Boffa Miskell

Cuscuta campestris

Monitoring plan for the golden dodder progressive containment programme

Prepared for Department of Conservation

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Cover photograph: [Golden dodder (yellow spots) visible form helicopter – Reao Wetland] (Kerry Bodmin, Department of Conservation, 2020)

Executive Summary

Golden dodder (*Cuscuta campestris*) is an obligate parasitic plant that endangers horticultural and agricultural sectors and native habitats worldwide. Golden dodder is known to occur in various habitats, ranging from wetlands to high-intensity horticultural areas, displaying a wide climatic tolerance. It attaches easily to a diverse array of primarily dicotyledonous host species, with a more limited range of known monocotyledonous hosts.

In New Zealand, golden dodder was first naturalized in 1941 with the current known wild distribution in New Zealand confined to Whangamarino Wetland, wetland margins of Lakes Whangape, Rotongaro, and Rotongaroiti, and a private property in the wider Huntly area of the Waikato. These areas are under the active management by the Department of Conservation (DOC) as part of a progressive containment programme.

The primary objective of the monitoring plan is to produce consistent, repeatable data that assesses the effectiveness of the progressive containment programme and identifies potential limitations. To achieve this, the programme aims to answer the following monitoring questions:

- Determine changes in the extent and density of golden dodder over the course of its management.
- Evaluate any alterations in the vegetation assemblage and composition of the Whangamarino Wetland and Whangape-Rotongaro wetland complex resulting from current management practices and herbicide application.
- Track the impact of the current management approach on the extent and duration of exposed bare soil in the treatment area.
- Assess whether planting non-host species prevents successful germination, attachment, and establishment of golden dodder on hosts.

To address these monitoring questions, the proposed monitoring programme employs two distinct scales of monitoring:

Large-Scale Monitoring: The large-scale monitoring approach utilizes aerial imagery with automated mapping and digitisation to assess changes in golden dodder extent and distribution periodically. Ground and aerial based operational monitoring is used to supplement this data when budget constraints limit aerial surveillance. We have identified an opportunity to use this method for operational surveillance and monitoring for efficiency.

Small-Scale Monitoring: For small-scale monitoring, the programme uses Wraight plots (1m^2) on transects and portable drone-based photo capture. This method compares areas planted with non-host species to control areas and monitors extent and duration of bare soil in golden dodder control areas versus non-infested areas. This monitoring is proposed to be supplemented with portable drone based aerial photo points.

The monitoring plan recommends the implementation of both the large-scale and small-scale monitoring methods to evaluate the golden dodder progressive containment programme's efficacy. These methods will provide crucial insights into the management programme's success and identify opportunities for improvement.

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1.0 Introduction

The Department of Conservation Te Papa Atawhai (DOC) manages golden dodder (*Cuscuta campestris*) through a weed-led progressive containment programme. DOC have engaged Boffa Miskell Ltd to develop a multi-year monitoring plan to determine the efficacy of current control methods, non-target effects of control methods, and the efficacy of alternative approaches to the control of golden dodder.

1.1 Characteristics of golden dodder

Golden dodder is an obligate parasitic annual plant that poses a threat to agricultural sectors and native habitats worldwide (Department of Conservation Waikato District Office, 2018; Goldwasser et al., 2016). It can occur within a wide range of habitats from wetlands to high intensity horticultural areas (Parker, 2022). It has a wide climatic tolerance and can establish itself easily by attaching to a wide range of primarily dicotyledonous host species with a more limited range of known monocotyledonous host species (Parker, 2022).

Golden dodder has several unusual characteristics pertinent to both its management and monitoring strategies as summarised below.

Golden dodder has a short growing period where it where it rapidly forms a wiry tangle of stems with a distinctive and bright yellow colour early in the growing season. It reproduces primarily through seed production and can spread rapidly through both vegetative growth and seed dispersal. Dispersal can occur through water, animals, and bird ingestion, with the latter promoting (but not required for) seed germination through a process similar to acid scarification[1] (Costea et al., 2016; Department of Conservation Waikato District Office, 2018). Importation of contaminated crop seed appears to be the most common invasion pathway internationally (Parker, 2022). However, it appears that the main mechanism for incursion into new sites in New Zealand is through the movement of people and equipment[2].

Golden dodder extracts resources from its host plants through specialised structures called haustoria, to the extent that flowering and fruiting is inhibited, and the death of the host may result. Golden dodder has a leafless, threadlike stem that twines around other plants, forming coils with tendrils. Once attached to a host, golden dodder becomes entirely dependent on the host for water and nutrients. It produces numerous small flowers which mature to form dry capsules containing multiple seeds, which can form a persistent seed bank. Both flowers and capsules can be present on any one plant at any time. Seedlings of golden dodder can grow to approximately 10cm in length without attaching to a host before exhausting the reserves of the seed. Once attached to a host, the seedling root dies back, and the plant does not maintain connection to the soil. In addition to parasitism, golden dodder grows in a sprawling mass that can smother both host and non-host plants. (Parker, 2022).

The life history of golden dodder varies in response to temperature and water level fluctuations. Lower water levels allow host vegetation to emerge, and warmer temperatures increase the rate of seed germination (Goldwasser et al., 2016). The observed life history of golden dodder at

[1] Acid scarification is used in a laboratory setting to degrade the hard impermeable seed coats of golden dodder to increase germination rates as mature seeds are dormant when shed. In the field scarification is not necessary for germination, instead, a small percentage of previously dormant seeds are likely to germinate each year dependent on weather conditions and the degradation of the seed coat over time. (Hutchison & Ashton, 1980)

[2] (Pers. comm. Kerry Bodmin 2023)

Whangamarino during the 2015/16 and 2016/17 season is as follows (Department of Conservation Waikato District Office, 2018 with additional information from K Bodmin):

- November - December: initial round of seed germination/ plant emergence (timing expected to vary annually dependent on water levels).
- January - February: seed germination continues, patches visible aerially, flowering.
- Mid-February - April: flowering continues, seed formation.
- May - October: plants appear dead and/or are submerged in high water.

In New Zealand, golden dodder was first naturalised in 1941[3] and has since been recognized as a serious pest plant and has been classified as an Unwanted Organism under the Biosecurity Act (1993) which means it is illegal to propagate, sell, spread, or display golden dodder. It has been recorded in various locations, including the Whangamarino Wetland, Lake Whangape, and Opuatia Wetland (where it appears it has failed to establish[4]). Golden dodder has also been found occasionally in other regions[5], evidently due to contamination in seeds from international sources and not related to the only naturalised populations in New Zealand, which are restricted to the known sites in the Waikato under management by DOC.

The current surveillance area for golden dodder is as depicted in Figure 1 below. The surveillance area is much larger than the current known range of the naturalised golden dodder population and includes similar habitats nearby suitable for golden dodder growth. The current known distribution is across Whangamarino, wetland margins of Lakes Whangape, Rotongaro and Rotongaroiti and one private property in the wider Huntly area of the Waikato.

Hosts recorded inside the management area and observed in host testing are listed in Table 1 below (Champion, 2019; Department of Conservation Waikato District Office, 2018; Hackell & James, 2022). The most common/ main hosts observed in the field are *Lotus pedunculatus* and *Persicaria* spp.[6].

Table 1: List of confirmed host plants for golden dodder.

Binomial name **(* = native taxon)**	**Common name**	**Notes**
*Alternanthera nahui**	Nahui	
Alternanthera philoxeroides	Alligator weed	
Bidens frondosa	Beggar's tick	
Calystegia sepium subsp. *roseata**	Pink bindweed, pōhuehue	We anticipate the common hybrids of this species and *Calystegia silvatica* are likely to also be suitable hosts.
Chamaemelum nobile	Chamomile	
Cyperus eragrostis	Umbrella sedge	Confirmed in host testing but not observed in the field.
Daucus carota	Wild carrot	
Erechtites valerianifolia	Fireweed	
Hypochaeris radicata	Catsear	
Juncus sp.	*Juncus*	Species unknown – observed growing on *Juncus* sp. in the field at Whangamarino Wetland but requires confirmation of host status. Potentially a native species.
Lotus pedunculatus	*Lotus*	It is likely other species of this genus are also suitable hosts.

[3] https://www.nzpcn.org.nz/flora/species/cuscuta-campestris/ (Accessed 19/05/2023)

[4] K. Bodmin, Personal Communication, June 2023

[5] https://inaturalist.nz/observations?place_id=6803&taxon_id=76545 (Accessed 19/05/2023)

[6] K. Bodmin, Personal Communication, March 2023

Binomial name **(* = native taxon)**	**Common name**	**Notes**
Ludwigia palustris	Water purslane, marsh *Ludwigia*	
Ludwigia peploides subsp. *montevidensis*	Water primrose	
Lycopus europaeus	Gypsywort	
Mentha pulegium	Penny royal	
Paspalum distichum	Mercer grass	Observed in the field but no haustoria confirmed in host testing. Research required to confirm.
*Persicaria decipiens**	Slender knotweed	
Persicaria hydropiper	Water pepper	
Persicaria lapathifolia	Pale willow weed	
Persicaria maculosa	Willow weed	
Persicaria strigosa	Spotted knotweed	
Phalaris arundinacea	Reed canary grass	
Salvia farinacea	Mealy sage	
*Solanum americanum**	Small-flowered nightshade	Confirmed in host testing. Not currently noted or confirmed in the field.
Symphyotrichum subulatum	Bushy starwort, sea aster	

