Early detection using surveillance for aquatic weeds

Validating techniques and practices in Lake Ōkāreka

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Executive summary

Bay of Plenty Regional Council (BOPRC) undertake surveillance and monitoring to fulfill their stated intentions of excluding, reducing or containing pests under the Bay of Plenty Regional Pest Management Plan (RPMP). BOPRC wants to be confident that the best practices and technologies are being employed for submerged weed surveillance in the Rotorua Te Arawa lakes. BOPRC contracted NIWA's Freshwater Biosecurity team to undertake a scientific assessment and validation of surveillance practices and technologies for the lake environments and weed species of concern to the region.

This report reviews new and current detection methods based on a comprehensive literature search. Considered were passive methods incorporating citizen science, remote methods of satellite/aerial hyperspectral analysis, submerged camera videography, hydro-acoustics, laser scanning, and novel genetic detection methods. None of these methods proved to be suitable for detecting low incidence incursions of submerged aquatic weeds. However advances in technology, particularly auto-processing of imagery, may make these methods feasible in the future.

The most proven methods for early detection and delimitation of new incursions of submerged aquatic weeds in the literature and currently practiced, are in-water visual methods using divers transported by a range of methods. Most of these methods are currently used by BOPRC Natural Resource Operations staff in current surveillance and delimitation programmes for lakes.

We scientifically tested the best in-water diver methods in the field, under depth and clarity conditions typical of Lake Ōkāreka, the focus of recent issues with hornwort detection. Surrogates for aquatic weeds (totara branches) were used to test diver detection accuracy at different depths, levels of background vegetation development and for different heights of surrogates. Surrogates were placed within a 2 m wide, 100 m long transect that divers followed while making observations. Techniques tested included snorkel diving, scuba diving, underwater scooters and boat tows (snorkel or manta board tow). Also tested for comparison were sonar side-scan and underwater video.

The trials identified significant differences in the detection accuracy for surrogates between the techniques, depending on water depth. The greatest detection accuracy in shallow water was by snorkel (89%), while scuba/scooter techniques had intermediate accuracy (83-85%), and snorkel tow had the lowest accuracy (69%). In deeper water, detection by snorkel was not possible and scuba/scooter techniques were most accurate (74-77%), followed by scuba with manta board tows (44%).

Height of the surrogates relative to background vegetation significantly influenced detection rates with only a few of the short surrogates being detected in comparison to most of the taller surrogates being detected that were taller than the surrounding canopy. Therefore, frequency of surveillance should factor in plant growth and the increased detectability of potential targets over time.

There were significant differences in the speed of the different methods (three-fold variation), which should be considered in terms of efficiency for effort/time. For instance, the more frequent use of rapid methods with a lower detection accuracy may have an advantage over low frequency use of a highly effective detection method.

Trials also detected significant diver differences in detection ability despite the dive team having similar diver qualifications.

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Best practice guidelines for submerged weed surveillance are provided that incorporate information and findings to enable the selection of methods according to water depth, water clarity and littoral width.

In conclusion prioritised and systematic underwater searches of at-risk areas provide the best chance of intercepting new submerged weed incursions. Current BOPRC surveillance and incursion delimitation practices are in keeping with that approach. Recommendations to improve surveillance performance include:

- Develop a systematic and documenting procedure for planning and carrying out surveillance on a lake by lake basis (e.g., defining site, frequency, timing, methods see http://www.niwa.co.nz/freshwater-and-estuaries/research-projects/waitaki-weed-surveillance-plan)

- Incorporate targeted searching of high risk sites to afford greater coverage or frequency of surveillance than other areas.

- For prioritised sites, build up sonar map resources of bathymetry and vegetation biovolume using new available processing services and compatible sonar equipment.

- Collate and use resources for training divers on recognition of target weeds under variable lake and plant conditions.

- Rotate divers among sites between surveys.

1   Introduction

1.1   Background

Early detection of submerged weed infestations is critical for a range of control, containment and eradication options to be effective. However, the early detection of new incursions of submerged aquatic weeds is particularly challenging. Casual detection is unlikely as most infestations are at a depth within lakes that cannot be viewed from the surface and colonies become obvious only when a large amount of biomass has developed.

Bay of Plenty Regional Council (BOPRC) undertake a macrophyte surveillance programme for selected waterbodies, utilizing accepted surveillance techniques of shoreline searches and diver observations via snorkel, spot dives, manta board tows or underwater scooters. Other initiatives that have assisted the macrophyte surveillance programme is the establishment of weed cordons (Lass 2012) at high risk lakes (Ōkataina, Rotoma, Ōkāreka) or weed source lakes (Rotoehu). While surveillance programmes have successfully detected incursions or evidence of weed presence, the difficulty of locating initial establishment sites at an early stage was highlighted in Lakes Ōkāreka and Ōkataina where many months passed between the initial detection of fragments and successful identification of the source. Following the first report of hornwort in Lake Ōkāreka in April 2012 by a local tourism operator, BOPRC undertook a surveillance and delimitation response (BOPRC 2013). Fragments and scattered plants were located initially. However, monitoring undertaken one year later did locate the primary infestation site, including one dense area of around 50 m^2 in size. Approximately 17 ha of hornwort was delimited, out of an estimated 102 ha of potential habitat (BOPRC 2013).

BOPRC need to have better information on the efficiency of surveillance for detecting pests for the level of effort spent and be confident that the best practices and technologies are being employed for submerged weed surveillance in the region. NIWA's Freshwater Biosecurity team were contracted by BOPRC to undertake a scientific assessment and validation of surveillance practices and technologies, including those used by the BOPRC or that have the potential to be applied to lake environments and weed species of concern to the region.

Lake Ōkāreka is a lake of key interest to establish effective surveillance practices, following its recent issues with hornwort detection that has challenged surveillance detection capabilities and compromised timely management responses.

This report reviews international literature for new and current technologies and practices that have application for aquatic weed surveillance in the Rotorua Te Arawa Lakes. The current surveillance programme and practices of BOPRC are briefly described. Trials on current and key new methods for detection of new incursions were trialled in Lake Ōkāreka and findings are reported here. Finally a synthesis of reviews and findings are bought together in guidelines for best practice for weed surveillance in the Rotorua Te Arawa Lakes.

1.2   Biosecurity terms and definitions

'Biosecurity surveillance' as defined by the Ministry for Primary Industries (MPI) in New Zealand means 'looking for pests, diseases, animals, plants and other living things, which either don't belong in New Zealand, or which can cause problems for animals, plants or the environment'. It is used to find out whether they're already here, where exactly they are and if they're not already present, to detect them early if they arrive (MAF Biosecurity New Zealand 2009).

'Early detection' is a critical part of surveillance and may make the difference in being able to appropriately manage, control, or eradicate a weed species before it has a chance to spread and further impact negatively on the surrounding environment.

Should a new invasive species be found then the focus of surveillance moves from detection to 'weed delimitation'. Delimitation surveys of an area following a new incursion are important to describe the exact location of a weed species and for setting boundaries for management actions (e.g., control or eradication).

'Active surveillance' is defined as the systematic checking of a site for new incursions of invasive weeds and is a planned activity, part of a weed strategy or weed surveillance programme. In comparison, 'Passive surveillance' is used for more casual inspections such as a fortuitous weed sighting whilst engaged in other activities, or opportunistic shoreline checks of weed drift.

'Targeted surveillance' is the use of search methods that maximise the chances of detection in relation to time spent. Targeted surveillance is often part of an on-going program and used for both early detection and weed delimitation surveys.

2 Review of surveillance methods

The following review of new and current detection methods provides a brief description, identifies their potential for application to submerged weed detection (especially coverage and scope for detection) and discusses their strengths and weaknesses. The review was based on a literature review of major online reference and full-text databases (Web of Science, ASFA, NIWA library catalogue, Google Scholar) using appropriate search terms to extract relevant available literature since 1990. Search terms targeted new and current submerged weed surveillance practices, techniques and technologies; including DNA-based technologies, remote sensing (sonar and satellite imagery) and SCUBA diving, snorkelling, manta board tows, use of scooters, drop cameras. In addition relevant 'grey' literature (e.g., technical reports, manufacturer's data sheets) was also sought by a general internet search.

2.1 Passive surveillance

2.1.1 Citizen science

Broadly defined as 'the involvement of volunteers in science' (Tweddle et al. 2012), citizen science has grown rapidly over the past decade and provides a means by which the general public can help aid and benefit science investigations, primarily through the making of observations and collection of data. Programs can vary from the involvement of only one person to tens of thousands of people all collaborating towards a common scientific goal (Cohn 2008).

Citizen science can benefit both volunteers and researches. Volunteers can increase their knowledge and understanding of the scientific process, gain deeper understanding of issues of importance, strengthen their attitudes toward their natural environment and participate in making science-based recommendations. On the other hand, citizen science programs can also provide researchers with an opportunity to increase public awareness concerning their areas of study and can make it possible to answer research questions that require observations spread over time or space that would otherwise not have sufficient resources (Gommerman and Monroe 2012). The use of citizen science in New Zealand is further endorsed by The Royal Society of New Zealand who state that 'citizen science should play a much stronger role in monitoring and surveillance for pests in New Zealand' (The Royal Society of New Zealand 2014).

Although citizen science programs have commonly been used to survey and monitor native species, few have involved invasive species issues and those that have were usually short term or focused on eradication efforts (Delaney et al. 2008). Currently however there is increasing awareness of the importance of documenting the distribution and spread of invasive species (Fitzpatrick et al. 2009).

'The Invaders of Texas' program is an example of a successful citizen science initiative focused on the long-term monitoring of invasive plants in Texas and where data collected is used to help researchers better understand invasive species distribution (http://www.texasinvasives.org). Of more relevance to the Rotorua Te Arawa Lakes is an example from North America where the University of Wisconsin Oshkosh have now produced a protocol for citizens to monitor lake shorelines for aquatic invasive species including plants (Miller et al. 2014).

In New Zealand, Nature Watch NZ is gaining recognition as the biggest citizen science program of its kind in the country. It has a website (http://naturewatch.org.nz) dedicated to building a record of nature in New Zealand including invasive aquatic plant species. It allows anyone to add an observation of anything natural they have spotted and observations with photos can then be verified

by experts involved in the project before the data is made available on line. This information can then be used by researchers and managers to help map invasive species and spread.

