Feasibility study on the eradication of parrot's feather (*Myriophyllum aquaticum*) 2020/21

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Executive summary

The West Coast Regional Council has a regional leadership role under the Biosecurity Act 1993 to manage invasive species. The invasive aquatic weed parrot's feather (*Myriophyllum aquaticum*) is classified in the West Coast Regional Pest Plant Management Plan 2018 – 2028 as an organism requiring 'Progressive Containment' with the aim of containing and reducing the geographic distribution of the pest species in the West Coast region.

West Coast Regional Council engaged NIWA in 2020/21 through an MBIE Envirolink Medium Advice Grant, on behalf of landowners in the Kongahu Swamp area of Karamea, to provide advice and report on herbicide field trials to determine the feasibility of eradication of parrot's feather in the region.

This report describes the results of field trials using the herbicides metsulfuron-methyl, imazapyr isopropylamine and triclopyr triethylamine to control parrot's feather and indicates potential use patterns for inclusion in control programmes in the region. NIWA has incorporated information from the international literature to compare with the results from the field study.

Experimental plot trials were established in a drainage system within Kongahu Swamp area. Field trials were designed by NIWA and were implemented by West Coast Regional Council, including site selection, trial setup, herbicide application (December 2020), pre-herbicide and initial post-herbicide treatment monitoring (0 and 44 days after herbicide treatment (DAT), respectively). NIWA provided guidance on the trial setup, conducted the final efficacy assessment (85 DAT) and completed data analysis.

Following herbicide application, all treatments resulted in large reductions in parrot's feather abundance at 44 DAT, with triclopyr and metsulfuron providing the greatest reductions in plant abundance. By 85 DAT a significant amount of regrowth had occurred in all plots, with the high rates of triclopyr (2 kg a.i. (active ingredient) ha^{-1}) and metsulfuron (0.05 kg a.i. ha^{-1}) providing the greatest level of control. Imazapyr was less effective than triclopyr and metsulfuron for controlling parrot's feather, however imazapyr provided large reductions in abundance at 44 DAT.

Triclopyr has previously been demonstrated in New Zealand to provide effective control of parrot's feather. In the current plot trial, triclopyr applied at 2 kg a.i. ha^{-1} demonstrated effective short-term control of parrot's feather with a single herbicide application, corroborating previous results.

Further research to understand the optimal timing of individual herbicide applications, the effect of multiple herbicide applications per season and combination / sequential herbicide treatments, will support the development of more effective management solutions.

Control of parrot's feather using herbicide (e.g., triclopyr triethylamine) is recognised as the most efficacious method for management of large infestations internationally. However, this assessment showed that one application applied during December 2020 did not provide long-term control over a growth season with any of the herbicides tested.

Physical, mechanical or biological control methods are not regarded as efficient alternatives to herbicide control for eradication of large infestations of parrot's feather in the Kongahu area, but physical/mechanical removal can be integrated to form part of an eradication programme.

An eradication programme would include:

1. Regular (three-monthly) delimitation of all suitable habitats within Kongahu, using effective detection techniques (e.g., local teams of trained plant spotters).
2. Multiple triclopyr applications, up to three applications (three-monthly in spring, summer and early autumn) per year for multiple years.
3. Once abundance is reduced (< 5% cover), physical or mechanical removal of plants, starting at the most upstream end of the infestation, while continuing herbicide use downstream to ensure sources of reinfestation are minimised.
4. Continued physical or mechanical removal of plants working downstream until all plants are removed.
5. Regular monitoring to detect any regrowth early, to allow removal of all plant material (including underwater parts) before plant biomass can recover.
6. Effective hygiene measures for any machinery brought into the treatment area to ensure no reinfestation occurs (i.e., adhere to Check, Clean, Dry principles).
7. Exclusion of livestock from drains and infested areas to prevent fragmentation and subsequent spread.

1 Introduction

The West Coast Regional Council (WCRC) has a regional leadership role under the Biosecurity Act 1993 to manage invasive species. The West Coast Regional Pest Plant Management Plan (RPMP) outlines the framework to efficiently and effectively manage or eradicate specified organisms in the West Coast region to:

- Minimise the actual or potential adverse or unintended effects associated with those organisms.
- Maximise the effectiveness of individual actions in managing pests through a regionally coordinated approach.

Many organisms in the West Coast region are considered undesirable or a nuisance, including the introduced invasive aquatic weed parrot's feather (*Myriophyllum aquaticum*) originating from South America. Parrot's feather is classified in the West Coast RPMP as an organism requiring 'Progressive Containment' (WCRC 2018). The intermediate outcome of a Progressive Containment programme is to contain or reduce the geographic distribution of the pest species to an area over time.

As part of a previous MBIE Envirolink Advice Grant (2012-WCRC187) in 2019/20, NIWA developed a series of trials using herbicides to optimise control of parrot's feather. Unfortunately, the experimental plots and channels designated for the trial were sprayed with an unknown herbicide by a farm manager, nullifying that trial. WCRC subsequently re-engaged NIWA in 2020/21 through an Envirolink Medium Advice Grant (2134-WCRC198), on behalf of landowners in the Kongahu Swamp area of Karamea. This report provides advice on and documents the herbicide field trials to determine the feasibility of eradicating parrot's feather from the region.

1.1 Scope

This NIWA report provides WCRC with:

- Results from a field study conducted by WCRC with guidance from NIWA in 2020/21 to elucidate the efficacy of herbicides permitted for aquatic use by the EPA, for control of parrot's feather.
- Information to support decision making by WCRC and recommendations how to proceed with parrot's feather control in the region.