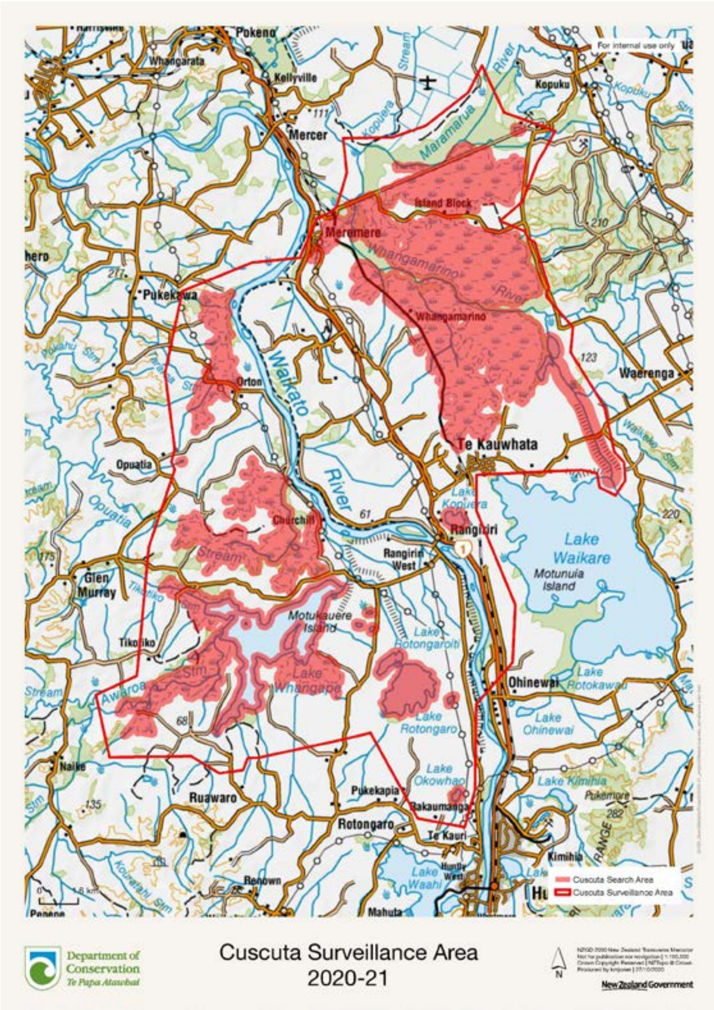

Figure 1: Golder dodder surveillance area

1.1.1 Management

Golden dodder was first found in Lake Whangape in 1990 and in Whangamarino in 2015. The Whangamarino population been under management since shortly after its discovery, with herbicide trials occurring in 2016 and a weed led programme developed in 2018 (Department of Conservation Waikato District Office, 2018) which gives a detailed account of the history and actions taken prior to this date. Since 2020/21, DOC's golden dodder management and funding from Bio18 Freshwater Biosecurity Programme allocated to the programme has been increased and resulted in more intensive and coordinated control works.

Surveillance is undertaken from the ground around farm edges and 100m into the public conservation land (PCL), while aerial surveillance is carried out outside of these areas throughout the range of the infestation area, plus a 200m buffer and within similar adjacent habitats (Figure 1).

Surveillance utilising drone technology was trialled in March 2021 within the Reao Wetland infestation area (Flightworks, 2021). This survey used full motion video (FMV) capture as a means of capturing imagery and manual digitisation of golden dodder detected. It is not stated within the report why FMZ was preferred over orthomosaic imagery. Several recommendations came from this trial; we note that some are related to better capture of FMV which does not appear to be relevant to improving golden dodder detection/ survey outcomes.

Key recommendations with respect to future aerial based surveys are to ensure the timing and conditions are optimal for detection, i.e., when it is sunny and during the right time in the season, so the golden dodder shows up bright yellow. It was also determined that the altitude flown which was 94m with a 20mp camera produced an inadequate resolution for this purpose. An altitude of 70m was recommended. Unfortunately, no indication of the resolution achieved in the original survey or what would be appropriate for future surveys is given (or the required data to calculate this resolution) in terms of ground sample distance (GSD) (in m/pixel for example).

Aerial surveillance is carried out when golden dodder is well established, but prior to flowering (generally January). During this surveillance, GPS data is captured for golden dodder infestations. This is followed up as soon as possible with aerial control using glyphosate delivered via a combination of boom spraying and spot spraying dependent on infestation size. This surveillance and control process is repeated in 6-8 weeks' time.

Surveillance and control from the ground is used to target patches too small for aerial control. Golden dodder is controlled by spraying both it and its host plant with either glyphosate (a non-selective herbicide), or metsulfuron-methyl (a selective herbicide with limited activity in most monocotyledonous plants), or a mixture of metsulfuron-methyl and glyphosate. Control is achieved through the killing of the host plant, as well as translocation of herbicide through haustoria (Dawson & Saghir, 1983; Mishra, 2009).

Unfortunately, while the control approach results in control of golden dodder and its hosts, it can also create areas of bare soil which are ideal for the germination and reestablishment of annual herbaceous plants, which in turn are generally suitable hosts for golden dodder. One potential concern is that several years of herbicide control at the same location may create a disturbance regime which inhibits perennial sedge or rush establishment. Prevention of perennial vegetation establishment in turn may facilitate more (annual dicot) host plant establishment, and more successful golden dodder establishment.

Management of host availability is also being trialled, with some areas being planted with non-host species such as *Carex geminata, Cordyline australis, Carex secta, Phormium tenax, Coprosma robusta,* and *Cyperus ustulatus*. These infested areas were once predominantly *Carex* sedgeland, however changes to the hydrology of the site and land management have meant that the vegetation communities have shifted to exotic dominated, herbaceous wetland vegetation. Much of the area is no longer suitable for *Carex* to return to its former dominance, and native sedges are likely to remain limited to smaller areas where favourable conditions remain (Bodmin & Champion, 2010; Department of Conservation Waikato District Office, 2018).

1.2 Monitoring objectives and questions

The objective of the monitoring programme is to produce repeatable, consistent data that determines how effective current management is and what limitations are present.

This will be done by answering the following monitoring questions:

1. Determine how the extent and density of golden dodder has changed over the management of the species.
2. Show if any changes to the vegetation assemblage and composition of the Whangamarino Wetland and Whangape-Rotongaro wetland complex has occurred as a result of current management practices and herbicide application.

3. Track the effect of the current management approach on the extent and duration of bare soil exposed in the treatment area.
4. Determine whether planting of non-host species prevents golden dodder from successfully germinating and attaching to a host and/or establishing new populations[7].

The parameters within which these objectives must be meet include:

- A staffing resource of 0.125 FTE of two people equating to up to one week every two months over 12 months or one week a month over the approximately 6-month golden dodder season.
- Funding is to be determined annually with a budget range of $5,000, $10,000, or $20,000 in any financial year. Therefore, some protocols may only occur intermittently.
- Methods need to be easily and consistently replicable in the field by DOC rangers with a range of experience and knowledge in biosecurity and botany. A primary consideration in this context is there must be no assumption of continued institutional knowledge or reliance on consistency of observer/ surveyor bias or variance.

1.3 Existing data

Existing data from the previous several years of control is primarily documentation of "search and destroy" operations, where the infestation is captured primarily as GIS point data.

In addition, spatial data from the 2021 drone survey trial over the Reao Wetland area captured both point and polygon data. This survey provides somewhat of a comparative baseline for future monitoring in this location. During this trial an aerial photo point was also established providing a static baseline in the area (Flightworks, 2021).

2.0 Methods

To develop the monitoring methods for the golden dodder control programme we have taken a multi-criteria approach to determine appropriate methods. The approach is outlined as follows.

2.1 Assessment and comparison criteria

To create a robust framework to determine appropriate methods for monitoring, a list of characteristics and constraints posed by the biology of the target organism and the area of interest/study site was developed. These factors were used as primary filters to exclude monitoring methods that aren't appropriate to the species or the site. Site and species factors were also used to evaluate and compare the practicality of prospective monitoring methods.

Secondly, we developed a set of assessment and comparison criteria to assess the suitability of methods in achieving the monitoring objectives outlined in Section 1.2. These criteria relate to operational and data requirements.

[7] We have modified this objective from the original wording provided in engagement documentation.

For this comparison process we grouped the monitoring questions into two broad groups related to appropriate scale:

> **Group one** questions require larger scale survey to track overall trends and changes. This includes the monitoring of the extent and density of golden dodder and the monitoring of changes in the vegetation assemblage and composition.
>
> **Group two** questions either require, or are suited to, smaller scale monitoring such as the effect of planting non-host plants.

The tracking of the extent and duration of bare soil could fall within either group and therefore assessed this question within both groups.

Small-scale surveys could be used to assess trends with respect to many of the group one questions at small spatial scales, and these trends could be extrapolated to larger scales.

2.2 Identification of suitable monitoring methods

Prospective monitoring methods were compiled and adapted from primary and secondary literature. Bespoke or unique monitoring solutions for individual monitoring programmes were discarded as they require training, trialling, and development of statistical analyses to be tailored to individual projects, and limit comparability between monitoring projects.

Sources of existing monitoring methods were:

- Standard monitoring methods (or modified versions of these) developed and employed by DOC for monitoring vegetation, such as those methods outlined in the DOC Biodiversity inventory and monitoring toolbox – vegetation[8].
- Existing data capture methods used in surveillance and control works in the golden dodder programme.
- Methods used nationally for monitoring similar vegetation types, such as the methods for plots in the Coordinated Monitoring of New Zealand Wetlands (CMNZW) monitoring hand book (Clarkson et al., 2004) and National Vegetation Survey (NVS) methods[9].
- Aerial and spatial methods previously employed at similar locations e.g.: Reeves and Haskew (2003).

2.3 Evaluation of monitoring methods

Prospective monitoring methods were evaluated to understand their suitability and limitations against the assessment criteria identified in section 2.1. Preferred methods were selected and opportunities were identified to combine and/or modify methods to develop a fit for purpose framework. These modified or combined methods were used to form the basis of the monitoring plan, along with potential methods to be employed in the instance of budget and resourcing increases.

[8] https://www.doc.govt.nz/our-work/biodiversity-inventory-and-monitoring/vegetation/ (Accessed 19/05/2023)

[9] https://nvs.landcareresearch.co.nz/Resources/FieldManual (Accessed 19/05/2023)

2.4 Development of monitoring plan

A monitoring plan was developed for the golden dodder control programme using methods devised as outlined in Section 2.3. The following resources and specifications were developed as part of the monitoring plan:

- Field guide for implementation.
- Field sheets.
- Field equipment list.
- Data capture, storage and processing guide.
- Statistical analysis guide with example data and worked example.
- Anticipated resourcing required for implementation of baseline methods.

3.0 Results

3.1 Assessment and comparison criteria

A primary criterion used to guide the monitoring framework was priority of control. While monitoring of efficacy is important for tracking progress of pest plant control programmes, the primary concern should be achieving high control efficacy. Effective monitoring methods must work within the context of the control programme. Methods which rely on experimental controls that restrict or prevent the control of golden dodder in discrete areas are not appropriate.

