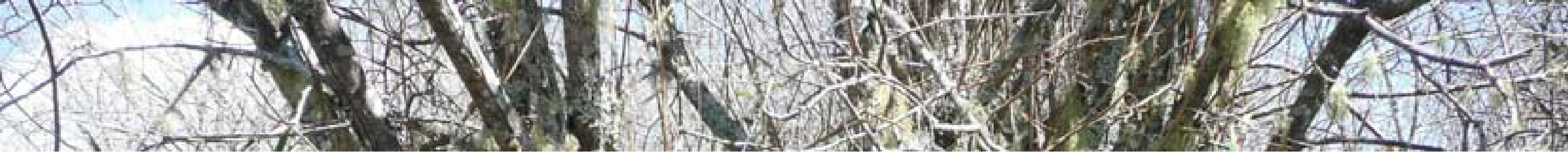

# Garlon® 360 trial for the control of wetland weeds

SCIENCE FOR CONSERVATION 311

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Cover: Regrowth under treated (dead) willows 2 years after treatment with Garlon® 360.
*Photo: Paul Champion*.

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# Garlon® 360 trial for the control of wetland weeds

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## ABSTRACT

In 2007, Dow Agrosciences New Zealand Ltd registered Triclopyr triethylene amine in New Zealand for use in wetlands and aquatic sites. Its registered name is Garlon® 360. This report outlines pot trials and field trials (Waikato River Delta, island on the Waikato River near Rangiriri, South Taupo Wetland near Turangi and Cockayne Wetland in Christchurch) carried out to test the ability of Garlon® 360 to control various weeds, and to assess its impact on non-target species. The field trials targeted grey willow (*Salix cinerea*), alder (*Alnus glutinosa*), water celery (*Apium nodiflorum*) and purple loosestrife (*Lythrum salicaria*). Garlon® 360 appears to have controlled all weed species tested, but grey willow trees treated by aerial application had significant regrowth after 1 year and aerial treatment of this species needs further evaluation. Native monocotyledonous species (especially grasses, rushes and most sedges) mostly survived herbicide application, indicating that Garlon® 360 is more selective for these species than glyphosate. However, both pot and field trials showed damage or death of native dicotyledons. Ground-based application of Garlon® 360 as a spot spray provided more selectivity of control. Garlon® 360 should prove a useful tool for the management of endangered species where selective control of weeds would be beneficial, either to remove competition or to provide disturbance necessary to manage early successional species. A number of endangered species (including *Ranunculus macropus*, *Pterostylis paludosa* and *Ophioglossum petiolatum*) either increased in abundance, or were recorded for the first time, 1 year after herbicide treatment at the South Taupo Wetland trial site.

Keywords: triclopyr, Garlon® 360, selective weed control, endangered species management, grey willow, alder, purple loosestrife, water celery


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# 1. Introduction

There is a growing awareness that weed invasions threaten the viability of many of New Zealand's native species and community types (Williams & Timmins 1990; Owen 1997). This is particularly the case in wetlands, where the effects of weed invasions compound the loss of over 90% of these areas since 1840 (Cromarty & Scott 1996). Much of the remaining wetland habitat is fragmented, which increases the likelihood of weed invasion. Some widespread and invasive wetland weeds (e.g. grey and crack willow (*Salix cinerea* and *S. fragilis*) are particularly damaging to wetland habitats because they overtop and shade-out many native herbaceous and shrub wetland vegetation types (Champion 1994; Partridge 1994)).

Wetland weed control generally involves mechanical methods (physical destruction and removal), the use of a relatively limited range of non-specific herbicides (such as glyphosate and diquat), and combinations of mechanical and chemical methods. When used as foliar sprays, most presently available herbicides often damage other non-target vegetation. Combination techniques, such as application of herbicides to cut stumps, and drilling and injecting herbicide, may limit off-target damage, but are very costly to carry out and are inappropriate for sites where access is difficult or hazardous. There is a need for herbicides that can be applied as foliar sprays to target specific weeds while limiting affects on non-target wetland species.

This study evaluated the triethylamine (TEA) salt of the herbicide triclopyr (sold in New Zealand as Garlon® 360, Dow AgroSciences (NZ) Ltd) as an additional tool for wetland weed management. The study comprised four stages:

- A literature review of triclopyr TEA and existing methods of chemical control of wetland and aquatic weed species in New Zealand
- A vegetation survey of four wetlands proposed for trial applications of Garlon® 360 to ascertain existing non-target/endangered species and weed impacts
- A pot trial to evaluate Garlon® 360 for control of eight invasive wetland weed species and likely off-target damage to 12 native wetland plant species
- Herbicide trials in four field sites to evaluate the impact of Garlon 360® on wetland weeds and non-target plant species

# 2. Management of wetland and aquatic weeds with herbicides: a review of literature relevant to New Zealand

## 2.1 HERBICIDES USED TO CONTROL WETLAND AND AQUATIC WEEDS IN NEW ZEALAND

Before the registration of triclopyr TEA in 2007, the only herbicides registered for use in New Zealand where contamination of water may occur were diquat dibromide monohydrate (Reglone®, Syngenta New Zealand; commonly called diquat) and some formulations of glyphosate (e.g. Roundup Transorb™, Nufarm Ltd).

Diquat is a contact dessicant, rapidly absorbed by green plant tissue, which is then killed on exposure to light (Wilcock 1994). It is primarily used in aquatic situations for the control of submerged weeds and is ineffective as a foliar spray against many of the wetland weeds, especially woody species (pers. obs.).

Glyphosate is a non-selective and non-residual herbicide that is absorbed by foliage and non-woody stems and translocated throughout terrestrial plants. Its mode of action is inhibition of protein synthesis (Wilcock 1994). It has been successfully used for aerial willow control where willows form a dense canopy over desirable species (e.g. Champion 2006a), and also for stem injection or cut stump treatments (Ray 1994; Ray & Davenhill 1998). However, where willows form a more open canopy, glyphosate used as a foliar spray can damage non-target plants such as sedges, grasses and rushes that are often the dominant vegetation components of natural wetlands unaffected by weeds. It also damages a wide range of endangered wetland species (Champion 1998, 2000). Glyphosate does not give good control of a range of rhizomatous or stoloniferous species such as alligator weed (*Alternanthera philoxeroides*), parrot's feather (*Myriophyllum aquaticum*), water primrose (*Ludwigia* spp.) and Manchurian wild rice (*Zizania latifolia*) (Hofstra et al. 2003, 2006; Champion & Hofstra 2006; Meisler 2008).

Other herbicides have been used to control specific wetland weeds, but their use requires a resource consent, as they are not registered for this purpose. For example, the grass-specific herbicide haloxyfop-R methyl ester (Gallant® NF, Dow AgroSciences (NZ) Ltd) is successfully used in many Department of Conservation (DOC) Conservancies to manage estuarine cordgrasses (*Spartina* spp.) (Shaw & Gosling 1997), following extensive studies on its toxicity and persistence attributes and the development of appropriate monitoring programmes designed to evaluate any off-target impacts (e.g. Roper et al. 1996; Turner & Hewitt 1997). It has also been successfully used to selectively control Manchurian wild rice and reed canary grass (*Phalaris arundinacea*) in freshwater wetlands (Champion 2006b; Champion & Hofstra 2006). Metsulfuron methyl ester (Escort®, DuPont NZ Ltd) is used under a Resource Consent granted by Environment Waikato for the control of alligator weed (Champion 2008).

Champion (1998, 2000) also evaluated a range of other selective herbicides for the control of weeds of ephemeral turfs. These included fluazifop (Fusilade®), haloxyfop (Gallant®), clethodim (Centurion®), clopyralid (Versatill™), triclopyr butoxyethyl ester (Grazon®), dicamba (Banvel®), dicamba/2,4-D (Banvine®) and glyphosate (Roundup G2®). These were applied to 13 introduced weeds and 18 native wetland plants, including 9 endangered species, in a pot trial to evaluate their control of weeds and off-target damage. Small-scale trials were then undertaken at field sites with moderate to low conservation value to evaluate the effect of haloxyfop, clethodim, clopyralid and triclopyr on established weed infestations. Those herbicides were then applied to wetland turf vegetation at Lake Lyndon and Mount Barker tarns (Canterbury), Tarndale (Marlborough), and Lake Whangape (Waikato). Good selectivity of control was obtained with haloxyfop, clopyralid and triclopyr butoxyethyl ester.

In addition to glyphosate, other herbicides used for the management of willows (*Salix* spp.) through cut stump or drill and inject treatments include ammate (ammonium sulphamate), metsulfuron, dicamba, picloram gel, various triclopyr butoxyethyl ester/2,4-D/picloram combinations (Tordon® formulations) and imazapyr (Ray 1994; Ray & Davenhill 1998).

## 2.2 TRICLOPYR TEA

The triethylamine salt formulation of the herbicide triclopyr (3,5,6-trichloro-2-pyridinyl oxyacetic acid, triclopyr TEA) is registered for aquatic plant or ditch bank broadleaf and woody plant control in the USA, registered by the SePRO Corporation as Renovate® 3 and by Dow AgroSciences as Garlon® 3A. Both formulations contain 44.4% active ingredient (a.i.) or 31.8% acid equivalent (a.e.).

