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Distribution and Density of Vegetative Hydrilla Propagules in the Sediments of Two New Zealand Lakes

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ABSTRACT

The distribution and density of hydrilla (*Hydrilla verticillata* (L.f.) Royle) turions and tubers in two New Zealand lakes were assessed by sampling cores of sediment from Lakes Tutira and Waikapiro each year from 1994 to 1997. Turion and tuber density differed with water depth, with maximum numbers of tubers and turions found in the 1-2 m and 1.5-4 m water depth ranges respectively. A high turion to tuber ratio was observed, with turions accounting for over 80% of the propagules. The relatively low numbers of turions and tubers compared with other reports, and the distribution of most tubers within the shallow water is likely to be associated with black swan grazing (*Cygnus atratus* Latham), which maintains a canopy of hydrilla consistently 1 m below the water surface.

Key words: turion, tuber, sediment cores, *Hydrilla verticillata.*

INTRODUCTION

Dioecious male hydrilla is an introduced macrophyte in New Zealand, which was first recorded in Lake Tutira in 1963 (Clayton et al. 1995). Currently its distribution is limited to four lakes in the Hawke's Bay region. The two largest lakes, Tutira (147 ha) and Waikapiro (11 ha) have extensive hydrilla distribution. Control measures have not been effective in reducing hydrilla abundance in these two lakes. In particular, diquat, the only herbicide registered for aquatic use has failed to reduce plant biomass, while mechanical methods have limited suitability on account of the increased risk of spread, and short duration of control. Containment measures, aimed at minimizing the risk of fragments escaping and becoming more widespread have been implemented on both lakes and include the prohibition of motorized boats and netting for fish. Hydrilla has been more effectively managed in both of the smaller lakes Opouahi (6 ha) and Eland (4 ha). In Lake Opouahi hydrilla presently has a restricted distribution and low abundance, with some localized control obtained using weed mat. In Lake Eland all of the original hydrilla stands have been removed using grass carp, which have been present for ten years (Clayton et al. 1995).

Hydrilla turions and tubers (subterranean turions) represent different survival and dispersal strategies (Van and Steward 1990). Turions are produced on stems in the water column and are smaller than tubers, which are produced in the hydrosoil on geotropic shoots (Yeo et al. 1984, Spencer et al. 1994). Turions are more likely than tubers to be dispersed through normal water movement, currents and tides, and have a greater probability of growing in an unoccupied area (Spencer and Rejmanek 1989, Miller et al. 1993), whereas tubers provide a means of perennation in the currently occupied habitat (Van and Steward 1990). Additionally, tubers remain viable for longer than turions. Tubers from monoecious hydrilla plants have survived in undisturbed sediment for over four years, whilst turions germinate readily and expire after one year (Van and Steward 1990). In New Zealand on going studies in Lake Eland sediment have recorded viable tubers for up to 8 years, while turions were only viable for two years (personal observation).

Tubers and turions are the major source of regrowth after herbicide treatments, drawdown periods and grazing by herbivorous fish (Sutton and Portier 1985). Because of the effectiveness with which these propagules hamper hydrilla control programmes, a number of studies have reported on the conditions under which tubers and turions are produced and germinate in different strains of hydrilla (Netherland 1997, Miller et al. 1993, Sutton et al. 1992, Thullen 1990, Spencer and Rejmanek 1989, Van 1989, Bowes et al. 1979, Van et al. 1978, Haller et al. 1976, Miller et al. 1976). However, compared with the number of studies on the production and germination of propagules very little information is available on the relative abundance of turions and tubers (Sutton 1996). Given that these are the primary means for regrowth and dispersal, there is a need to determine the relative frequency and distribution of turions and tubers in the lake environment. Determining the relative frequency and distribution of these propagules in New Zealand's Lakes Tutira and Waikapiro should enable a better understanding of the importance of the vegetative propagule bank (Spencer and Rejmanek 1989) and the potential for hydrilla regrowth or reinfestation following future implementation of control programmes.

MATERIALS AND METHODS

Field Sampling. Lakes Tutira and Waikapiro in the Hawke's Bay were visited during April and December 1994, and April 1995, 1996 and 1997. A total of five sites were sampled from each lake over the duration of the study. The sites were T1-T5 from Lake Tutira and W1-W5 from Lake Waikapiro (Figure 1).