The following characteristics of golden dodder biology and constraints around invaded sites were identified as elements any monitoring methods would need to address:

- Timing – golden dodder germinates and grows to maturity over a period of about four months. Growth is rapid, so that undetectable infestations in one survey may be obvious in the next as small spots, and small spots have become extensive enough to require boom spray control just two weeks thereafter. Germination is continuous throughout the growing season with additional germination delays in low-lying areas where flood waters take longer to recede. Therefore, single surveys can underestimate density and distribution. Ideal monitoring methods allow for repeat surveys within a single season to capture accurate data, and/or enable flexible timing of surveys to account for the life history of golden dodder.

- Disturbance sensitivity – golden dodder occurs primarily in wetland ecosystems which are sensitive to disturbance from people trampling as they conduct monitoring. Consistent monitoring may only then serve to measure the effects of trampling over time rather than the objectives of the monitoring plan. This is particularly a concern in the vegetation communities where golden dodder is present, which have a high percentage cover of annual plants. Ideal monitoring methods avoid the need to repeatedly traverse areas within plots or transects. Surveys should preferably be conducted from the air, photographs, or plots small enough that accurate data can be captured by observers from outside the plot.

- Access and visibility – the vegetation and terrain in the infestation areas is not easy to access on foot, and visibility across large areas is poor. Ideal monitoring methods will focus on easily accessed areas, will not require a large-scale view or survey, or will rely on aerial methods to provide a top-down view. Golden dodder is visible from the air to the extent it is evident in both publicly available aerial imagery and satellite imagery. The impacts of control and seasonal dieback are also visible in aerial imagery with identifiable areas of dead vegetation and/or bare soil (Figure 2).

- Biosecurity – golden dodder can be spread from fragments and seeds. Methods which require extensive movement of people and/or equipment within the infestation areas risk spreading golden dodder. This is a particular constraint where control sites may need to be set up that do not have golden dodder infestations. This issue can be mitigated by in-field biosecurity precautions, and by ensuring the experimental control sites (where golden dodder is absent) are visited first prior to infestation sites, to avoid cross-contamination of sites with golden dodder seeds or fragments on people and equipment.

Figure 2: Visible infestations of golden dodder (bright yellow) from satellite imagery (left – February 2017) and less obvious but still visible effects of control such as dead vegetation (brown spots - several spots circled/indicated by arrow for reference) in aerial imagery (right – exact date unknown – Waikato 0.3m 2016-2019 aerial imagery).

Assessment and comparison criteria derived from the monitoring objectives and parameters set out in Section 2 include:

- Scale – the monitoring must be over an appropriate scale to track the changes in vegetation and bare ground. Group one questions require a larger scale to track trends over wider areas, whereas group two questions require more detailed analysis of smaller scale interventions and changes.

- Complexity – the monitoring is to be carried out by DOC rangers with varying degrees of experience and prior knowledge. The programme implementation is to be simple and understandable to a new audience without the need for extensive training.

- Botany – the methods are to be based on identification of structural or vegetative groups with no specific reliance on precise species resolution in the field (primarily a concern for group two questions which will be surveyed at smaller scales). Methods will focus on structural classes or other easily 'field recognisable' metrics. This approach is viable in the case of golden dodder because the vegetation composition in the area of interest is relatively simple.

- Quality and precision of data/observer variation – monitoring will extend over a long period of time and is unlikely to be done by the same surveyors throughout the life of the programme. Therefore, methods that are sensitive to variations between surveyors (for example, those which rely on observers making estimation of cover over large areas) are not suitable. Group one ("larger scale") questions will require methods that are less sensitive to this issue. Group two questions will use methods that do not require surveyors to estimate cover over larger plots (>20m) or will direct surveyors to sub-sample smaller areas to reduce variation between observers.
- Quality and precision of data/sensitivity – the monitoring methods are to be sensitive enough to detect both long and short-term trends in vegetation composition, and prevalence of golden dodder. Group one questions require a lower level of sensitivity due to the large scale and longer-term trends, but group two questions require sensitivity to smaller scale and more rapid changes.
- Cost and resourcing – both groups of monitoring questions require methods that are cost effective and robust to a level of inconsistency in delivery if funding and resourcing changes. Group two questions will be more sensitive to inconsistency in delivery as the smaller areas involved will change more rapidly.

3.2 Potential monitoring methods

The following standardised monitoring methods were identified as potentially suitable methods for the golden dodder monitoring programme:

- RECCE method for describing New Zealand vegetation (Hurst et al., 2022; McNutt, 2012)
    - A 20m x 20m plot-based vegetation survey method which captures cover/abundance within six standard fixed height tiers.
- Scott height frequency transects (Rose, 2012a)
    - A transect and subplot-based vegetation survey method which captures the frequency of species within defined 5cm height intervals. Often includes a modified RECCE plot covering transect area.
- Wraight plots (Rose, 2012b)
    - A transect and subplot-based vegetation survey method which captures the frequency of species and ground cover in small (15cm diameter subplots) Subplots can include different measures, such as frequency, or the use of different sizes to capture cover class data. Often includes a RECCE plot covering transect area.
- CMNZW Wetland plots (Clarkson et al., 2004)
    - Wetland vegetation plot of, normally, 2m x 2m. Captures cover over a variable (but maximum of three: substrate/groundcover, sub canopy, and canopy) non-fixed vegetation height layers.
- Operational monitoring

    - This can be considered the “do nothing additional” approach. Where no specific monitoring is targeted for the programme.
    - Opportunistic monitoring and capture of golden dodder distribution and extent while carrying out surveillance and control works. This is currently being implemented by recording point and polygon spatial data when carrying out surveillance and control from both the ground and air.
- Aerial monitoring large scale – several methods have been included in this broad category, but all rely on capturing aerial imagery. The method of capture is not specified as technology is advancing quickly in terms of both unmanned aircraft (drones) and satellite imagery. Instead, it is best to stipulate the image quality requirements when using aerial monitoring methods. With this fixed requirement, the method that is most cost effective can be used to gather the required data. If imagery data is regularly available through open source/access sources taken at the right time of year, this can be used instead.

  Note: imagery-based techniques that require specialised capture of multi-spectral imagery, lidar, synthetic-aperture radar, and infrared have been excluded. These techniques may provide some marginal advantages in detection of vegetation types and golden dodder over simple capture of aerial imagery. However, detection of the visually distinct golden dodder, and simple/distinct composition of vegetation types within the wetlands, do not justify the added complexity and cost associated with these capture techniques/technologies.

    - Manual mapping of orthorectified imagery.
        - Involves a person manually digitising the visible golden dodder infestation and/or the visible vegetation types from geo-referenced imagery.
    - Automated mapping of orthorectified imagery.
        - Involves the automated classification and digitisation of the golden dodder infestation and/or the visible vegetation types from geo-referenced imagery.
        - Classification can use a multitude of techniques with the most common being pixel-based classification, image segmentation, and object-oriented classification. The development of classification techniques is an active area of research. The benefit of automated classification is that the classification technique, if updated after several years of monitoring, can be run retrospectively on historic data to ensure consistency of comparison and robustness of temporal trends. This allows continuous improvement in techniques while maintaining comparability.
- Aerial monitoring small scale – portable drone-based photo capture.
    - Involves the use of portable drones by staff or contractors to capture single images of plots and track changes over time, much like an aerial photo plot.
    - Can be incorporated into or used as a supplement to plot-based ground methods.

3.3 Assessment and comparison of methods

Each of the identified monitoring methods identified in Section 3.2 were assessed against the assessment and comparison criteria identified in Section 3.1. A matrix of this assessment and comparison is provided below in Table 2.

A synopsis of our assessment for each method is as outlined below.

- RECCE method for describing New Zealand vegetation (Hurst et al., 2022; McNutt, 2012)
    - The RECCE method has the ability to deliver a high-quality assessment of changes in vegetation likely at a finer scale than actually required. The limitations of this method include potential for observer variation, increased disturbance, and biosecurity risk.
    - As a standalone method, we have not included this method.
- Scott height frequency transects (Rose, 2012a)
    - Transect based and small-scale sub-plots have benefit in limiting disturbance. Biosecurity risk still present. In most vegetation types of the area of interest the complexity of recording species defined height tiers and very small-scale subplots are unnecessarily complex for the questions being asked.
    - Not pursued as suitable method.
- Wraight plots (Rose, 2012b)
    - Transect based and small-scale sub-plots have benefit in limiting disturbance. Biosecurity risk still present. In most vegetation types of the area of interest the simple cover class metrics would be adequate and explanatory. The use of $1m^2$ plots along transects and classification of vegetation cover into cover classes seems to be a good compromise between many of the scale, complexity and access issues identified.
    - Proposed to be incorporated into the group two questions (bare soil and effect of planting *Carex*).
- CMNZW Wetland plots (Clarkson et al., 2004)
    - Compared very well against all other field-based measures. Implementation and data outcome likely similar to the $1m^2$ plot based Wraight plots but not constrained to transects. Some of the summary statistics captured may be useful in understanding aspects of the site.
    - Concepts of plots and data capture to be considered in the incorporation with the suggested modified Wraight plots method.
- Operational monitoring
    - Provides useful metrics for trends in density and extent of golden dodder but significant limitation in only capturing data within control areas and at control frequency.
    - The efficacy of control is not captured as part of works.
    - The “do-nothing additional” option considered not adequate to effectively track the infestation and efficacy of control as a standalone approach.

    - Data still valuable and a good approximation for density and extent of golden dodder, nonetheless.
- Aerial monitoring large scale
    - Will provide high-quality large-scale capture of data without the risks associated with assessing on foot the area of interest.
    - Relatively high cost of imagery capture means it is not suitable as a recommended required baseline monitoring method but can be periodically carried out to provide snap shots of progress.
        - Manual mapping of orthorectified imagery.
            - Unlikely to be a sustainable and suitable method for capturing data over large areas. If changes in vegetation are easily visible to human observer, then automation should be preferred.
            - Can be used as an interim measure if required.
        - Automated mapping of orthorectified imagery.
            - Several factors regarding the visibility of golden dodder and the simple composition of vegetation types in the area of interest mean that automated methods have a high chance of success and accuracy.
            - Initial cost of establishing and ground truthing method offset by ongoing efficiencies.
            - Ability to retroactively improve methods over time by analysing previous aerial imagery is a considerable benefit of the method. This means new and improved classification techniques can be developed and implemented without losing the ability to compare vegetation composition and trends to previous surveys.
            - A benefit not captured in this analysis is that aerial image capture will provide trends of vegetation type changes across all the area of interest. Provides additional value beyond the defined objectives of this control programme.
            - Has the ability to replace the initial aerial surveillance component of the control programme allowing automated mapping and classification of control targets for aerial spot and booms spraying and ground control.
- Aerial monitoring small scale – portable drone-based photo capture.
    - Has potential to add value when incorporated as a component of field-based survey. The preferred approach is smaller scale plots with aerial photo points which capture a larger area, to assist with the understanding of larger scale changes in the study area.