In February 2007, triclopyr TEA was registered in New Zealand by Dow Agrosciences New Zealand Ltd as Garlon® 360 (Dow Agrosciences 2007). The formulation contains 360 g triclopyr/L. This herbicide is recommended for use in wetlands for the control of the aquatic weeds alligator weed and parrot's feather following trials in both contained situations and the field (Hofstra et al. 2003, 2006). The label also recommends its use as a basal stump treatment for willows.

Recommendations for use obtained from labels applied to the product in other countries and from previous studies are reviewed in the following subsections.

### 2.2.1 Control of woody species

The Garlon® 3A and Renovate® 3 labels (Dow AgroSciences 1999; SePRO 2002) both list willows and alder (*Alnus* spp.) as woody species controlled by triclopyr TEA. Other species controlled by triclopyr TEA that are weedy in wetland/riparian habitats in New Zealand are blackberry (*Rubus* spp.), broom (*Cytiscus scoparius*), Asiatic knotweed (*Reynoutria japonica*), hawthorn (*Crataegus* spp.), elderberry (*Sambucus* spp.), maples (*Acer* spp.) and poplar (*Populus* spp.). Herbicide rates are not specified for each species, but rates for control of woody plants vary between 9.35 and 18.71 L/ha, with the addition of a non-ionic surfactant recommended. A spray rate of 900 to 3600 L/ha is recommended depending on the density and height of the target vegetation.

Triclopyr TEA was trialled as a foliar spray for several scrubweeds including barberry (*Berberis glaucocarpa*), sweet briar (*Rosa rubiginosa*) and blackberry, giving excellent control of these species (Forgie et al. 1977; MacDiarmid 1977). MacDiarmid (1977) also reported good control by triclopyr TEA of broom, tree lupin (*Lupinus arboreus*), woolly nightshade (*Solanum mauritianum*) and gorse (*Ulex europaeus*).

In addition to their use as foliar sprays, registration for cut surface application is also included on the labels of both Garlon® 3A and Renovate® 3. Application methods include tree injection, hack and squirt, frilling, and spreading over stumps. Hartley & Popay (1982) successfully used triclopyr TEA to treat cut stumps of gorse.

Triclopyr TEA is also being investigated as a possible willow control method in Australia (SCA & DEC 2007).

### 2.2.2 Control of purple loosestrife

The Renovate® 3 label (SePRO 2002) recommends application rates between 14.03 and 18.71 L/ha to control purple loosestrife (*Lythrum salicaria*), and the addition of a non-ionic surfactant. A minimum spray volume of 450 L/ha is recommended for ground-based application, or 280 L/ha for aerial application. Application when plants are in bud or full-flower is recommended on the Renovate® 3 label.

Gabor et al. (1995) report the impact of triclopyr TEA applied at rates of 9, 18 and 27 L/ha to a wetland with between 40 and 60 stems of purple loosestrife per $m^2$. All adult plants were killed by the 27 L/ha rate, with approximately 10 and 20 stems/m remaining after treatment with the 9 and 18 L/ha rates, respectively. The following year, large numbers of purple loosestrife seedlings germinated, especially in the sites treated with higher herbicide rates. Nelson et al. (1996) showed reduction of purple loosestrife to 5% of pre-treatment rates 10 weeks after treatment with triclopyr TEA applied at 10 L/ha.

### 2.2.3 Control of sprawling emergent, floating-leaved and free-floating aquatic weeds

The Renovate® 3 label (SePRO 2002) recommends rates between 4.68 and 18.71 L/ha to control vegetation emergent above or floating on the water surface, with spray rates of 190 to 1900 L/ha, depending on the height and density of foliage. Susceptible species present as naturalised weeds in New Zealand and listed on the Renovate® 3 label include alligator weed, parrot's feather, yellow water lily (*Nuphar* spp.), water lily (*Nymphaea* spp.), pennywort (*Hydrocotyle* spp.), water hyacinth (*Eichhornia crassipes*) and water primrose.

No trial data were found for treatment of the species scheduled to be trialled in this study (monkey musk (*Mimulus guttatus*), watercress (*Nasturtium officinale*), primrose willow (*Ludwigia peploides* var. *montevidensis*) and water celery (*Apium nodiflorum*)), although triclopyr TEA was used to control water primrose (including *L. peploides*) in a field trial in California (Meisler 2008). Meisler (2008) found that triclopyr TEA effectively controlled water primrose, but the resulting decaying biomass reduced dissolved oxygen in surrounding waters. Thus, triclopyr TEA was not recommended for widespread control of the species unless dead material was harvested and removed.

### 2.2.4 Control of submerged aquatic weeds

Renovate® 3 is registered for aquatic use to control submerged weeds (SePRO 2002), primarily Eurasian milfoil (*Myriophyllum spicatum*), a species which, fortunately, is not known to occur in New Zealand. It can be applied to a maximum concentration of 2.5 ppm in the treated waterbody. Other milfoils (*Myriophyllum* spp.) are included on the label, but in New Zealand the native species are rarely problematic and only emergent forms of the weedy parrot's feather usually require control (e.g. Hofstra et al. 2006). Thus, Garlon® 360 is not registered in New Zealand for use on submerged species.

### 2.2.5 Tolerant species

Hofstra et al. (2006) reported no damage to ditchbank grasses or floating sweet grass (*Glyceria declinata*) by triclopyr TEA application to control parrot's feather, with either no damage to *Potamogeton cheesemanii* and *Persicaria decipiens* or recovery of these species by 4 weeks after treatment. At Kaituna Wildlife Management Reserve, *P. cheesemanii* and the charophyte alga *Nitella* aff. *cristata* colonised the open areas left following control of parrot's feather using this herbicide (authors' unpublished data). A study by Sprecher & Stewart (1995) showed no damage to the submerged species *Elodea canadensis* and *Vallisneria americana* at application rates of 2.5 and 1 ppm triclopyr TEA. *Stuckenia pectinata* biomass was reduced (but not eliminated) at 2.5 ppm, and showed no reduction at 1 ppm, whereas the species targeted for control (*Myriophyllum spicatum*) was eliminated at both the 2.5 and 1 ppm treatments. Washington State (2004) lists the following plants as tolerant to triclopyr TEA at the rates recommended for use in water: rushes (genera *Juncus* and *Scirpus*—the taxonomic treatment of this sedge genus in the USA includes the New Zealand genera *Schoenoplectus, Bolboschoenus* and *Isolepis*), *Typha* spp., *Potamogeton* spp., *Ceratophyllum demersum, Elodea canadensis* and *Paspalum* spp. Most algal species are also tolerant at these concentrations.

For wetlands, no long-term reduction in monocotyledon species was noted in purple loosestrife-infested sites treated with triclopyr TEA by Gabor et al. (1995). Grass density (stem number) was not affected by 9, 18 and 27 L/ha application rates, but sedge (*Carex* spp.) density initially declined at the highest treatment rate, then recovered to pre-trial densities 1 year after herbicide application.

# 3. Pot trials

## 3.1 SELECTION OF SPECIES

Some wetland weed species are not readily controlled by the herbicides presently registered in New Zealand for use where contamination of water may occur (see section 2). Species of concern to DOC include the woody species grey and crack willow and alder, and the broadleaf herbaceous species purple loosestrife, monkey musk, watercress, primrose willow and water celery. Of those species, grey and crack willow, purple loosestrife and primrose willow are unwanted organisms under the Biosecurity Act (1993), with eradication programmes in place (DOC and Regional Councils) for purple loosestrife at most sites where it occurs. Weed species chosen for the pot trials are shown in Table 1.

The native species chosen for the pot trial are also shown in Table 1. In addition to the species mentioned in sections 3.1 to 3.5, the dominant swamp forest tree kahikatea (*Dacrycarpus dacrydioides*) and the herbaceous plants *Crassula helmsii* and *Mazus radicans* were also chosen. Kahikatea forests are invaded by several of the weed species chosen for the pot trial, especially willows (Champion 2006a). Several endangered species of *Crassula* and *Mazus* are threatened by herbaceous weeds such as water celery, watercress and primrose willow.

## 3.2 MATERIALS

The introduced weeds and native species were collected or purchased as follows:

- Purple loosestrife seedlings were sourced from Lake Virginia, Wanganui and later from Koromatua near Hamilton. Grey willow and alder seedlings, and cuttings of crack willow, monkey musk, watercress, primrose willow and water celery were collected from sites in the vicinity of Hamilton City.
- Potted plants of kahikatea, oioi (*Apodasmia similis*), swamp sedge (*Carex virgata*), *Juncus pallidus,* harakeke (*Phormium* spp., New Zealand flax) and *Mazus radicans* were sourced from Annton Nursery, Cambridge. Spike sedge (*Eleocharis acuta*) and swamp millet (*Isachne globosa*) were collected from the vicinity of Hamilton City. *Carex cirrhosa, Amphibromus fluitans, Triglochin striata, Crassula helmsii* and *Selliera rotundifolia* were grown in the NIWA plant collection, Ruakura, Hamilton.

An Exemption Permit under Section 52/53 under the Biosecurity Act 1993 was obtained from MAF Biosecurity New Zealand to collect and cultivate unwanted organisms. Unwanted organisms were cultivated in the secure facilities at NIWA and at AgResearch, Ruakura Research Centre, Hamilton.