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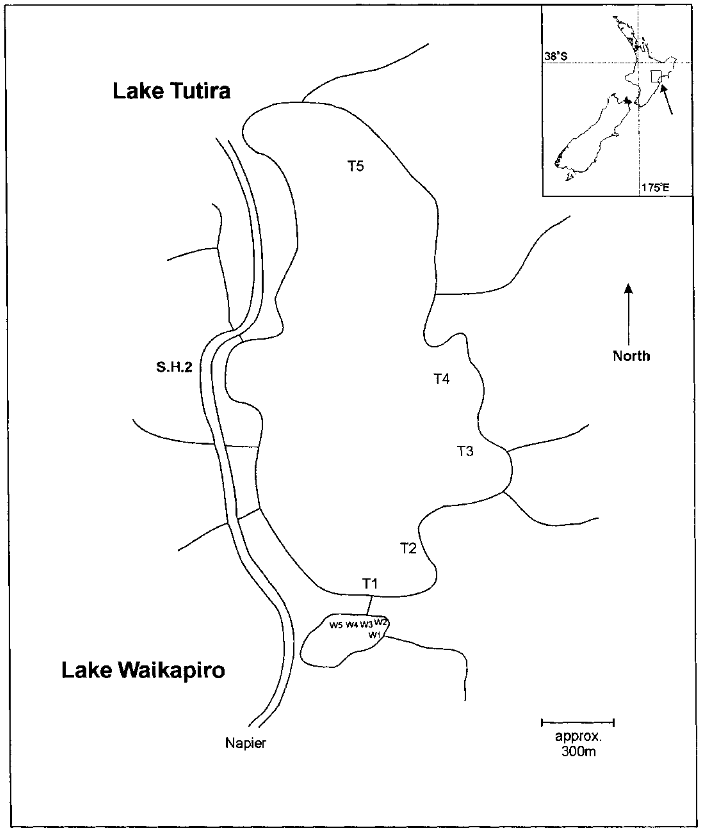

Figure 1. Lake Tutira and Lake Waikapiro sample sites. The inset map of New Zealand (top right corner), shows the location of these lakes.

At each sample site a SCUBA diver recorded the depth distribution of plant species, their relative abundance, cover and height, within a 2 m wide area from the water's edge down to the maximum depth of plant growth (Clayton 1983).

The distribution of vegetative propagules was assessed following collection of sediment samples at water depths of 0.5, 1, 1.5, 2, 3, 4, 5, 6, 7 and 8 m. At all ten sites at least six cores (nine in 1996 and 1997) were taken at each depth and retained in mesh bags for sorting. Sediments were washed in mesh bags to remove most of the hydrosoil and the retained material was sorted on trays and hydrilla turions and tubers were counted. In 1994 different core sizes were tested (100 mm was the smallest and 435 mm was the largest), and from 1995 to 1997 the core size was standardized to 220 mm diameter by 290 mm long.

Data Analysis. Turion and tuber numbers at each site were rank transformed because the data were not consistent with distributions used in standard parametric models. The t-test of the ranked data was used to determine if there were differences between the lakes at each water depth interval. A second comparison was made using a simple sign test, between adjacent water depths to determine if propagule numbers had changed significantly from one depth interval to the next.

RESULTS

Vegetation. Lakes Waikapiro and Tutira vegetation was characterized by an assemblage of shallow water, low-growing plants between 0.2 to 1.0 m depth, that included species of *Ruppia, Chara, Glossostigma* and *Myriophyllum* (Table 1), and by large tall-growing stands of hydrilla, which were present from a depth of 1 to 6 m, with a few shorter plants to a depth of ca. 8 m. Hydrilla grew to a maximum height of 6 m and 5 m in Lakes Tutira and Waikapiro respectively. *Elodea canaden-*

TABLE 1. SPECIES COVER AND DISTRIBUTION ALONG LAKE PROFILES.