In the Rotorua Te Arawa Lakes, while citizen science has scope to provide some real benefits to volunteers and managers, its usefulness as a method for the early detection of a new pest is questionable. Volunteers however should be encouraged to keep an eye out for invasive species and report any findings of new plants to an area. Members of the public could also be provided with training and resources to carry out shoreline searches in high risk areas (see Section 2.1.2, Shoreline search).

2.1.2   Shoreline search

Shoreline searches for invasive submerged weeds involves carrying out a visual search of the shoreline and waters' edge for plant fragments. Washed up fragments range in length from as small as a centimetre to a metre or more long and are usually most abundant on shore following periods of rough weather (Figure 1).

The obvious benefits of this method is that it is easy to carry out and requires no special equipment or skills apart from weed species identification. Lakes Ōkataina, Taharoa and Ohau are all recent New Zealand examples of where fragments of weed have been first detected on shore. However, a limitation of this method is that a shoreline fragment of a previously unrecorded species is not necessarily evidence of an in-lake infestation. This proved to be the case for Lake Ohau, where *Lagarosiphon major* was identified at the lake edge adjacent to a boat ramp; however extensive in-lake searches failed to confirm any established presence during subsequent annual surveys over the next nine years. Weed fragments can easily dislodge from a boat or trailer during preparation for or during launching. Partially desiccated fragments are likely to float when released into water and there is a high change they would become stranded on the shoreline.

Another major limitation of this method for early detection is that by the time shoreline drift fragments are found, the infestation may be well established meaning any chance of a rapid response and the hope of eradication may not be possible. Furthermore, it is not always possible to identify the source area of infection from fragments found on the shore. This was highlighted in Lake Ōkataina where many months passed between the initial detection of shoreline fragments and the successful identification of its source.

Where shoreline searches may have most merit is as part of citizen science initiatives where volunteer's (lake care groups) could be encouraged to participate in regular searches. Searching high risk areas (e.g., access points and deposition zones) would provide the best chance of detection.

Figure 1:   **Weed fragments washed up on the shore of Lake Rotoehu.**

2.1.3   Glass bottom boats and viewing scopes

Glass bottom boats and viewing scopes work very much in the same way, allowing viewing into the water from above the surface. Observers require no specialised skills beyond weed species recognition. While a glass bottom boat and viewing scopes may provide some opportunity for observations within lakes where good water clarity and shallow depths allow, depth and light become limiting factors further from the lake edge.

Very few examples in the literature could be found for the use of glass bottom boats for surveillance purposes. Glass bottom boats have been used in Canada to carry out eel counts from rivers (Cairns et al. 2008) and more recently in Japan a glass bottom boat was used in measuring florescence characteristics for monitoring coral viability (Sasano et al. 2013).

In New Zealand, glass bottom boats have been used in Lakes Wanaka and Waikaremoana for the purpose of locating new infestations of *Lagarosiphon major*. In the late 1970's lagarosiphon was under intense management in Lake Wanaka and a glass bottom boat was used to search for infestations outside the managed area. This method was abandoned after several years and replaced using diver tows with scuba or snorkel. More recently until c. 2012, a glass bottom boat was the key detection method used to search for lagarosiphon in the main body of Lake Waikaremoana, following its eradication from Rosie Bay. Unfortunately this method failed to detect a well-established and spreading infestation of lagarosiphon, which also resulted in replacement using scuba and snorkel divers with boat tows or underwater scooters (authors' observations).

While glass bottom boats have limits to which they can be used, they still have potential for use by citizen science groups where something is better than nothing.

Viewing submerged plants directly over the edge of a boat may also have merit on days when exceptionally good water clarity and stillness allow.

2.2   In-water visual methods

In-water visual methods include those where the observer is required to carry out a visual assessment of an area while in the water snorkelling or Scuba diving.

Masks used for diving are mostly fitted with a flat lenses that creates a layer of air between the glass and the eyes and enables vision underwater. Through the mask, water refraction makes objects appear 33% bigger and 25% closer than they actually are. With regular masks, around 75% of a person's normal field of view (c. 180°) above water can be lost and there may be some merit in diver's trialling different mask designs for detection. For example, translucent mask casings can cause image reflection off the inside of the lenses, thereby potentially reducing image clarity and definition. New mask designs found during the literature search also claim to offer zero distortion vision with wider viewing angles (www.hydrooptix.com) which maybe worthy of further investigation. Divers can also compensate for constrained fields of view by 'panning' from side to side and also by moving towards an object of interest.

All in-water observations require good clarity for clear vision. Apart from diver mask designs, an observer's visibility underwater is reliant on several additional factors. These include the optical properties of the water (clarity), and the bottom; the characteristics of the target (size, shape, reflectivity, etc.,) the diver's acuity; and external lighting conditions (Zanevald & Pegau (2003).

Secchi disk and black disk are standard water quality measurements that provide a measure of visibility and detection distances. In brief, the better the water clarity the better the distance for detection. The black disc has been identified as a simple parameter for usefully predicting diver visibility (Zanevald & Pegau 2003) and provides a measure of gradual loss in intensity of light through water for horizontal viewing. However if viewing vertically through the water column the best parameter may be Secchi disk distance, which integrates decrease in light levels with depth (Kirk 2011).

2.2.1   Snorkelling

Snorkelling allows an observer to see underwater for extended periods of time with relatively little skill compared to Scuba. However, it is not without risk and the comfort of the snorkeler in colder waters can also limit the time available for carrying out searches. The other major limitation of snorkelling is the requirement for good water clarity for the detection and identification of plant species at depth.

Snorkelling is effective for targeted searches of smaller shallow (c. 3-5 m) areas such as within bays or areas close to the lake shore. For larger areas snorkelling can be used in combination with a tow rope attached to the back of a boat for a 'snorkel tow' (Figure 2). This method allows much larger areas including whole lake margins to be searched with less physical effort required from a snorkeler than a Scuba diver.

Van Egeren (2011) included snorkel investigations at boat ramps and additional sites representing different habitat types in early detection monitoring for aquatic invasive species in Wisconsin lakes. Most recently, in New Zealand snorkel tows have proven to be the most effective method for detecting invasive plants along large areas of shoreline around the margins of Lakes Wanaka and Benmore in the South Island and Waikaremoana in the North Island (authors' observations).

Figure 2: A snorkeler uses a ski rope to be towed around the margins of Lake Ōkāreka while carrying out surveillance trials in April 2014.

2.2.2 SCUBA

Scuba diving refers to a form of underwater diving in which divers use a self-contained underwater breathing apparatus (SCUBA) to breath underwater. Using Scuba, divers have the ability to adjust position and depth in the water body and are able to move freely to investigate objects or areas of interest (Figure 3).

Good visibility is preferable when carrying out searches, while low visibility (<2m) would make it unfeasible.

The use of qualified divers to carry out surveillance is necessary due to the hazards of diving. All employed Scuba divers in New Zealand must hold a Code of Compliance Certificate issued by Work Safe New Zealand.

Scuba diving has been used to carry out visual searches to detect invasive species in marine environments (Campbell et al. 2007, Mooney et al. 2005, Kanary et al. 2010, Issaris et al. 2012). Visual searches carried out using Scuba continue to be the most common and effective surveillance method used for the detection of invasive plant species in New Zealand lakes (authors' observations).

Figure 3: **Scuba diver undertakes surveillance for targets in Lake Ōkāreka.**

2.2.3   Manta board

A manta board allows Scuba and snorkel divers to manoeuvre through the water while being towed behind a boat. Manta boards vary in design but are basically rectangular in shape and most commonly made out of wood (Figure 4). It is essentially a hydrodynamic plane angled by the divers arms to control depth (Miller and Müller, 1999). The boards are attached to a boat using a tow line, while a diver then holds onto the board to be pulled through the water. The biggest advantage of manta tows is that they allow a diver to travel considerably faster than with scuba diving alone, although towing speed must be managed for diver comfort as well as efficiency. Manta tows are particularly effective for covering large areas quickly and boats equipped with GPS can systematically cover a nominated area.

Manta board tows are widely used to assess broad scale changes in coral reefs (Miller et al. 2009). Evaluations carried out to assess manta tows in field conditions concluded that the manta tow technique is valid and reproducible for aquatic habit assessments over moderate spatial scales (Miller and Müller 1999).

Figure 4: **Manta board use gives a diver some manoeuvrability while covering areas at a greater speed than scuba alone.**

2.2.4 Scooter

An underwater scooter, also known as an underwater propulsion vehicle, consists of a pressure resistant watertight casing containing a battery powered electric motor which drives from a propeller. The use of scooters allows divers to cover a greater area underwater with less fatigue which can also result in less air being used. Major limitations are battery life, which can restrict the spatial range of investigations.

Figure 5: **A scooter allows divers to cover distances faster with less effort.**

2.3   Remote methods

2.3.1   Laser line scan

Laser line scan (LLS) is an underwater optical imaging method capable of imaging at a high resolution (cm accuracy). This uses a sensor and laser system to concentrate intense light over a small area in order to illuminate distant targets and record underwater imagery. The effective range of laser systems is several meters in water but is reduced under highly turbid conditions (Gillham 2011). LLS typically requires motion in order to generate an image and a real time image of the bottom can be generated (Wernli 1999).

The ideal application for an underwater LLS involves short-range, high-detail measurements of specific locations on an asset such as in archaeological documentation (Gillham 2011). The high optical resolution offered by these systems makes them an ideal tool for applications such as limited area search, corridor surveys (e.g., pipelines and cable routes), and high resolution environmental surveys (Wernli 1999). LLS has been evaluated as a tool intermediate in resolution to video survey and acoustic technologies for evaluating fish habitat at a resolution of a 2 cm pixel size (Yoklavich 2005).

We note that Mooney et al. (2005) discounted LLS as a surveillance method for *Caulerpa taxifolia* during initial tests, although they do not state the reason. Gillham (2011) concluded that LLS of a large area is time-consuming and more expensive than sonar. A major drawback is the cost of LLS systems which is substantial e.g., US$700,000 (Wernli 1999).

2.3.2   Hydro-acoustic methods

Hydro-acoustics techniques (aka sonar or echo sounder) use sound frequencies to detect underwater objects. By sending sounds of a recognised frequency and by receiving the 'echo' of sound that bounces back, the position of objects in the water column can be determined. The acoustic properties of the object reflect its density difference from the surrounding water, so some differentiation of objects is possible.