TABLE 1. INTRODUCED WEEDS AND NATIVE PLANTS USED IN THE POT TRIAL AND THEIR RESPECTIVE MANAGEMENT STATUS UNDER THE BIOSECURITY ACT 1993 OR CONSERVATION STATUS (AFTER DE LANGE ET AL. 2004).

| SPECIES | COMMON NAME | FAMILY | ABBREVIATION USED IN SUBSEQUENT TABLES | STATUS |
|---|---|---|---|---|
| INTRODUCED SPECIES | | | | |
| *Alnus glutinosus* | Alder | Betulaceae | Ag | No management status |
| *Apium nodiflorum* | Water celery | Apiaceae | An | No management status |
| *Ludwigia peploides* subsp. *montevidensis* | Primrose willow | Onagraceae | Lp | Unwanted organism |
| *Lythrum salicaria* | Purple loosestrife | Lythraceae | Ls | Unwanted organism |
| *Mimulus guttatus* | Monkey musk | Phrymaceae | Mg | No management status |
| *Nasturtium officinale* | Water cress | Apiaceae | No | No management status |
| *Salix cinerea* | Grey willow | Salicaceae | Sc | Unwanted organism |
| *Salix fragilis* | Crack willow | Salicaceae | Sf | Unwanted organism |
| NATIVE SPECIES | | | | |
| *Amphibromus fluitans* | Water brome | Poaceae | Af | Nationally endangered |
| *Apodasmia similis* | Oioi | Restionaceae | As | Not endangered |
| *Carex cirrhosa* | | Cyperaceae | Cc | Gradual decline |
| *Carex virgata* | Swamp sedge | Cyperaceae | Cv | Not endangered |
| *Crassula helmsii* | | Crassulaceae | Ch | Sparse |
| *Dacrycarpus dacrydioides* | Kahikatea | Podocarpaceae | Dd | Not endangered |
| *Eleocharis acuta* | Spike sedge | Cyperaceae | Ea | Not endangered |
| *Isachne globosa* | Swamp millet | Poaceae | Ig | Not endangered |
| *Juncus pallidus* | | Juncaceae | Jp | Not endangered |
| *Mazus radicans* | | Phrymaceae | Mr | Not endangered |
| *Phormium tenax* | Harakeke (New Zealand flax) | Hemerocallidaceae | Pt | Not endangered |
| *Selliera rotundifolia* | | Goodeniaceae | Sr | Gradual decline |
| *Triglochin striata* | Arrow grass | Juncaginaceae | Ts | Not endangered |

## 3.3 CULTIVATION OF PLANTS

The plants were then grown in the AgResearch glasshouse at Ruakura for at least 2 months prior to herbicide application. All plants were grown in potting mix (Daltons Premium Mix) except for primrose willow plants, which were grown in beds of sand in water-filled 40-L tubs.

Plants were deemed to be ready for herbicide application once the kahikatea, harakeke, oioi, spike sedge, swamp sedge and purple loosestrife were between 0.5 and 1 m tall, and the remaining herbaceous species once they formed dense mats over their pots or tubs.

## 3.4 GARLON® 360 RATES AND APPLICATION

Plants were taken outside the AgResearch glasshouse, and ten pots of each weed species and five pots of each native plant type were selected at random and arranged to receive each Garlon® 360 treatment. An equivalent number of plants was left untreated as a control.

A knapsack sprayer was used to apply the various Garlon® 360 herbicide mixtures. Rates of Garlon® 360 used, amount of active ingredient (a.i.) and dates applied are summarised in Table 2. The highest concentration used (5% v/v) was equivalent to a rate of 8.1 kg ai/ha (22.5 L Garlon® 360/ha), assuming a spray rate of 400L/ha. This approximated the highest trial rates reported in the literature (see section 2.2). The non-ionic surfactant Citowett® was added to each treatment at 0.025%, and the spray mix was applied to all plants, ensuring all vegetation was treated. As different species grew at different rates, herbicide treatment times varied, dependant on which species were available (see section 3.3).

In the first two spray applications (13 October and 2 November 2006), concentrations of Garlon® 360 from 0.5% to 5% were applied to all plants treated. Additional pots of purple loosestrife, arrow grass (*Triglochin striata*) and *Crassula helmsii* were treated with the lowest rate (0.25% v/v) on 21 December 2006, and other native species were also treated with concentrations from 0.25% to 2.5%, while the weed species were treated with concentrations from 0.25% to 5%. Oioi and *Carex cirrhosa* were treated with concentrations from 0.25% to 2.5% on 13 January 2007. Lower herbicide rates were used in the later trials as most weed species were killed by the 0.5% rate in the first two trials.

After being left to dry for several hours, the treated plants were then carefully returned to the glasshouse, making sure there was no contact between plants treated with different Garlon® 360 concentrations.

TABLE 2. CONCENTRATIONS OF GARLON® 360 (% VOLUME/TOTAL VOLUME), EQUIVALENT AMOUNTS OF ACTIVE INGREDIENT, AND DATES APPLIED TO WEED AND NATIVE SPECIES DURING THE POT TRIAL.

| CONCENTRATION OF GARLON® 360 (% v/v) | mg a.i. triclopyr/L | DATE APPLIED AND SPECIES* TREATED | | | |
|---|---|---|---|---|---|
| | | 13 OCT 2006 | 2 NOV 2006 | 21 DEC 2006 | 13 JAN 2007 |
| 5.00 | 18.0 | Mg, An, Ls<br>Ch, Af, Cv, Mr, Ts | No, Sf<br>Dd | Ls, Sc, Ag | |
| 2.50 | 9.0 | Mg, An, Ls<br>Ch, Af, Cv, Mr, Ts | No, Sf<br>Dd | Ls, Sc, Ag, Lp<br>Jp, Sr, Ch, Ts, Ea, Ig | As, Cc |
| 1.25 | 4.5 | Mg, An, Ls<br>Ch, Af, Cv, Mr, Ts | No, Sf<br>Dd | Ls, Sc, Ag, Lp<br>Jp, Sr, Ch, Ts, Ea, Ig | As, Cc |
| 0.50 | 1.8 | Mg, An, Ls,<br>Ch, Af, Cv, Mr, Ts | No, Sf<br>Dd | Ls, Sc, Ag, Lp<br>Jp, Sr, Ch, Ts, Ea, Ig | As, Cc |
| 0.25 | 0.9 | | | Ls, Sc, Ag, Lp<br>Jp, Sr, Ch, Ts, Ea, Ig | As, Cc |

* Plant species indicated by abbreviations. See Table 1 for plant names.

## 3.5 MONITORING AND DATA ANALYSIS

The treated plants were monitored on the following dates after being sprayed with Garlon® 360: 16 November, 20 November and 1 December 2006, and 9 January, 13 February, 6 March and 10 April 2007. Any plants that appeared to have died were checked for any living tissue. If none was apparent, they were discarded (for glasshouse hygiene). Monitoring involved visual assessment of the health of each plant compared with control plants, by estimating percentage damage (from 0% to 100%).

## 3.6 RESULTS

### 3.6.1 Weed species

Table 3 shows the assessed impact of the various Garlon® 360 treatments on the eight weed species used in the pot trial. All species were killed at all application rates, with the exception of two of the purple loosestrife plants treated at the 0.5% rate, which survived for 20 weeks. However, all purple loosestrife plants died at the same application rate (and at 0.25%) in a second experiment using different plants.

TABLE 3. WEEKS AFTER SPRAYING WITH GARLON® 360 UNTIL ALL TREATED WEED SPECIES IN POT TRIAL HAD DIED ('–' INDICATES RATES NOT TESTED ON THAT SPECIES).

| CONCENTRATION OF GARLON® 360 (% v/v) | MONKEY MUSK | WATER CELERY | PRIMROSE WILLOW | WATER-CRESS | PURPLE LOOSESTRIFE | CRACK WILLOW | GREY WILLOW | ALDER |
|---|---|---|---|---|---|---|---|---|
| Control (0) | All survived | All survived | All survived | All survived | All survived | All survived | All survived | All survived |
| 0.25 | – | – | 8 | – | 8 | – | 8 | 8 |
| 0.50 | 7 | 7 | 8 | 11 | 8* | 19 | 3 | 8 |
| 1.25 | 7 | 7 | 8 | 11 | 3 | 4 | 3 | 3 |
| 2.50 | 7 | 7 | 8 | 11 | 3 | 4 | 3 | 3 |
| 5.00 | 7 | 7 | – | 11 | 3 | 4 | 3 | 3 |

* Two plants survived 20 weeks after treatment. A second trial using this and a lower (0.25%) rate killed all plants after 8 weeks.

### 3.6.2 Native species

Tables 4 and 5 show the impact of various Garlon® 360 treatments on the 13 native species used in the pot trial. Table 4 provides details of the species that were killed during the trial, and Table 5 provides details of the species that survived or partially survived the trial.

The broadleaf species *M. radicans*, *C. helmsii* and *S. rotundifolia* and the monocotyledons harakeke and arrow grass were all killed at all treatment rates by the conclusion of the trial. Spike sedge and the rush *J. pallidus* were severely damaged at all rates, with damage reaching > 50% in all treatments. Other monocotyledon species in the Poaceae, Cyperaceae and Restionaceae and the gymnosperm kahikatea were still alive at the conclusion of the trial, at least at the lowest application rates. Two grasses—swamp millet and water brome—completely recovered in all treatments, apart from the water brome treated at the 5% rate. At the completion of the trial, less than 50% damage was recorded for swamp sedge, *C. cirrhosa* and oioi treated at the 0.5% rate, with similar levels of damage recorded at the 1.25% rate in the case of *C. cirrhosa.* Kahikatea appeared to fully recover from the 0.5% rate, with < 50% damage at the 1.25% and 2.5% rates.