This project provides the results of field trials using the herbicides metsulfuron-methyl, imazapyr isopropylamine and triclopyr triethylamine to control parrot's feather and indicates potential use patterns for implementation into control programmes in the region. NIWA has incorporated information from the international scientific literature to compare with the results from the field study.

1.2 Description of parrot's feather (*Myriophyllum aquaticum*) in New Zealand

Parrot's feather is a robust stoloniferous perennial plant that grows rapidly in aquatic habitats as a submerged or sprawling emergent plant. It is considered a major weed internationally (Guillarmod 1979, Murphy et al. 1993, Sytsma and Anderson 1993; Hussner and Champion 2012) as well as in New Zealand (Hofstra et al. 2006). Parrot's feather is native to South America and forms floating mats of vegetation across the surface of water bodies. It forms mats in still or slow-moving water or on damp ground and is particularly competitive in high nutrient eutrophic environments. Growth is most vigorous when high nitrogen levels are present (Sutton 1985), and most of the required nitrogen and phosphorus are absorbed from the sediment (Sytsma and Anderson 1989). Parrot's feather chokes waterways, impedes water flow, exacerbates siltation and flooding and outcompetes native vegetation (Wersal and Madsen 2008a).

Until its inclusion on the national list of plants banned from sale and distribution under the Biosecurity Act (1993) in New Zealand, it was often cultivated in ornamental garden ponds from which it escaped, with subsequent spread by contaminated drain clearing machinery. It is an aggressive and troublesome weed in drainage systems and shallow waterbodies (Coffey and Clayton 1988) and is ranked in the top 20 worst aquatic weeds in New Zealand with an aquatic weed risk assessment model (AWRAM) score of 56 out of a maximum score of 100 (Champion and Clayton 2000).

Parrot's feather propagates through asexual reproduction and is spread by stem fragmentation. It does not produce viable seed in New Zealand, with only female flowers occurring outside its native range. No specialised vegetative propagules such as tubers or turions exist (Sytsma and Anderson 1989), thus reproduction occurs entirely from stem fragmentation and vegetative growth. Human mediated dispersal is therefore recognised as a leading vector of dispersal within and between catchments (Cooke et al. 2005; Bickel 2015). Within catchments parrot's feather also spreads by hydrochory, which is the passive dispersal of fragments by water currents (Johansson and Nilsson 1993).

Parrot's feather is now widely naturalised in the North Island (locally common in Auckland, Waikato, Wairarapa and Manawatu) but relatively rare in the South Island. The invasive species is tolerant of a wide range of environmental conditions and coupled with its ability to easily disperse, means it could result in a significantly increased distribution in the South Island. Major impacts on water body utility and ecology are caused by the establishment of monospecific populations growing within waterways, displacing other aquatic flora, impacting aquatic fauna and in-stream processes.

In other countries where parrot's feather has been introduced, control has proven to be difficult. Attempts to remove the plant by mechanical or other physical methods provides immediate and localised clearance but can produces numerous fragments, many of which are viable, and can result in an increase in the number of infestations (Guillarmod 1979, Moreira et al. 1999, Hofstra et al. 2006).

Management using herbicides, is recognised as one of the most effective and widely used control options for invasive aquatic plants worldwide (Cooke et al. 2005, Petty 2005, Madsen 2006, Gettys et al. 2009). Herbicide applications have been more effective for longer term control of parrot's feather than mechanical techniques (Hofstra et al. 2006). Selecting the appropriate herbicide for a given species and situation is critical.

Different products or formulations of the same herbicide vary in their efficacy on targeted plants. Use restrictions are particularly important in aquatic environments and are generally based on water use (e.g., recreation, irrigation, stock watering, etc.) and toxicological data. Herbicides are approved for use by government authorities (i.e., Environmental Protection Authority - EPA), to protect the health and safety of humans, animals, and crops utilising the treated water, as well as providing effective control of the target species. EPA give permissions to management agencies that control the way products are used and specify required monitoring.

In New Zealand, parrot's feather is regarded by waterway managers as a problematic plant that has limited effective control options available (Hofstra et al. 2006).

1.3 Parrot's feather management in the West Coast region

Parrot's feather is regarded as an environmental weed and a pest of production lands, particularly in the hump and hollow farms near Karamea. Parrot's feather regularly achieves nuisance levels in areas where high nutrient availability stimulates growth (Wersal and Madsen 2008a). Land occupiers within the West Coast region are required to destroy any infestations on their property, not less than once annually, to contain the species to land already infested and minimise the risk of spread and the impacts on production and the environment (WCRC 2018). Parrot's feather is listed as a 'Progressive Containment' plant in the WCRC Regional Pest Plant Management Plan, with a long-term goal to move towards 'Eradication' in the Kongahu Swamp area dependent on the availability of effective control tools to achieve this outcome.

Previous NIWA research assessed the efficacy of triclopyr triethylamine to control parrot's feather and showed this herbicide successfully reduced the cover and presence of parrot's feather (Hofstra et al. 2006). The research led to this herbicide being used previously at Kongahu. Control at the site was achieved, but parrot's feather has subsequently continued to spread in Blackwater Creek. The area is largely used for dairy farming, reliant on a complex drainage system to farm this land. The drainage systems in the area contain extensive infestations of parrot's feather. After several years of attempted control by aerial application of herbicide and physical removal of biomass, there has been little progress made towards eradication or even sustained control. In its present state, Blackwater Creek is classified as a degraded site partly due to being infested with parrot's feather. In the longer term, WCRC hope to reverse this classification and create or enhance habitat for native biota including the at-risk declining migratory galaxiids (e.g., īnanga, *Galaxias maculatus*) and aquatic plants formerly known from this water body (e.g., stout water milfoil, *Myriophyllum robustum*) (Figure 1-1).