Table 2: Potential survey methods as assessment of suitability for golden dodder monitoring against evaluation criteria.

Survey method	Timing	Disturbance sensitivity	Access and visibility	Biosecurity	Scale	Complexity	Botany	Quality and precision – observer variation	Quality and precision – data sensitivity	Cost and resourcing
RECCE plots	Flexible in timing and easily replicated over season if required.	Within plot disturbance high due to large plot size (20m x 20m) and need to record all species within plot (standard method).	Plot location dependent but does require on foot access.	Requires movement between plots and extensive movement within plots. Problematic if untreated plots required.	Individual plots occur at a relatively large scale. Multiple plots can be used to gather more representative data.	Reasonably simple plot-based sampling method. Large plot size, and structural height tiers can be a matter of complexity for less experienced practitioners. However, application in structurally simple habitats less complex.	Standard method would require species level botanical resolution. Can be adapted to lowered botanical resolution such as structural classes or a defined classification of vegetation such as genera.	Requirement for estimation of cover over large areas can cause considerable variation between observers. Can be controlled by supplementing field survey with small scale aerial imagery.	Sensitive to changes at the relevant scales.	Can be time consuming to carry out survey but does not require specialised equipment or data processing.
Scott height frequency transects		Transect based sub-plots (approximately 0.15-1m) allows access alongside sub-plots minimising disturbance. Continued access along the same transect can impact vegetation.	Transect location dependent does require on foot access.	Requires movement between transects. Problematic if untreated plots required.	Individual sub-plots occur at a very small scale. Large number of sub-plots needed to ensure representative data. Multiple transects can be used to gather more representative data. Supplementation with small scale aerial imagery capture can provide larger scale data.	The small sub-plot frequency counts at the height tiers can be initially confusing but a technique quickly learnt. Doesn't require estimation of cover. Unsuitable for many wetland species that are sward or mat forming. Golden dodder also scrambles across hosts so individual plants can't be determined. Precise height tier data not critical in answering survey questions.		Small scale plots that either count frequency or cover classes less prone to variation between observers. Small changes in sub plot locations and approach can influence results.	Scale of resolution finer than needed for the monitoring of the predominately larger scale changes being investigated.	Can be time consuming to carry out survey but does not require specialised equipment or data processing. The standard addition of a RECCE plot at least doubles time resource requirement.
Wraight plots						Standard method where sub-plots only count occurrence. No complication of height tiers or cover estimation. Can include categorisation of occurrence into cover classes and use of 1x1m plots rather than smaller sub-plots				
CMNZW Wetland plots		Small plot size enables assessment from exterior of plot and an ability to avoid in plot disturbance.	Plot location dependent but does require on foot access.	Requires movement between plots. Potentially problematic if untreated plots required.	Individual plots occur at a relatively small scale. Multiple plots can be used to gather more representative data.	Smaller plot size makes cover estimation easier. The looser definition of height tiers can cause confusion to the less experienced which can create variability in field data capture (which can be later corrected).		Smaller plot and estimation of cover classes lessen the observer variation but can still be considerable. Can change absolute cover to cover classes to reduce variation or by supplementing field survey with small scale aerial imagery.	Sensitive to changes at the relevant scales.	Quickest and least time demanding field-based survey method. Does not require specialised equipment or data processing

Survey method	Timing	Disturbance sensitivity	Access and visibility	Biosecurity	Scale	Complexity	Botany	Quality and precision – observer variation	Quality and precision – data sensitivity	Cost and resourcing
Operational monitoring	Opportunistic data capture associated with control and surveillance works. Biased toward control operations which is timed for maximum likelihood of golden dodder detection and repeated at least twice per year.	Not applicable – any disturbance associated with control works.	Not affected by access as methods of control are tailored to site constraints. Potential to miss golden dodder not visible in ground or aerial delimitation.	Not applicable – any disturbance associated with control works.	Scale determined by control and surveillance extent.	Simplest method – required for operational monitoring.	Low – capture of golden dodder infestation data only. Not suitable to capture more detailed vegetation composition data.	Low variation expected – data capture primarily GPS based.	Scale and sensitivity will be variable with control effort.	Data is essentially cost and resource neutral as it needs to be captured as part of control and audit works.
Aerial monitoring large scale – manual mapping	Timing sensitive. Cost associated with the capture of imagery means a single capture is preferred. However, timing of flights is flexible.	Nil to negligible disturbance[10].	Access unaffected by this constraint. Visibility may be affected where golden dodder is under a canopy[11] or colour contrast between golden dodder vs other vegetation colour is insufficient for mapping.	Additional biosecurity risks largely avoided by all aerial methods.	Large scale.	Simple method based on visual identification and mapping. Only need competency in simple GIS programs. Summary statistics can be easily derived (ha of cover, number of plant clusters, % cover, etc.)	Low – limited botany skills required for post ground-truthing of broad vegetation types.	Capture is unaffected by between observer variation if minimum standards are met. Manual mapping unlikely to have large variation between processor but search fatigue and tedium of process can be a factor.	Has ability to detect large scale changes. Finer scale changes in composition unlikely to be detected.	Capture of imagery expensive. Considerable staff time each year for manual processing and classification of vegetation. Potential to replace the initial aerial survey prior to control.
Aerial monitoring large scale – automated mapping						Data capture is simple. Initial development of automated classification does require advanced GIS knowledge. Once set up the process can be very simple and rapid. Summary statistics can be easily derived. (ha of cover, number of individual/clusters of plants, % cover, etc.)		Automated classification process avoids variation between processors. Considerable benefit of process is that the methods developed to classify images can be applied retrospectively so changes or improvements to the technology used can be applied across the whole monitoring period no matter when developed which allows continuous improvement to monitoring methods.		Capture of imagery expensive. Initial development of classification method can be expensive. Ease of golden dodder detection means bespoke methods or large amount of analysis is unlikely. Initial ground truthing adds to set up cost. Once initial set up is complete the method is very staff time efficient. Has the potential to replace the initial aerial survey prior to control if adequate accuracy is achieved.

[10] There may be a requirement to place

[11] For example, under a willow canopy. Golden dodder generally doesn't prefer shade, but golden dodder is known to occur on margins of crack and grey willow infestations or beneath individual trees / small patches where high light levels. (pers. com. K Bodmin August 2023)

Survey method	Timing	Disturbance sensitivity	Access and visibility	Biosecurity	Scale	Complexity	Botany	Quality and precision – observer variation	Quality and precision – data sensitivity	Cost and resourcing
Aerial mapping small scale	Flexible in timing and easily replicated over season if appropriate.	Limited disturbance – photos can be taken from an appropriate vantage point and avoid direct impacts on monitoring area.			Scale responsive to survey needs. Best for detailed and small-scale photo points or as an addition to other methods.	Provided practitioners have experience in piloting a small portable drone the capture and analysis of imagery is relatively simple.	Variable. Depends on type of method used and botanical resolution of monitoring required.	Variable. Depends on method employed and botanical resolution required. Imagery has the benefit of being able to be reviewed by several people to achieve a level of consistency.	Scale able to be adapted and can be sensitive to small scale changes.	Very time and cost efficient when using inhouse equipment. Processing of data and classification of imagery could be automated.

4.0 Discussion and conclusion

Group one research questions – large scale changes:

1. Determine how the extent and density of golden dodder has changed over the management of the species.
2. Show if any changes to the vegetation assemblage and composition of the Whangamarino wetland and Whangape-Rotongaro complex has occurred as a result of current management practices and herbicide application.
3. Track the effect of the current management approach on the extent and duration of bare soil exposed in the treatment area.

We propose to use aerial monitoring with automated mapping of orthorectified imagery, combined with field based operational monitoring to supplement this data for golden dodder density and distribution. We consider the aerial imagery capture will occur periodically and not necessarily every year with the data captured as and when budget and resource allows unless it is used in replacement of the aerial surveillance prior to control works.

A brief summary of the method is as follows:

- Determine the optimal time to fly (assessed each growth season) based on field observation of golden dodder life cycle and weather conditions. Ideally the site will be flown twice each season, including once prior to control works (just before or at commencement of flowering) and once post control works (this can be incorporated with follow up surveillance prior to the second control round). However, depending on the cost of aerial capture, it may be more cost-effective to use operational monitoring data for golden dodder extent and distribution, and aerial capture for post control works.

  Note: the ability of the aerial imagery to detect trends in density and distribution of golden dodder relies on accurate timing of the aerial capture. The survey schedule must be guided by the life cycle of golden dodder rather than fixed dates.

- Capture aerial imagery with a minimum resolution of 0.05m/pixel across the entire area of interest. Method of capture irrelevant and the most cost-effective method should be utilised (this may change over time).
- Classify image using automated process. Vegetation classes to align with those defined by Reeves and Haskew (2003) with the added classes of “golden dodder”, “dead vegetation” and “bare soil”.
- Data will provide near census capture of absolute measures of extent and distribution of vegetation classes, golden dodder, and bare soil.

Preliminary steps will be required:

- An automated classification method will need to be developed. We do not anticipate this being a difficult process nor needing novel technologies.
- Once developed, the classification method should be ground truthed and compared to someone manually classifying vegetation classes to assess accuracy of classification.

Data analysis:

- As the survey is essentially a census, analysis will capture and compare distribution (i.e., number of patches) and extent of vegetation classes over a set area. Summary statistics such as total cover and graphed trends over time are therefore suitable metrics for comparison and interrogation with sample statistics is not needed.
- Sub samples of areas can be interrogated to compare cover of vegetation classes between areas.
- Suggested subsets of analysis could be vegetation composition and cover in areas under golden dodder control, versus those areas outside of control.