TABLE 4. NATIVE SPECIES THAT WERE KILLED BY SPRAYING WITH GARLON® 360 AT DIFFERENT APPLICATION RATES IN THE POT TRIAL, SHOWING WEEKS UNTIL 100% MORTALITY ('–' INDICATES RATES NOT TESTED ON THAT SPECIES).

| CONCENTRATION OF GARLON® 360 (% v/v) | WEEKS UNTIL 100% MORTALITY | | | | |
|---|---|---|---|---|---|
| | *Crassula helmsii* | *Selliera rotundifolia* | *Mazus radicans* | ARROW GRASS | HARAKEKE |
| Control (0) | All survived | All survived | All survived | All survived | All survived |
| 0.25 | 7 | 7 | – | 7 | 7 |
| 0.50 | 7 | 2 | 12 | 7 | 7 |
| 1.25 | 7 | 2 | 7 | 7 | 7 |
| 2.50 | 2 | 2 | 7 | 7 | 7 |
| 5.00 | 7 | – | 7 | 7 | 7 |

TABLE 5. NATIVE SPECIES THAT SURVIVED SPRAYING WITH GARLON® 360 IN THE POT TRIAL, WITH PERCENTAGE SURVIVAL AT COMPLETION OF TRIAL (OR AT VARIOUS WEEKS AFTER TREATMENT), AT EACH APPLICATION RATE. ('–' INDICATES RATES NOT TESTED ON THAT SPECIES).

| CONCENTRATION OF GARLON® 360 (% v/v) | % SURVIVAL AT COMPLETION OF TRIAL (OR AT VARIOUS WEEKS AFTER TREATMENT) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | WATER BROME | SWAMP MILLET | *Juncus pallidus* | *Carex cirrhosa* | KAHIKATEA | SWAMP SEDGE | *Eleocharis acuta* | OIOI |
| Control (0) | All survived | All survived | All survived | All survived | All survived | All survived | All survived | All survived |
| 0.25 | – | 100% (8) | 48% (16) | 70% (8) | – | – | 50% (16) | 98% (8) |
| 0.50 | No damage after treatment | 100% (11) | 48% (16) | 70% (8) | 100% (14) | 59% (18) | 24% (16) | 58% (8) |
| 1.25 | 100% (19) | 100% (11) | 28% (16) | 70% (8) | 76% (14) | 3% (18) | 0% (16) | 32% (8) |
| 2.50 | 100% (19) | 100% (11) | 2% (16) | 48% (8) | 68% (14) | 0% (7) | 0% (11) | 0% (8) |
| 5.00 | 80% (19) | – | – | – | 0% (14) | 0% (7) | – | – |

## 3.7 DISCUSSION

Triclopyr TEA appears to provide good control of broadleaf wetland weeds at similar rates to glyphosate.

Triclopyr TEA is much more selective in action than glyphosate, with limited damage recorded on some non-target species. These results show the relative tolerance of several native wetland monocotyledon species and also the swamp forest tree kahikatea. The concentrations applied to non-target species in these pot trials are likely to be much higher than those that would be received in a field situation, either because these plants would usually be present in the understory beneath a canopy of treated *Alnus* or *Salix* spp., and not receive the full dose of herbicide, or the target weeds would be spot-sprayed so that spraying of non-target plants is minimised.

For more detail of these pot trials see Champion et al. (2008a, b).

# 4. Field trials

## 4.1 METHODS

Sites impacted by the study weed species (grey willow, alder, water celery and purple loosestrife) were chosen for field trials of triclopyr TEA (Garlon® 360) based on either existing weed control being undertaken at the site, and/or the site being under DOC management and/or of concern to iwi. Four sites were initially chosen (see sections 4.1.1 to 4.1.4). One was unavailable and was replaced with a fifth (see section 4.1.5).

Belt transects were established (each comprising ten quadrats) within the areas where the different Garlon® 360 treatments would be applied. Vegetation in each treatment area was assessed before treatment. Species presence for each area was recorded, along with species presence and cover in all belt transect quadrats.

Each belt transect comprised ten 10 m × 10 m quadrats, making an overall area of 1000 $m^2$ (0.1 ha). As the Waikato River water celery site (see section 4.2.3) had low species diversity with no woody vegetation, ten smaller quadrats (1 m × 1 m) were sampled with an overall area of 10 $m^2$.

Assessment of vegetation after treatment was carried out approximately 1 year after treatment, with earlier assessments carried out at some sites. Data analysis (end of this section) was carried out, comparing pre-treatment and 1 year post-treatment.

### 4.1.1 South Taupo Wetland

South Taupo Wetland is located at the southern end of Lake Taupo (Taupomoana), central North Island. Grey willow is actively invading the wetland and is displacing a range of herbaceous wetland types. Native species growing in the area include the restiad oioi, swamp sedge, spike sedge, the grass swamp millet and harakeke. In addition, the wetland could potentially support populations of the Nationally Endangered[1] grass water brome *Amphibromus fluitans.*

A 14-ha area of the wetland was selected for aerial application of Garlon® 360 over vegetation dominated by grey willow. Four belt transects (as described in section 4.1 above, making a total area of 4000 $m^2$) were established parallel to beach ridges and the Lake Taupo (Taupomoana) shoreline. GPS points for each transect are as follows:

| | |
|---|---|
| Belt transect 1 | 2754456 E, 6246290 N |
| Belt transect 2 | 2755623 E, 6246349 N |
| Belt transect 3 | 2754456 E, 6246290 N |
| Belt transect 4 | 2755481 E, 6246143 N |

[1] Species threat classifications follow the New Zealand Plant Conservation Network website, following the classification of de Lange et al. (2004).

For each of the four transects, presence and cover estimates were made for all species occupying ≥ 1% in each quadrat during a reconnaissance on 6 December 2006. Table 6 shows the mean and standard deviation of cover for each species present at greater than 3% averaged over the 40 quadrats.

The area was boom-sprayed by helicopter on 21 December 2007 with 18.7 L of Garlon® 360 applied per hectare (6.7 kg a.i./ha). The total volume of water used was 400 L/ha, which was applied during four passes of the helicopter, with each pass spraying 100 L of water at 90° to the previous pass. Quadrats in the treated area were surveyed on 11, 14, 20 and 24 November 2008.

### 4.1.2 Waikato River islands

There are several islands along the Lower Waikato River, northwestern North Island, which have been invaded by a wide range of wetland weeds including alder, crack willow and primrose willow. Alder and willows dominate the vegetation of many of the islands. These weeds are of concern to DOC (which is responsible for the management of some of the islands) and also to the Ngā Muka Tribal Development Trust based in the Te Kauwhata–Rangiriri area (A. Hopkins, pers. comm.). Native species growing in the area include swamp sedge and harakeke.

A DOC-administered island between Ohinewai and Rangiriri on the Lower Waikato River was selected as the trial site. Most of the island area was dominated by alder forest and a 0.6-ha area bounded by the GPS points 2700220 E 6414670 N, 2700255 E 6414675 N, 2700155 E 6414860 N and 2700185 E 6414900 N was targeted for herbicide application.

One belt transect (as described in section 4.1 above, making a total area of 1000 $m^2$, or 0.1 ha) was established parallel to the long axis of the island, starting at GPS point 2700178 E, 6414657 N. During a reconnaissance of the area on 7 December 2006, species presence and cover estimates for all species in each quadrat were recorded.

On 12 January 2008, the island was sprayed aerially using a helicopter with a boom attachment, following the GPS coordinates given previously. Garlon® 360 was applied at a rate of 28 L/ha (over an area of 0.6 ha) (10 kg a.i./ha). The total volume of water applied was 400 L/ha. A quadrat assessment of the treated area was carried out on 25 November 2008.

### 4.1.3 Waikato River mouth

Large areas of the Waikato River Delta (northwestern North Island) are dominated by sprawling mats of water celery interspersed with alligator weed. Environment Waikato (Waikato Regional Council) has an eradication programme for alligator weed. No native species occur amongst the weeds in these areas.

A large patch of water celery growing on a silt bank on Motukakaho Island in the Waikato River delta was selected as the trial site.

One belt transect comprising ten 1-$m^2$ quadrats, making a total of 10 $m^2$ was established parallel to the channel bisecting the island starting at the GPS point 2666760 E, 6428790 N. The vegetation on the site was assessed on 6 December 2007.

Garlon® 360 was applied to the transect on 12 January 2008 using a knapsack sprayer containing a 1% v/v solution of the herbicide, which was applied until all target vegetation was completely wetted. A quadrat assessment of the treated area was carried out on 3 December 2008.

