
Management Options Assessment Report for *Hydrilla verticillata*



Hydrilla shoot (photo by R Wells)

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Prepared for

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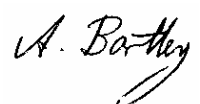
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1. Introduction

MAF BNZ (Ministry of Agriculture and Forestry, Biosecurity New Zealand) is undertaking a project to identify which pest management programmes it will deliver nationally. This process involves identification of potential species, and in-depth assessment to provide the information required to be able to prioritise each pest programme. The assessments include an organism consequence assessment (Hofstra and Champion 2006), a management options assessment and a cost benefit analysis.

MAF BNZ have contracted NIWA to undertake a management options assessment for hydrilla (*Hydrilla verticillata* (L.f.) Royle), addressing what management tools are available, and for which management objectives (i.e., eradication, control, containment and mitigation), the timeframes, impacts, feasibility, practicality, acceptability and monitoring required for each option and any associated constraints. Many of the methods used overseas are not relevant in New Zealand, based on the status and management aims of hydrilla here. Where methods are not relevant in the New Zealand context, these are only noted and referenced in the text, but not included in management scenarios (Section 4).

2. Species description and impacts

2.1 Description

Hydrilla (*Hydrilla verticillata*) is a submerged, rooted, monoecious or dioecious, annual or perennial aquatic macrophyte, which passes through unfavourable conditions as seed or turions or tubers. In New Zealand only the dioecious male hydrilla is present as perennial weed beds, and whilst turions and tubers are formed, no seed is produced.

The stems of hydrilla vary in length from a few centimetres to several metres and are either creeping and stoloniferous or erect (see front cover). The leaves occur in opposite pairs, or typically in whorls of 4, although numbers may range from 3 to 8 (rarely up to 12) per whorl. Leaves are sessile and linear to lanceolate, terminating in a single spine cell at the apex, and up to 20 mm long and 4 mm wide (usually about 12 mm long and 2 mm wide). Leaves are generally green, but often have small reddish-brown spots and stripes. The midrib is distinct and occasionally bears unicellular spines on the abaxial surface. The margin is strongly serrulate with fine, translucent teeth that are visible to the naked eye (Cook and Luond 1982).

The male flowers are sessile and solitary, or in pairs in the axils of leaves. They have 3 broad sepals and 3 narrow petals and whitish in colour (Aston 1973). When the flower is released from the plant it floats to the water surface where it opens, with widely recurved sepals and petals, and explosively discharges the pollen grains into the air (Sculthorpe 1967). Hydrilla is highly gregarious and in flowering populations the surface of the water can be white with floating pollen.

Reproduction of New Zealand's hydrilla is solely vegetative. Aside from reproduction via stem fragmentation, hydrilla also produces specialised vegetative structures called turions and tubers. Turions, also called axillary turions, are formed on erect stems in the water column. The mature turion is a green, ovate structure ca 10 mm in length (they can be smaller or larger), on a short stem, covered with numerous overlapping pointed leaf scales. Turions usually develop from axillary buds situated in the axils of leaves or branches, and when mature the turion breaks off the plant and sinks to the sediment. However when newly formed and still attached to a plant fragment they may float for a time and be dispersed by water currents (Thullen 1990).

Tubers, also known as subterranean turions, are swollen, brown to white structures up to 15 mm long, which develop in the hydrosol. The mature tuber becomes free from the parent plant when the attached stem decomposes or is ruptured (Yeo et al. 1984).

Turions are viable for one to two years, while tubers have remained viable for four years (Van and Steward 1990) and probably in excess of 10 years in New Zealand conditions (Hofstra et al. 1999).

2.2 Impacts

Hydrilla is an invasive aquatic macrophyte, which has earned worldwide recognition as one of the world's worst weeds amongst submerged plants. It is characterised by its prolific growth over a wide range of ecological conditions, its vegetative reproduction and long-lived propagules, and its ability to displace native vegetation and form mono-specific stands that can degrade fish and wildlife habitat. Weed beds of hydrilla are also a direct nuisance to lake users such as bathers, anglers and boaties, and plant material washed ashore by wind and wave action (later putrefying on the beaches) reduces the aesthetic value of the lakes, and access to the water.

In New Zealand hydrilla is only known from four Hawkes Bay lakes where it can grow to water depths of ~ 9 m and forms dense monospecific stands. Hydrilla poses a significant threat to the amenity, cultural and biodiversity values of other waterways (Walls 1994; Hofstra et al. 2000; DOC 2001).

3. Management tools

This section outlines the management tools that have been used successfully for hydrilla eradication, control or containment either in New Zealand or overseas.

