 1982; Wagner 1997).

Because of the high nitrogen content, various species are used in agriculture as a green manure or biofertilizer (Lumpkin and Plucknett 1982). Some species, including *A. caroliniana*, are used as ornamental plants in aquaria and decorative pools (Lellinger 1985; L. H. Bailey Hortorium 1976). Other uses and applications are summarized by Wagner (1997). In some situations *A. caroliniana* has been a serious weed disrupting aquatic ecology and interfering with human activities (Thieret 1980). The reduction of light (up to 90%) and reduced oxygen levels (50% or more) in the water column under *Azolla* mats can have such an affect on other vegetation that it has been studied as a means of weed control in rice paddies (Wagner 1997).

Azolla caroliniana at Ottawa

In September of 1997 a population of *A. caroliniana* was found in the westerly pond of Brown's Inlet off the Rideau Canal in Ottawa, Ontario (Figure 1, site 1; Appendix 1, specimen 1). Individual plants and mats in patches up to about 0.5 m in diameter were common around the perimeter of the pond among other floating and emergent plants. Other vegetation studies in this pond during the previous two years had failed to detect the fern (personal observations).

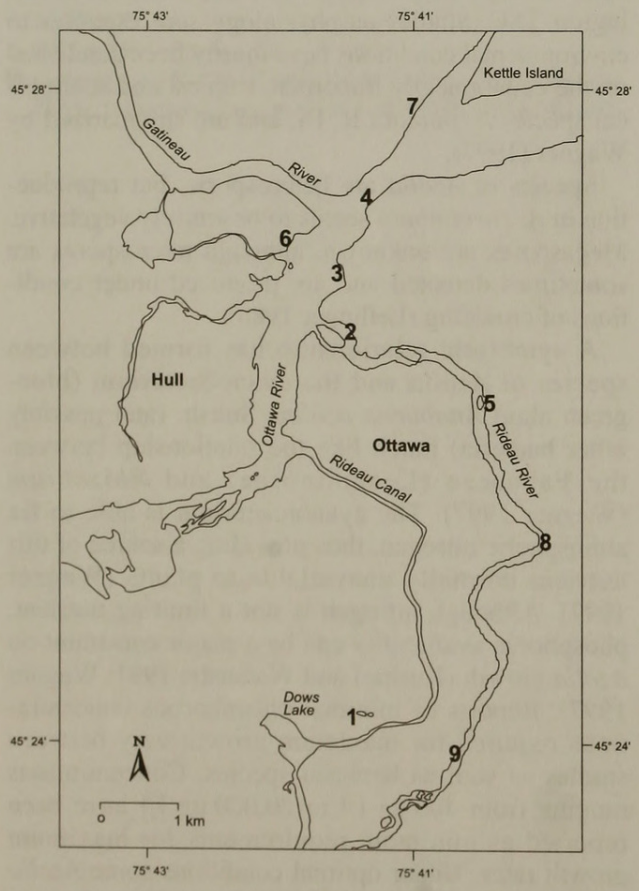

FIGURE 1. Map of the area of the Rideau and Ottawa Rivers where *Azolla caroliniana* populations occurred in 1997 and 1998. Numbers correspond to approximate locations of collections listed in Appendix 1.

The pond, being connected to the Rideau Canal system, is completely drained in the autumn (usually October) of each year. Draw-down of water in the Canal commenced on 15 October 1997. Drainage of the pond was complete by 18 October and mats of *A. caroliniana* were left stranded on the wet mud. On 19 and 20 October, daily minimum temperatures were about -3°C. The first significant snowfall occurred on October 21 (9 cm) and then again on October 26 (18 cm); however, persistent snow cover did not occur until November 15. During this time minimum temperatures of less than -5°C were recorded on six days (24, 26 and 27 October, and 12, 13 and 14 November), including the minimum of -9.4°C on 13 November. Stranded plants would have had little protection from dessication and cold temperatures for more than a month. Continued observations during the next two years did not detect *A. caroliniana* at Brown's Inlet. It is presumed that these winter conditions proved too harsh for the vegetative material to over-winter.