### 4.1.4 Lake Horowhenua and Hokio ephemeral wetlands

Lake Horowhenua in the southern North Island had the largest infestation of purple loosestrife in New Zealand. In 1996, this formed a purple margin around much of the lake. After 1996, management actions by Horizons (Manawatu-Wanganui) Regional Council had reduced this infestation to occasional plants, but recent access issues that had prevented on-going control had led to an increase in its cover to almost to 20% of its former area, and it was expected to soon revert to pre-management levels. The area supported a mixed native and introduced vegetation, including several native *Juncus* and *Carex* species and spike sedge. South of the Hokio Stream (the Lake Horowhenua outlet) were a series of ephemeral dune wetlands where purple loosestrife was beginning to establish. Native species threatened by this species included oioi, arrow grass (*Triglochin striata*) and the at-risk species *Mazus novaezeelandiae* subsp. *impolitus* (Serious Decline) and *Selliera rotundifolia* (Gradual Decline).

Permission to conduct a herbicide trial at Lake Horowhenua was sought from the Lake Horowhenua Trust, but was not obtained. Another trial site was selected and assessed in December 2007 (see section 4.1.5).

### 4.1.5 Leonard Cockayne Reserve, Christchurch

The Cockayne Reserve is located in Christchurch City, South Island. It comprises two basins, one brackish and the other predominantly freshwater. Purple loosestrife at the freshwater site had been actively controlled by Christchurch City Council Park Staff (J. Roberts, pers. comm.). Native species growing in the area include swamp sedge, harakeke and *Juncus pallidus*.

The freshwater basin (swamp) of the Cockayne Reserve was selected as the trial site. The vegetation was mixed *Carex secta* and harakeke with various weed species (including purple loosestrife) scattered throughout the area. One belt transect (as described in section 4.1 above, making a total area of 1000 $m^2$) was established parallel to New Brighton Road at the GPS point 2486850 E, 5744598 N.

During a reconnaissance of the area on 19 December 2006, species presence and cover were estimated for all species in each quadrat and recorded.

Unlike the other three trials, the target weed in this trial was a sparse component of the vegetation. Garlon® 360 was applied on 19 December 2007 with a knapsack sprayer using a 1% v/v concentration of the herbicide to spot-spray all plants of purple loosestrife located in all quadrats. Associated vegetation growing around these plants was also affected by the herbicide treatment. A quadrat assessment of the treated area was carried out on 4 December 2008.

### 4.1.6 Data analysis

Vegetation composition and cover pre- and post-spray was compared by performing a paired *t*-test. In addition to comparing individual species or genera, the following classes were also compared in each quadrat:

- Total introduced and native species.
- Total broadleaf, fern, grasses, sedges and rush species.
- Total dicotyledon and monocotyledon species.

## 4.2 RESULTS

### 4.2.1 South Taupo Wetland

Fifty-seven species were recorded on 6 December 2006, all but 17 being native (Appendix 1). The dominant canopy species was grey willow, with occasional mānuka (*Leptospermum scoparium*). Shrub species included *Coprosma* × *cunninghamii* and both parent species, with lesser amounts of *Olearia virgata* and *Pittosporum tenuifolium*. Tall harakeke and raupo (*Typha orientalis*) were also abundant. Ground cover species included the sedges *Carex maorica, C. secta*, swamp sedge, *Baumea arthrophylla, B. rubiginosa* and spike sedge; the grasses toetoe (*Cortaderia toetoe*), swamp millet and the introduced Yorkshire fog (*Holcus lanatus*); swamp kiokio (*Blechnum novae-zelandiae*), oioi and a range of herbaceous dicotyledons, especially the native *Epilobium chionanthum, E. pallidiflorum, Hydrocotyle pterocarpa, Lobelia angulata* × *perpusilla, Myriophyllum propinquum, Ranunculus amphitrichus* and *R. macropus*, and the introduced *Galium palustre, Lotus pedunculatus, Ludwigia palustris, Lycopus europaeus* and *Ranunculus flammula*.

A visual assessment of the treated area was carried out on 20 May 2008. There appeared to be 95% mortality of grey willow, with some mortality of swamp kiokio, mānuka, oioi and *Coprosma* spp., although living specimens were also abundant, and mānuka seedlings were common. Lotus major (*Lotus pedunculatus*) was absent from the treated area, but still common under untreated willows. No *Epilobium* spp. were seen, either in treated or untreated sites. Yorkshire fog appeared to have increased in the treated area.

Quadrats in the treated area were surveyed on 11, 14, 20 and 24 November 2008. Table 6 shows the mean and standard deviation of cover for each species initially present on the transects at greater than 3% averaged over the 40 quadrats before and 1 year after herbicide application. Table 7 presents the change in mean % cover of the species that exhibited significant change in cover following spraying.

TABLE 6. SOUTH TAUPO WETLAND BELT TRANSECTS ASSESSED PRE- AND 1 YEAR POST-SPRAYING WITH GARLON® 360 SHOWING SPECIES WITH INITIAL AVERAGE COVER EXCEEDING 3%. NOTE: SPRAYING WAS CARRIED OUT IN DECEMBER 2007.

| SPECIES | AVERAGE COVER (DECEMBER 2006) % (± SD) | AVERAGE COVER (NOVEMBER 2008) % (± SD) |
|---|---|---|
| *Salix cinerea* | 29.4 (± 29.9) | 2.1 (± 6.3) |
| *Baumea* spp. | 16.7 (± 15.6) | 10.7 (± 11.3) |
| *Blechnum novae-zelandiae* | 4.1 (± 7.2) | 0.0* (± 0.3) |
| *Carex* spp. | 13.7 (± 16.8) | 13.5 (±10.4) |
| *Cortaderia toetoe* | 3.1 (± 6.6) | 4.0 (±7.0) |
| *Isachne globosa* | 4.3 (± 7.0) | 0.9 (±2.8) |
| *Leptospermum scoparium* | 4.9 (± 14.8) | 0.2 (±0.5) |
| *Lotus pedunculatus* | 8.8 (± 11.7) | 0.0 |
| *Typha orientalis* | 9.8 (± 10.8) | 7.6 (±14.9) |

* Actual value 0.03.

TABLE 7. SOUTH TAUPO WETLAND BELT TRANSECTS COMPARING QUADRATS PRE- AND 1 YEAR POST-SPRAYING WITH GARLON® 360 SHOWING SPECIES WITH SIGNIFICANT CHANGE IN COVER (* $P < 0.05$,** $P < 0.01$, *** $P < 0.001$). TABLE DOES NOT INCLUDE SPECIES ABSENT PRE-SPRAYING.

| SPECIES | CHANGE IN MEAN % COVER | STANDARD DEVIATION | *t*-TEST SIGNIFICANCE |
|---|---|---|---|
| *Salix cinerea* | −27.33 | 28.79 | *** |
| *Holcus lanatus* | 2.30 | 5.64 | * |
| *Isachne globosa* | −3.40 | 6.15 | ** |
| *Lotus pedunculatus* | −8.75 | 11.70 | *** |
| *Typha orientalis* | 3.03 | 5.28 | ** |
| Total dicotyledons | −5.85 | 3.20 | ** |

The following species also had observable changes in abundance 1 year after spraying (described below), although statistical analysis did not show these changes to be significant. This was usually because the species were uncommon or sparse within most plots:

**Dicotyledon species**

- The native herbs *Myriophyllum propinquum* and *Epilobium chionanthum* (Gradual Decline; de Lange et al. 2004)) were eliminated from virtually all plots. Smaller herbs such as *Hydrocotyle pterocarpa* and *Lobelia angulata* × *perpusilla* were reduced in abundance, although they were still present in many plots. *Ranunculus macropus* (Gradual Decline) increased slightly in abundance and extent (32 plots in 2006/2007 and 34 in 2008).
- A range of weeds in the Asteraceae family including *Cirsium vulgare, C. arvense, Conyza sumatrensis, Sonchus oleraceus, Mycelis muralis* and *Senecio* spp. have appeared since spraying, generally on the lower mounds around large grey willows.
- Shrubby native species including mānuka, *Coprosma* spp. and *Olearia virgata* were reduced in presence and cover in all transects. However, in many places on the transects, seedlings, particularly of mānuka, were common and taller shrubs that were not killed at the time of Garlon® 360 application appeared to be recovering.

**Moncotyledon species**

- *Eleocharis sphacelata* (tall spike sedge) was eliminated from seven plots on Transect 2 and oioi had almost been eliminated in the open but was recovering where it occurred beneath a willow canopy. There appeared to be some minor dieback of *Baumea* species which had reduced in cover, although they appeared to be recovering quickly.
- Yorkshire fog (*Holcus lanatus*) and other introduced grasses appeared to have become more common.
- The endangered bog greenhood (*Pterostylis paludosa*), ranked as Serious Decline (de Lange et al. 2004), had increased in abundance and another greenhood species (*P. graminea*) was found for the first time in sprayed plots.

**Fern species**

- Swamp kiokio had suffered significant dieback and was reduced in cover in all transects, with covers below 1%; however, was still present in most plots it was originally found in. Other ferns were similarly affected, though new species were discovered, including *Rumohra adiantiformis*.
- The most significant species found in surveys following spraying with Garlon® 360 at the South Taupo Wetland was the endangered stalked adder fern (*Ophioglossum petiolatum*), ranked as Nationally Critical (de Lange et al. 2004). This was discovered within a quadrat on Transect 4 in November 2008. This is the first record of the species in Tongariro Whanganui Taranaki Conservancy and represents one of only nine extant sites known nationally.