3.1 Mechanical/physical

3.1.1 Hand removal

Hand weeding of hydrilla has been used overseas, with some success for isolated and routinely surveyed populations. In New Zealand, hand weeding by Scuba divers was attempted in Lake Opouahi, where widespread occurrences of low-density weed growth was common. Regrowth of hydrilla was noted at all sites where hand weeding was attempted, the rhizomatous nature of the plant and inter-twined growth with surrounding charophytes, reducing the effectiveness of this control method (J. Clayton pers. comm.). Hand weeding is not considered a suitable option for the current hydrilla infestations due to the scale of infestations, and the rhizomatous nature of hydrilla and risks of spread associated with fragmentation. However, this method could be utilised should any new infestations of hydrilla be detected at an early stage of colonisation, through surveillance activities.

Manual removal of hydrilla plants washed up during storm events was suggested by Hofstra et al. (2003) as a mechanism to reduce the likelihood of the public dispersing hydrilla via collection of plants for aquarium and ornamental pond use or accidental transfer with water craft.

3.1.2 Harvesters and diggers

Mechanical methods of physical weed control include cutting and harvesting, rototilling (rotary hoeing), dredging or the use of mechanical diggers. Cutting and harvesting methods are in use overseas and may significantly reduce plant biomass and improve lake and waterways access. Additionally, cutting may reduce the ability of hydrilla to produce tubers (Fox et al. 2002) although it has no impact on the sprouting of tubers (Netherland and Haller 2006). Although these methods are in use around New Zealand for submerged aquatic weed control, they are not suitable for use on hydrilla due to the associated risks of fragmentation, and increased likelihood of plant spread from its current localities (Hofstra et al. 2003).

3.2 Chemical - herbicides

Many different chemical products have been evaluated for the control of hydrilla both overseas and in New Zealand (Pieterse and Murphy 1990; Rattray et al. 1993; Langeland and Laroche 1994; Van and Vandiver 1994; Pennington et al. 2001; Hofstra et al. 2000; Hofstra and Clayton 2001; Hofstra et al. 2001). Of these, the three products used most successfully for hydrilla control overseas are fluridone, diquat and endothall (Swarbrick et al. 1981; Westerdahl and Getsinger 1988; MacDonald et al. 1993; Hofstra and Clayton 2001; Pennington et al. 2001; Hofstra et al. 2003).

Fluridone (Sonar® (1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4(1H)-pyridinone)) is a systemic aquatic herbicide that targets the photosynthetic pathway (ie disrupts the carotenoid biosynthetic pathway by inhibiting phytoene desaturase) (Sprecher et al. 1998). Since its registration in the USA in 1986, fluridone has been used to control hydrilla and other nuisance aquatic macrophytes. In the USA eradication of hydrilla has been reported using low concentration of fluridone in whole lake treatments over at least a three year period (Koschnick (SePRO), pers. comm. to J. Clayton), at the North American Lake Management Society meeting, November 2006). However in recent years a lack of efficacy has also been observed in some previously susceptible US hydrilla populations as a result of increasing resistance amongst plants (Michel et al. 2004).

New Zealand studies have shown that fluridone produced only transient chlorotic growing tissue, with little damage to older shoots and did not provide effective control in the short term (Wells et al. 1986). In longer term studies (five months) hydrilla biomass may be reduced without resulting in plant death, and indicates a difference between hydrilla in New Zealand compared with the US plants (Hofstra and Clayton, 2001). Despite the unfavourable outcome from New Zealand experimental trials, it is also possible that different results could be achieved in the field (Hofstra and Clayton, 2000). However, it would be difficult to maintain concentration or contact time equivalent to experimental treatments or those used for treating entire lakes in the US (due to the greater water depths in the New Zealand infested lakes), which would indicate that infestations of the New Zealand's hydrilla may not show a significant reduction in biomass or plant death using fluridone. In addition the development of resistance amongst US hydrilla poses some concern over the long-term efficacy of the product. Fluridone is not currently registered in New Zealand.

Diquat was first used on submerged aquatic weeds in New Zealand in the 1960's (Clayton, 1986) and is currently available in the aqueous formulation Reglone® (Syngenta). Diquat (6,7-dihydrodipyrido[1,2- α :2',1'-c]pyrazinedium dibromide) is a relatively fast acting contact herbicide, that interrupts the electron transport system in

plant photosynthesis and causes the destruction of cell membranes and desiccation of green tissues (Cassidy and Rodgers 1989). Diquat has been reported to give good control of hydrilla in clear water overseas (Swarbrick et al. 1981; Westerdahl and Getsinger 1988), however mesocosm and field trials using diquat in New Zealand have shown that it is not effective on hydrilla here (Walls 1994).

Endothall (Aquathol®K (7-oxabicyclo[2,2,1]heptane-2,3-dicarboxylic acid dipotassium)) is a selective contact herbicide that is a desiccant and defoliant (MacDonald et al. 2002). It has been registered for use in the USA since the 1960's and was recently registered for aquatic use in New Zealand (see later in this section). In the USA it is used extensively for the control of submerged macrophytes including hydrilla (Westerdahl and Getsinger 1988; Skogerboe and Getsinger 2002).