Group two research questions – small scale changes:

1. Track the effect of the current management approach on the extent and duration of bare soil exposed in the treatment area.
2. Determine whether associated planting of non-host species prevents golden dodder from successfully germinating and attaching to a host and/or establishing new populations.[12]

We propose to use Wraight plots (1m^2) on transects supplemented by small scale aerial monitoring using portable drone-based photo capture. The target of this survey method will be to:

a. compare areas planted with *Carex* sp. to untreated[13] (unplanted) areas where no such intervention has occurred and determine whether the non-host plant planting is successful in inhibiting the establishment of golden dodder.

b. compare the ground cover of areas of golden dodder control compared to untreated areas where golden dodder does not occur.

These smaller monitoring scales will also provide data on the changes of golden dodder density over time. We have based the method on three impact sites and three untreated sites for each of the monitoring questions and a total of four repeats of survey throughout the season. If resources or budget decrease, this can be constrained to the first and last of the four survey repeats. An increase in budget resource can be used to conduct additional repeats beyond the proposed timeframes of the surveys to understand longer term trends in bare areas post control, but this is contingent on water levels and access as the season progresses.

Wraight plots will be surveyed with a minimum botanical resolution of genera. This botanical resolution should yield an understanding of the vegetation composition and the prevalence of both host and non-host species. In summarisation and analysis this can be simplified to structural classes, host/ non-host etc. if needed.

The drone captured aerial image will provide a larger scale view of the impact and untreated areas, providing an overview of the changes in vegetation patterns that can be validated by comparison with ground survey data.

A brief summary of the method is as follows:

- Core method follows DOC inventory toolbox (Rose, 2012b)

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[12] We have modified this objective from the original wording provided in engagement documentation.

[13] "untreated" areas are used as an experimental control. The terminology is chosen to avoid confusion with the control (killing of golden dodder).

- Establish 20-metre-long permanent untreated and impact transects:
    - Extent and duration of bare soil:
        - Untreated transects - Determine three suitable areas where there is no current or historical record of golden dodder that are readily accessible and establish three transects per area through representative swaths of vegetation.
        - Impact transects - determine three suitable areas of golden dodder infestation under active control in an area of ready access where bare soil is evident and establish three transects per area through representative swathes of vegetation.
    - Effect of planting non-host plants (*Carex* sp.):
        - Untreated transects - Determine three suitable areas as close as possible to the planted areas and establish three transects through representative swaths of vegetation.
        - Impact transects - determine three suitable areas[14] of *Carex* planting and establish three transects through representative swaths of vegetation.
        - The length and number of transects may need adaptation to the areas of *Carex* planting available/implemented.
- Conduct a preliminary survey at the start of the season prior to the control works. Carry out survey within the untreated site of the extent and duration of bare soil site study first (the only site chosen which is not supposed to have golden dodder present) to prevent spread into the untreated area. We anticipate that set up of a single transect will take 1 hour with subsequent surveys taking no more than 30-45 minutes as field teams establish a routine and experience.
- Conduct subsequent surveys as follows: first resurvey to occur post initial control works (timed to be long enough after control works where controlled areas have died), second resurvey to occur just prior to second control operation, final resurvey to occur post second control period (timed to be long enough after control works where controlled areas have died).
- In the instance where resourcing and staff time is restricted the preliminary survey at the start of the season should be the priority with the final survey being the second priority.
- Data collected can be summarised using simple summary statistics and paired t-tests to compare the density of golden dodder, bare soil, and other vegetation genera or structural classes between survey years.
- In addition to the above transect/sub-plot-based survey the use of portable drones to capture a fixed photo point over the established transects can be implemented when equipment is available, and resource and budget allow.
    - The aerial photo point should be taken for each transect centred on the 20m long transect. To establish a view of at least 20x20m within the image. This

[14] Dependent on number and extent of areas planted with *Carex* sp.

should be done while the tape is extended for the purpose of carry out the ground-based survey.

- o The image can then be manually processed to map the vegetation classes as established for the group one survey method or the automated process established in the group one survey method be applied to image.
- o This aerial photo essentially provides a time efficient analogue to the standard 20mx20m RECCE plot paired with standard Wraight transects.

5.0 Summary of recommendations

We recommend two distinct methods be applied to the monitoring of golden dodder control programme. These methods will document large scale vegetation trends occurring within the area of interest, along with fine-scale trends and impacts of control and management interventions (such as planting of non-host species).

The large-scale methods focus on the use of aerial imagery and automated classification of vegetation types to specified vegetation classes. This monitoring can occur periodically as budget allows. In years where budget does not allow aerial imagery to be flown, the tracking of golden dodder density and distribution will rely on the operational monitoring data captured during the search and surveillance works. If not, annually we considered aiming for a time frame between captures of aerial imagery of every three years and a maximum of five years would be best to understand the operational efficacy of golden dodder control over time.

Fine-scale monitoring uses a Wraight plot/transect method using 1m^2 plots along 20m transects. These transects will be established in control and treatment areas to compare the effects of the management inputs to areas not under management. These plots are proposed be surveyed preferably twice a year (once before the control season starts, and once after) with a possible two further surveys occurring before and after control operations occurring within the season.

This two-part monitoring protocol will allow the tracking of the efficacy of the golden dodder control programme, the non-target effects of the control of golden dodder, and the efficacy of alternative methods of management such as planting non-host species.

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Appendix 1: Golden dodder monitoring method guide.

1.0 Guide to monitoring method – Group one monitoring questions:

Group one monitoring questions:

1. Determine how the extent and density of golden dodder has changed over the management of the species.
2. Show if any changes to the vegetation assemblage and composition of the Whangamarino Wetland and Whangape-Rotongaro wetland complex has occurred as a result of current management practices and herbicide application. *Large scale changes.*
3. Track the effect of the current management approach on the extent and duration of bare soil exposed in the treatment area. *Large scale changes.*

Group one monitoring questions will be monitored by a large-scale aerial capture of ortho-rectified imagery to monitor vegetation in the area of interest. Aerial imagery is intended to be automatically processed to classify vegetation types and golden dodder infestations however manual processing is an acceptable (but more time consuming in the long term) method for classifying vegetation types if automated processing isn't available such as in an instance when budgetary constraints mean such a system hasn't been developed but there is staff time available to process data.

1.1 Guide for implementation

The steps for the implementation of this method have been split by one-off and ongoing requirements. One-off requirements are those associated with establishing and ground truthing the data of the automated processing system. These steps can be repeated if updates or improvements to the processing system/s are made or on an ongoing basis for data validation of sample areas as a mechanism of quality control. The steps for the process are as follows:

1. Data capture

- Procure a supplier for capturing aerial imagery with a minimum 0.05m/pixel resolution at the scale of the surveillance area for this project. Method is irrelevant – procurement should be based on conforming to capture resolution and cost efficiency. This step maybe a one-off if a contract was tendered for several years of this service or preferred supplier arrangement established.
- Carry out field based and/or aerial surveillance monitoring to track and monitor the life history of golden dodder to confirm the optimal time for aerial survey. This is also the optimal time to target the area for the first control operation.

- Fly area in optimal weather window for aerial survey (sunny, clear day). Survey flights must be carried out each year when golden dodder is well established but just before flowering. Survey flights should not be restricted to a date as the optimal time for survey will vary year-to-year due to environmental factors.
- Receive and migrate aerial imagery data into internal GIS system.

2. *One-off* - development of automated classification model

- Either internally (dependent on capability) or through procurement of appropriate supplier – develop a suitable automated data processing method to characterise vegetation types into the following categories. Follow guidance from Table 1 in Reeves and Haskew (2003) for the preliminary vegetation classification[15]:
    - Sedges and rushes
    - Manuka
    - Manuka with royal fern
    - Grey willow
    - Crack willow
    - Seasonal adventives and grasses
    - Kahikatea
    - Flax
    - *Carex* sedgeland
    - *Eleocharis* reedland
    - Raupo reedland
    - *Bolboschoenus* reedland
    - Marginal vegetation
    - Golden dodder
    - Bare soil
    - Dead vegetation
- Run initial model and capture results.
- Data validation - Manually classify a minimum of 10% of the area of aerial capture to the above vegetation types and manually digitise the results. Chose several areas covering the spectrum of vegetation composition, golden dodder density, and bare soil presence.
- Data validation - Ground truth data by field visits at selected sample sites following those manually digitised. Map and digitise on the ground vegetation composition (broad scales aligned with list above). These areas can align with the survey work caried out as part of the small-scale surveys outlined below to avoid duplication of effort.
- Data validation – compare results of automated model, manual processing, and field data. Carry out iterative modifications and changes to the model until the model performs to expected results based on field data capture and meets or exceeds the accuracy of manual digitising.
- Resolution interrogation (optional) – A fine level of resolution has been initially recommended to ensure data capture is adequate for the purpose. This can be tested by experimentally digitally downscaling the aerial imagery to lower levels of resolution

[15] We note preliminary as it is likely that the models available to classify images will have an ability to resolve vegetation at a finer resolution than that used by Reeves and Haskew (2003).

(for example 0.075m/pixel to 0.5m/pixel) and re-run the model to compare results. This process can be used to find the minimum resolution required to accurately monitor the area. This then can be the level of resolution required for aerial imagery capture, which if less than 0.05m/pixel, can be more cost effective to capture reducing costs or enabling larger areas of survey/surveillance.

3. **Processing of aerial imagery – automated classification**

   - Use automated classification method to classify and digitise extents of vegetation classes, golden dodder extent, bare soil, and dead vegetation.
   - Output from the model should include polygons of all types of vegetation/classifications, summary statistics of areas of extents, and percentages of cover.
   - Extract summary statistics which can be output on the basis of total area of surveillance and at any other finer scale sub-sample.

4. **Data storage, analysis, and communication**

   - All information captured should be stored within a spatial GIS system. We consider the ideal system would be an ArcGIS StoryMap system that enables a user to scroll through different survey periods to observe the changes in vegetation over time. The story map should have summary statistics for each survey and be able to be queried at a user defined sub-area level for finer analysis.
   - Data is census level and therefore summary statistics should be compared directly between years/seasons/operational steps and sample statistics (for example t-tests) is not required.