In late summer of 1998, colonies of *A. caroliniana* were seen in substantial mats along the shores of the Rideau River. Through the month of September surveys were conducted along the Rideau River and the Ottawa River downstream from the mouth of the Rideau River. Although a much wider area was surveyed (upstream on the Rideau River to Manotick, downstream on the Ottawa River to Cumberland, and the Rideau Canal from Mooney's Bay to the Ottawa River), *A. caroliniana* was found only between collection sites 7 and 9 (Figure 1; Appendix 1). Over this stretch of about 10 kilometres it was abundant, often completely swathing the shore for considerable distances. Mats became sparser at the upstream and downstream extremes of the distribution and where the river shores were exposed to strong currents or waves. Mats were mostly along shores and becoming thick and continuous in quiet bays and around protecting emergent vegetation such as Cattails (*Typha latifolia* L.) or Reed Canary Grass (*Phalaris arundinacea* L.). Sometimes mats would become dislodged in currents and drift downstream. In fast running water the mats would disintegrate into individual plants or small clumps, but in slow moving water contiguous mats of about a hundred square metres were sometimes seen. While not at optimum growth levels, phosphorous concentrations measured every two weeks in the Rideau River showed a plentiful supply of this nutrient as well as a peak during the major population expansion in mid-July, 1998 (Figure 2).

Systematic and repeated searches in August and September of 1999 throughout the area of the previous year's infestation failed to detect a single plant of *A. caroliniana*. Less detailed searches in 2000 were also negative. The large population seems to be the result of a single introduction at a point close to collection site number 9 (Figure 1). Figure 2