Mesocosm studies with endothall in New Zealand have evaluated the susceptibility of hydrilla as well as a number of other weed species, native macrophytes (milfoils and pondweeds) and charophytes. Control of hydrilla was achieved at almost all concentrations and contact times tested, with no discernible impact on the non-target species (desirable native charophytes) (Hofstra and Clayton 2001). Endothall was further evaluated in mesocosm studies with hydrilla and native charophytes to better determine the minimum contact time required to kill hydrilla at maximum label rate. More recently, the application of endothall significantly reduced hydrilla biomass in Lake Waikopiro for a year. Endothall offers significant promise for being able to achieve targeted hydrilla control in discrete areas, such as lake margins or access points (Hofstra et al. 2003).

Endothall has recently been registered for aquatic use in New Zealand, with label rates specified for the control of hydrilla. Two formulations are available: Aquathol K is an aqueous formulation with 50.7% a.i. and Aquathol Super K is a granule with 63% a.i. Both formulations are manufactured by Cerexagri and imported into New Zealand by Elliott Chemicals. The label rates for hydrilla are 20 to 30 kg a.i./ha with a concentration in water of 2 to 4 ppm. Endothall use requires permitting from ERMA and a Resource Consent from the relevant regional council or unitary authority.

Aquatic use of herbicides is an emotive issue, with many people unhappy about their application in natural waterbodies. So too, however, is the invasion of waterways by alien species and the subsequent displacement of native flora. The trial with endothall in Lake Waikopiro was a testament to this, where concerned public and iwi consented to the trial once they had had the opportunity to review the pros and cons of the hydrilla threat and the use of endothall.

Thus endothall is the only herbicide available which controls the New Zealand type of hydrilla.

3.3 Biological

In the war to control hydrilla many studies have been undertaken overseas to identify potential biological control agents for hydrilla (Godfrey et al. 1994; Buckingham and Bennett 1996; Buckingham and Bennett 1998; Balciunas and Burrows 1996; Wheeler and Center 1996; Dray and Center 1996; Grodowitz et al. 1997; Cofrancesco 1998; Buckingham and Bennett 2001; Cuda et al. 2002; Habeck and Balciunas 2005). These insect studies resulted in the release of a tuber feeding weevil, two ephyrid flies, and a stem boring weevil in the USA. Of these *Hydrellia pakistanae* (a small fly native to Asia, with leaf-mining larvae) has been most successful and is widely distributed in Florida (Cofrancesco 1998), however population density has never reached levels high enough to produce a significant impact on hydrilla (Shabana et al. 2003). J.K. Balciunas (USDA, Albany, California) visited the New Zealand field sites of hydrilla in 1992 with NIWA scientists and agreed that these sites would not be conducive to biological control with *Hydrellia* or insect species due to the lack of surface reaching weed beds (swan browsing- see later in this section) and relatively stable water levels in those lakes.

Plant pathogens for inundative biocontrol have been investigated for hydrilla in the USA (Shearer 1993; 1997; 1998; Shabana et al. 2003). The most promising candidate organism is the fungus *Mycoleptodiscus terrestris* (Cofrancesco 1998; Shearer and Jackson 2006), although this is not yet commercially available. Research on mycoherbicide development for the control of hydrilla is also currently underway at NIWA.

Hydrilla has no naturally occurring herbivorous enemies in New Zealand, although the black swans (*Cygnus atratus*) feed on hydrilla in Lakes Tutira and Waikopiro. Swans can be seen browsing on the hydrilla weed beds, which they effectively crop and prevent from becoming surface-reaching. By cropping the weed beds to a depth approaching 1 m, the likelihood of entanglement with small watercraft is significantly decreased.

Grass carp (*Ctenopharyngodon idella*) have been used successfully overseas for the control of hydrilla (Shireman and Maceina 1981; DeKozlowski 1991; Hanlon et al. 2000), and are currently the only feasible biological control agent for hydrilla in New Zealand. In an effort to determine whether hydrilla could be controlled and/or eradicated, Elands Lake became the site of a grass carp trial in 1988 (Clayton et al.

1995). In 1988 there was a reported 1 ha of hydrilla covering the 1.5 - 4.5 m water depth zone. At this time 400 triploid grass carp were released. By April 1990, 99% of hydrilla biomass was gone, with remnant stands at the south end of the lake. Two and a half years after the original release of the grass carp (April 1991) there were occasional growths from turions, tubers and stem fragments. In subsequent years and as recently as April 2002, remnant hydrilla plants and buried viable tubers have still been found during annual lake surveys where there are fallen branches, logs or other impediments in the lake to successful carp grazing (authors pers. obs.). However grass carp have sustained a low hydrilla biomass (near zero density) and are currently the most effective option for minimising the further spread of hydrilla (Hofstra et al. 2000).