Hydro-acoustics is a viable technique for the survey of aquatic vegetation in estuaries or shallow lakes (Sabol et al. 2002, Valley et al. 2005, Winfield et al. 2007, Sabol et al. 2009, Abukawa et al. 2013). Nevertheless, there are no claims in the literature that hydro-acoustic signals can distinguish between different species of plant species (i.e., detect an invasive weed) based on their acoustic signature. For instance, Sabol et al. (2012) states 'there is currently no general capability to discriminate submerged aquatic vegetation species or even general classes of submerged aquatic vegetation', and Kenworthy et al. (2012) list a limitation of sonar as its inability to discriminate species. However, some differentiation was possible where two species differed greatly in height (Sabol et al. 2008).

Two main types of hydro-acoustic technology are now readily available relatively cheaply; down-looking sonar and, from 2005 onwards, side-scan sonar (Figure 6). These technologies differ in the area that they cover and the level of information that is recorded.

In down-looking sonar, a transducer sends sound signals downwards. Because the cone angle of the sound signals is limited, the acoustic 'footprint' sampled is smallest in shallow water, and becomes larger with depth. With a cone angle 20° (e.g., Lowrance HDS9 and LSS-2 HD transducer at standard 200 kHz frequency), the diameter of the most sensitive sample area in 1 m depth of water is 0.36 m diameter, and at 10 m is 3.64 m. A cone angle of 1.1° (e.g., Lowrance high definition 'Structure Scan'

at 455 kHz) the area sampled in 1 m depth of water is only 0.03 m diameter, and at 10 m is 0.183 m diameter.

Side-scan sonars transmit sound waves to either side of the vessel, with returning signal pulses reflected from submerged features then used to produce a two-dimensional image of the underwater landscape. These images do not contain associated depth, position or signal return data, except immediately below the transducer. Therefore they are analogous to a photograph. Subjective image interpretation is possible using cues provided by sonar shadows and image tonal changes (Kaeser et al. 2012, Kenworthy et al. 2012).

Side-scan hydro-acoustic technology has a wider footprint and therefore holds more promise for the detection of newly-invading aquatic weeds. Commercially available models (e.g., Lowrance, Hummingbird) can scan distances of up to 49 m either side of a vessel (Kaeser et al. 2012), however coverage is influenced by topography and structures that throw 'sonar shadows'. Side-scan images may be viewed in real time, as well as recording for later post-processing.

Recommended boat speeds for recording vegetation by sonar are typically stated as between 3.7- 11 kph (Sabol et al. 2012).
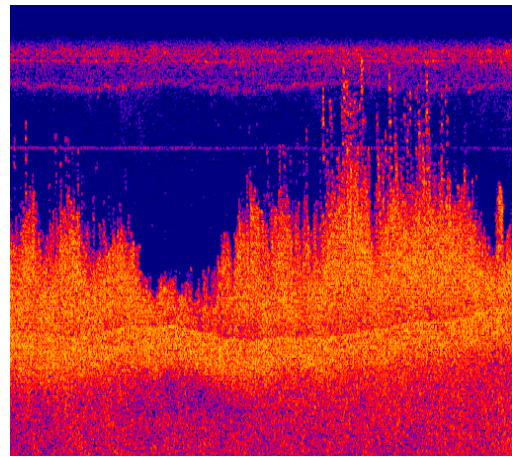
Figure 6: **Images of a Lowrance unit and examples of down-scan (top right & bottom right) and side scan (bottom left) output.**

2.3.3 Underwater video

Underwater video used for surveillance is the deployment of a camera within selected areas for surveillance (Figure 7). This can involve real-time viewing, with any sightings subsequently marked (GPS or buoys). If post-processed, time/GIS information linked to footage would be needed to determine the location of any suspicious sightings. An advantage of underwater video is that it avoids restrictions and costs of diver time.

Video surveillance methods have similar constraints to in-water visual detection methods such as water clarity and distance to target for recognition (see Section 2.2, In-water visual methods). However, video cameras have a more limited field of view than human vision (Tessier et al. 2005), unless synchronised and merged into single wide-angled video such as described by Assis et al. 2013). Comparisons with visual surveys showed wide-angle video footage even in a static situation was of lower resolution and had problems of low contrast imagery under extreme visibility (both low and high visibility) conditions (Assis et al. 2013). Comparisons of high-definition video transects with diver observations over the same area showed video detected significantly fewer (77% to 85%) of the species obtained in the visual census (Pelletier et al. 2011). Similarly, a visual method was found to be more accurate than video for determining species richness (Tessier et al. 2005). These limitations suggest video is of lower accuracy for detecting submerged weeds at low occurrence situations for early weed invasions than in-water visual surveillance methods.

In a recent review of underwater video techniques, Mallet and Pelletie (2014) reported speeds for towed camera systems of 0.93 to 3.6 kph, although some reviewed techniques were for the capture of still images. Kenworthy et al. 2012 found the maximum forward speed without blurred (recorded still) images was between 0.93 and 1.85 kph, while Lefebvre et al. (2009) reviewing footage at half-speed, or paused and still reported blurring at speeds above 3.7 kph.

Figure 7: A drop camera deployed for underwater video imagery, and screen viewed results showing a graduated 'T-bar' on the screen deployed to measure field of view.

2.3.4   Satellite and aerial image analysis

Images of the earth and water surface captured from satellite or aerial images have greatly expanded opportunities for data integration, analysis, modelling and map production for environment monitoring and assessment. Using remote sensing to map aquatic vegetation can overcome problems associated with access, scale and distribution, although it requires high-resolution images that have appropriate spectral characteristics (Ashraf et al. 2010).

However, use of these remote sensing techniques to detect low incidence invasive aquatic plants has been limited (but see Underwood et al. 2006, Hestir et al. 2008, Gidley 2009). This may be because the accurate detection of submerged vegetation using remote sensing imagery is also influenced by the depth of plant growth, water quality including turbidity, changes in sun angles, and local weather conditions (Underwood et al. 2006).

Spectrometry studies rarely map to the species level for submerged plants (Gidley et al. 2010). For instance, Gidley (2009) found no discernible spectral difference between two of the major types of submerged vegetation in the study area, while Hestir et al. (2008) concluded there was 'extensive variation resulting from the many confounding factors' and 'we have not yet demonstrated that the subtle spectral differences between submerged aquatic vegetation species are consistently detectable'.

Resolution is another limitation to the use of this technology for detecting low incidence submerged weeds. For example a high spatial resolution in space borne or aerial imagery is considered to be only 2.5-5 m (Gidley, 2009; Underwood et al. 2006). The resolution of images at this level does not allow for the consistent detection of an invasive plant to a species level from within a water body due the plants size and low occurrence (Gidley, 2009; Hestir et al. 2008). Previous studies using high resolution images (e.g., Quickbird) have concluded that a sudden spread of the invasive species within the lake could go unnoticed without field data (Gidley, 2009).

2.3.5   eDNA based technology

Recent advances in DNA based technologies have generated much interest into the possible use of environmental DNA (eDNA) for the identification and detection of invasive species in aquatic ecosystems such as lakes.

Environmental DNA methodologies are based on the principle that all aquatic species release genetic material (eDNA) into the environment such as through faeces, urine, scraped-off tissue cells, fish slime, eggs or lavae, and from cells released from death or decay. In brief, methods then rely on trace amounts of these suspended eDNA fragments being collected from within water samples, extracted, then amplified to identify a specific organism.

Methodologies using eDNA promise a number of advantages over traditional monitoring methods for invasive species management. Because traditional monitoring methods are often reliant on intensive and time consuming visual surveys, DNA-based methods can offer enhanced detection sensitivity, reduced turn-around times and monitoring costs and increased specificity of target identifications (Darling and Mahon, 2011). However despite the promises of DNA-based monitoring methods, the development of these tools remains challenging. For example, eDNA based methods would need to be able to recognise the presence of a species even when it exists at very low population densities (Jerde et al. 2011), to be useful for invasive species management. In water this would be even more challenging as eDNA is diluted and can be distributed by currents and other hydrological processes

over time and depending on environmental conditions has been found to last only 7-21 days (Dejean et al. 2011). This would mean that a positive result could indicate that the target species was in the area recently. However a negative result would not necessarily mean that no target organisms were present in the area being sampled, but only that that no eDNA was found from within the water sample.

While there is much in the literature focusing on the development of eDNA detection methods (Darling and Blum 2007) for aquatic organisms, no methods were found looking at the detection of submerged aquatic plants. The closest example was that developed for the detection of *Didymosphenia geminate* (Didymo), a microscopic alga of current biosecurity interest in New Zealand. This DNA-based method (Cary et al. 2007) relies on the cells shed by Didymo being collected and extracted from within the flowing waters in which it grows.

Other current eDNA-based methodologies have focused on organisms such as fish, mussels, algae and crabs that also all produce and excrete waste products into the environment allowing for easier detection of eDNA. As plants do not deposit scales, skin, urine, faeces or shed cells that are readily available in the water column, it seems unlikely that any protocols for the detection of invasive plants will become available in the near future.

3   Bay of Plenty Regional Council surveillance practices

This section reviews current BOPRC aquatic weed surveillance practices and documents the sources of developed protocols and procedures where possible.

3.1   Regional Pest Management Plan

Amongst responsibilities to manage natural ecosystems such as lakes and rivers, the BOPRC manage pest plants in the region under the Regional Pest Management Plan (RPMP) (BOPRC 2011a).

Included in the RPMP are three submerged aquatic weeds (Table 1) that are managed under the rules for containment pest plants, specifically; Section D (3): 'Landowners and occupiers must destroy *Egeria densa*, lagarosiphon and hornwort in all areas defined in Figure 3' (these areas listed in Table 1). The RPMP also states 'the Crown (or Crown Agent) is responsible for managing aquatic pests in the Rotorua Te Arawa Lakes, through the Te Arawa Lakes Deed of Settlement (except in Lake Rotokakahi and Lake Ōkaro). In the event of a new incursion, an incursion response plan is developed by Council in consultation with Te Arawa Lakes Trust and Land Information New Zealand, or the lake owners (Lakes Rotokakahi and Ōkaro).