Although the reduction of grey willow cover resulting from the application of Garlon® 360 was highly significant (Table 7), the percentage mortality of grey willow trees was not particularly high, with a mean of 17.7% overall from all four transects (Table 8). Mortality of small trees (e.g. Transects 4/5) was higher in comparison with tall willow forest (e.g. Transect 3). The majority of trees that survived resprouted from epicormic buds (dormant buds located near the base of the trunk), generally ≤ 1 m from the ground.

One of the authors (N. Singers, unpubl. data) has trialled different concentrations of Garlon® 360 for control of small (2–3-m tall) grey willow shrubs. Garlon® 360 was applied to 30 grey willow trees for each treatment (at rates of 0.5%, 1%, 2%, and 4%). The 0.5% rate resulted in 73.3% mortality (8/30 trees were resprouting epicormically from their bases), with 100% mortality at the other rates. He noted a difference in non-target damage on *Carex* and *Juncus* species between the 1% and 4% trial areas, with very minor non-target vegetation damage around the 1% treated plants. Based on the same water rate as the South Taupo Wetland trial, use of the 1% rate would equate to a reduction in herbicide used from 18.7 L to 4 L per hectare.

TABLE 8. MORTALITY OF GREY WILLOW TREES PRESENT IN ALL PLOTS FROM ALL TRANSECTS 1 YEAR AFTER APPLICATION OF GARLON® 360.

| | NUMBER OF LIVE WILLOWS REMAINING | NUMBER OF DEAD WILLOWS REMAINING | MORTALITY (%) |
|---|---|---|---|
| Transect 2 | 42 | 12 | 22.2 |
| Transect 3 | 200 | 6 | 2.9 |
| Transect 4 | 44 | 35 | 44.3 |
| Transect 5 | 25 | 14 | 35.9 |
| Total | 311 | 67 | 17.7 |

### 4.2.2 Waikato River island

In total, 71 species were recorded in the reconnaissance on 7 December 2007, of which only 18 species were native (Appendix 1). The dominant canopy species was alder, with occasional box elder (*Acer negundo*), Japanese walnut (*Juglans ailantifolia*) and cabbage tree (*Cordyline australis*). Shrub species included the native *Coprosma* × *cunninghamii* and both parent species, and introduced Chinese privet (*Ligustrum sinense*), along with tall herbaceous species such as inkweed (*Phytolacca octandra*) and pampas (*Cortaderia selloana*). Ground cover species included the native species swamp sedge *Haloragis erecta*, swamp willow weed (*Persicaria decipiens*) and the fern *Diplazium australe*, but the dominant species were all introduced. Yellow flag (*Iris pseudacorus*), creeping buttercup (*Ranunculus repens*) and creeping bent (*Agrostis stolonifera*) were prevalent in openings in the alder canopy, and wandering Jew (*Tradescantia fluminensis*) and water pepper (*Persicaria hydropiper*) were dominant in dry and wet shaded areas respectively.

An assessment of the treated area was carried out on 22 May 2008. There appeared to have been 99% mortality of alder, although some smaller tree species, especially Japanese walnut, Chinese privet and the native cabbage tree and karamū (*Coprosma robusta*) and shade-tolerant inkweed still survived, probably because they had been sheltered to some extent by the alder canopy. Most ground cover species had been killed or significantly reduced, with the exception of the introduced grass creeping bent. The native *Diplazium australe* was still present, but average cover in each quadrat had reduced from 0.6% to 0.4%. Swamp sedge was recorded in two quadrats for the first time, probably because it had been obscured by smothering weedy species during previous assessments.

A quadrat assessment of the treated area was carried out on 25 November 2008. The average vegetated cover was 72% (±12.5% SD) compared with nearly 100% in December 2007. Table 9 shows the mean and standard deviation of cover for each species initially present on the transect at greater than 3% averaged over the ten quadrats before and nearly 1 year after herbicide application. Table 10 presents the change in mean % cover of the species that exhibited significant changes in cover following spraying.

The following species (described below) also had observable changes in abundance following spraying, although statistical analysis did not show these changes to be significant. This was usually because the species were uncommon or sparse within most plots:

- The native shrubs *Coprosma* × *cunninghamii* and their parent species found outside the alder-dominated vegetation were all killed. Conversely, shrubs under the alder canopy were mostly unaffected by the Garlon® 360 application.

TABLE 9. WAIKATO ISLAND BELT TRANSECT ASSESSED PRE- AND NEARLY 1 YEAR POST-SPRAYING WITH GARLON® 360, SHOWING SPECIES WITH INITIAL AVERAGE COVER CLOSE TO OR EXCEEDING 3%. NOTE: THE TRANSECT WAS SPRAYED IN JANUARY 2008.

| SPECIES | AVERAGE COVER (DECEMBER 2007) % (± SD) | AVERAGE COVER (NOVEMBER 2008) % (± SD) |
|---|---|---|
| *Alnus glutinosa* | 37.1 (± 23.9) | 1.4 (± 3.0) |
| *Agrostis stolonifera* | 3.7 (± 15.4) | 15.1 (± 27.7) |
| *Iris pseudacorus* | 3.9 (± 23.8) | 4.2 (± 16.4) |
| *Ligustrum sinense* | 7.5 (± 25.3) | 6.1 (± 18.2) |
| *Persicaria hydropiper* | 2.6 (± 10.0) | 12.1 (± 10.7) |
| *Ranunculus repens* | 38.1 (± 23.9) | 9.9 (± 9.4) |
| *Tradescantia fluminensis* | 19.0 (± 23.8) | 2.5 (± 6.5) |

TABLE 10. WAIKATO ISLAND BELT TRANSECT COMPARING QUADRATS PRE- AND NEARLY 1 YEAR POST-SPRAYING WITH GARLON® 360, SHOWING SPECIES WITH SIGNIFICANT CHANGE IN COVER (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$). TABLE DOES NOT INCLUDE SPECIES ABSENT PRE-SPRAY, BUT PRESENT 1 YEAR AFTER SPRAY.

| SPECIES | CHANGE IN MEAN % COVER | STANDARD DEVIATION | *t*-TEST SIGNIFICANCE |
|---|---|---|---|
| *Alnus glutinosa* | −35.50 | 25.02 | ** |
| *Bidens frondosa* | 1.10 | 0.57 | *** |
| *Carex scoparia* | 0.50 | 0.53 | * |
| *Cirsium vulgare* | 0.90 | 0.99 | * |
| *Glyceria maxima* | 0.50 | 0.53 | * |
| *Iris pseudacorus* | 0.70 | 0.67 | ** |
| *Myosotis laxa* | 0.40 | 0.52 | * |
| *Persicaria hydropiper* | 9.60 | 11.16 | * |
| *Ranunculus repens* | −28.20 | 24.53 | ** |
| *Rorippa sylvestris* | 1.90 | 1.37 | ** |
| *Solanum chenopodioides* | 0.70 | 0.82 | * |
| *Solanum nigrum* | 0.80 | 1.03 | * |
| *Sonchus asper* | 1.80 | 1.75 | ** |
| Total introduced species | −0.90 | 0.74 | ** |
| Total native species | 0.14 | 0.18 | * |
| Total broadleaf species | −1.05 | 0.49 | *** |
| Total sedges | 0.34 | 0.19 | *** |
| Total dicotyledons | −1.11 | 0.51 | *** |
| Total monocotyledons | 1.22 | 1.48 | * |

- Some taller herbs growing under alder (such as inkweed, wandering Jew and *Haloragis erecta*) also declined in abundance 1 year after Garlon® 360 application.
- The native herbs *Alternanthera* aff. *sessilis, Callitriche petriei, Centipeda aotearana, Limosella lineata* and the sedge *Isolepis reticularis* were all found in the quadrats for the first time in November 2008. *Pseudognaphalium luteoalbum* increased in abundance 1 year after Garlon® 360 application.
- The introduced grass *Agrostis stolonifera* markedly increased in the quadrats not shaded by alders (quadrats 1 to 3).
- A range of introduced weeds including *Barbarea stricta, Cardamine flexuosa*, *Mentha spicata* and *Veronica anagallis-aquatica* also appeared for the first time, or markedly increased in abundance and extent.
- The native sedge *Cyperus ustulatus* was observed in one quadrat prior to Garlon® 360 application, and was killed by the herbicide. In November 2008, a large number of seedlings of a *Cyperus* species were noted in the vicinity of the dead plant. Conversely, *Carex* species increased in abundance following the Garlon® 360 application.

The reduction of alder cover after spraying with Garlon® 360 was highly significant (Table 10). This species, which formed an average of 51.4% (± 14.6%) canopy in quadrats 4 to 10, had reduced to 1.7% (± 3.4%) 1 year after treatment. The highest remaining alder cover (8%) occurred on the edge of this area, where young alder plants would have been sheltered by the alder canopy. One dead alder tree had fallen over when observed in November 2008.

### 4.2.3 Waikato River mouth

All plots were 100% covered by 1-m-tall water celery on 6 December 2007.

A quadrat assessment of the treated area was carried out on 30 May 2008. The plots were found to be completely bare.

The trial site was visited again on 3 December 2008. Seedlings (< 10 mm tall) of water celery occupied 15% of the treated area, with 5% cover of starwort (*Callitriche stagnalis*). A floating mat of water celery had been deposited into the trial site and occupied 20% of the area. Much of the remainder of the area (50%) had been eroded away and was under water at the time of inspection.