Any proposed use of grass carp must follow the application and approval process outlined in the Department of Conservation SOP (Standard operating procedure for Grass and/or Silver Carp transfers and/or releases). Release of grass carp is dependent on obtaining appropriate consent, which requires an environmental impact assessment and an operational plan for grass carp, and also depends on the availability of fish. There has been considerable opposition to the use of grass carp for aquatic plant control in New Zealand, with the Elands Lake trial postponed for several years while consultation with concerned parties was undertaken. Their possible use in any management programme in lakes of high recreational value (i.e., Lakes Tutira, Waikopiro and Opouahi) are likely to be unpopular amongst certain sectors of the population, especially trout fishers.

3.4 Habitat manipulation

3.4.1 Drawdown

The use of lake water drawdown for hydrilla control has long been recommended for reservoirs in the USA and elsewhere (Swarbrick et al. 1981), especially if the drawdown is timed to minimise or prevent tuber production and to stimulate subsequent sprouting of tubers (Haller et al. 1976; Poovey and Kay 1998; Doyle and Smart 2001). However drawdowns do not completely eliminate hydrilla tubers from the sediment, indicating that although they may be used to manage hydrilla there is little chance that eradication can be achieved with this method alone (Doyle and Smart 2001). Obviously drawdowns are also limited to lakes or waterways that have sufficient water control structures and hydrologic characteristics to adequately control water level without interfering with other water uses (Langeland 1996). The current populations of hydrilla in New Zealand occur in lakes where water level is not

controlled and drawdown is not seen as a viable option for control in hydrilla in New Zealand.

3.4.2 Bottom-lining

Weed mat laid over the top of hydrilla infestations can provide restricted weed-free areas and theoretically be used to eradicate small clumps of this plant. In New Zealand weed mat was laid over a 50 x 20 m bed of hydrilla in Lake Opouahi (from 1 m to 6 m deep) in 1988/1989 to control the main infestation in the lake, with a smaller area laid at a boat ramp in Lake Tutira. The use of weed mat appears to have slowed down the spread of hydrilla within Lake Opouahi (Clayton et al. 1995), but was largely unsuccessful in Lake Tutira. Weed matting effectiveness is limited to areas of shallow gradients and low exposure to wave action, and requires regular maintenance to minimise uplifting, to repair disturbance due to human activities and to reduce recolonisation by hydrilla (J. Clayton pers comm.).

Bottom-lining is a relatively high cost option and the placing of weed mat to ensure complete coverage of hydrilla patches, including the possible range of subterranean rhizomes, using Scuba divers is a difficult exercise. However, it does provide a potential eradication tool for new incursions (Section 4).

3.5 Other

3.5.1 Legislation

Hydrilla was declared a Class B Noxious Plant in 1982 under the Noxious Plants Act (1978). This prohibited its sale, distribution and propagation. This ban from sale continued under the Biosecurity Act (1993) under Sections 52 and 53 of that act. In August 2001 hydrilla was declared an Unwanted Organism by the Chief Technical Officer of DOC, under the Biosecurity Act (DOC 2001) and in October 2006 hydrilla was afforded Notifiable Organism status (New Zealand Government 2006). This places a duty on any person who becomes aware of the presence of the organism in a new place to notify BNZ.

Hydrilla is a surveillance plant in the Hawke's Bay Regional Council Plant Pest Management Strategy, but no active management of the plant is carried out by that authority. DOC assumed control responsibilities for hydrilla in 2004, this passing on to BNZ in 2006. Management actions by these organisations have been restricted to surveillance and education programmes (Sections 3.5.3 and 3.5.4).

3.5.2 Activity controls

Activity controls on the three hydrilla infested lakes (Tutira, Waikopiro and Opouahi) that are publicly accessible aim to reduce the risk of hydrilla spread. Motorised boats are prohibited on Lakes Tutira and Waikopiro (the Orakai, Tutira and Waikopiro Wildlife Refuge Order 1973) and Lake Opouahi, and commercial eeling is also prohibited (Walls 1994). Current signage beside the lakes with hydrilla warns the public to clean boats and equipment of waterweeds before leaving the lake.

3.5.3 Public awareness

Public awareness is an integral part of the successful containment of hydrilla. The public can have a significant impact on the containment of weed species, not only because weed transfer is often linked to human activities (Johnstone et al. 1985), but also because new weed incursions may first be observed by members of the public (Timmins and Braithwaite 2002). Lakeside signage and public awareness needs to be adequate to minimise the risk of responsible lake users inadvertently transferring hydrilla to other waterbodies (DOC 2001).

Known lake user groups can be specifically targeted with the development of a public awareness campaign to raise the profile of hydrilla. Groups to target with educational material should include those known to use the lakes that contain hydrilla (e.g.; schools, Guthrie Smith Outdoor Education Centre, Local Dive club, Scinde Anglers, local Iwi and landowners adjacent to waterbodies) as well as those who frequent or visit other waterways in the region (such as eelers or fishers, DOC and Regional Council staff and contractors) who may be the first people to spot a new infestation.