BOPRC developed an annual Operational Plan (BOPRC 2011b) for implementing the RPMP which sets out the extent of monitoring and surveillance and budget for each pest. For submerged weeds BOPRC proactively monitors selected lakes/high risk areas (Table 1) for new infestations and follows up on all reports of new infestations. Selected lakes/high risk areas (Table 1) are inspected twice per year as part of the macrophyte surveillance programme. BOPRC also 'proactively pursue improved or alternative control technology by sharing information with other agencies.'

Table 1:   Lakes indicated in BOPRC RPMP in which nominated species must be destroyed.

Lake	Hornwort (*Ceratophyllum demersum*)	Egeria (*Egeria densa*)	Lagarosiphon (*Lagarosiphon major*)
Rotoma	✓	✓	
Ōkāreka	✓		
Tikitapu	✓	✓	
Rotokakahi	✓	✓	✓
Rerewhakaaitu	✓		
Rotoehu		✓	
Ōkataina		✓	
Rotomahana			✓
Ōkaro	✓	✓	✓

3.2   Current practices

In 2006 BOPRC contracted NIWA to trial a surveillance programme for aquatic weeds as part of the proposed Rotorua Te Arawa Lakes Aquatic Pest Operational Strategy. This involved a method to prioritise lakes for surveillance, identify the level of weed threat posed and the design of a programme which would maximise the probability of detecting new weed incursions at a very early stage (Champion et al. 2006).

For the six highest priority lakes, high public use areas where the likelihood of weed introduction and establishment was considered greatest were identified by staff of NIWA, EBOP, the Rotorua Harbourmaster, and Fish and Game using maps and aerial photographs. Shore wave fetch maps were also used to rule out less likely establishment areas. Areas targeted for surveillance were described and plotted on maps of the lake as future resources (Champion et al. 2006).

Search techniques trialled by NIWA at the selected lake sites included; a series of dives parallel to the shore at depths where weed colonisation was likely, manta board tows over larger areas, remote sensing with sonar to detect any tall vegetation and shoreline checks for plant fragments (Champion et al. 2006). However, no recommendations were made on site suitability of surveillance techniques at that time.

BOPRC have carried out monitoring and surveillance for aquatic weeds at eight Rotorua Te Arawa lakes since 2005 (Kelly 2013). The annual Operational Plan for implementing the RPMP sets out the extent of monitoring and surveillance (BOP 2011).

The RPMP lists lakes Rotoma, Ōkāreka, Tikitapu, Rotokakahi, Rerewhakaaitu, Rotoehu, Ōkataina, Rotomahana and Ōkaro. As well as goals of early detection of new weeds, information from surveillance activities is also used to inform LINZ in regards to key priorities for annual aquatic weed control at sites with a biosecurity focus (Kelly 2013). One element of BOPRC's recommendations is provision of defoliating herbicide treatments to improve target weed detection at incursion sites (Champion 2009).

BOPRC's monitoring and surveillance programme and methods were reviewed by NIWA in 2009 (Champion 2009). This assessment found that prioritisation of lakes and sites are undertaken using appropriate parameters, with site rankings used as a decision–support method to allocate resources.

Surveillance of the Rotorua Te Arawa Lakes occurs twice annually; February/March and October/November. BOPRC divers 'complete approximately four weeks' worth of diving each monitoring period. This is a team of core divers who are familiar with the sites and monitoring techniques. The lakes and sites identified in Champion (2006) are consistently monitored. Access to Lake Rotokakahi has been restricted, which has prevented monitoring in this lake. If resources become limited, sites are revised with priority going to sites of importance. If the opportunity arises (weather, time, budgets) BOPRC divers will extend search areas of sites in cases where it is believed valuable to do so. For example, lakes Ōkataina and Ōkāreka have had new sites added on account of the delimitation responses for hornwort.

Surveillance methods include manta board, scooter, scuba and snorkelling. Generally, the same dive methods are used at the same sites, but are changed to match ambient water clarity conditions or weather conditions at the time of survey. Usually, for large bays and good visibility (>5m) sites, divers will use manta boards and scooters. BOPRC utilize manta boards that have a 20 m tow line, and tow at speeds of 2.8 to 3.3 kph. Where visibility is low (<2m) scuba is used (e.g., weed cordons). Where sites are shallow and/or a lot of surface reaching weed is present, snorkel is used for minimum disturbance and manoeuvrability through the weed (e.g., raupo margins). It is important that divers are flexible and confident with all monitoring methods.

For incursion delimitation, the sites are determined from previous surveillance efforts where target weeds have been recorded. New sites are checked on a reactive basis (where new incursions are reported). Surveillance efforts are intensified for new incursions with extra resources to allow for searches over a greater area. In Lake Ōkāreka, following the discovery of hornwort in 2012 a full delimitation survey was carried out and annual monitoring has increased.

4 Testing and validation of methods

A focus for this report was to trial new and existing surveillance techniques and methods capable of detecting new invasive weed species of concern in the Rotorua Te Arawa Lakes. The most feasible methods from our review (see Section 2, Review of surveillance methods), which included current surveillance practices used by BOPRC staff, were tested in trials. Field work was focused in Lake Ōkāreka which has experienced recent issues with hornwort detection and used surrogates for aquatic weeds as the detection target.

4.1 Methods

4.1.1 Determining detection distances

A relationship between Secchi Disc depth and the maximum distance of recognition of surrogates was investigated in nine Bay of Plenty lakes. Totara branches (c. 0.5 m x 0.4 m) were used as surrogates (Figure 8). Secchi depth was measured with a 20 cm (n = 1-3). From the boat, weighted surrogates were lowered from the surface to the deepest depth they could be recognised by the observer before the loss of detail on leaves and branches that identified them (n = 1-4 observers).

Figure 8: **A simple surrogate was used to estimate detection distances** in a range of lake water clarities, and compared with Secchi disc depths.

In-water detection distances were tested in Lake Ōkāreka using eleven divers in April 2014. Two sizes of surrogates were tested; a single branch (small), and three branches together (large) placed at 2.5m depth. For each surrogate size, a separate approach line led divers on a horizontal direction towards the surrogates. When the surrogate was recognised, the divers raised a taunt tape measure to their mask to measure visual distance from the target (Figure 9).

Figure 9: A diver measures in-water distances from which a surrogate was recognised.

4.1.2 Performance of surveillance methods

Trials to determine the performance and time-taken by different surveillance methods (Table 2) were carried out in Lake Ōkāreka. Trials 1-4 were completed in April 2014, with Trials 5 and 6 in September 2014. Trials were undertaken in three areas of Lake Ōkāreka (Figure 10).

Table 2: **Surveillance methods tested in each trial** with depth and black disc noted.

Trial	Depth range (m)	Black disc (m)	Diver methods					Remote methods	
			Snorkel tow	Snorkel	Manta board tow	Scooter with scuba	Scuba	Side-scan sonar	Drop camera
1	2 - 3.5	4.42	✓	✓		✓	✓	✓	
2	2 - 3.5	4.42	✓	✓		✓	✓	✓	
3	4 - 5.5	4.3			✓	✓	✓	✓	
4	2 - 3.5	4.7	✓	✓✓			✓	✓	
5	2 - 3.5	-		✓				✓	✓
6	4 - 5.5	6.5					✓	✓	✓

Trials 1, 2 and 5 were undertaken in the large shallow bay, south-east of Taumaihi Point. The trial area was 2 to 3.5 m depth, within weed beds that are dominated by *Lagarosiphon major*. Trials 3 and 6 were undertaken in 4 to 5.5 m depth on the western shore of Taumaihi Point. This deeper vegetation comprised a mixture of pondweeds and charophytes. Trial 4 was undertaken within the boat cordon area adjacent to Acacia Road, in an area maintained for a low background vegetation by periodic diquat herbicide treatments with a prior treatment in December 2013. At the time of the trial, this area was partially bare of vegetation, but had some patches of native pondweed and low growing charophytes.
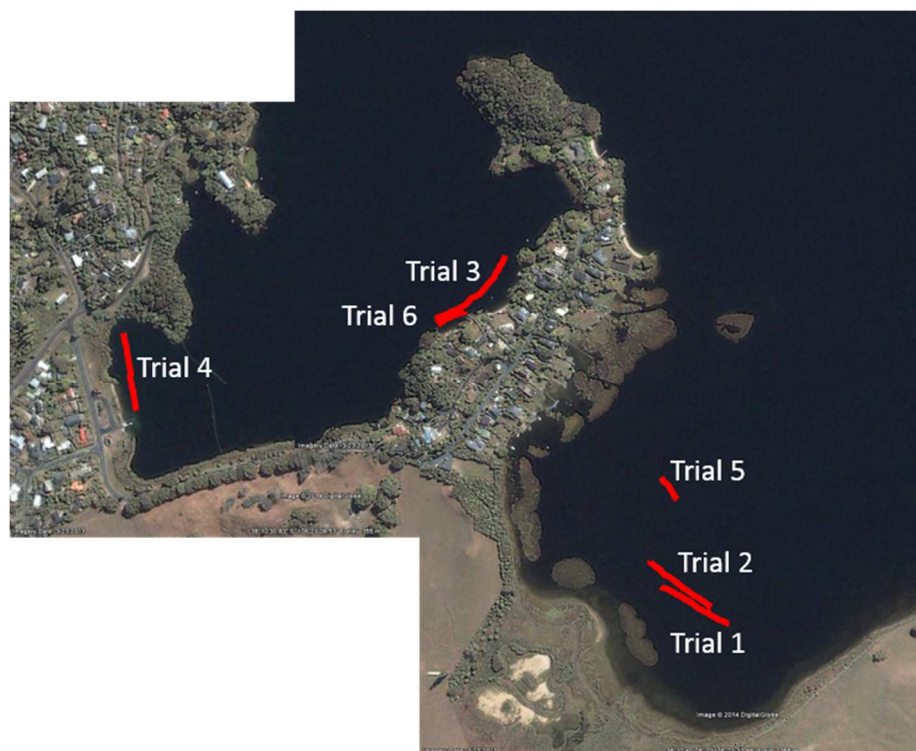

Figure 10: Location of trial sites in the south-west of Lake Ōkāreka.