### 4.2.4 Leonard Cockayne Reserve, Christchurch

Thirty species were recorded in the reconnaissance on 7 December 2007, with all except 13 being native (Appendix 1). The swamp vegetation was dominated by the native sedge *Carex secta*, which averaged 1.4 m in height, with taller pedestals of that species and harakeke around 2 m tall. The most abundant introduced species were yellow flag and purple loosestrife, the latter species being the target species for this trial. It occupied an average cover of 2.5% within the vegetation, occurring in each of the ten quadrats. Occasional seedlings and saplings of grey willow were located in the quadrats. These were hand-pulled and removed from the wetland.

An assessment of the treated area was carried out on 13 February 2008. Dead purple loosestrife plants were found throughout the vegetation, but new young plants of this species were also seen, with an average cover of 1.1% compared with the 2.4% observed in the transect pre-spraying (December 2007) and covers averaging 6.5% outside of the treated area in February 2008. It is likely that the majority of plants seen in the February inspection of the treated plots had germinated after the herbicide application. Although spray damage was noted on adjacent vegetation, no other species were dead at the time of inspection.

A quadrat assessment of the treated area was carried out on 4 December 2008. Table 11 shows the mean and standard deviation of cover for each species initially present at greater than 3% averaged over the ten quadrats before and 1 year after Garlon® 360 application. Table 12 presents the change in mean % cover of the species that exhibited significant changes in cover following spraying. The native *Coprosma robusta, Apium prostratum* and *Juncus edgariae* and the introduced *Hypochaeris radicata* and *Landoltia punctata* were recorded in December 2008 but not December 2007.

TABLE 11. LEONARD COCKAYNE RESERVE BELT TRANSECT ASSESSED PRE- AND 1 YEAR POST-SPRAYING WITH GARLON® 360, SHOWING SPECIES WITH INITIAL AVERAGE COVER EXCEEDING OR CLOSE TO 3%. NOTE: THE TRANSECT WAS SPRAYED IN DECEMBER 2007.

| SPECIES | AVERAGE COVER (DECEMBER 2006) % (± SD) | AVERAGE COVER (NOVEMBER 2008) % (± SD) |
|---|---|---|
| *Lythrum salicaria* | 2.4 (± 1.0) | 1.2 (± 0.4) |
| *Carex secta* | 40.5 (± 7.6) | 49.0 (± 10.7) |
| *Iris pseudacorus* | 27.0 (± 10.6) | 24.0 (± 9.7) |
| *Phormium tenax* | 14.3 (± 4.0) | 13.1 (± 3.9) |

TABLE 12. LEONARD COCKAYNE RESERVE BELT TRANSECT COMPARING QUADRATS PRE- AND 1 YEAR POST-SPRAYING, SHOWING SPECIES WITH SIGNIFICANT CHANGE IN COVER (* $P < 0.05$,** $P < 0.01$, *** $P < 0.001$). TABLE DOES NOT INCLUDE SPECIES ABSENT PRE-SPRAYING, BUT PRESENT 1 YEAR AFTER SPRAYING.

| SPECIES | CHANGE IN MEAN % COVER | STANDARD DEVIATION | *t*-TEST SIGNIFICANCE |
|---|---|---|---|
| *Lythrum salicaria* | −1.20 | 1.03 | ** |
| *Carex secta* | 8.50 | 6.26 | ** |
| *Isolepis prolifer* | 0.40 | 0.52 | * |
| *Mentha piperita* | 0.40 | 0.52 | * |
| *Schedonorus phoenix* | 0.50 | 0.53 | * |
| Total native species | 0.53 | 0.39 | ** |
| Total broadleaf species | −0.16 | 0.22 | * |
| Total fern species | 0.30 | 0.42 | * |
| Total grass species | 0.30 | 0.16 | *** |
| Total sedge species | 1.31 | 0.89 | ** |
| Total monocotyledon species | 0.41 | 0.33 | |

# 5. Discussion

In all four trials, the target weed species (grey willow, alder, water celery and purple loosestrife) were significantly reduced in cover. There was not a complete kill of the two tree species, with minor regrowth evident 1 year after herbicide treatment. Further monitoring of the herbicide trials was not funded by DOC, but in the case of South Taupo Wetland, there had been considerable recovery in leaf cover on grey willow trees 2 years after the herbicide trial (authors (KB), pers. obs.). The use of Garlon® 360 for aerial treatment of willows and other trees is therefore not recommended until further research into its use is undertaken.

Ground-based treatment using Garlon® 360 appeared to be highly successful. Water celery and purple loosestrife were killed, but recolonised through seed germination (after 11 months and 2 months respectively). A strategy to manage seed banks of such species (e.g. several treatments prior to seed-set) needs to be factored into their management.

General trends noted in the field trials were a reduction in extent of dicotyledonous species, apart from annual or short-lived colonising species, either small native turf plants such as *Callitriche petriei, Centipeda aotearana* and *Limosella lineata* or a wide range of introduced weedy species such as the composites *Cirsium vulgare, C. arvense, Conyza sumatrensis, Sonchus* spp., *Hypochaeris radicata, Mycelis muralis, Pseudognaphalium luteoalbum* and *Senecio* spp. Other species, such as *Barbarea stricta, Cardamine flexuosa*, *Bidens frondosa, Myosotis laxa* and *Veronica anagallis-aquatica*, increased in abundance 1 year after herbicide application. Some perennial species with extensive underground stems such as the native *Ranunculus macropus* and the introduced *Rorippa sylvestris* also recovered 1 year after herbicide application. However, the stoloniferous creeping buttercup (*R. repens*) and rhizomatous *Lotus pedunculatus* were reduced in abundance.

Generally, monocotyledons increased in abundance following spraying with Garlon® 360. Most grasses and sedges and raupo increased significantly. Notable exceptions were swamp millet, *Eleocharis sphacelata* (tall spike sedge) and *Cyperus ustulatus*, all of which were reduced in abundance. The jointed rush oioi was almost completely eliminated in open areas, but recovered under a willow canopy at South Taupo Wetland. Interestingly, swamp sedge (*Carex virgata*) appeared to be sensitive to Garlon® 360 in pot trials, but was barely harmed in the four field trials (being relieved of smothering growths of weed at the Waikato island site). Conversely, oioi appeared to be relatively tolerant of Garlon® 360 in the pot trial, but was almost completely killed in the South Taupo Wetland field trial. Perhaps this species is more stressed growing in waterlogged fen conditions compared with the more terrestrial conditions in which the potted plants grew. At South Taupo Wetland, the summer-green *Pterostylis* orchids appeared to increase in abundance following herbicide application.

Ferns were of limited abundance in the trial sites and although the cover of the most abundant species, *Blechnum novae-zelandiae*, declined at South Taupo Wetland, it was showing signs of recovery 1 year after treatment.

Thus, compared with glyphosate (the only other herbicide registered for situations where contamination of natural water bodies may occur), Garlon® 360 appeared to provide selective control of target woody and broadleaf wetland weeds in both pot trials and field trials, particularly when the target species were growing in predominantly monocotyledonous vegetation. Non-target damage was primarily restricted to other dicotyledons, although some monocotyledons and ferns were also severely damaged in the field trials. Grasses, rushes and most sedges increased in extent following Garlon® 360 treatment. Ground-based application of Garlon® 360 as a spot spray provided more selectivity of control, and although some local damage to *Carex secta* was noted 2 months after spraying during the spot-spraying trial, this species fully recovered and had significantly expanded in area 1 year after the herbicide was applied.

Garlon® 360 should prove to be a useful tool for the management of endangered species where selective control of weeds would be beneficial, either to remove competition or to provide disturbance necessary to manage early successional species. A number of endangered species including *Ranunculus macropus*, *Pterostylis paludosa* and *Ophioglossum petiolatum* either increased in abundance, or were recorded for the first time 1 year after herbicide treatment at the South Taupo Wetland trial site.

Future work could involve trialling application of the herbicide at lower rates to improve cost efficiency and, possibly, improve selectivity of control. It is therefore recommended that further trials be undertaken to optimise control of each weed species using Garlon® 360.