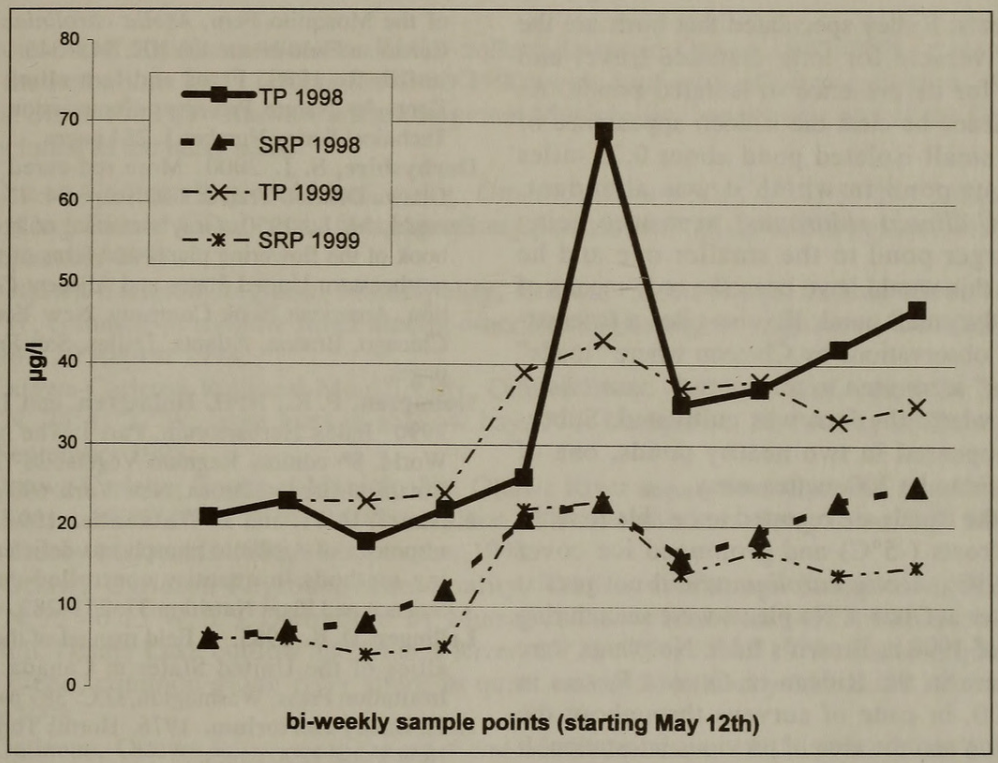

FIGURE 2. Plot of the total phosphorus (TP) and soluble reactive phosphorus (SRP) in the Rideau River during the summers of 1998 and 1999 (Paul Hamilton, personal communication). Samples were taken at 2 week intervals starting May 12 at station #103 (St. Patrick Street Bridge), about half way between points 2 and 5 on Figure 1.

indicates that phosphorous concentrations would not have been a limiting factor in 1999, so the complete disappearance is most likely the result of winter-kill.

Dispersal of *Azolla*

The west bank of the Rideau River at collection site 9 has a gentle slope allowing easy access to the water and is immediately adjacent to a small residential enclave. The introduction could have easily occurred here from the dumping of aquarium contents. Species of *Azolla* are easily and often grown in aquaria for decorative purposes and used in science teaching to demonstrate the nitrogen fixing heterocysts of the symbiotic cyanobacteria. Small (1935) considered the occurrences of *A. caroliniana* around southeastern New York State and northern New Jersey (and by implication further north) to be colonies naturalized from human introductions. Fernald (1950) also considered northern occurrences as being likely spread from cultivation.

In recent years a number of exotic aquarium-trade species have been reported as introduced into the Rideau Canal and Rideau River round Ottawa, including several tropical fish species (Renaud and Phelps 1999; Renaud and Phelps 2001) and a turtle (Darbyshire 2000). It may well be that the introduction of *A. caroliniana* into the Rideau River occurred coincidental with the dumping of fish or other aquarium animals early in season of 1998. The occurrence of the plant in Brown's Inlet (collection 1, Appendix 1) was most likely a deliberate introduction. Brown's Inlet consists of two ponds in an urban residential area. They are separated from each other and from the Rideau Canal by roadbeds, but all connected by submerged culverts. *Azolla* was found only in the upper pond which has a small municipal park on the south side and residential property to the north. Other exotic plants sold for aquaria and ponds have also been collected in this same pond. Some of these have established and persisted for many years (e.g., *Nymphoides peltata* (Gmel.) Kuntze), while others have been ephemeral (e.g., *Pistia stratiotes* L.).

Cranfill (1980), observing the ephemeral nature of populations and the species' North American distribution, speculated that *A. caroliniana* is continually re-introduced by migrating waterfowl. The most upstream site of the 1998 infestation, collection site 9, is immediately downstream from a shallow area in the Rideau River which attracts large numbers of ducks. Extensive parks with ready shore access on the east side of the river (especially immediately upstream) are popular areas for people to feed waterfowl generating an additional attraction for birds.

Ridley (1930) made some very interesting observations on the various actual and probable distribution vectors of *Azolla* species in Europe and Great Britain. In addition to river flow and flood water, he cited water-birds, frogs, and human activity as

dispersal agents. Ridley speculated that birds are the most likely vehicle for long distance travel and explanation for its presence in isolated ponds. As indirect evidence he cites the sudden appearance of *Azolla* in a small isolated pond about 0.25 miles from a larger pond in which it was abundant. Moorhens (*Gallinula chloropus*) were seen going from the larger pond to the smaller one and he claimed that this would have been the only means of transport to the small pond. He also cites a fascinating series of observations by Chateau where "toads" and/or "frogs" were seen to transport *A. caroliniana* out of pans where the fern was cultivated. Subsequently it appeared in two nearby ponds, one of which was said to be 200 metres away.