The study presented in this report established experimental trials in a drainage area within the region and tested chemical control options to enable experimental results to be delivered. The herbicides metsulfuron-methyl, imazapyr isopropylamine and triclopyr triethylamine, permitted for aquatic use by the EPA, were evaluated at label and half-label application rates for controlling parrot's feather.

Figure 1-1: (A) Parrot's feather (*Myriophyllum aquaticum*) growing as a dense infestation. (B) Single stem of stout water milfoil (*Myriophyllum robustum*), an 'At Risk: Declining' species in New Zealand, growing in amongst kutakuta (*Eleocharis sphacelata*).

2 Methods

2.1 Field trials

Field trials were established within the Kongahu Swamp (41° 18.065'S; 172° 5.935'E). Field trials were implemented by WCRC including site selection, trial setup, herbicide application, pre-herbicide and initial post-herbicide treatment monitoring. NIWA provided guidance on the trial setup, conducted the final efficacy assessment and data analysis.

The experiment was designed by NIWA to incorporate two trials at two different spatial scales including:

1. ***Plot Trial***: to allow for direct comparisons between herbicide treatments (Figure 2-1, Plot 1 to Plot 28, Table 2-1).

2. ***Channel Trial***: to demonstrate herbicide effectiveness on a larger channel scale. Following WCRC conducting the pre-herbicide monitoring and applying the individual herbicide treatments to the channel trial, the channels were subsequently sprayed with an unknown herbicide by a farm manager. For this reason, the channel trial is not mentioned further in this report and results of the plot trial are compared to information in the international scientific literature.

2.1.1 Timing of key experimental steps

The timing of key steps in the 2020/21 plot trial were:

- WCRC re-established a series of trial plots in December 2020 in a drainage system within the Blackwater Creek catchment and conducted an initial on-ground vegetation assessment (Pre-treatment, described throughout this report as 0 days after herbicide treatment (DAT)) of each plot.
- WCRC applied herbicide treatments to trial plots on the 20th December 2020.
- WCRC conducted the initial post-herbicide treatment monitoring (44 DAT) to determine the efficacy of the herbicide treatments on parrot's feather.
- NIWA conducted the final post-herbicide treatment monitoring (85 DAT).
- At each monitoring interval plant abundance metrics (infestation size, % cover, plant height) was assessed. WCRC also collected drone imagery of each plot on each monitoring occasion, to enable NIWA to conduct an aerial image analysis to determine plant cover within plots.

2.1.2 Plot trial layout and experimental design

The experimental site was selected at Kongahu, West Coast (entry to farm: 41° 18.385'S; 172° 5.514'E). The site was contained within one drainage channel adjacent to a hump and hollowed paddock (41° 18.065'S; 172° 5.935'E). Experimental plots were positioned in a ca. 280 m length of channel (Figure 2-1). Prior to herbicide treatment the site contained a uniform dense cover of parrot's feather within the channel, allowing for effective comparisons of herbicide efficacy to subsequently be made.

Twenty-eight treatment plots of 5 m in length were established along the channel. Each plot was separated by at least a 4 m length of untreated dense parrot's feather to avoid any potential cross-contamination between treatments. Each plot was marked with a flagged pin and GPS referenced. Each plot was treated with a randomly designated herbicide treatment (Table 2-1). Treatments were replicated 4 times (in 4 randomised blocks), including 4 untreated control plots.