5. ***Optional* - Continuous improvement**

   - Periodically (we suggest every three years), review the model used for automated classification. Improvements may be available through better technology (improved models and artificial intelligence/machine learning) or through small changes to the model to better differentiate between vegetation types.
   - If changes are made, retrospectively process previous survey’s imagery to update with the improved model to ensure continuity and consistency of processing method.

6. **Repeat aerial survey**

   - Repeat survey by returning to step one.
   - Ideally the aerial survey, if it is only used as a survey tool, should be carried out once per year. However, it will only be able to occur as budget allows. Long-term trends will still be able to be monitored with periodic aerial surveys.

1.2 Opportunities for aerial survey

There is a potential, post validation of an automated processing model, that the use of orthorectified imagery capture and automated classification of vegetation could replace the initial helicopter-based surveillance flights used within the control programme currently. This would enable rapid capture and digitisation of GIS data on extent and density of golden dodder and then could be grouped by patch size to be targeted by aerial spot spraying or boom spraying.

This replacement of methods has the potential to streamline both monitoring data capture, aerial surveillance, and operational planning. This has the potential to result in considerable efficiencies in both cost and staff time resource requirement involved in the operational works of the programme while providing higher quality spatial vegetation data of the operational area.

1.3 Operational data capture

Data capture during operational works (both control and surveillance) should continue as standard – capturing GIS point data classified into spot and boom spray targets/control activities. This should be added to the above-mentioned StoryMap to show aerial survey, distribution of golden dodder, and commensurate control activity locations.

Ideally tracking data of both ground-based crews and aerial surveillance/control is also overlayed on the map to show the spatial pattern of effort in both control and surveillance.

2.0 Guide to monitoring method – Group two monitoring questions:

Group two monitoring questions:

1. Show if any changes to the vegetation assemblage and composition of the Whangamarino Wetland and Whangape-Rotongaro wetland complex has occurred as a result of current management practices and herbicide application. *Small scale changes.*
2. Track the effect of the current management approach on the extent and duration of bare soil exposed in the treatment area. *Small scale changes.*
3. Determine whether planting of non-host species prevents golden dodder from successfully germinating and attaching to a host and/or establishing new populations.

Group two questions will be monitored by a series of Wraight plot type transects. The core monitoring will be covered by a series of twelve 20m long transects. Along each transect, ten 1m x 1m plots will be measured for vegetation composition collecting cover class information for plants identified to genus level. The transects/plots will be as follows:

- o Monitoring of the extent and duration of bare soil:
    - ▪ Untreated transects - Determine three suitable areas where there is no current or historical record of golden dodder infestation under active control in an area of ready access and establish three transects per area through representative swath of vegetation. The purpose of these plots is to track vegetation changes in areas not subject to the disturbance regime of golden dodder control. It may be prudent to include several additional untreated transects if there is a risk that golden dodder may invade the

untreated area, this will provide resilience and redundancy if this were to occur. These transects should be numbered: BSU-01 to 03.

- Impact transects - determine three suitable areas of golden dodder infestation under active control in an area of ready access where bare soil is evident and establish three transects per area through representative swathes of vegetation. These transects should be labelled: BSI-01 to 03.

o Effect of planting non-host plants:

- Untreated transects - Determine three suitable areas as close as possible to the planted areas and establish three transects through representative swaths of vegetation. These transects should be labelled: NHPU – 01 to 03.
- Impact transects - determine three suitable areas[16] of non-host planting and establish three transects through representative swaths of vegetation. The length and number of transects may need adaptation to the areas of non-host planting available/implemented. Such as substituting a greater number of shorter transects to achieve the same number of 1x1m sub plots. These transects should be labelled: NHPI – 01 to 03 (or greater number if shorter transects are required).

2.1 Field guide for implementation.

The steps for the implementation of this method have been split by one-off and ongoing requirements. One-off requirements are those associated with establishing permanent transects. Detailed information on Wraight Plots is provided in Rose (2012b).

Note to prevent the spread of golden dodder to areas it does not already occur all field surveys should involve surveying transects BSC-01 to 03 first. These transects are intentionally not within an active area of golden dodder infestation.

1. **Timing**
   - Carry out field based and/or aerial surveillance monitoring to track and monitor the life history of golden dodder to confirm the optimal time for survey. This is also the optimal time to target the area for the first control operation.
2. ***One-off* – Transect establishment**
   - Establish plots by selecting areas which fit the descriptions of the four categories of transects. Within these areas select transect locations which are appear representative of the vegetation type present.
   - Mark the beginning of the transects with a fibreglass rod marker and using a 20m tape measure extend the transect to 20m and place another rod. We recommend another rod at 10m is placed to assist in relocating transects in the future and to increase the consistency of survey.
   - Label marker roads with transect identifiers and rod position. For example, for transect 1 of the non-host planting trials the roads should be labelled "NHPC-01-00m" for the transect start marker, "NHPC-01-10m" for the middle marker,

[16] Dependent on number and extent of areas planted with *Carex* sp.

and “NHPC-01-20m” for the transect finish marker. Labelling is to follow a convention of “Transect group, Transect number, distance along transect”.

- Records of the transect should be collected for future reference: Which include the GPS waypoints for the three marker rods. Notes for the relocation of the transect such as access points. Compass bearing of the transect from marker 00m to 20m. A photo should also be taken of the marker rods and an oblique photo of the transect length.

3. Field survey – plot data collection

- Locate the transect through GPS and transect information.
- Run out the tape measure along the transect from the 00m marker to the 20m marker.
- ***Hold point:*** If a drone photo point is to be taken, at this point carry out this task. Once this is complete return to this section to continue. This photo should be taken now, prior to access along the transect for collecting plot data which may disturb vegetation.
- A field sheet for transect/plot data is provided as Table 4 below with a populated example provided in Table 5.
- Carry out vegetation survey plots. A 1m x 1m plot is to be measured every 2 metres. Plots should alternate between the right- and left-hand side of the transect. An ideal survey would involve plots measured at 2, 4, 6, 8, 10, 12, 14, 16, 18, & 20m along the transect[17]. Plots should use a rigid 1x1 quadrat placed next to the transect (avoiding the area of disturbance where field staff walk along the transect).
- Plot data should be collected to genus level taxonomic resolution (other than for golden dodder). If genus is not known, collect a sample and take a photo of the plant. Cover is to be assessed within one of the following cover classes: 1 = less than 1%, 2 = 1-5%, 3 = 6-25%, 4 = 26-50%, 5 = 51-75%, 6 = more than 75% for each taxon. Where the plot is not covered entirely by vegetation descriptors such as “bare soil” or “open water” should be entered into the both the “Taxa” and “Structural class” column.
- Field data should be collected on field sheets, or in a GIS system on tablets with data capture fields pre-setup to capture the relevant information as defined in Table 4 below.

4. *Optional* - Field survey – aerial photo point data collection

- Once the transect has been located and the tape has been established along its length. Fly the drone to a point above the transect where the entirety of the transect is visible plus at least another 5m of area. The aim is to have a photo that captures at minimum a 25m x 25m area with the transect as a central line bisecting the plot.
- Return to on ground plot survey works.

5. Data collation and storage – Digitisation

[17] Do not start the plots at the starting point of the transect, this area tends to have a higher level of disturbance related to finding the transect, organising equipment, etc.

- Once data has been collected it will either need to be digitised into excel or extracted from the GIS input system to enter into spreadsheet for project (Example data and processing provided as Appendix 2).
- *Part of optional method* – Drone imagery – Use the visible 20m long tape in image to define a 20x20m area. Within this 20x20m area digitise (either manually or using the automated digitisation tool from the large-scale aerial survey method) the extents of the vegetation types within the plot. Capture summary data of area of each vegetation type.

6. **Repeat survey**
    - Repeat survey by returning to step one.
    - Ideally this survey should be carried out four times with the first survey being prior to the first control operation, second survey to occur post initial control works (timed to be long enough after control works where controlled areas have died), third survey to occur just prior to second control operation, final resurvey to occur post second control period (timed to be long enough after control works where controlled areas have died). It is likely that in many years there will be insufficient time to have a meaningful difference between the second and third surveys to occur. In this instance the survey would only have three repeats in a season.
    - If resourcing and budget provides a limitation to the replicates, the first and last survey should be prioritised.

2.2 Field Equipment list

The equipment needed onsite:

- Pencils
- Field sheets (preferably on waterproof paper) and/or tablet for electronic capture of data. (Field sheets should always be carried as a backup to electronic systems)
- 1x1m rigid plot quadrat (can be constructed as a collapsible quadrat with 4 x 1m 20mm PVC pipe and 4x 90˚ elbows with a string run through the piping to keep it together when collapsed).
- 20m tape (minimum length).
- GPS and spare batteries.
- Camera and spare batteries.
- Guidance document.
- Plant identification book.
- Large Ziplock bags for unidentified plant material.
- Waterproof notebook for both field notes and to cut/tear into plant labels if required.

If establishing transects you will also require:

- Fibre glass rod track marker (recommend 1.5m x 9.5mm orange and white track marking fibreglass rod). Minimum 2 per transect, preferably 3 (one deployed at the 10m midway mark).
- Permanent transect markers (e.g., permolat).
- Stainless steel tie wire for attaching labels to markers.
- Hammer for installing markers.

If carrying out drone photo point survey carry drone and all equipment necessary for using drone. A marker card should be carried (A4 size) to write plot numbers onto for a back-up for georeferencing imagery. This card should be laid visible to drone imagery next to plots with plot numbers clearly written. Refer to internal SOP documentation for drone use.

2.3 Data and statistics processing guide

Appendix 2 (provided as an electronic version of an excel sheet) provides a worked example of summary statistics and t-test (Equal variance). A t-test is used to compare the means of one sample group with another, the hypothesised difference in means is zero (assumes the groups are the same), the p-value (use two-tail as the difference in means can be higher or lower) shows the probability the hypothesised difference between the group of means is different. A difference would be considered significant when there is less than a 5% chance (“P(T<=t) two-tail” is less than 0.05) the hypothesised difference is true. Note in the example provided in Appendix 2 we have used random number values for the cover class column, it is therefore expected that there should be no difference between the means of the impact and untreated group.

Table 3 provides a guide for how to enter the data into a spreadsheet using the defined headings. For the taxa column we recommend that after the initial survey this field is constrained to a drop-down list of the taxa detected. This is to ensure consistent and avoid spelling errors contributing to incorrect summary of taxa and cover means.