Site	Species	Cover *average & (max.)	Depth range (m)
Tutira (T1)	*Hydrilla verticillata* (L.f.) Royle	6 (6)	1.0-6.5
	Elodea canadensis Michx.	5 (6)	1.0-1.5
	Myriophyllum triphyllum Orchard	2 (2)	1.0-1.5
	Chara globularis Thuill.	1 (2)	1.5
	Chara corallina Willd.	1 (1)	1.0-1.5
	Lilaeopsis ruthiana Affolter	1 (1)	1.0-1.5
Tutira (T2)	*Hydrilla verticillata*	6 (6)	1.0-7.5
	Myriophyllum triphyllum	2 (3)	0.5-0.5
	Elodea canadensis	5 (6)	0.5-1.5
	Ruppia polycarpa R. Mason	1 (2)	0.5-0.5
Tutira (T3)	*Hydrilla verticillata*	6 (6)	1.5-7.5
	Elodea canadensis	4 (6)	0.5-1.5
	Ranunculus limosella F. Muell. ex Kirk	1 (2)	0.2-0.5
	Chara globularis	1 (2)	0.5-1.0
	Potamogeton ochreatus Raoul	2 (3)	0.5-1.0
	Glossostigma diandrum (L.) Kuntze	1 (2)	0.2-0.5
Tutira (T4)	*Hydrilla verticillata*	6 (6)	1.5-7.5
	Elodea canadensis	5 (6)	0.-1.5
	Chara globularis	2 (3)	0.5-1.0
	Chara corallina	1 (1)	0.-1.0
	Lilaeopsis ruthiana	1 (2)	0.-1.0
Tutira (T5)	*Hydrilla verticillata*	6 (6)	1.0-8.5
	Elodea canadensis	6 (6)	0.5-1.0
	Potamogeton crispus L.	1 (1)	0.5
	Chara globularis	1 (1)	0.5
	Ruppia polycarpa	1 (1)	0.5-1.0
	Lilaeopsis ruthiana	1 (1)	0.5
Waikapiro (W1)	*Hydrilla verticillata*	6 (6)	0.5-6.5
	Glossostigma elatinoides Benth.	2 (5)	0-0.7
	Chara corallina	1 (1)	0-0.7
	Chara globularis	1 (1)	0-0.7
	Potamogeton ochreatus	1 (1)	0-0.7
	Potamogeton cheesemanii A. Benn.	1 (1)	0-0.7
Waikapiro (W2)	*Hydrilla verticillata*	6 (6)	0.1-5.0
	Chara globularis	1 (2)	0.1-1.0
	Chara corallina	2 (4)	0.3-1.0
	Nitella hyalina (D.C.) Ag.	1 (2)	0.1-0.3
	Myriophyllum triphyllum	1 (1)	0.1-1.0
Waikapiro (W3)	*Hydrilla verticillata*	6 (6)	0.3-5.0
	Chara globularis	3 (6)	0.1-1.0
	Chara corallina	2 (4)	0.3-1.0
	Potamogeton crispus	1 (1)	0.3-1.0
	Lilaeopsis ruthiana	1 (2)	0.1-0.3
Waikapiro (W4)	*Hydrilla verticillata*	6 (6)	1.0-8.0
	Chara corallina	2 (3)	0-2.0
Waikapiro (W5)	*Hydrilla verticillata*	6 (6)	1.0-6.5

*Average and maximum cover values correspond to the following, 6 = 96-100% cover, 5 = 76-95% cover, 4 = 51-75% cover, 3 = 26-50% cover, 2 = 6-25% cover, and 1 = 1-5% cover.

sis was not common in Lake Waikapiro, while in Lake Tutira it occasionally occupied the same depth range as hydrilla and often formed a shallow band of weed between the shallow-water, low-growing community and the hydrilla.

Propagule Density and Distribution. Tubers were recorded in eight of the ten sample sites, W1, W2, W3, W5, T1, T2, T3 and T5, and were located at water depths between 1 and 5 m. Maximum tuber densities occurred between 1 and 2 m water depth across all sites and the maximum tuber density (mean from all sites) was 8 m^{-2} at 1.5 m (Figure 2).

Turions on average accounted for 81% (SE = 7) of all propagules, and were more common than tubers from all sites in both lakes Tutira and Waikapiro. Turions were recorded from all sample sites over a 1 to 7 m depth range, with a maximum (mean from all sites) density of 40 to 55 m^{-2} at 1.5 to 4 m water depths. There was no significant difference in turion and tuber numbers between lakes, but turion densities changed significantly between water depths. There was a significant increase in turion numbers between 1-2 m and a decrease between 4-5 m and 5-6 m. Tuber numbers did not differ significantly between adjacent water depths, however tubers were not found beyond 5 m.