Although the fronds are reported to be able to withstand hard frosts (-5°C) and prolonged ice cover (Lumpkin 1993), *Azolla caroliniana* did not persist over the winter at Ottawa. No plants were seen during the summer of 1998 at Brown's Inlet. No plants were seen anywhere in the Rideau or Ottawa Rivers in 1999 or 2000, in spite of surveys throughout the growing season and the area of previous infestation. It is not known what mechanism brought *A. caroliniana* to the Ottawa area in two separate years at two separate locations. It is possible that it arrived early in the growing season transported from more southerly populations by migrating waterfowl. Circumstantial evidence and the prevalence of recent reports of liberated aquarium fauna and flora suggest that human agents are the most likely cause, especially in the case of Brown's Inlet.

Acknowledgements

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APPENDIX 1.

Voucher specimens of *Azolla caroliniana* Willd. collected around Ottawa 1997–1998. A complete set is deposited at the herbarium DAO (Holmgren et al. 1990) with duplicates of some collections distributed to other herbaria. Since 1998 the Ottawa-Carleton Regional Municipality has became part of the City of Ottawa and now is included in the latter name.

1. Ontario, Ottawa-Carleton Regional Municipality, Ottawa, Brown's Inlet, 45°23′55"N, 75°41′28″W, artificial pond along Rideau Canal, mats forming among patches with *Nymphoides peltata*, S. J. Darbyshire 4748, 7 September 1997.
2. Ontario, Ottawa-Carleton Regional Municipality, Ottawa, Green Island, Rideau River, 45°26′23″N, 75°41′28″W, common in shallow water among other floating/emergent vegetation, S. J. Darbyshire & P. Ouellet 4984, 30 August 1998.
3. Ontario, Ottawa-Carleton Regional Municipality, Ottawa River, Governor Bay, below 24 Sussex Drive, 45°26′45″N, 75°41′27″W, large mats in shallow bay, S. J. Darbyshire, M. Murray & Tracey McDonald 4985, 10 September 1998.
4. Ontario, Ottawa-Carleton Regional Municipality, Ottawa River across from Gatineau (Quebec), Rockcliffe Park Boathouse, 45°27′18″N, 75°41′16″W, common in sheltered waters along shore, S. J. Darbyshire, M. Murray & Tracey McDonald 4986, 10 September 1998.
5. Ontario, Ottawa-Carleton Regional Municipality, Vanier, Cummings Bridge over Rideau River, 45°25′54″N, 75°40′15″W, S. J. Darbyshire, M. Murray & Tracey McDonald 4987, 10 September 1998.
6. Quebec, Hull, Leamy Lake outflow and Ottawa River, 45°26′57″N, 75°42′19″W, shallow, quiet water near mouth of creek, common along river shore in quiet water, S. J. Darbyshire & M. Murray 4998, 29 September 1998.
7. Quebec, Gatineau, Ottawa River, near the west end of Kettle Island, 45°27′51″N, 75°40′55″W, shallow water among emergent vegetation, with *Scirpus, Pontederia, Sagittaria, Lemna, Typha*, S. J. Darbyshire & M. Murray 5000, 29 September 1998.
8. Ontario, Ottawa-Carleton Regional Municipality, Ottawa, Hurdman Bridge, Rideau River, 45°24′59″N, 75°39′53″W, large patches around *Phalaris arundinacea* and emergent vegetation, with *Spirodella*, S. J. Darbyshire & M. Murray 5001, 29 September 1998.
9. Ontario, Ottawa-Carleton Regional Municipality, Ottawa, near George McIlraith Bridge, Rideau River, 45°24′07″N, 75°40′10″W, shallow water along shore with emergent vegetation, S. J. Darbyshire & M. Murray 5002, 29 September 1998.

An additional specimen is at the Canadian Museum of Nature (CAN). This collection was made about halfway between sites 2 and 5 in Figure 1.

Ontario, Ottawa-Carleton Regional Municipality, Rideau River at the St. Patrick Street bridge, east bank just south of bridge, 45°26.2′N, 75°40.5′W, band of emergent and subemergent vegetation in area with moderate flow, hard gravel/mud substrate; small green and red floating plants, forming a mat along shore over a large area; tiny leaves, roots hanging 5–10 cm, M Richard & R. Boles 98-217, 30 September 1998.