Table 3: Guide for data entry for golden dodder survey

Transect group	NHPU, NHPI, BSU, or BSI	**Date-**	Date of Data collection	
Transect	**Plot in transect**	**Taxa**	**Structural class**	**Cover class**
“Transect group” - (1, 2 or 3)	*Number of 1x1m plot along transect will be 1 to 10*	*Genus sp.*	*Text*	*1 to 6*

2.3.1 How to summarise data

Appendix 2 shows an example of summary data, this should be done using functions within excel, not manually. This will require a basic understanding of excel functions and operations. The worked example can be looked at to understand how functions are used, the cell ranges used, and as a template for future analysis.

The first column is an automated list of taxa or structural class (dependent on the analysis required). This should be created using a combination of UNIQUE (Returns a list of unique entries from a single column) & TOCOL (required to combine multiple columns within the UNIQUE function) functions.

If analysing taxa the equation is:

=UNIQUE(TOCOL((“Cell range of the taxa for column one”: “Cell range of the taxa for column two”))).

For the two lists of taxa in Appendix 2 this looks like: =UNIQUE(TOCOL((J3:J74,C3:C74)))

The second column is an automated average of the cover classes for each taxa. This uses the AVERAGEIF function.

If analysing taxa the equation is: =AVERAGEIF(“Cell range of the taxa list”**,** “Cell containing the taxa you wish to produce the average cover class of”**,** “Cell range of the cover classes”)

In Appendix 2 this looks like: =AVERAGEIF($C$3:$C$74,A79,$E$3:$E$74) for the averages of taxa within the untreated plots. The “$” symbols indicate fixed ranges so when the function is copied down, these ranges do not change. This can be achieved either manually or selecting the cell reference in the text bar of excel and pressing “F4” on your keyboard.

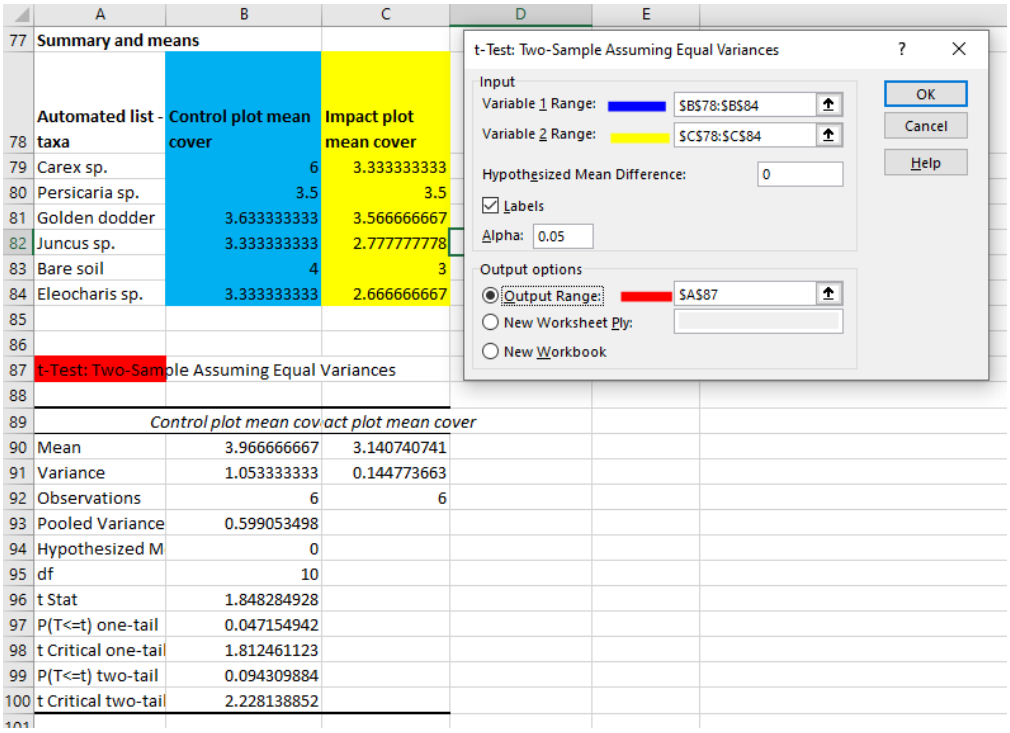
This automated average function can be used for each column where needed.

2.3.2 Statistical analysis

A t-test can then be carried out using the data analysis package in excel (located on the data tab, generally far right of tool ribbon “Data Analysis”). Click this then scroll down the list and select “t-Test: Two-Sample Assuming Equal Variances”.

For variable range 1 and 2 select the range of means to be statistically compared. For output range – choose where you would like the output to occur, default is generally a new worksheet, but you may wish to output it directly below your summary statistics. Figure 3 provides a visual indication of the data intended for each field colour coded, in this example we have chosen to output the results directly below the summary statistics. Beware this will overwrite existing data if it already occurs within the selected range. Note: the output of the analysis has already been produced in this figure. In this example the difference between the plant cover between the impact plots and untreated plots were not significant.

The summary statistics can be carried out at multiple scales and comparisons. For example, all plot data for a season can be aggregated to compare all data within untreated plots and impact plots for a season or compare between years. The functions and t-Test instructions can apply to any summary chosen to be analysed.



	A	B	C
77	**Summary and means**		
78	**Automated list - taxa**	**Control plot mean cover**	**Impact plot mean cover**
79	Carex sp.	6	3.333333333
80	Persicaria sp.	3.5	3.5
81	Golden dodder	3.633333333	3.566666667
82	Juncus sp.	3.333333333	2.777777778
83	Bare soil	4	3
84	Eleocharis sp.	3.333333333	2.666666667
85			
86			
87	t-Test: Two-Sample Assuming Equal Variances		
88			
89		*Control plot mean cov*	*act plot mean cover*
90	Mean	3.966666667	3.140740741
91	Variance	1.053333333	0.144773663
92	Observations	6	6
93	Pooled Variance	0.599053498	
94	Hypothesized M	0	
95	df	10	
96	t Stat	1.848284928	
97	P(T<=t) one-tail	0.047154942	
98	t Critical one-tail	1.812461123	
99	P(T<=t) two-tail	0.094309884	
100	t Critical two-tail	2.228138852	

Figure 3: Example of t-Test

Table 4:Golder dodder monitoring plot sheet.

Golden dodder – Wraight transect plot sheet	
Transect:	Date:
Measured by:	Recorded by:
Notes:	

Cover classes: **1** = less than 1% , **2** = 1-5%, **3** = 6-25%, **4** = 26-50%, **5** = 51-75%, **6** = more than 75%

Plot #	**Taxa**	**Structural class**	**Cover class**	**Plot #**	**Taxa**	**Structural class**	**Cover class**

Cover classes: **1** = less than 1% , **2** = 1-5%, **3** = 6-25%, **4** = 26-50%, **5** = 51-75%, **6** = more than 75%

Table 5:Golder dodder monitoring plot sheet – populated example.

Golden dodder – Wraight transect plot sheet	Transect sheet *1* of *1*
Transect: ***NHPC1***	Date:***27/01/2023***
Measured by: ***ABl***	Recorded by: ***DAt***

Notes:
Golden dodder well established in transect area
Water levels low, no standing water in transect area.
Drone used to capture 20x20m photos of transect area – Photo numbers DSC-003432- DSC-003438
Area of disturbance/vegetation damage along transect 13m-17m – unknown cause.
Photos taken of plots: 1 = DSC-001234, 2 = …35-36, 3 = …37, 4= …38, 5= …39, 6 = …40, 7 = …41-42, 8 = …43, 9= …44, 10= …45-46.

Cover classes: **1** = less than 1% , **2** = 1-5%, **3** = 6-25%, **4** = 26-50%, **5** = 51-75%, **6** = more than 75%

Plot #	Taxa	Structural class	Cover class	Plot #	Taxa	Structural class	Cover class
1	*Carex sp*	*Sedge*	*2*	*6*	*Persicaria sp.*	*Herb*	*4*
1	*Persicaria sp.*	*Herb*	*5*	*6*	*Golden dodder*	*Parasitic herb*	*4*
1	*Golden dodder*	*Parasitic herb*	*4*	*6*	*Bare soil*	*Bare soil*	*2*
2	*Persicaria sp.*	*Herb*	*6*	*7*	*Golden dodder*	*Parasitic herb*	*6*
2	*Golden dodder*	*Parasitic herb*	*2*	*8*	*Persicaria sp.*	*Herb*	*5*
3	*Juncus sp.*	*Rush*	*1*	*8*	*Golden dodder*	*Parasitic herb*	*3*
3	*Persicaria sp.*	*Herb*	*4*	*8*	*Eleocharis sp.*	*Sedge*	*1*
4	*Golden dodder*	*Parasitic herb*	*5*	*9*	*Persicaria sp.*	*Herb*	*6*
4	*Juncus sp.*	*Sedge*	*1*	*9*	*Golden dodder*	*Parasitic herb*	*1*
4	*Persicaria sp.*	*Herb*	*4*	*10*	*Golden dodder*	*Parasitic herb*	*6*
4	*Golden dodder*	*Parasitic herb*	*5*				
5	*Juncus sp.*	*Sedge*	*1*				
5	*Persicaria sp.*	*Herb*	*4*				
5	*Golden dodder*	*Parasitic herb*	*5*				

Cover classes: **1** = less than 1%, **2** = 1-5%, **3** = 6-25%, **4** = 26-50%, **5** = 51-75%, **6** = more than 75%

Appendix 2 – Example digital data storage and statistics.