A pool of 12 NIWA and BOPRC divers were utilised in the trials, with a minimum dive qualification of Department of Labour 'scientific diver'. Five in-water surveillance methods were trialled (Table 2). A snorkel tow line of 15.2 m length and BOPRC manta boards with a 20 m tow line for all trials. The Seadoo RS1 and Halcyon HDV-14 scooter models were used for these trials. Totara branches were used as surrogates for aquatic weeds (Figure 11).

Trials 1-4 involved the placement of surrogates within 2 m distance either side of a 100 m long transect line (Figure 12). Divers moved along the transect line in one direction, using each diver method once and counting all surrogates they saw. Each diver and method was timed (±1 second) and the number of surrogates seen recorded. Methods were carried out in the same order by each diver in each trial. Remote methods (Table 2) could not be tested and analysed in the same way but a general comparison was made. Trials 5 and 6 that tested a drop camera, involved a 30 m transect line and the random placement of 10 surrogates within 2 m distance of the line. This transect line was shorter than the other trials due to the difficulty of vessel navigation at the slow speeds required for operation of the drop camera.

In Trial 1, the size/detectability of surrogates was tested by positioning them at different heights relative to the canopy of the background vegetation (Figure 12). The 100 m transect line was divided

Early detection using surveillance for aquatic weeds

into three equal sections, with surrogates positioned below the canopy in the first section, at canopy height in the second section, and protruding above the canopy in the third section. Divers recorded the number of surrogates detected in each section, but their times were measured only over the full 100 m transect line.

Figure 11: **Totara branches (c. 1 m tall) were surrogates for aquatic weed species (e.g., hornwort, Egeria)** due to their comparative, yet distinctive, foliage colour and architecture.

In Trial 2 and 3, 20 surrogates were randomly positioned at the canopy height of background vegetation (Figure 12). In Trial 3 the transect line and surrogates followed the contour of the outer depth limit of vegetation (Figure 12). These two trials differed in depth of water, so snorkel methods in Trial 2 were substituted by manta board tows in Trial 3 (Table 2). In Trial 4, 23 surrogates were randomly positioned at the equivalent height of the canopy in the tallest background vegetation along the transect line.

The time taken by divers for each method was analysed for each trial by ANOVA in GenStat 17 with diver as a blocking effect. Differences in times between methods were identified by least significant difference (LSD).

Surrogate number detected was expressed as a proportion of the total placed in each trial. For each trial, the proportion detected by method was analysed as a Generalised Linear Mixed Model (GLMM, c.f. Schall 1991) in GenStat 17 with a logit link and binomial distribution and diver as a random effect.

For Trial 1, the proportion detected in each category of canopy height was transformed (arcsine square root) and analysed by ANOVA in GenStat 17 with diver as a blocking effect. Differences between detection by surrogate height and methods were identified by least significant difference (LSD). Untransformed data was also analysed as a GLMM with a logit link and diver as a random effect and diver differences were identified.

To test the ability of side-scan sonar to detect surrogates in Trials 1-4, a Lowrance™ HDS9 depth sounder/GPS/chart plotter was used with a LSS-2 HD transducer. Position was logged using the point 1 antenna. Two vessel runs were made as close as possible over the top of the 100 m line in each trial. Vessel runs were in the same direction as the divers, at an average boat speed of 5-6 km per hour (kph). 'Structure scan' (455 kHz) side-scan sonar traces were the focus of this test, however, standard, down-looking traces (200 kHz) and 'Structure scan' down-looking traces (455 kHz) were also recorded.

For trials 5 and 6, a drop camera (Deep Blue Pro Splash Cam) and 19 inch Sharp LCD colour monitor (see Appendix A for specifications) were tested and compared to snorkel or scuba, and sonar (Table 2). This camera/monitor combination had an immersed, horizontal field of view of 56°, i.e., a horizontal width of view of approximately 1 m when the camera was at 1.07 m distance from the bottom. Pre-trial tow speeds for the cable-mounted camera showed camera shake occurred at very low speeds (i.e., couldn't be done), therefore the camera was mounted on a 2.5 m long pole that was manoeuvred manually during the trials. The vessel was navigated as directly as possible over the 30 m long transect line. Surrogates detected were counted on the monitor mounted in the boat, while the time to traverse the transect line was recorded.

Trial 1 – Weed detection height
10 surrogates randomly placed within each height section.

33.3 m   33.3 m   33.3 m

Below canopy   At canopy   Above canopy

2 m   2 m
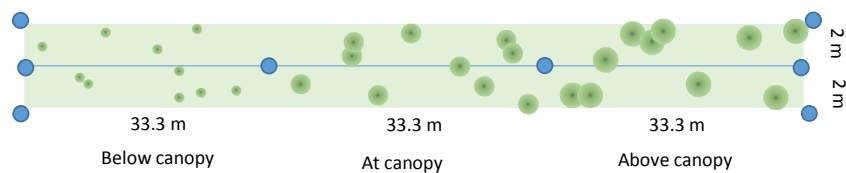
Trial 2 – Weed detection number
20 surrogates randomly placed throughout 100 m distance

100 m

2 m   2 m
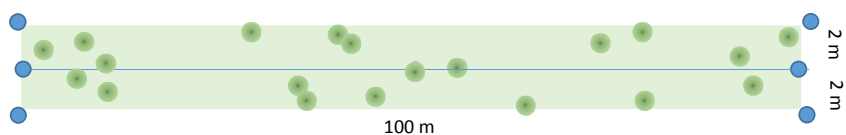
Trial 3 – Weed detection at depth
20 surrogates randomly placed throughout 100 m distance at 4.5. to 5.5 m depth

Deeper edge of vegetation   100 m

2 m   2 m
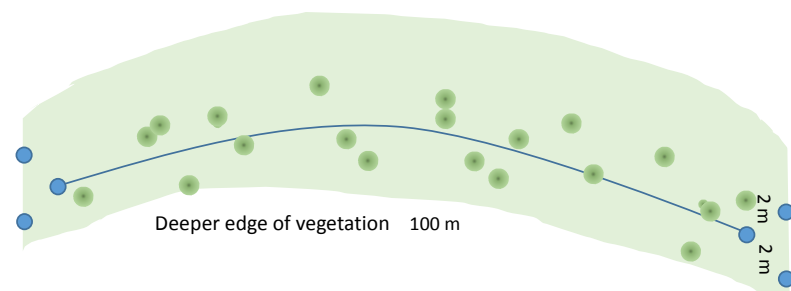
Trial 4 – Weed detection in sprayed area
23 surrogates randomly placed throughout 100 m distance

100 m

2 m   2 m
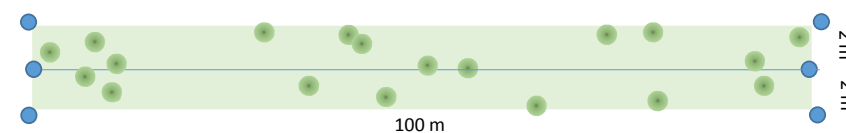
Trial 5 – Drop camera comparison
10 surrogates randomly placed throughout 30 m distance

30 m

2 m   2 m
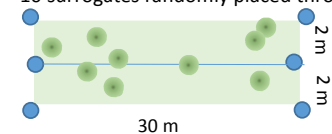
Trial 6 – Drop camera comparison
10 surrogates randomly placed throughout 30 m distance

30 m

Deeper edge of vegetation

2 m   2 m

Legend:
- Buoys for marking lines
- Transect line
- Surrogates
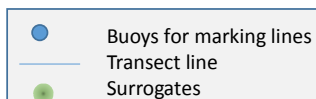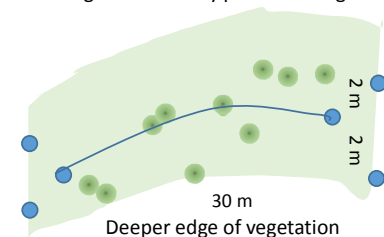
Figure 12: **Pictorial representation of Trials 1-4.**

4.2 Results

4.2.1 Determining detection distances

There was a relationship between Secchi depth and depth to which a surrogate could be lowered to and still recognised (Figure 13). The best line fit appeared to be a power curve (r^2 = 0.93) suggesting that surrogate detection distances are little more than half of Secchi disk measurements at a site. The maximum distance for detection was in highly transparent waters but this increasingly attenuated at higher clarities.
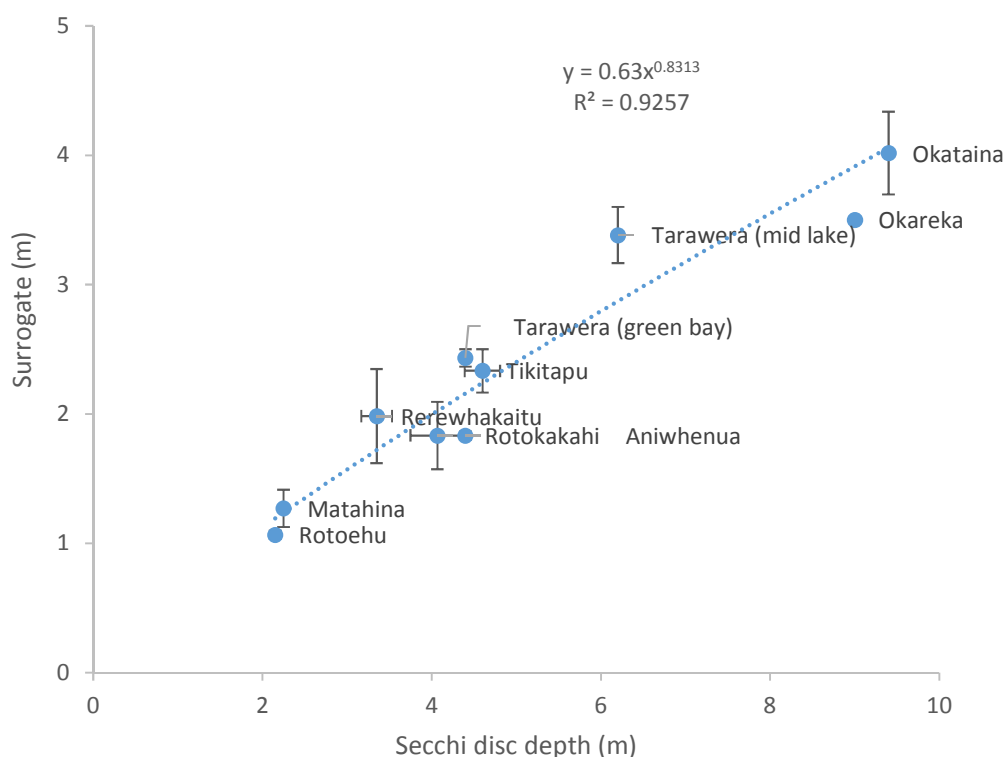
Figure 13: **Relationship between Secchi depth and depth allowing recognition of aquatic weed surrogates from above the water surface in nine Bay of Plenty lakes.**

The in-water test of detection distances by divers established that surrogates could be recognised in Lake Ōkāreka at an average distance of 2.5 m (±0.14 SE, n = 23 observations). Paired t-tests established there was no difference in diver measurements for large and small surrogates (df = 10, P = 0.6271).