DISCUSSION

Miller et al. (1976) observed an increase in tuber number with increasing water depth between 0.3 and 1.5 m, and described tuberisation (the production of tubers) of hydrilla as occurring in any depth of water at which a rooted canopy grows. Tubers in Lakes Tutira and Waikapiro were recorded to 5 m water depth. The absence of tubers in sediment from water deeper than 5 m was associated with a lack of hydrilla canopy formation. A maximum shoot height of 5 and 6 m (mean height 4 and 5 m) was recorded in Lakes Waikapiro and Tutira respectively, with a canopy consistently 1.0 to 1.1 m below the water surface. Once water depth exceeded 5 m

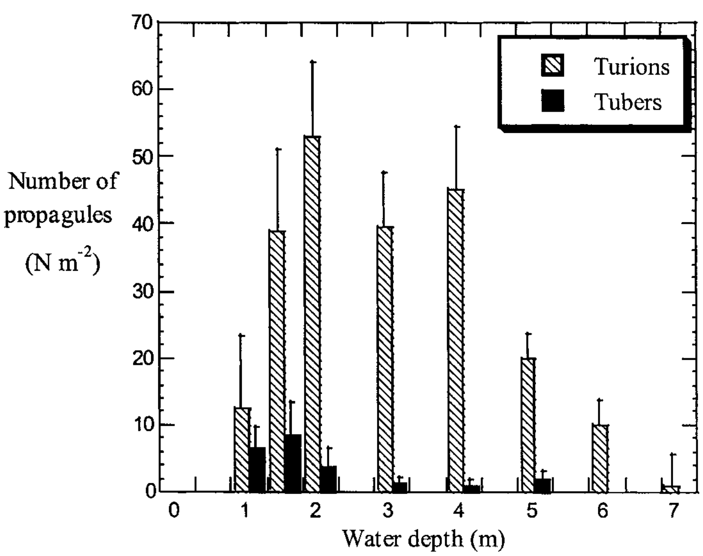

Figure 2. Mean number of propagules in lake sediments from different water depths in Lakes Tutira and Waikapiro. Bars represent the mean number of propagules present in cores (n = 6) from all profiles. Vertical lines on each bar indicate the standard error.

the plants were less dense and no longer as close to the surface of the water.

In shallow water systems where hydrilla is able to form a canopy over most of the lake, tuber production could be expected to be greater than in lakes with narrower littoral margins. Reported studies that have examined sediment for tubers appear to have sampled typically < 2.5 m (Bowes et al. 1979, Sutton and Portier 1985, Miller et al. 1976, Sutton 1996), and make no mention of tuber density or distribution at greater water depths. Tuber densities are generally higher than those found in the present study (Netherland 1997). For example, Lake Ocklawaha, which has an infestation of female dioecious plants was reported to have 300-600 tubers m^{-2}, at water depths of 0.3 to 0.9 m (Miller et al. 1976). Similarly, Bowes et al. (1979) reported tuber densities from 20 to 510 tubers m^{-2}, at a water depth of 1 m in three Florida lakes.

The maximum turion densities observed in Lakes Tutira and Waikapiro were 40-55 m^{-2} (mean data). Published data on turion density would suggest that turions are rare or absent in dioecious female hydrilla (Thullen 1990). However, a sediment survey by Sutton (1996) reported a maximum turion density of 918 turions m^{-2} in water 2 m deep in a Florida canal in autumn. Sutton (1996) also found variation in turion density between sampling dates and sampling sites in the same river system, the latter being attributed to local environmental factors, such as shade, resulting in lower plant biomass and fewer propagules. Sutton and Portier (1985), found no indication of seasonal fluctuation in propagule density in five South Florida lakes. They suggested that a steady state condition exists, in which the rate of formation of new propagules equals that of germination, with the maximum number for a body of water dependent on sediment type, nutrient concentration, water quality and other factors. In the present study turions occurred throughout a 7 m depth range, only 1 to 1.5 m less than the maximum depth of the hydrilla plants. There was no difference in turion number associated with sampling site, however there was significant variation in turion distribution with water depth, which may reflect turion production in the hydrilla stand. A maximum number of turions between 2 to 4 m water depths, could be attributed to high light intensity and plant biomass, and the subsequent reduction in turion density at 5 to 7 m could largely be due to the reduction in light intensity with increasing water depth.

Apart from preventing motorized boat access to these lakes, an additional factor reducing the risk of hydrilla escape from Lakes Waikapiro and Tutira is the grazing of weed beds by the Australian black swan. Large numbers of these birds congregate on the littoral margins where they crop weed bed canopies to approximately 1 m of the water surface, also reported by Howard-Williams and Davies (1988) in other New Zealand lakes. This has the effect of reducing weed drift along the shoreline and may also contribute to the lower incidence of tuber and turion densities compared to other reported studies.