Educational and publicity packages should highlight what hydrilla is, what it looks like, the risks and means of spread, what lake users can do to help, where it is found and what to do (i.e., who to contact) if they suspect it is somewhere new. In addition to targeting known lake users, awareness amongst the general public could be initiated through the local media, focusing on what hydrilla is and its associated threats.

3.5.4 Surveillance

Additionally, regular surveillance monitoring of high-risk sites (lakes and waterways at greatest risk of hydrilla incursions (Hofstra et al. 2003; Hofstra and Clayton 2006) outside of the current infested lakes is an important management tool for hydrilla containment and control. Surveillance is crucial for the early detection of a new hydrilla invasion, and early detection is the key to success of any containment, control

or eradication strategy. In particular, the longer (ie more than one growing season) that hydrilla is at a new site, the greater the number of tubers (long lived subterranean propagules) that are likely to be produced and the greater the costs and timeframe for any control programme. Specifically, hydrilla tuber viability in the USA has been reported up to 4 years (Van and Steward 1990, Sutton 1996). In New Zealand, plant and tuber records from Elands Lake indicate that hydrilla tubers are viable in excessive of this period (Hofstra et al. 1999). In addition plants as small as ca 20 cm in height have been found to produce new tubers (authors pers. obs.).

4. Management objectives

This section describes the management objectives for hydrilla using the appropriate tools described in Section 3.

4.1 Eradication

Eradication, as described by MAF BNZ in this contract, is “the permanent removal of the entire pest population”. More specifically hydrilla must be killed at a faster rate than the replacement rate at all densities, immigration must be zero (pathways and vectors), all individuals in the population must be at risk from the control technique, and monitoring must be able to detect low densities.

Currently there are no feasible tools available to achieve the eradication of hydrilla, as described above, although a high level of control (near zero density) has been achieved with grass carp in Lake Elands, experience has shown that not all plants are available to the grass carp when there are impediments to grazing in the lake (e.g., fallen branches). Additionally, when water clarity is poor, monitoring to detect further remnant plants is impeded.

In the event that longer term surveillance monitoring of Lake Elands provides evidence that eradication has been achieved in that lake (in the future), the feasibility of eradicating hydrilla from all New Zealand lakes is still questionable. Hofstra et al. (2003) outline the control tools that could be used to manage remaining impacted waterbodies to near zero hydrilla density, including endothall (both formulations), grass carp and manual removal of stranded hydrilla fragments.

There is unlikely to be public support for the devegetation (as seen in Lake Elands for over a decade) of Lakes Tutira and Waikopiro for an uncertain eradication outcome, which would also require long-term commitment from management agencies.

Should hydrilla be detected in new sites either through the surveillance programme in Hawkes Bay or by other means an incursion response programme would be needed. Dependent on the size and accessibility of the new incursions, management tailored to eradication of the new hydrilla population could be attained through a combination of hand-weeding and covering all plants with weed mat. If the size of the incursion is assessed as too great for management by these means then the default management objective becomes containment, through the use of control methods described previously.

4.2 Control

Control is referred to by MAF BNZ in this contract either as a single management action, sustained control or containment/exclusion. A single management action would result in “long term or permanent reduction of impacts through management action eg exclusion fencing.” Sustained control would be “a threshold density is established, where the benefits of control equal the costs of control. Density will be above zero. Pathways and vectors may need to be managed also.” Containment and/or exclusion refers to “containing pests within a specified range, usually a small existing range or reduced range; or exclusion of pests from an unoccupied range. This may include buffer zones, and pathways and vectors may need managing also.”

4.2.1 Single management action

There are currently no feasible single action management tools that can provide a permanent reduction of hydrilla impacts in New Zealand. Even actions that may be regarded as a one-off such as a single liberation of grass carp would require ongoing maintenance of containment structures and contingencies for increasing or decreasing fish numbers.

4.2.2 Sustained control

Grass carp, at a desirable stocking rate, can consistently maintain a low hydrilla biomass (for the life of the fish), providing sustained control that will reduce the threat of hydrilla to other lakes and waterways by reducing the risk of transfer. This is relatively low cost control for hydrilla dominated lakes (Tutira and Waikopiro), where submerged native vegetation has already been significantly impacted by the presence of hydrilla. Historically however, community support for the use of grass carp in the area has been lacking.

Success would be measured as sustained low levels of hydrilla, with maintained (or improved) biodiversity and amenity values. This would require an ongoing monitoring programme, with management intervention if detrimental non-target effects were observed. Additionally, at least until such time as the hydrilla is controlled, containment measures (below) would also need to be implemented.