Transect group	NHPU	Date	3/02/2023	
Transect	Plot in transect	Taxa	Structural class	Cover class
NHPU-01	1	Carex sp.	Sedge	6
NHPU-01	1	Persicaria sp.	Herb	6
NHPU-01	1	Golden dodder	Parasitic herb	3
NHPU-01	2	Persicaria sp.	Herb	5
NHPU-01	2	Golden dodder	Parasitic herb	5
NHPU-01	3	Juncus sp.	Rush	5
NHPU-01	3	Persicaria sp.	Herb	1
NHPU-01	4	Golden dodder	Parasitic herb	3
NHPU-01	4	Juncus sp.	Sedge	6
NHPU-01	4	Persicaria sp.	Herb	1
NHPU-01	4	Golden dodder	Parasitic herb	5
NHPU-01	5	Juncus sp.	Sedge	5
NHPU-01	5	Persicaria sp.	Herb	1
NHPU-01	5	Golden dodder	Parasitic herb	6
NHPU-01	6	Persicaria sp.	Herb	4
NHPU-01	6	Golden dodder	Parasitic herb	2
NHPU-01	6	Bare soil	Bare soil	6
NHPU-01	7	Golden dodder	Parasitic herb	4
NHPU-01	8	Persicaria sp.	Herb	5
NHPU-01	8	Golden dodder	Parasitic herb	3
NHPU-01	8	Eleocharis sp.	Sedge	6
NHPU-01	9	Persicaria sp.	Herb	3
NHPU-01	9	Golden dodder	Parasitic herb	4
NHPU-01	10	Golden dodder	Parasitic herb	5
NHPU-02	1	Carex sp.	Sedge	6
NHPU-02	1	Persicaria sp.	Herb	4
NHPU-02	1	Golden dodder	Parasitic herb	1
NHPU-02	2	Persicaria sp.	Herb	1
NHPU-02	2	Golden dodder	Parasitic herb	1
NHPU-02	3	Juncus sp.	Rush	1
NHPU-02	3	Persicaria sp.	Herb	5
NHPU-02	4	Golden dodder	Parasitic herb	2
NHPU-02	4	Juncus sp.	Sedge	2
NHPU-02	4	Persicaria sp.	Herb	2
NHPU-02	4	Golden dodder	Parasitic herb	4
NHPU-02	5	Juncus sp.	Sedge	1
NHPU-02	5	Persicaria sp.	Herb	2
NHPU-02	5	Golden dodder	Parasitic herb	6
NHPU-02	6	Persicaria sp.	Herb	5
NHPU-02	6	Golden dodder	Parasitic herb	2
NHPU-02	6	Bare soil	Bare soil	2
NHPU-02	7	Golden dodder	Parasitic herb	4
NHPU-02	8	Persicaria sp.	Herb	3
NHPU-02	8	Golden dodder	Parasitic herb	5
NHPU-02	8	Eleocharis sp.	Sedge	2
NHPU-02	9	Persicaria sp.	Herb	2
NHPU-02	9	Golden dodder	Parasitic herb	4
NHPU-02	10	Golden dodder	Parasitic herb	2
NHPU-03	1	Carex sp.	Sedge	6
NHPU-03	1	Persicaria sp.	Herb	6
NHPU-03	1	Golden dodder	Parasitic herb	6
NHPU-03	2	Persicaria sp.	Herb	2
NHPU-03	2	Golden dodder	Parasitic herb	6
NHPU-03	3	Juncus sp.	Rush	4
NHPU-03	3	Persicaria sp.	Herb	4
NHPU-03	4	Golden dodder	Parasitic herb	5
NHPU-03	4	Juncus sp.	Sedge	1
NHPU-03	4	Persicaria sp.	Herb	4
NHPU-03	4	Golden dodder	Parasitic herb	6
NHPU-03	5	Juncus sp.	Sedge	5
NHPU-03	5	Persicaria sp.	Herb	6
NHPU-03	5	Golden dodder	Parasitic herb	3
NHPU-03	6	Persicaria sp.	Herb	3
NHPU-03	6	Golden dodder	Parasitic herb	2
NHPU-03	6	Bare Soil	Bare soil	4
NHPU-03	7	Golden dodder	Parasitic herb	2
NHPU-03	8	Persicaria sp.	Herb	5
NHPU-03	8	Golden dodder	Parasitic herb	1
NHPU-03	8	Eleocharis sp.	Sedge	2
NHPU-03	9	Persicaria sp.	Herb	4
NHPU-03	9	Golden dodder	Parasitic herb	1
NHPU-03	10	Golden dodder	Parasitic herb	6

Transect group	NHPI	Date	4/02/2023	
Transect	Plot in transect	Taxa	Structural class	Cover class
NHPI-01	1	Carex sp.	Sedge	3
NHPI-01	1	Persicaria sp.	Herb	2
NHPI-01	1	Golden dodder	Parasitic herb	2
NHPI-01	2	Persicaria sp.	Herb	4
NHPI-01	2	Golden dodder	Parasitic herb	1
NHPI-01	3	Juncus sp.	Rush	1
NHPI-01	3	Persicaria sp.	Herb	6
NHPI-01	4	Golden dodder	Parasitic herb	3
NHPI-01	4	Juncus sp.	Sedge	4
NHPI-01	4	Persicaria sp.	Herb	1
NHPI-01	4	Golden dodder	Parasitic herb	4
NHPI-01	5	Juncus sp.	Sedge	3
NHPI-01	5	Persicaria sp.	Herb	1
NHPI-01	5	Golden dodder	Parasitic herb	2
NHPI-01	6	Persicaria sp.	Herb	6
NHPI-01	6	Golden dodder	Parasitic herb	3
NHPI-01	6	Bare soil	Bare soil	2
NHPI-01	7	Golden dodder	Parasitic herb	1
NHPI-01	8	Persicaria sp.	Herb	2
NHPI-01	8	Golden dodder	Parasitic herb	3
NHPI-01	8	Eleocharis sp.	Sedge	3
NHPI-01	9	Persicaria sp.	Herb	1
NHPI-01	9	Golden dodder	Parasitic herb	6
NHPI-01	10	Golden dodder	Parasitic herb	6
NHPI-02	1	Carex sp.	Sedge	5
NHPI-02	1	Persicaria sp.	Herb	6
NHPI-02	1	Golden dodder	Parasitic herb	3
NHPI-02	2	Persicaria sp.	Herb	3
NHPI-02	2	Golden dodder	Parasitic herb	3
NHPI-02	3	Juncus sp.	Rush	1
NHPI-02	3	Persicaria sp.	Herb	2
NHPI-02	4	Golden dodder	Parasitic herb	5
NHPI-02	4	Juncus sp.	Sedge	4
NHPI-02	4	Persicaria sp.	Herb	2
NHPI-02	4	Golden dodder	Parasitic herb	1
NHPI-02	5	Juncus sp.	Sedge	4
NHPI-02	5	Persicaria sp.	Herb	5
NHPI-02	5	Golden dodder	Parasitic herb	6
NHPI-02	6	Persicaria sp.	Herb	6
NHPI-02	6	Golden dodder	Parasitic herb	1
NHPI-02	6	Bare soil	Bare soil	5
NHPI-02	7	Golden dodder	Parasitic herb	6
NHPI-02	8	Persicaria sp.	Herb	5
NHPI-02	8	Golden dodder	Parasitic herb	6
NHPI-02	8	Eleocharis sp.	Sedge	3
NHPI-02	9	Persicaria sp.	Herb	1
NHPI-02	9	Golden dodder	Parasitic herb	2
NHPI-02	10	Golden dodder	Parasitic herb	5
NHPI-03	1	Carex sp.	Sedge	2
NHPI-03	1	Persicaria sp.	Herb	5
NHPI-03	1	Golden dodder	Parasitic herb	5
NHPI-03	2	Persicaria sp.	Herb	3
NHPI-03	2	Golden dodder	Parasitic herb	5
NHPI-03	3	Juncus sp.	Rush	1
NHPI-03	3	Persicaria sp.	Herb	3
NHPI-03	4	Golden dodder	Parasitic herb	3
NHPI-03	4	Juncus sp.	Sedge	3
NHPI-03	4	Persicaria sp.	Herb	4
NHPI-03	4	Golden dodder	Parasitic herb	1
NHPI-03	5	Juncus sp.	Sedge	4
NHPI-03	5	Persicaria sp.	Herb	6
NHPI-03	5	Golden dodder	Parasitic herb	4
NHPI-03	6	Persicaria sp.	Herb	2
NHPI-03	6	Golden dodder	Parasitic herb	4
NHPI-03	6	Bare soil	Bare soil	2
NHPI-03	7	Golden dodder	Parasitic herb	4
NHPI-03	8	Persicaria sp.	Herb	6
NHPI-03	8	Golden dodder	Parasitic herb	4
NHPI-03	8	Eleocharis sp.	Sedge	2
NHPI-03	9	Persicaria sp.	Herb	2
NHPI-03	9	Golden dodder	Parasitic herb	3
NHPI-03	10	Golden dodder	Parasitic herb	5

Summary and means

Automated list - taxa	Control plot mean cover	Impact plot mean cover
Carex sp.	6	3.333333333
Persicaria sp.	3.5	3.5
Golden dodder	3.633333333	3.566666667
Juncus sp.	3.333333333	2.777777778
Bare soil	4	3
Eleocharis sp.	3.333333333	2.666666667

Automated list - Functional groups	Control plot mean cover	Impact plot mean cover
Sedge	4	3.333333333
Herb	3.5	3.5
Parasitic herb	3.633333333	3.566666667
Rush	3.333333333	1
Bare soil	4	3

t-Test: Two-Sample Assuming Equal Variances

	Control plot mean cove	*pact plot mean cover*
Mean	3.966666667	3.140740741
Variance	1.053333333	0.144773663
Observations	6	6
Pooled Variance	0.599053498	
Hypothesized Mea	0	
df	10	
t Stat	1.848284928	
P(T<=t) one-tail	0.047154942	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.094309884	
t Critical two-tail	2.228138852	

t-Test: Two-Sample Assuming Equal Variances

	Control plot mean co	*pact plot mean cover*
Mean	3.693333333	2.88
Variance	0.089666667	1.152555556
Observations	5	5
Pooled Variance	0.621111111	
Hypothesized Me	0	
df	8	
t Stat	1.631751147	
P(T<=t) one-tail	0.070688359	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.141376718	
t Critical two-tail	2.306004135	

About Boffa Miskell

Boffa Miskell is a leading New Zealand professional services consultancy with offices in Whangarei, Auckland, Hamilton, Tauranga, Wellington, Nelson, Christchurch, Dunedin, and Queenstown. We work with a wide range of local and international private and public sector clients in the areas of planning, urban design, landscape architecture, landscape planning, ecology, biosecurity, cultural heritage, graphics and mapping. Over the past four decades we have built a reputation for professionalism, innovation and excellence. During this time we have been associated with a significant number of projects that have shaped New Zealand's environment.

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