# 6. Acknowledgements

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# Appendix 1

## PLANT SPECIES RECORDED IN THE RECONNAISSANCE OF EACH FIELD SITE

| SPECIES | FIELD SITE | | | | |
|---|---|---|---|---|---|
| | SOUTH TAUPO | WAIKATO ISLAND | WAIKATO DELTA | HORO-WHENUA | COCKAYNE |
| **Native (80 spp.)** | | | | | |
| *Alternanthera* aff. *sessilis* | | y | | | |
| *Apium prostratum* | | | | | y |
| *Apodasmia similis* | y | | | | |
| *Azolla rubra* | | | | | y |
| *Baumea arthrophylla* | y | | | | |
| *Baumea rubiginosa* | y | | | | |
| *Baumea tenax* | y | | | | |
| *Blechnum novae-zelandiae* | y | | | | y |
| *Callitriche petriei* | | y | | y | |
| *Calystegia sepium* | | y | | | |
| *Carex diandra* | y | | | | |
| *Carex geminata* | | y | | | |
| *Carex maorica* | y | | | y | y |
| *Carex secta* | y | | | y | y |
| *Carex sinclairii* | y | | | | |
| *Carex virgata* | y | y | | | y |
| *Centipeda aotearana* | | y | | | |
| *Coprosma propinqua* | y | y | | | y |
| *Coprosma robusta* | y | y | | | y |
| *Coprosma* × *cunninghamii* | y | y | | | y |
| *Cordyline australis* | y | y | | | y |
| *Cortaderia richardii* | | | | | y |
| *Cortaderia toetoe* | y | | | | |
| *Cotula coronopifolia* | | | | y | |
| *Cyathea dealbata* | | y | | | |
| *Cyperus ustulatus* | | y | | | |
| *Deparia petersenii* | | y | | | |
| *Dicksonia fibrosa* | y | | | | |
| *Diplazium australe* | | y | | | |
| *Eleocharis acuta* | y | | | y | |
| *Eleocharis sphacelata* | y | | | | |
| *Epilobium chionanthum* | y | | | | |
| *Epilobium pallidiflorum* | y | | | | |
| *Euchiton limosus* | | | | | |
| *Euchiton sphaericus* | | y | | | |
| *Glossostigma elatinoides* | | y | | y | |
| *Haloragis erecta* | | y | | | |
| *Histiopteris incisa* | | | | | y |
| *Hydrocotyle novae-zelandiae* | y | | | y | |
| *Hydrocotyle pterocarpa* | y | | | | |
| *Hypolepis ambigua* | y | | | | |

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| SPECIES | FIELD SITE | | | | |
|---|---|---|---|---|---|
| | SOUTH TAUPO | WAIKATO ISLAND | WAIKATO DELTA | HORO-WHENUA | COCKAYNE |
| *Isachne globosa* | y | | | | |
| *Isolepis prolifer* | | | | y | y |
| *Isolepis reticularis* | | y | | | |
| *Juncus australis* | | | | y | |
| *Juncus edgariae* | y | | | y | |
| *Juncus pallidus* | | | | | y |
| *Juncus pauciflorus* | y | | | | |
| *Juncus sarophorus* | | | | y | |
| *Lachnagrostis* sp. | y | | | | |
| *Lemna minor* | | | | | y |
| *Lepidosperma australe* | y | | | | |
| *Leptospermum scoparium* | y | | | | |
| *Limosella lineata* | | y | | y | |
| *Lobelia angulata* | y | | | | |
| *Lycopodium volubile* | y | | | | |
| *Microsorum pustulatum* | y | y | | | |
| *Microtis uniflora* | y | | | | |
| *Muehelenbeckia australis* | | y | | | |
| *Myriophyllum propinquum* | y | | | y | |
| *Olearia virgata* | y | | | | |
| *Ophioglossum petiolatum* | y | | | | |
| *Paesia scaberula* | y | | | | |
| *Persicaria decipiens* | y | y | | y | |
| *Phormium tenax* | y | | | y | y |
| *Pittosporum tenuifolium* | y | | | | |
| *Pseudognaphalium luteoalbum* | | y | | | |
| *Pseudopanax arboreus* | y | | | | |
| *Pteris tremula* | | y | | | |
| *Pterostylis graminea* | y | | | | |
| *Pterostylis paludosa* | y | | | | |
| *Ranunculus amphitrichus* | y | | | | |
| *Ranunculus macropus* | y | | | | |
| *Rorippa palustris* | | y | | y | |
| *Rumohra adiantifolius* | y | | | | |
| *Schoenus maschalinus* | y | | | | |
| *Senecio hispidulus* | | | | y | y |
| *Senecio minimus* | y | | | | |
| *Typha orientalis* | y | | | y | y |
| *Weinmannia racemosa* | y | | | | |
| **Introduced (91 spp.)** | | | | | |
| *Acer negundo* | | y | | | |
| *Agrostis stolonifera* | y | y | | y | y |
| *Alium triquetrum* | | y | | | |
| *Alnus glutinosa* | | y | | | |
| *Alocasia brisbanensis* | | y | | | |
| *Alternanthera philoxeroides* | | | y | | |
| *Anthoxanthum odoratum* | y | | | | |
| *Apium nodiflorum* | | | y | y | |
| *Aster subulata* | | y | | y | |
| *Barbarea stricta* | | y | | | |

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| SPECIES | FIELD SITE | | | | |
|---|---|---|---|---|---|
| | SOUTH TAUPO | WAIKATO ISLAND | WAIKATO DELTA | HORO-WHENUA | COCKAYNE |
| *Betula pendula* | | | | | y |
| *Bidens frondosa* | y | y | | y | |
| *Callitriche stagnalis* | | | y | y | |
| *Cardamine flexuosa* | | y | | | |
| *Cardamine pratensis* | | y | | | |
| *Carex ovalis* | y | | | | |
| *Carex scoparia* | | y | | | |
| *Centaurium erythraea* | y | | | | |
| *Cirsium vulgare* | y | y | | y | |
| *Conyza sumatrensis* | y | y | | y | |
| *Cortaderia selloana* | | y | | | |
| *Crategus monogyna* | | y | | | |
| *Crocosmia* x *crocosmiiflora* | | y | | | |
| *Cyperus eragrostis* | | y | | | |
| *Dactylis glomerata* | | y | | | |
| *Duchesnia indica* | | y | | | |
| *Epilobium ciliatum* | | y | | | |
| *Galium aparine* | | y | | | |
| *Galium palustre* | y | y | | y | |
| *Glyceria maxima* | | y | y | y | |
| *Glyceria declinata* | | y | | | |
| *Holcus lanatus* | y | y | | y | y |
| *Hypochaeris radicata* | | | | y | y |
| *Iris pseudacorus* | | y | | | y |
| *Juglans ailantifolia* | | y | | | |
| *Juncus acuminatus* | y | | | | |
| *Juncus articulatus* | y | | | y | |
| *Juncus bufonius* | y | | | y | |
| *Juncus effusus* | | | | y | |
| *Juncus subnodulosus* | | | | y | y |
| *Landoltia punctata* | | | | | y |
| *Lepidium coronopus* | | y | | | |
| *Leycesteria formosa* | y | | | | |
| *Ligustrum sinense* | | y | | | |
| *Lonicera japonica* | | y | | | |
| *Lotus pedunculatus* | y | | | y | |
| *Ludwigia palustris* | y | | | y | |
| *Lycopus europaeus* | y | y | | | |
| *Lysimachia nummularia* | | y | | | |
| *Lythrum hyssopifolia* | | | | y | |
| *Lythrum salicaria* | | | | y | y |
| *Mentha piperita* | | y | | | y |
| *Mentha pulegium* | | | | y | |
| *Mentha spicata* | | y | | | |
| *Mycelis muralis* | y | | | | |
| *Myosotis laxa* | y | y | | y | y |
| *Myosotis sylvatica* | | y | | | |
| *Parentucellia viscosa* | | | | y | |
| *Paspalum distichum* | | | | y | |
| *Persicaria hydropiper* | | y | | y | |

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| SPECIES | FIELD SITE | | | | |
|---|---|---|---|---|---|
| | SOUTH TAUPO | WAIKATO ISLAND | WAIKATO DELTA | HORO-WHENUA | COCKAYNE |
| *Persicaria persicaria* | | | | y | |
| *Phalaris arundinacea* | | | | y | |
| *Phytolacca octandra* | | y | | | |
| *Plantago australis* | | | | y | |
| *Plantago lanceolata* | | | | y | |
| *Poa annua* | | y | | | |
| *Ranunculus flammula* | y | | | | |
| *Ranunculus repens* | | y | | y | |
| *Raphanus raphanistrum* | | y | | | |
| *Rorippa sylvestris* | | y | | | |
| *Rubus fruticosus* agg. | y | y | | | |
| *Rumex conglomeratus* | | y | | y | |
| *Rumex crispus* | | | | | y |
| *Salix cinerea* | y | | | | y |
| *Salix fragilis* | | y | y | y | |
| *Schedonorus phoenix* | | | | y | y |
| *Senecio bipinnatisectus* | | y | | | |
| *Senecio sylvaticus* | y | | | | |
| *Senecio vulgaris* | | y | | | |
| *Solanum chenopodioides* | | y | | | |
| *Solanum nigrum* | | y | | | |
| *Sonchus asper* | y | y | | | |
| *Sonchus oleraceus* | y | | | y | |
| *Stachys sylvatica* | | y | | | |
| *Stellaria graminea* | | | | y | |
| *Teline monspessulana* | | | | | y |
| *Tradescantia fluminensis* | | y | | | |
| *Urtica dioica* | | y | | | |
| *Verbena bonariensis* | | y | | | |
| *Veronica anagallis-aquatica* | | y | y | y | |
| *Zantedeschia aethiopica* | | y | | | |

***How effective is Garlon® 360 for controlling wetland weeds?***

*There is a need for herbicides that can be applied as foliar sprays to target specific weeds in wetlands while limiting effects on non-target species. This study evaluated the triethylamine (TEA) salt of the herbicide triclopyr (recently registered for sale in New Zealand as Garlon® 360) as an additional tool for wetland weed management. Garlon® 360 controlled all weed species tested. Native monocotyledonous species (especially grasses, rushes and sedges) mostly survived application of Garlon® 360, indicating that it is more selective for these species than glyphosate; but some regrowth of grey willows was observed 2 years after the trials, indicating the need for further research into aerial application of this herbicide.*

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New Zealand Government