4.2.3 Containment

Successful containment of hydrilla means that there are no new infestations. These management methods are ongoing, low cost and feasible. The likelihood of success in

achieving this objective is high, so long as the risk of hydrilla spread is minimised and a regular surveillance program is maintained for early detection of any new incursion (and its control) before establishment of a large population.

Aside from legislation, activity controls and public awareness the risk of hydrilla spread can be further reduced by decreasing the probability of the public coming into contact with hydrilla, through a combination of reducing plant biomass at high use lake access points (localised treatment with endothall) and removing lake shore drift (Hofstra et al. 2003).

5. Uncertainty summary

There is no proven method for eradication of hydrilla in New Zealand, although the continued grazing pressure of grass carp, possibly associated with other techniques may eventually achieve this goal.

If the management regime proposed by Hofstra et al. (2003) is followed, the greatest uncertainties will be in gaining public acceptance of these actions. The alternative of lesser management efforts, or not managing this plant in its current locations are likely to place a large risk to other waterbodies elsewhere in New Zealand, based on the impacts of this species documented in the USA and in New Zealand waterbodies.

Of note, in the state of Florida \$174 million has been spent on hydrilla control over the last 25 years. If the magnitude of consequences had been known at the time of discovery, there would have been no hesitation to take whatever actions and costs were required to eradicate the first known infestation (Koschnick (SePRO), pers. comm. to J. Clayton).

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7. References

- Aston, H.I. (1973). Aquatic plants of Australia. Melbourne University Press.
- Balciunas, J.K.; Burrows, D.W. (1996). Distribution, abundance and field host-range of *Hydrellia balciunasi* Bock (Diptera: Ephydriidae) a biological control agent for the aquatic weed *Hydrilla verticillata* (Lf) Royle. *Australian Journal of Entomology* 35: 125-130.
- Buckingham, G.R.; Bennett, C.A. (1996). Laboratory biology of an immigrant Asian moth *Parapoynx diminutalis* (Lepidoptera: Pyralidae) on *Hydrilla verticillata* (Hydrocharitaceae). *Florida Entomologist* 79(3): 353-363.
- Buckingham, G.R.; Bennett, C.A. (1998). Host range studies with *Bagous affinis* (Coleoptera: Curulionidae) and Indian Weevil that feeds on hydrilla tubers. *Biological Control* 27(2): 469-479.
- Buckingham, G.R.; Bennett, C.A. (2001). Life history and laboratory host range tests of *Parapoynx seminealis* (Walker) (Crambidae: Nymphulinae) in Florida USA. *Journal of the Lepidopterists Society* 55(3): 111-118.
- Cassidy, K.; Rodgers, J.H. (1989). Response of hydrilla (*Hydrilla verticillata* (Lf) Royle) to diquat and a model of uptake under nonequilibrium conditions. *Environmental Toxicology and Chemistry* 8: 133-140.
- Clayton, J.S.; Champion, P.D.; McCarter N.H. (1995). Control of *Hydrilla verticillata* in a New Zealand lake using triploid Grass Carp. In: E. S. Delfosse and R. R. Scott (ed.). Proc. 8th Int. Symp. on Biological Control of Weeds, Lincoln, New Zealand pp. 275-285.
- Cofrancesco, A.F. (1998). Overview and future direction of biological control technology. *Journal of Aquatic Plant Management* 36: 49-53.
- Cook, C.D.K.; Luond, R. (1982). A revision of the genus *Hydrilla* (Hydrocharitaceae). *Aquatic Botany*, 13: 485-504.
- Cuda, J.P.; Coon, B.R.; Dao, Y.M.; Center, T.D. (2002). Biology and laboratory rearing of *Cricotopus lebetis* (Diptera: Chironomidae) a natural enemy of the

- aquatic weed hydrilla (Hydrocharitaceae). *Annals of the Entomological Society of America* 95(5): 587-596.
- De Kozlowski, S.J. (1991). Lake Marion sterile grass carp stocking project. *Aquatics*, 13: 13-16.
- Department of Conservation (2001). Hydrilla in New Zealand: A review of the problems and recommendation for the future actions. Series No. 9 of East Coast Hawkes Bay Technical Series.
- Doyle, R.D.; Smart, R.M. (2001). Effects of drawdowns and desiccation on tubers of hydrilla an exotic aquatic weed. *Weed Science* 49: 135-140.
- Dray, F.A.; Center, T.D. (1996). Reproduction and development of the biocontrol agent *Hydrellia pakistanae* (Diptera: Ephydriidae) on monoecious Hydrilla. *Biological Control* 7: 275-280.
- Fox, A.M.; Haller, W.T.; Cuda, J.P. (2002). Impacts of carbohydrate depletion by repeated clipping on the production of subterranean turions by dioecious hydrilla. *Journal of Aquatic Plant Management* 40: 99-104.
- Godfrey, K.E.; Anderson, L.W.J.; Perry, S.D.; Dechoretz, N. (1994). Overwintering and establishment potential of *Bagous affinis* (Coleoptera: Curculionidae) on *Hydrilla verticillata* (Hydrocharitaceae) in Northern California. *Florida Entomologist* 77(2): 221-230.
- Grodowitz, M.J.; Center, T.D.; Cofrancesco, A.F.; Freedman, J.E. (1997). Release and establishment of *Hydrellia balciunasi* (Diptera: Ephydriidae) for the biological control of the submersed aquatic plant *Hydrilla verticillata* (Hydrocharitaceae) in the United States. *Biological Control* 9: 15-23.
- Habeck, D.H.; Balciunas, J.K. (2005). Larvae of Nymphulinae (Lepidoptera: Pyralidae) associated with *Hydrilla verticillata* (Hydrocharitaceae) in North Queensland. *Australian Journal of Entomology* 44: 354-363.
- Haller, W.T.; Miller, J.L.; Garrard, L.A. (1976). Seasonal production and germination of hydrilla vegetative propagules. *Journal of Aquatic Plant Management* 14: 26-29.