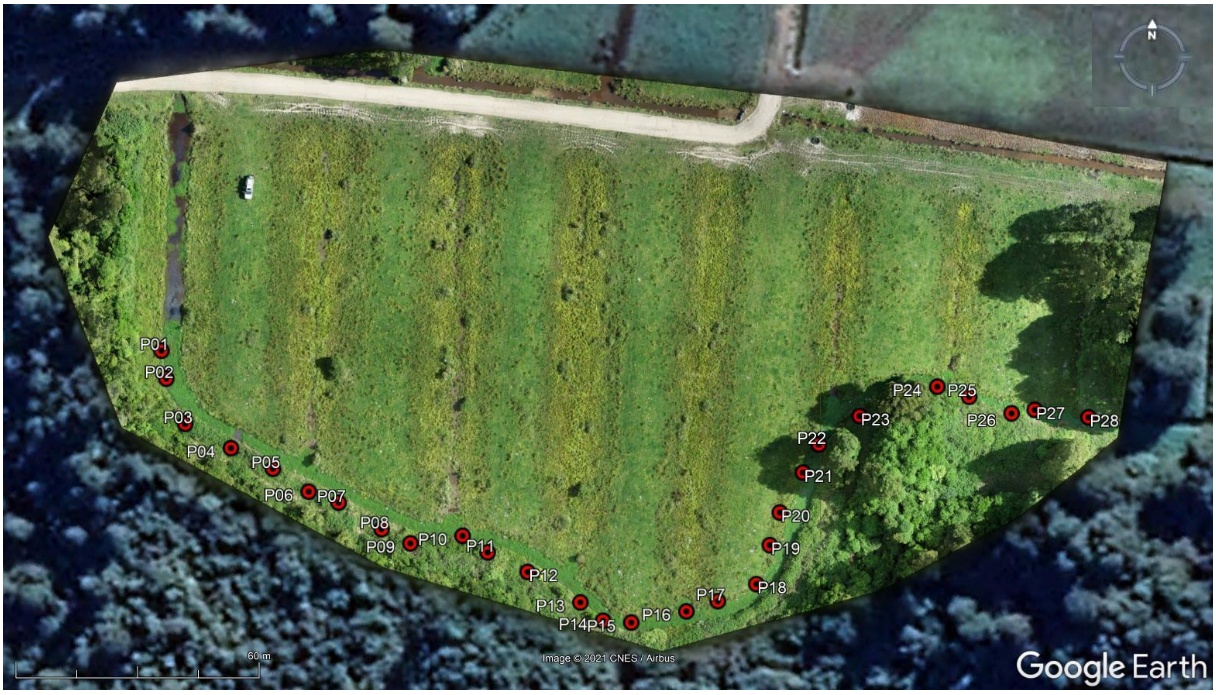

Figure 2-1: Site map showing the locations of experimental plots 1 to 28 within the Kongahu Swamp area of Karamea, West Coast (41° 18.065'S; 172° 5.935'E). Parrot's feather is the bright green plant occupying the drain near the forest boundary.

Table 2-1: Experimental treatments applied to trial plots in late December 2020. There were 4 replicate plots of each of the 7 treatments, equating to 28 plots. a.i. = active ingredient.

Treatment Number	Herbicide Treatment	Application Rate (kg a.i. ha^{-1})
1	Control (no herbicide)	None
2	Metsulfuron: label rate	0.05
3	Metsulfuron: 0.5 x label rate	0.025
4	Imazapyr: label rate	1
5	Imazapyr: 0.5 x label rate	0.5
6	Triclopyr: label rate	2
7	Triclopyr: 0.5 x label rate	1

2.1.3 Herbicide application

West Coast Regional Council applied herbicide treatments to the designated trial plots in December 2020. Maximum label rates of each of the herbicide active ingredients (a.i.) were used (Table 2-1): metsulfuron at 0.05 kg a.i. ha^{-1}; imazapyr at 1 kg a.i. ha^{-1}; triclopyr at 2 kg a.i. ha^{-1}. Each of these herbicides were also applied to plots at ½ of this rate (0.025, 0.5 and 1 kg a.i. ha^{-1}, respectively). Herbicides were applied with a non-ionic surfactant using a knapsack, sprayed until runoff from emergent parrot's feather foliage. Spray equipment was washed thoroughly between herbicide treatments.

2.1.4 Data collection and timing

Plant condition within each plot was assessed by WCRC prior to treatment (0 DAT; 16 December2020) and at 6 weeks after treatment (44 DAT; 2 February 2021). A final assessment of plots to determine the effectiveness of the herbicides was conducted by NIWA at 3 months after treatment (85 DAT; 15 March 2021).

Within each experimental plot on each assessment date:

- A 3 m wide band in the centre of each 5 m plot (i.e., excluding one meter from each end of each plot) was assessed. The exclusion zone at each end of the plot was designed to exclude regrowth of parrot's feather from outside of the plots influencing the assessment.
- The maximum length and width of the infestation within each plot was recorded.
- A visual estimate of the percentage cover of parrot's feather within each plot was made and the typical height of parrot's feather stems above the water recorded.
- A DJI Matrice 200 series drone captured an aerial image (RGB) of each plot at 40 m elevation on each assessment date. An on-ground photo of each plot was also recorded.

During NIWA's 85 DAT plot assessment, the core treatment area (2 x 2 m area within each plot) was also assessed (parrot's feather area and cover within the core 4 m^2 treatment area) to give a further indication of herbicide efficacy. The water depth and the sediment depth, to the channel hardpan, was also recorded within each plot at this time.

2.1.5 Data analysis

On-ground monitoring data and aerial images from each monitoring event were analysed by NIWA to determine efficacy of the herbicide treatments to control parrot's feather.

From the on-ground monitoring data, the area of infestation within each plot and the cover values were multiplied to give an area metric calculation, termed 'area occupied' by parrot's feather. This metric was used to make comparisons of herbicide efficacy.

Aerial images of each plot from each monitoring event were analysed to determine the emergent cover of parrot's feather over the duration of the trial. To calculate the amount of foliage present, each aerial colour (RGB) image was converted into a HSB (Hue Saturation Brightness) stack and the threshold within each image adjusted to highlight parrot's feather foliage. The area of the image occupied by foliage (%) was then calculated. This post-processing was undertaken using ImageJ 1.51v, a freeware image processing and analysis program (http://imagej.nih.gov/ij).

The reported herbicide efficacy outcomes from the field trial were compared to the relevant international literature.

3 Results

3.1 On-ground monitoring data

Prior to herbicide treatment trial plots contained a uniform cover of parrot's feather averaging 83% cover (SD 11.8) and 11.2 m^2 (SD 2.4) within each plot (Figure 3-1). Water depth and sediment depth was consistent across the trial site. Water depth averaged 0.65 m (SD 0.1) and sediment depth averaged 0.88 m (SD 0.1) at the 85 DAT monitoring event.