The results of this study indicate that once hydrilla has become established, the wide depth ranges over which tubers and turions can occur will continue to provide an extensive resource for regrowth following either adverse environmental conditions or control measures.

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LITERATURE CITED

Bowes, G., A. S. Holaday and W. T. Haller. 1979. Seasonal variation in the biomass, tuber density and photosynthetic metabolism of *Hydrilla* in three Florida lakes. J. Aquat. Plant Manage. 17: 61-65.

Clayton, J. S. 1983. Sampling aquatic macrophyte communities. In: B. J. Briggs, J. S. Gifford and D. G. Smith (ed.). Biological Methods for Water Quality Surveys. Water and Soil miscellaneous Publication 54, Ministry of Works and Development, Wellington. pp. AM/1-AM/22.

Clayton, J. S., P. D. Champion and N. H. McCarter. 1995. Control of *Hydrilla verticillata* in a New Zealand lake using triploid grass carp. In: E. S. Delfosse and R. R. Scott (ed.). Proc. of the Eigth Int. Symp. on Biological Control of Weeds, February 1992, Lincoln, New Zealand. pp. 275-285.

Haller, W., J. L. Miller and L. A. Garrard. 1976. Seasonal production and germination of *Hydrilla* vegetative propagules. J. Aquat. Plant Manage. 14: 26-29.

Howard-Williams, C. and J. Davies. 1988. The invasion of Lake Taupo by the submerged water weed *Lagarosiphon major* and its impact on the native flora. N. Z. J. Ecol. 11: 13-19.

Miller, J. L., W. T. Haller and M. S.Glenn. 1993. Turion production by dioecious *Hydrilla* in North Florida. J. Aquat. Plant Manage. 31: 101-105.

Miller, J. L., L. A. Garrard and W. T. Haller. 1976. Some characteristics of *Hydrilla* tubers taken from Lake Ocklawaha during drawdown. J. Aquat. Plant Manage. 14: 29-31.

Netherland, M. D. 1997. Turion ecology of *Hydrilla*. J. Aquat. Plant Manage. 35: 1-10.

Spencer, D., L. Anderson, G. Ksander, S. Klaine and F. Bailey. 1994. Vegetative propagule production and allocation of carbon and nitrogen by monoecious *Hydrilla verticillata* (L.f.) Royle grown at two photoperiods. Aquat. Bot. 48: 121-132.

Spencer, D. and G. C. Ksander. 1994. Phenolic acid content of vegetative propagules of *Potamogeton* species and *Hydrilla verticillata*. J. Aquat. Plant Manage. 32:71-73.

Spencer, D. and M. Rejmanek. 1989. Propagule type influences competition between two submersed aquatic macrophytes. J. Aquat. Plant Manage. 81: 132-137.

Sutton, D. L. 1996. Depletion of turions and tubers of *Hydrilla verticillata* in the North New River canal, Florida. Aquat. Bot. 53: 121-130.

Sutton, D. L. and K. M. Portier. 1985. Density of tubers and turions of *Hydrilla* in South Florida. J. Aquat. Plant Manage. 23: 64-67.

Sutton, D. L., T. K. Van and K. M. Portier. 1992. Growth of dioecious and monoecious *Hydrilla* from single tubers. J. Aquat. Plant Manage. 30: 15-20.

Thullen, J. S. 1990. Production of auxillary turions by the dioecious *Hydrilla verticillata*. J. Aquat. Plant Manage. 28: 11-15.

Van, T. K. 1989. Differential responses to photoperiods in monoecious and dioecious *Hydrilla verticillata*. Weed Sci. 37: 552-556.

Van, T. K., W. T. Haller and L. A. Garrard. 1978. The effect of daylength and temperature on hydrilla growth and tuber production. J. Aquat. Plant Manage. 16: 57-59.

Van, T. K. and K. K. Steward. 1990. Longevity of monoecious *Hydrilla* propagules. J. Aquat. Plant Manage. 28: 74-76.

Yeo, R. R., R. H. Falk and J. R Thurston. 1984. The morphology of hydrilla (*Hydrilla verticillata* (L.f.) Royle). J. Aquat. Plant Manage. 22: 1-7.