- Hanlon, S.G.; Hoyer, M.V.; Cichra, C.E.; Canfield, D.E. (2000). Evaluation of macrophyte control in 38 Florida lakes using triploid grass carp. *Journal of Aquatic Plant Management* 38: 48-54.
- Hofstra, D.E.; Champion, P.D. (2006). Organism Consequence Assessment *Hydrilla verticillata*. NIWA Client Report HAM2006-058f.
- Hofstra, D.E.; Champion, P.D.; Clayton, J.S. (2000). Hydrilla in the Hawke's Bay – A discussion document. NIWA Report.
- Hofstra, D.E.; Champion, P.D.; Clayton, J.S. (2003). Hydrilla – An operational plan for containment and eradication research. NIWA Client Report DOC03249.
- Hofstra, D.E.; Clayton, J.S. (2006). Hydrilla surveillance 2006. NIWA Client Report MAF06202.
- Hofstra, D.E.; Clayton, J.S. (2001). Evaluation of selected herbicides for the control of exotic submerged weeds in New Zealand I. The use of endothall, triclopyr and dichlobenil. *Journal of Aquatic Plant Management* 39: 20-24.
- Hofstra, D.E.; Clayton, J.S.; Champion, P.D.; Green, J.D. (1999). Distribution and density of vegetation hydrilla propagules in the sediments of two New Zealand lakes. *Journal of Aquatic Plant Management* 37: 41-44.
- Hofstra, D.E.; Clayton, J.S.; Getsinger, K.D. (2001). Evaluation of selected herbicides for the control of exotic submerged weeds in New Zealand II. The effects of turbidity on diquat and endothall efficacy. *Journal of Aquatic Plant Management* 39: 25-27.
- Johnstone, I.M.; Coffey, B.T.; Howard-Williams, C. (1985). The role of recreational boat traffic in interlake dispersal of macrophytes: a New Zealand case study. *Journal of Environmental Management* 20: 263-279.
- Langeland, K. (1996). *Hydrilla verticillata* “ The Perfect Aquatic Weed. *Castanea* 61: 293-304.
- Langeland, K.A.; Laroche, F.B. (1994). Persistence of bensulfuron methyl and control of hydrilla in shallow ponds. *Journal of Aquatic Plant Management* 32: 12-14.

- MacDonald, G.E.; Querns, R.; Shilling, D.G.; McDonald, S.K.; Bewick, T.A. (2002). Activity of endothall on hydrilla. *Journal of Aquatic Plant Management*, 40: 68-71.
- MacDonald, G.E.; Shilling, D.G.; Doong, R.L.; Haller, W.T. (1993). Effects of fluridone on hydrilla growth and reproduction. *Journal of Aquatic Plant Management* 31: 195-198.
- Michel, A.; Arias, R.S.; Scheffler, B.E.; Duke, S.O.; Netherland, M.; Dayan, F.E. (2004). Somatic mutation-mediated evolution of herbicide resistance on the non-indigenous invasive plant hydrilla (*Hydrilla verticillata*). *Molecular Ecology* 13: 3229-3237.
- Netherland, M.D.; Haller, W.T. (2006). Impact of management on the sprouting of dioecious hydrilla tubers. *Journal of Aquatic Plant Management* 44: 32-26.
- New Zealand Government (2006). Biosecurity (Notifiable Organisms) Order 2006. (http://www.lexisnexis.co.nz/products/bulletins/legislation/nz_regulation_SR-2006-320.txt accessed 2006)
- Pennington, T.G.; Skogerboe, J.G.; Getsinger, K.D. (2001). Herbicide/copper combination for improved control of *Hydrilla verticillata*. *Journal of Aquatic Plant Management* 39: 56-58.
- Pieterse, A.H.; Murphy, K.J. (1990). Aquatic Weeds. The Ecology and Management of Nuisance Aquatic Vegetation. Oxford University Press.
- Poovey, A.G.; Kay, S.H. (1998). The potential of a summer drawdown to manage monoecious hydrilla. *Journal of Aquatic Plant Management* 36: 127-130.
- Rattray, M.R.; MacDonald, G.; Shilling, D.; Bowes, G. (1993). The mechanism of action of bensulfuron-methyl on hydrilla. *Journal of Aquatic Plant Management* 31: 39-42.
- Sculthorpe, C.D. (1967). The Biology of Aquatic Vascular Plants. Edward Arnold Publishers, London.
- Shabana, Y.M.; Cuda, J.P.; Charudattan, R. (2003). Combining plant pathogenic fungi and leaf-mining fly (*Hydrellia pakistanae*) increase damage to hydrilla. *Journal of Aquatic Plant Management* 41: 76-81.