Following herbicide application, all treatments achieved large reductions in parrot's feather abundance at 44 DAT (Figure 3-1), with triclopyr and metsulfuron providing the greatest reductions in plant abundance. By 85 DAT, a significant amount of regrowth (and incursion from outside of plots) had occurred in all plots, with the high rates of triclopyr (2 kg a.i. ha^{-1}) and metsulfuron (0.05 kg a.i. ha^{-1}) providing the greatest level of control (Figure 3-1).

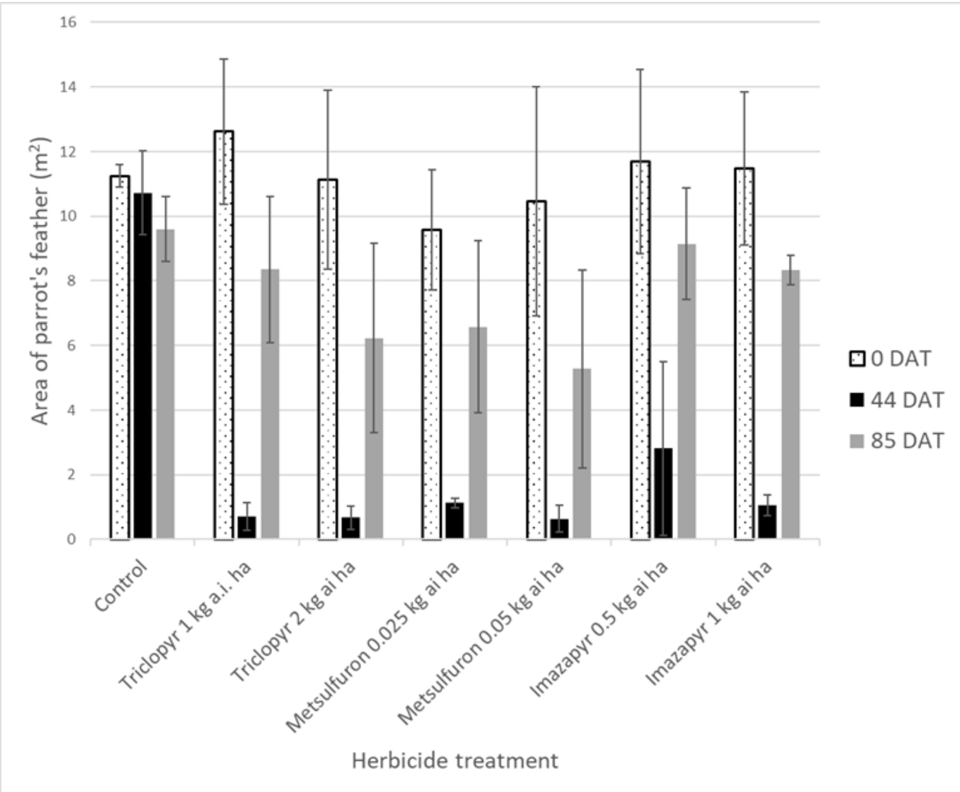

Figure 3-1: Area occupied by parrot's feather in each plot (n=4) before and at intervals after herbicide application. Herbicide was applied once only (20th December 2020). DAT = Days after herbicide treatment.

At 85 DAT, maximum herbicide efficacy was achieved in the core treatment area (2 x 2 m area within each plot) with triclopyr and metsulfuron (Figure 3-2A). Triclopyr (2 kg a.i. ha^{-1}) regularly reduced parrot's feather abundance and was more consistent across the trial than metsulfuron which showed some variability between plots (Figure 3-2A).

The typical height of emergent parrot's feather in control plots (no herbicide) at 85 DAT averaged 37.5 cm (SD 8.7), compared to the <10 cm for the high rates of triclopyr (2 kg a.i. ha^{-1}) and metsulfuron (Figure 3-2B). Imazapyr treatments (0.5 and 1 kg a.i. ha^{-1}) were less effective at controlling parrot's feather than the high rates of triclopyr (2 kg a.i. ha^{-1}) and metsulfuron at both 44 and 85 DAT (Figure 3-1, Figure 3-2). However, imazapyr still provided large reductions in parrot's feather abundance at 44 DAT (Figure 3-1).