4.2.2 Performance of Surveillance methods

The time taken for divers to complete the different surveillance methods over a 100 m distance differed significantly (Table 3, Figure 14). Snorkel tow was the fastest method in Trials 1, 2 and 4, with times that were 3 to 4 times faster than scuba diving alone. Snorkel and use of a scooter with scuba were intermediate in speed, however, in the trials where both methods were used, the speed of these two methods did not differ significantly (Table 3). Although our experimental design precluded statistical comparisons between trials, with the exception of Trial 3, there was close agreement in the recorded speeds for the different methods (Figure 14). In the deeper Trial 3 (4.5 - 5

m depth) times were slower and more variable as the measurements included the ascent time of the diver from the bottom. In Trial 3 manta board tows were 3 times faster than scuba diving.

Table 3: Mean time (seconds) taken for each surveillance method over a 100 m distance and standard error of the difference between the mean (sed). Different superscript letters indicate statistically significant differences between the methods (Anova and LSD, p < 0.05, n = 10 – 12).

Trial	Surveillance method					sed
	Manta board tow	Snorkel tow	Snorkel	Scooter with scuba	Scuba	
1		69[a]	200[b]	190[b]	279[c]	8.1
2		73[a]	192[b]	196[b]	268[c]	9.1
3	116[a]			290[b]	373[c]	19.2
4		80[a]	192[b]		275[c]	4.7
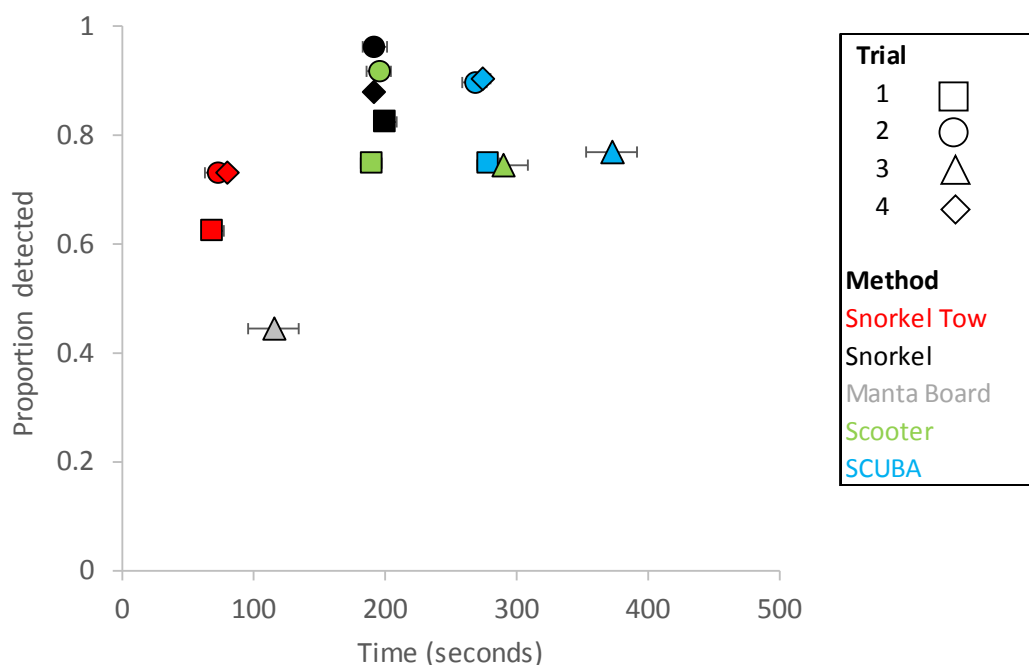
Figure 14: Predicted means (GLMM) for proportion of surrogates that were detected by each method in each trial, plotted against the time (±1 sed) taken to detect them (n = 10-12).

Total detection accuracy for surrogates differed significantly (anova, p < 0 .001) between the surveillance methods within each trial (Table 4, Figure 14,) when diver differences were removed as a random source of variation. Snorkel was the best detection method for Trials 1, 2 and 4 (LSD, p < 0.05), which were carried out in shallow depths of 2 – 3.5 m depth. Although divers embarked on the snorkel method for the deeper Trial 3, only 1 out of 5 divers could discern any surrogates through ≥4.5 m of water, therefore this method was abandoned. Instead, the best method at depth was, jointly, scuba and scooter with scuba (Table 4). The small differences in detection accuracy between snorkel and scooter in Trials 1 and 2 reflected that more individual divers performed better on snorkel (10 and 7 divers respectively), or equally well (5 divers in Trial 2), with only 2 divers performing better on scooter (Trial 1).

Table 4:   Predicted means (GLMM) for proportion of surrogates detected per method in each trial. Different superscript letters indicate statistically significant differences between the methods within each trial (p < 0.05, n = 10 – 12).

Trial	Surveillance method				
	Manta board tow	Snorkel tow	Snorkel	Scooter with scuba	Scuba
1		0.623[c]	0.824[a]	0.746[b]	0.746[b]
2		0.729[c]	0.963[a]	0.917[b]	0.896[b]
3	0.4435[b]			0.743[a]	0.768[a]
4		0.730[b]	0.877[a]		0.903[a]

See Appendix B for raw analysis results (Logit data).

Surveillance methods used in Trials 1, 2 and 4 had similar patterns of detection performance (Figure 14), although no statistical comparisons were made between trials. Trial 1 had the lowest detention accuracy, which may have been due to the challenge of observing the surrogates that had been placed below the canopy of the background vegetation. On the other hand, although Trial 4 had a much lower background vegetation, detection was not noticeably higher. The lowest detection accuracy was measured for the manta board tow, which also had the greatest variability in detections (data not shown).

For Trial 1, the height of the surrogates relative to the canopy of background vegetation significantly influenced detection (anova, p < 0.001), with differences in detection accuracy between all three heights (LSD, p < 0.05). Detection was lowest for those surrogates positioned below the canopy, while almost all surrogates that protruded above the canopy were counted (Table 5, Figure 15). The most effective detection method for this shallow water trial was snorkel, followed by scuba and scooter (Table 5).

Table 5:   Mean proportion of surrogates detected from three height categories per surveillance method in Trial 1.   Different superscript letters indicate statistically significant differences between the methods within each trial (Anova and LSD, p < 0.05, n = 12).

Surrogate height	Snorkel tow	Snorkel	Scooter with scuba	Scuba
Below canopy	0.221[b]	0.534[a]	0.398[a]	0.457[a]
At canopy	0.686[c]	0.936[a]	0.854[b]	0.821[b]
Above canopy	0.960[a]	1[a]	0.984[a]	0.96[a]

See Appendix C for raw analysis results (arcsine square root transformed).
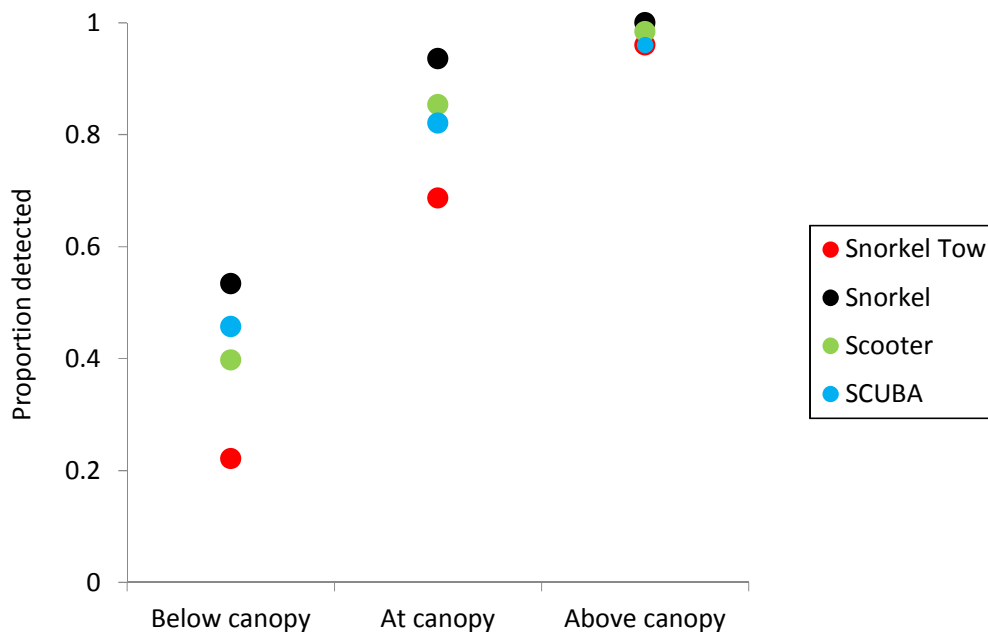
Figure 15: **Predicted means (GLMM) for proportion of surrogates detected from three height categories and surveillance method tested in Trial 1 (n = 12).**

Diver influence contributed little to the variation in time taken for the different surveillance methods, probably because of the number of methods with diver-independent propulsion (i.e., tows and scooters).