- Shabana, Y.M.; Cuda, J.P.; Charudattan, R. (2003). Evaluation of pathogens as potential biocontrol agents of hydrilla. *Journal of Phytopathology* 151: 607-613.
- Shearer, J.F.; Jackson, M.J. (2006). Liquid culture of microsclerotia of *Mycolpetodiscus terrestris* a potential biological control agent for the management of hydrilla. *Biological Control* 38: 289-306.
- Shearer, J.S. (1993). Biocontrol of hydrilla and milfoil using plant pathogens. Proceedings 27th Annual Meeting, Aquatic Plant Control Research Program. US Army Corps Engineer Miscellaneous Paper A-93-2.
- Shearer, J.S. (1997). Endemic pathogen biocontrol research an submersed macrophytes: Status report. Aquatic Plant Control Research Program. US Army Corps Engineer Technical Report A-97-3.
- Shearer, J.S. (1998). Biocontrol of hydrilla using an endemic fungal pathogen. *Journal of Aquatic Plant Management* 36: 54-56.
- Shireman, J.V.; Maceina, M.J. (1981). The utilization of grass carp (*Ctenopharyngodon idella* Val.) for hydrilla control in Lake Baldwin, Florida. *Journal of Fish Biology* 19: 629-636.
- Skogerboe, J.G.; Getsinger, K.D. (2002). Endothall species selectivity evaluation: northern latitude aquatic plant community. *Journal of Aquatic Plant Management* 40: 1-5.
- Sprecher, S.L.; Netherland, M.D.; Stewart, A.B. (1998). Phytoene and carotene response of aquatic plants to fluridone under laboratory conditions. *Journal of Aquatic Plant Management* 36: 111-120.
- Sutton, D.L. (1996). Depletion of turions and tubers of *Hydrilla verticillata* in the New North River Canal, Florida. *Aquatic Botany* 53: 121-130.
- Swarbrick, J.T.; Finlayson, C.M.; Cauldwell, A.J. (1981). The biology of Australian weeds 7. *Hydrilla verticillata* (Lf) Royle. *The Journal of the Australian Institute of Agricultural Science*, 183-190.

- Thullen, J.S. (1990). Production of axillary turions by the dioecious *Hydrilla verticillata*. *Journal of Aquatic Plant Management* 28: 11-15.
- Timmins, S.; Braithwaite, H. (2002). Early detection of invasive weeds on islands. In; Veitch, C.R.; Clout, M.N. (eds.). *Turning the Tide: The Eradication of Invasive Species. Proceedings of the International Conference on Eradication of Island Invasives*. pp 301-310.
- Van, T.K.; Steward, K.K. (1990). Longevity of monoecious *Hydrilla* propagules. *Journal of Aquatic Plant Management*. 28: 74-76.
- Van, T.K.; Vandiver, V.V. Jr. (1994). Response of hydrilla to various concentration and exposures of bensulfuron methyl. *Journal of Aquatic Plant Management* 32: 7-11.
- Walls, G. (1994). The New Zealand *Hydrilla* problem: A review of the issues and management options. Conservation Advisory Notes 71. Department of Conservation, Wellington.
- Wells, R.D.S.; Coffey, B.T.; Lauren, D.R. (1986). Evaluation of fluridone for weed control in New Zealand. *Journal of Aquatic Plant Management* 24: 39-42.
- Westerdahl, H.E.; Getsinger, K.D. (1988) Aquatic plant identification and herbicide use guide. Volume II: Aquatic plants and susceptibility to herbicides. Aquatic Plant Control Research Program, US Army Corps of Engineers, Technical Report A-88-9.
- Wheeler, G.S.; Center, T.D. (1996). The influence of hydrilla leaf quality on larval growth and development of the biological control agent *Hydrellia pakistanae* (Diptera: Ephydriidae). *Biological Control* 7: 1-9.
- Yeo, R.R.; Falk, R.H.; Thurston, J.R. (1984). The morphology of *Hydrilla* (*Hydrilla verticillata* (Lf) Royle). *Journal of Aquatic Plant Management* 22: 1-7.