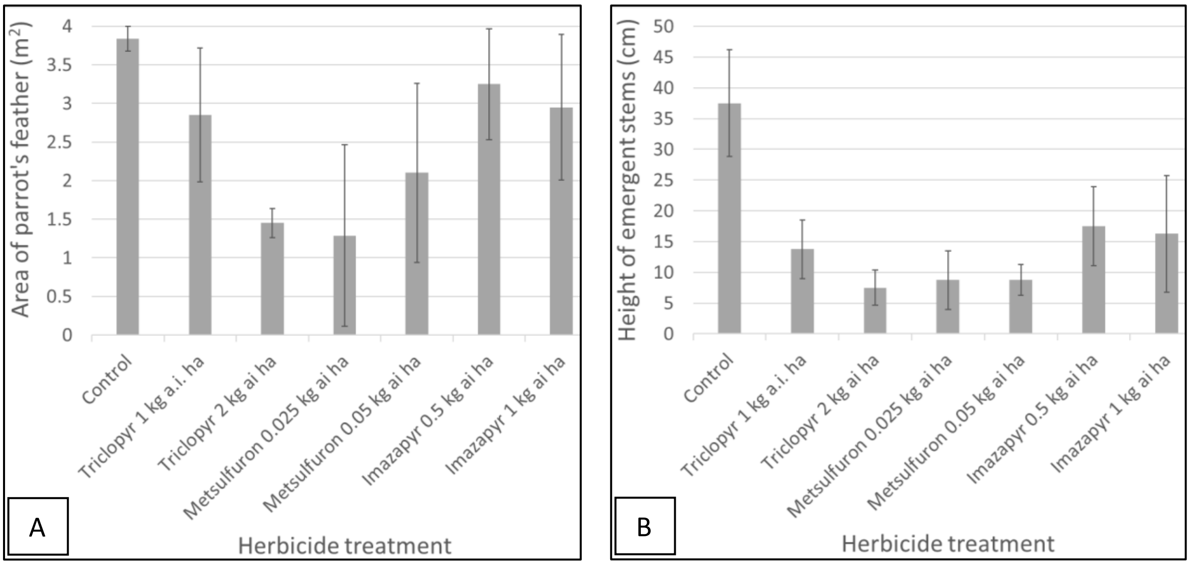

Figure 3-2: Area occupied (A) and typical height (B) of parrot's feather within plots at 85 DAT. Area occupied was recorded in the core treatment area (2 x 2 m area), and height is based on emergent foliage within plots (n=4).

3.2 Aerial image analysis

The analysis of aerial drone imagery largely reflected results from the on-ground monitoring (Section 3.1). Triclopyr (2 kg a.i. ha^{-1}) and metsulfuron (0.05 kg a.i. ha^{-1}) provided the most effective control at 85 DAT (Figure 3-3). However, there was much more variability in the aerial imagery analysis compared to the on-ground monitoring data, likely due to interactions between the image processing approach and the quality of the aerial imagery collected. The aerial image analysis showed triclopyr applied at a low rate (1 kg a.i. ha^{-1}) provided effective initial control at 44 DAT, however significant growth was recorded at 85 DAT.

Appendix A shows examples of aerial plot photos for each herbicide treatment.

Appendix B shows examples of on-ground plot photos of each herbicide treatment, these images align with the aerial plot photos presented in Appendix A.

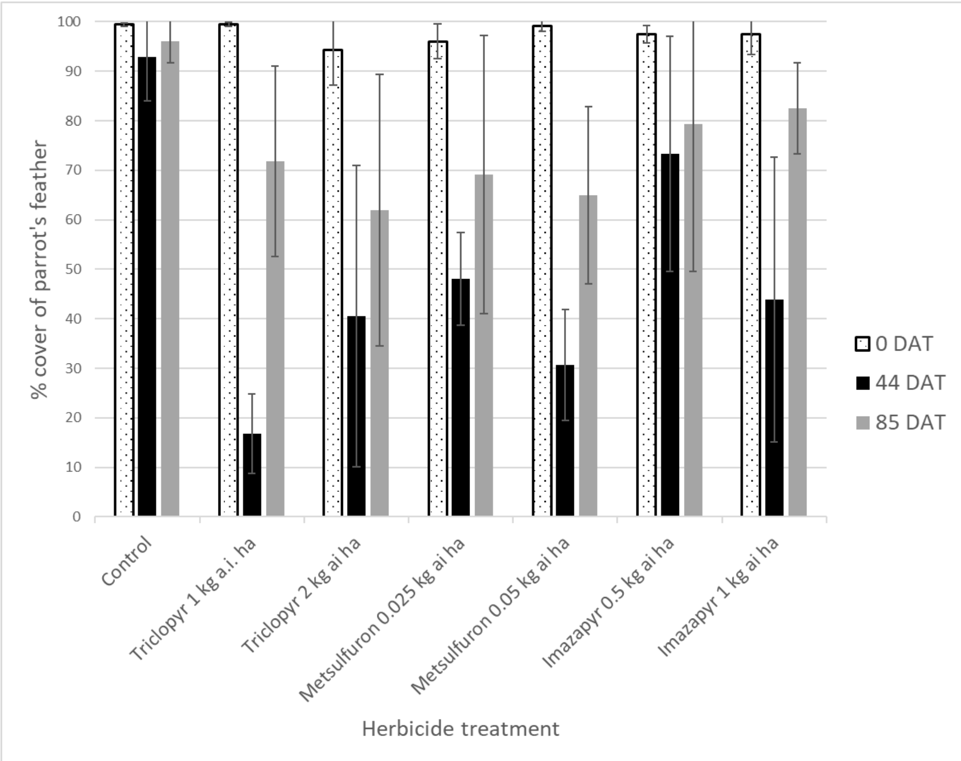

Figure 3-3: Cover of parrot's feather (%) in each plot assessed from aerial imagery collected before and at intervals after herbicide application.

4 Discussion

4.1 Potential future management options

4.1.1 Herbicide control

Triclopyr has previously been demonstrated to provide a better level of parrot's feather control in New Zealand than glyphosate at rates from 4 to 8 kg a.i. ha^{-1}, and rates lower than 2 kg a.i. ha^{-1} have been suggested to have potential application (Hofstra et al. 2006). In the current plot trial triclopyr applied at 2 kg a.i. ha^{-1} demonstrated effective short-term control of parrot's feather with a single herbicide application, corroborating previous triclopyr efficacy results. Metsulfuron provided a similar level of control to triclopyr, whereas imazapyr treated plots had more emergent regrowth at 85 DAT.

Comparisons of the longevity of control that is achieved with single versus multiple herbicide treatments within a growing season, would enable control programs to be optimised (Kuehne et al. 2018). This current study applied herbicide once in early summer and monitored herbicide efficacy up to 85 DAT. Given the logistical and resource challenges of managing parrot's feather, knowing the best time of year to apply a single treatment is a research question that could be targeted to support future management efforts.