However, there was a significant diver effect detected for the proportion of surrogates detected. GLMM analysis (Appendix D) revealed a 7% difference in detection for divers across all surrogate heights and methods in Trial 1 (Figure 16). Similar patterns across divers were identified for overall proportion detected in all trials (Figure 17). Analysis (GLMM, Appendix D) revealed a 1% difference across divers in Trial 2, a 12-13% difference in Trials 1 and 4, and 27% in Trial 3 (deeper water). This higher diver difference of Trial 3 may reflect the greater difficulty of this course, set at depth.
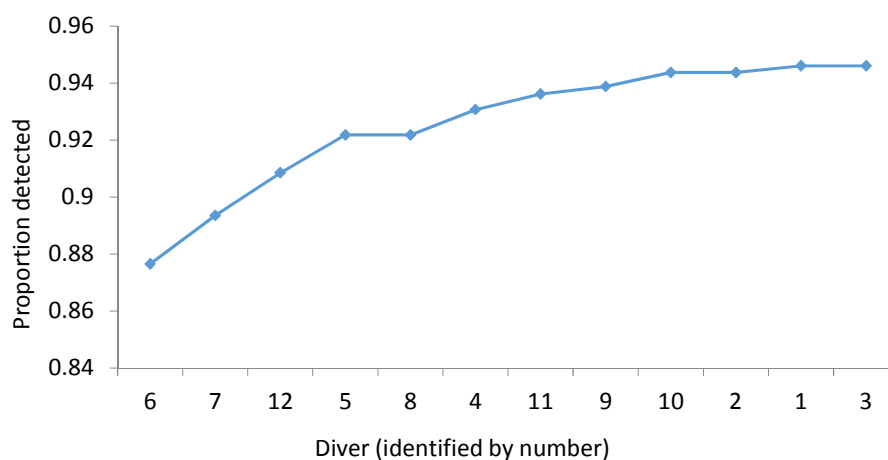
Figure 16: **Predicted means (GLMM) for proportion of surrogates detected by diver across all surrogate heights and methods in Trial 1 (n = 12).**
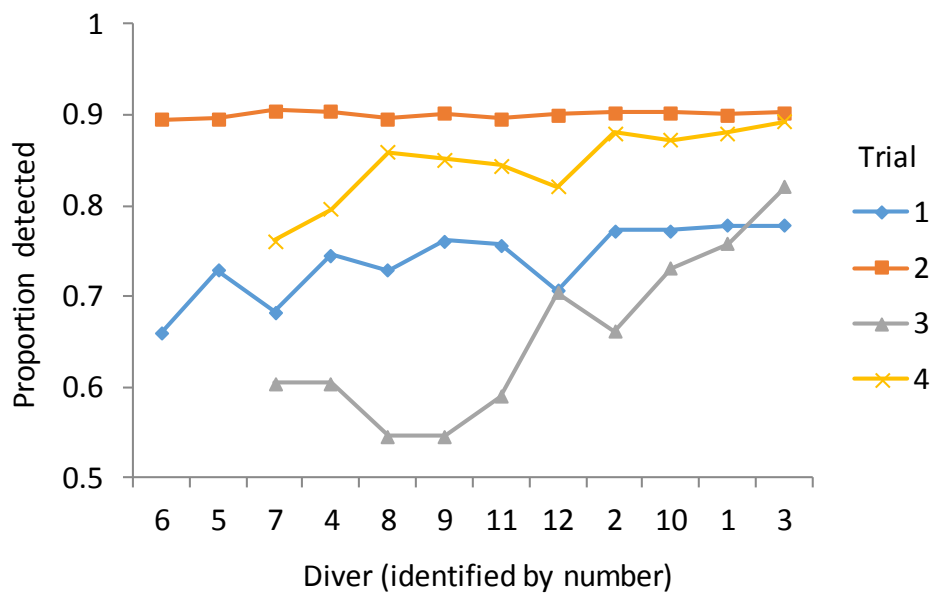
Figure 17: **Predicted means (GLMM) for proportion of surrogates detected by diver across all methods and Trials (n = 10- 12).**

Side-scan sonar could only discern surrogates in Trials 3 and 4 (Figure 18, Appendix E), and this required our prior knowledge of their position. No surrogates could be detected in Trials 1 and 2 (Appendix E), likely due to the density of background vegetation. Mean time to cover 100 m using sonar was 158 seconds (n = 8), faster than all methods but the diver tows.

Chart 157 side-scan example

Run parallel to shore with shallow side on left

Water depth under transducer was 2.6 to 3.1 m

High background vegetation

Plant growth through water column to surface will reflect (block) sound

'Dead zone' –if there is any missing data, it will be in the very narrow band directly beneath the transducer

Compression of near-field features (increases with width (depth) of the water column

Central area represents the water column, increases with depth

Objects directly beneath transducer appear as mirror images on either side

Individual totara branches clearly discerned only where no background vegetation

Low background vegetation

Direction of boat travel (red arrow)

Figure 18: Side-scan sonar image example from Trial 4, showing general features of side-scan images (left hand side) and interpreted features (right hand side).

Detection accuracy using the drop camera was lower than snorkel (shallow trial) or scuba (deeper trial), although the time calculated over a 100 m equivalent distance suggested this method was faster than all but diver tow methods.

Table 6: Mean proportion of surrogates detected and time (seconds over a 100 m distance equivalence) taken for each surveillance method by each method.

Trial	Drop camera	Time (seconds)	n =	Snorkel or scuba	Time (seconds)	n =
5	0.74	128.4	5	0.9	155.0	2
6	0.67	203.3	3	0.9	293.3	2

4.3 Discussion of trial results

There are relatively few published accounts that validate in-water, visual methods to detect aquatic invasive organisms, particularly for pests with a potential distribution over large spatial areas (but see Mooney et al. 2005, Kanary et al. 2010 and Issaris et al. 2012).

Mooney et al. (2005) used decoy targets to assess the ability of dive teams to detect small patches of *Caulerpa taxifolia* in a California lagoon. Patches of artificial *C. taxifolia* were placed at two sites with contrasting water clarity and two habitat types (one with background vegetation and the other without). Detection rates from divers during regular dive surveys were then used to quantify confidence placed in the surveillance efforts at each of the sites. Kanary et al. (2010) used 'decoy' balloons to represent tunicates and experiments were carried out in a North American estuary to estimate diver detection distances and false negative error rates (i.e., unsuccessful detection). Issaris et al. (2012) used diver transect lines and natural populations of an invasive mollusc and green seaweed in Greece to calculate the error in estimated species occupancy associated with individual observers and to calculate the increased accuracy from multiple observers.

Like our approach, investigators have sought firstly to identify detection distances over which divers could recognise the pest or surrogates. Similar to our surrogate detection distances of 2.5 m in Lake Ōkāreka, Kanary et al. (2010) found divers could recognise much smaller tunicate decoys (50-60 mm length) on artificial (mussel culture) structures over mean horizontal distances of 2.7 to 2.8 m distance at a Secchi depth of 2.75 m within a North American estuary.

Anderson (2005), Mooney et al. (2005), and Kanary et al. (2010) acknowledged water clarity was a likely restriction on detection distance for underwater targets, but did not explore any relationship between visual measures and target recognition. The relationship between Secchi disc depth and diver recognition of our surrogate suggests detection distances are much lower than Secchi disk measurements for a site and increasingly attenuate at higher clarities, so there is a maximum distance for detection in highly transparent waters. We note it is possible to recognise larger individual plants of *Lagarosiphon major* through a water depth of 5 to 6 m in exceptional water clarity in Lake Wanaka, (authors' observations), but this would represent the upper limits of detection depth for most New Zealand lakes.

Size of the target and the presence of background vegetation of similar spectral character may be additional factors influencing target detection. Kanary et al. (2010) discovered that larger patches of decoy tunicates were detected over single decoys. However, these factors may be more relevant in moderate water clarity conditions (0.5 – 1.0 m estimated visibility), while in very poor water clarity conditions (0.2 – 0.5 m estimated visibility) diver vision was already constrained to the immediate area only (Mooney et al. 2005).

Differences in detection with the height of our surrogates suggests weed growth over time will be a critical factor affecting detectability. Tests of three heights indicate plants need to be tall enough to equal, or exceed the canopy height of any background vegetation in order to have a high possibility of detection. Likewise, Anderson (2005) stated important questions for the surveillance of *C. taxifolia* as 'what is the minimum size a colony has to attain to assure it will be detected 100% of the time in a standard search effort', and 'how long does it take for the plant to reach a minimum threshold size for assure detection'.

We could find no other comparisons between the in-water diver methods we tested within the literature. However, after initial testing, Merkel et al. (2006) similarly concluded in-water, diver transect methods were superior search methods for delimitation to alternatives such as remote cameras.

In our shallow water trials, scuba and scuba with scooter detection accuracy performed more poorly than snorkel, possibly because the lower diver position within the water column meant they lost the 'birds eye' view they had from the surface. However, this advantage for snorkel was lost in deeper water and would be more limited in lower clarity conditions. We also noted that use of scooter or manta board can potentially partially obscure the field of view of divers and also distract the divers' eye from focussing in the middle distance where the target was to be found. This limitation may be partially related to diver methods of use (e.g., scooter position held by the diver) and might be reduced by different designs of manta board. There is no set design for manta boards and designs can be varied according to the requirements of the survey (Zimmerman and Burton 1994).

We recorded time as a proxy for effort or expense, and identified a 3.7 fold difference between the shallow water methods (snorkel, snorkel tow, scuba and scooter, scuba alone) and a 3.2 fold difference between the deep water methods (manta board, scuba alone and scuba and scooter). This suggests that frequency of application of some methods may be used to compensate for their lower detection accuracy. For example, the benefit of using a rapid method to cover a site on more than once occasion may increase detection potential beyond that of using a more effective detection method only once.

Similar to our trial, scuba diver proportional detection accuracy for alien tunicate surrogates in a North American estuary averaged over 0.79 to 0.94 (Kanary et al. 2010) compared to our results of 0.75 to 0.90 for scuba methods. The proportional detection accuracy for *C. taxifolia* surrogates (135 mm tall) along transect lines (1 m width) ranged from 0.51 to 0.87 across different sites, with most variation in detected proportions being attributed to water clarity (Mooney et al. 2005).

Issaris et al. (2012) found that targets identified in underwater visual surveys varied among observers from proportions of 0.70 to 0.96 and improved to 0.93 when calculated from multiple observers. In comparison, the largest range in detection proportion across our divers was 0.55 to 0.82 in Trial 3 and the smallest difference was 0.89 to 0.90 in Trial 2. This finding suggests that testing observer detection rates may be useful, or having a number of observers and varying observers across sites.