While parrot's feather is an emergent aquatic weed, much of the biomass is located under the water, either as submerged stems or root mass. A study of allocation and growth in aquatic situations found that submerged stems of parrot's feather comprised 75 to 80% of the biomass, while emergent stems and leaves comprise 15 to 20% (Sytsma and Anderson 1989). Biomass allocation was found to be relatively constant with varying water depth. Therefore, only a small portion of the plant is available to apply herbicide by foliar spray, which is the most direct and reliable application technique. This relies on applied herbicides translocating to stems below the waterline to achieve effective control. Regrowth following herbicide treatments readily occurs from parrot's feather underwater. This was observed by NIWA at a wetland site at Birchfield Swamp, West Coast where parrot's feather had been treated with metsulfuron over multiple years (local DOC staff, pers. comm.) but was still largely present below the waterline enabling regrowth to occur from submerged plant parts (Figure 4-1).

Internationally, the systemic herbicides triclopyr, imazapyr and 2,4-D are reported among the most effective options for control of parrot's feather (Hussner and Champion 2012, Wersal et al. 2017, Kuehne et al. 2018). The systemic herbicide glyphosate and contact herbicide diquat, are both relatively well tested for parrot's feather control, but are not typically recommended because of the potential for rapid regrowth (Westerdahl and Getsinger 1988, Moreira et al. 1999, Kuehne et al. 2018). Based on the results of Wersal and Madsen (2007a), imazapyr applied at the rates of 1,123 and 584 g a.i. ha^{-1} were effective as a foliar application for control of parrot's feather in outdoor mesocosm experiments, complete control of the plant was achieved after 10 weeks with no regrowth. However, we did not achieve this level of control in the current field plot trials on the West Coast using imazapyr at the rates of 500 and 1000 g a.i. ha^{-1}. 2,4-D is not registered for use over water in New Zealand.

Figure 4-1: Parrot's feather biomass present below the waterline in a wetland at Birchfield Swamp, West Coast, South Island, following multiple metsulfuron-methyl herbicide treatments.

4.1.2 Mechanical and physical control

Mechanical or physical removal of parrot's feather is suitable for relatively small infested areas. The greatest risk of mechanical harvesting is fragmenting the stems, which remain highly viable and able to establish new populations downstream (Guillarmod 1979). Sutton (1985) also identified the seriousness of fragmentation and urged the further investigation into the development of effective mechanical control methods. Cilliers et al. (2003) noted that mechanical control is not practical unless all plant fragments are removed.

Smaller infestations of parrot's feather may be able to be removed by hand. However, such an approach is highly labour intensive and restricted to stream sections that have good access and where the water level is shallow enough to manage removal. In the end, eradication will not be achieved if small fragments are missed or upstream populations remain.

If mechanical or physical control methods are used, undertaking management works strategically in an upstream to downstream direction, clearing a catchment from top to bottom, will enhance management efforts. An integrated approach using both herbicide and mechanical/physical control methods is likely required to achieve eradication.

4.1.3 Habitat manipulation

Water level drawdowns in situations where the water body can be thoroughly drained to allow the bottom sediments to dry completely has been suggested (Wersal and Madsen 2007b). This control technique maybe of limited use on the West Coast and even if possible, some plant material may remain alive and regenerate when sediments are rehydrated. Water level drawdown may aid mechanical and physical control efforts.

Surface shading to control aquatic weeds is another control technique used for some invasive plant species, though it comes with its own set of limitations. Covering large areas can be costly, and covers can be dislodged by wind and water flow or removed or damaged. Wersal and Madsen (2008b) specifically tested parrot's feather response to shading. Their results indicate that parrot's feather responds strongly to reduced light by increasing the length of both emergent and submerged shoots. Given the costs and risks associated with surface covers and the positive response by parrot's feather to shading, it is not regarded as a viable control option.

4.1.4 Biological control

Several potential biological control agents have been investigated in a number of countries for use against parrot's feather. For example, flea beetles (*Lysathia ludoviciana* and *L. flavipes*) have been considered as potential biocontrol candidates (Habeck and Wilkerson 1980, Cordo and DeLoach 1982, Cilliers 1998). Preliminary tests on feeding preferences of *Lysanthia* spp. on our endemic milfoil *M. robustum* (Figure 1-1B) in South Africa have shown it is highly susceptible to damage from flea beetles (Grant Martin, Rhodes University, Grahamstown, pers. comm. 4/07/2014) and therefore permission to introduce those agents to New Zealand is unlikely. Fungal pathogens have also been isolated in South America which damage parrot's feather and have biological control potential. Also, an isolate of *Pythium carolinianum* from parrot's feather causes root and stem rot and leaf wilt (Bernhardt and Duniway 1984). Grass carp (*Ctenopharyngodon idella*) have shown potential as a biological control agent for parrot's feather (Pine and Anderson 1991, Armellina et al. 1998, Moreira et al. 1998). Of these potential biological control agents only grass carp are available in New Zealand, and they are seldom effective in a drainage environment (Wells et al. 2003, Hofstra et al. 2006).

5 Recommendations

- A consistent approach involving multiple herbicide applications, up to three applications per year, for multiple years are likely required to achieve effective control of patches of parrot's feather. Several studies recommend that repeated applications or herbicide combinations are necessary to provide seasonal control.
- An eradication programme would include:
  - Regular (three-monthly) delimitation of all suitable habitats within Kongahu, using effective detection techniques (e.g., local teams of trained plant spotters).
  - Multiple triclopyr applications, up to three applications (three-monthly in spring, summer and early autumn) per year for multiple years.
  - Once abundance is reduced (< 5% cover), physical or mechanical removal of plants, starting at the most upstream end of the infestation, while continuing herbicide use downstream to ensure sources of reinfestation are minimised.
  - Continued physical or mechanical removal of plants working downstream until all plants are removed.
  - Regular monitoring to detect any regrowth early, to allow removal of all plant material (including underwater parts) before plant biomass can recover.
  - Effective hygiene measures for any machinery brought into the treatment area to ensure no reinfestation occurs (i.e., adhere to Check, Clean, Dry principles).
  - Exclusion of livestock from drains and infested areas to prevent fragmentation and subsequent spread.
- Future research needs to optimise parrot's feather control include:
  - Understanding the optimal timing of individual herbicide applications and the effect of multiple herbicide applications per season.
  - Trialling combinations or sequential herbicide treatments to improve control outcomes (e.g., triclopyr triethylamine and glyphosate).
  - Trialling potential novel herbicides that internationally show promise for control of parrot's feather (e.g., florpyrauxifen-benzyl, not currently registered for use in water in New Zealand).
  - Fragmentation rates caused from herbicide treatments are not currently well understood for parrot's feather and require quantification.

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Appendix A Aerial plot photos – Examples of parrot's feather control in a drain in the Kongahu Swamp area of Karamea, West Coast, South Island.

Control plot – No herbicide (Plot 4)

Metsulfuron - Label rate: 0.05 kg a.i. ha^{-1} (Plot 5)

Imazapyr - Label rate: 1 kg a.i. ha^{-1} (Plot 11)

Triclopyr - Label rate: 2 kg a.i. ha^{-1} (Plot 3)

Metsulfuron – Half label rate: 0.025 kg a.i. ha^{-1} (Plot 1)

Imazapyr – Half label rate: 0.5 kg a.i. ha^{-1} (Plot 2)

Triclopyr – Half label rate: 1 kg a.i. ha^{-1} (Plot 12)

# Appendix B	On-ground plot photos – Examples of parrot's feather control in a drain in the Kongahu Swamp area of Karamea, West Coast, South Island.

Control plot – No herbicide (Plot 4)

Metsulfuron - Label rate: 0.05 kg a.i. ha^{-1} (Plot 5)

Imazapyr - Label rate: 1 kg a.i. ha^{-1} (Plot 11)

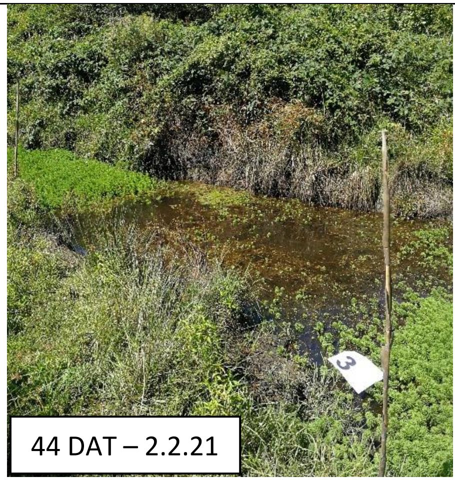

0 DAT – 16.12.20


44 DAT – 2.2.21


85 DAT – 15.3.21

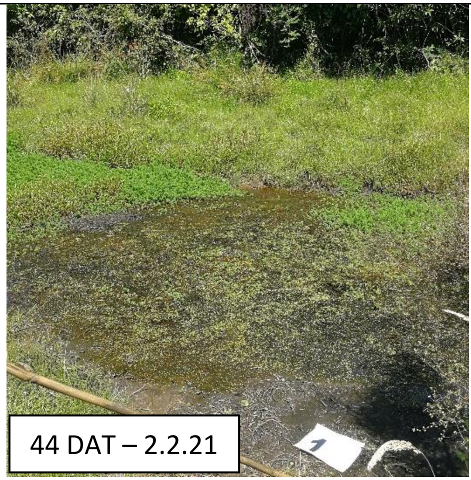
Triclopyr - Label rate: 2 kg a.i. ha^{-1} (Plot 3)

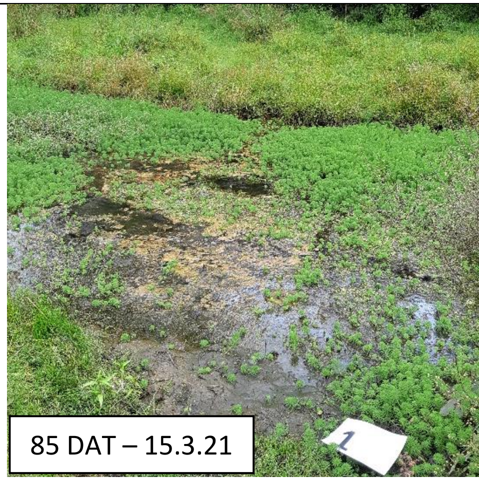

0 DAT – 16.12.20


44 DAT – 2.2.21


85 DAT – 15.3.21

Metsulfuron – Half label rate: 0.025 kg a.i. ha^{-1} (Plot 1)





Imazapyr – Half label rate: 0.5 kg a.i. ha^{-1} (Plot 2)

Triclopyr – Half label rate: 1 kg a.i. ha^{-1} (Plot 12)

 0 DAT – 16.12.20	 44 DAT – 2.2.21	 85 DAT – 15.3.21