Confidence in surveillance efforts for detecting infestations of the seaweed *C. taxifolia* were tested by Mooney et al. (2004) and were seen as a critical element in the successful eradication response (Merkel et al. 2006). Merkel et al. (2006) estimated the certainty of a successful eradication of *C. taxifolia* by extrapolating from the worst detection performance from trials using surrogates and projecting detection and removal over successive surveys. They also factored in the time taken for the alien target to grow to a size where detection was likely.

Hayes et al. (2005) state that the probability a survey will detect the presence of a target species depends on: the number of targets present, the distribution of those individuals, the area or volume of the water body, the visual distance (water clarity) required for detection, the number of survey areas, and the design of the survey. Similarly modelling confirmed that detectability differs in relation to species abundance (Issaris et al. 2012).

Our trials provide likely detection rates over relatively small, representative areas of Lake Ōkāreka. We recognise that the detection of extremely low occurrences of weed species is very difficult and absence of evidence for presence cannot be taken as evidence of absence. Here, we have identified those methods that performed the best in different lake conditions to give the best chance of detection. Further consideration should be given to how this approach may be scaled up to whole of lake surveys.

5   Best practice guidelines

These guidelines provide an integrated approach to enable the early detection and delimitation of a newly introduced submerged weed in the Rotorua/Te Arawa Lakes, so as to allow a timely response to eradicate, contain or control the incursion. The recommended approaches are drawn from our review of potential methods (see Section 2, Review of surveillance methods), take into account the current methodologies used by BOPRC (see Section 3, Bay of Plenty Regional Council surveillance practices) and utilises information from investigations testing different in-water methodologies (see Section 4, Testing and validation of methods). All diving operations should adhere to agreed protocols and procedures required under Department of Labour regulations (OSH 2004).

Figure 19 provides an overview of the main steps involved in planning a surveillance program. The best practices identified below relate to 'surveillance for detection' and 'incursion response' steps.
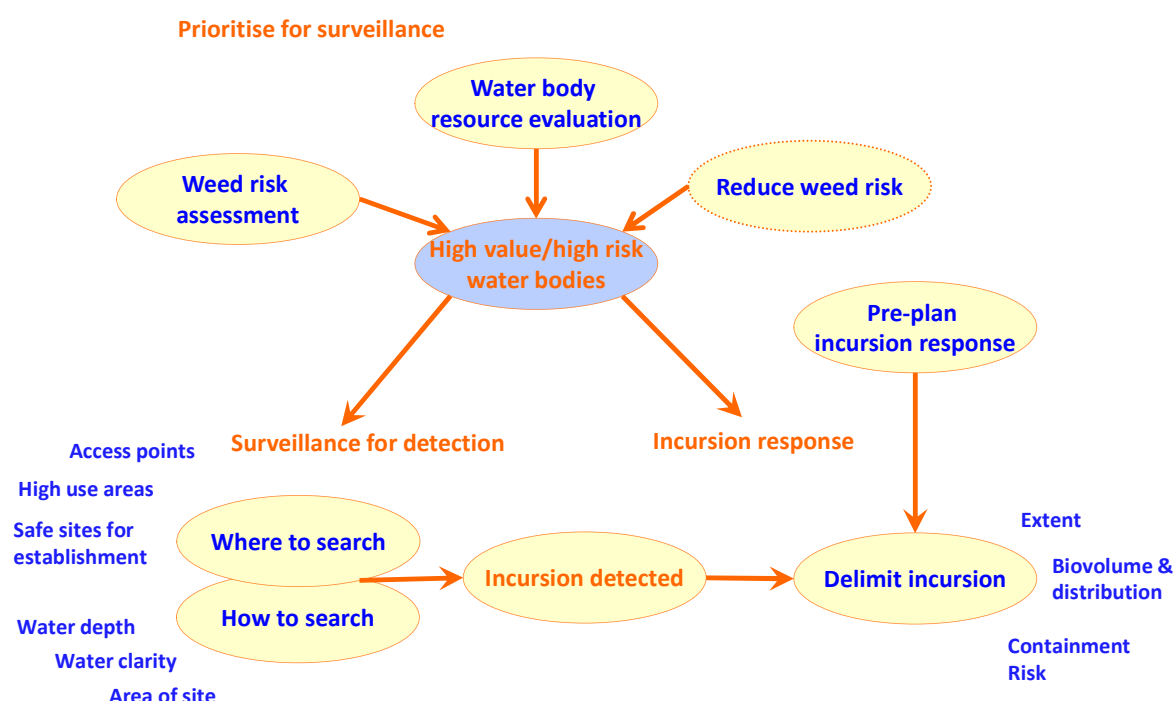
Figure 19:   Overview of surveillance planning from prioritising lakes and sites for surveillance to the information required to design a surveillance or delimitation for incursion response.

5.1   Surveillance methods for detection

The selection of methodologies at each site needs to consider:

- Water depth range for surveillance (species specific).

- Water clarity for visual detection distances.

- The area and configuration of each site.

- The frequency of surveillance.

- Herbicide clearance and defoliation.

5.1.1 Optimal species depth range

Table 7 provides an indication of the optimal establishment depth range for target species in the Rotorua Te Arawa Lakes.

Table 7: **Indication of optimum depth range for establishment of new incursions of three weeds under different trophic conditions in the Rotorua Te Arawa lakes.**

Species	Eutrophic	Mesotrophic	Oligotrophic
Lagarosiphon	2-4	1-5	1-6
Egeria	2-5	2-6	Not suitable
Hornwort	2-5	2-8	1 -12

5.1.2 Water clarity

Secchi disk depth is a routine water quality measure in lakes which may already be available to guide surveillance planning, or which can be measured prior to surveillance operations. Using the relationship between detection distance and Secchi disk depth established in section 4.1.1, we identify the types of in-water methods that are most appropriate. In Figure 20, the intersection of water depth and Secchi disk depth indicates the most appropriate method type.

Depth of detection from snorkelling at the water surface is also influenced by weed bed height within the 2-5m depth range. If weed beds form a canopy say a few m below the surface then snorkel use can be greatly extended in the search for an invasive species growing amongst vegetation. This would extend utility of snorkel search as shown by the hatched squares in Figure 20.
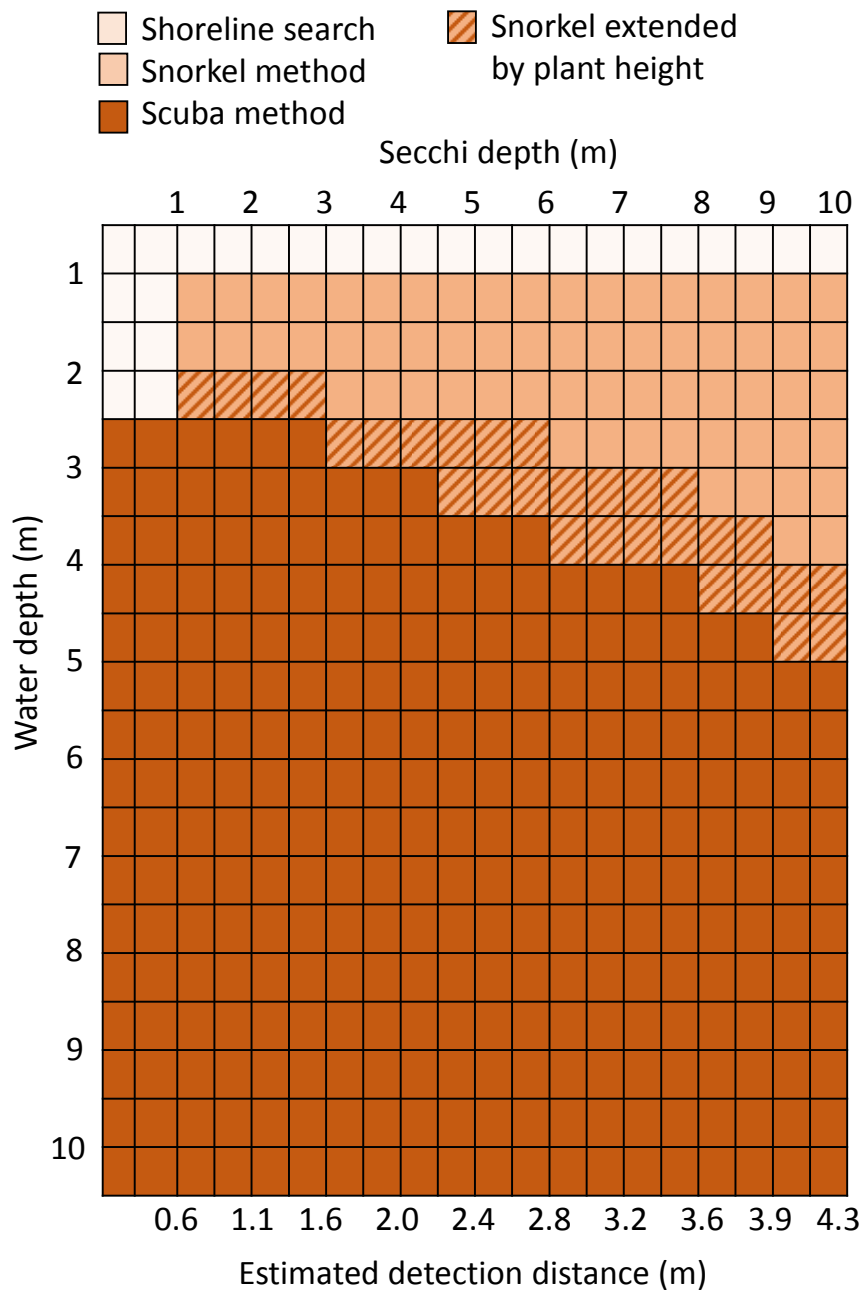
Figure 20: Selection of surveillance method type based on water depth and water clarity at surveillance sites.

5.1.3 Littoral width

The littoral area to be searched also needs to be considered based on field of view (water clarity) and the feasibility of coverage of the area in a practical time frame. We base the shift to more time-efficient methods (scooter or tows) on littoral width (assuming this the most important parameter for area configuration), and on the horizontal field of view (2 x detection distance calculated from Secchi disk depth). Another consideration is the safety of using a faster method under poor visibility. We consider two scenarios: 3 m depth of water and plants up to 1 m tall and 5 m depth of water with plants up to 1 m tall. In Figure 21 and Figure 22, the intersection of littoral width and Secchi disk depth indicates the most likely appropriate form of method for the two example water depths.
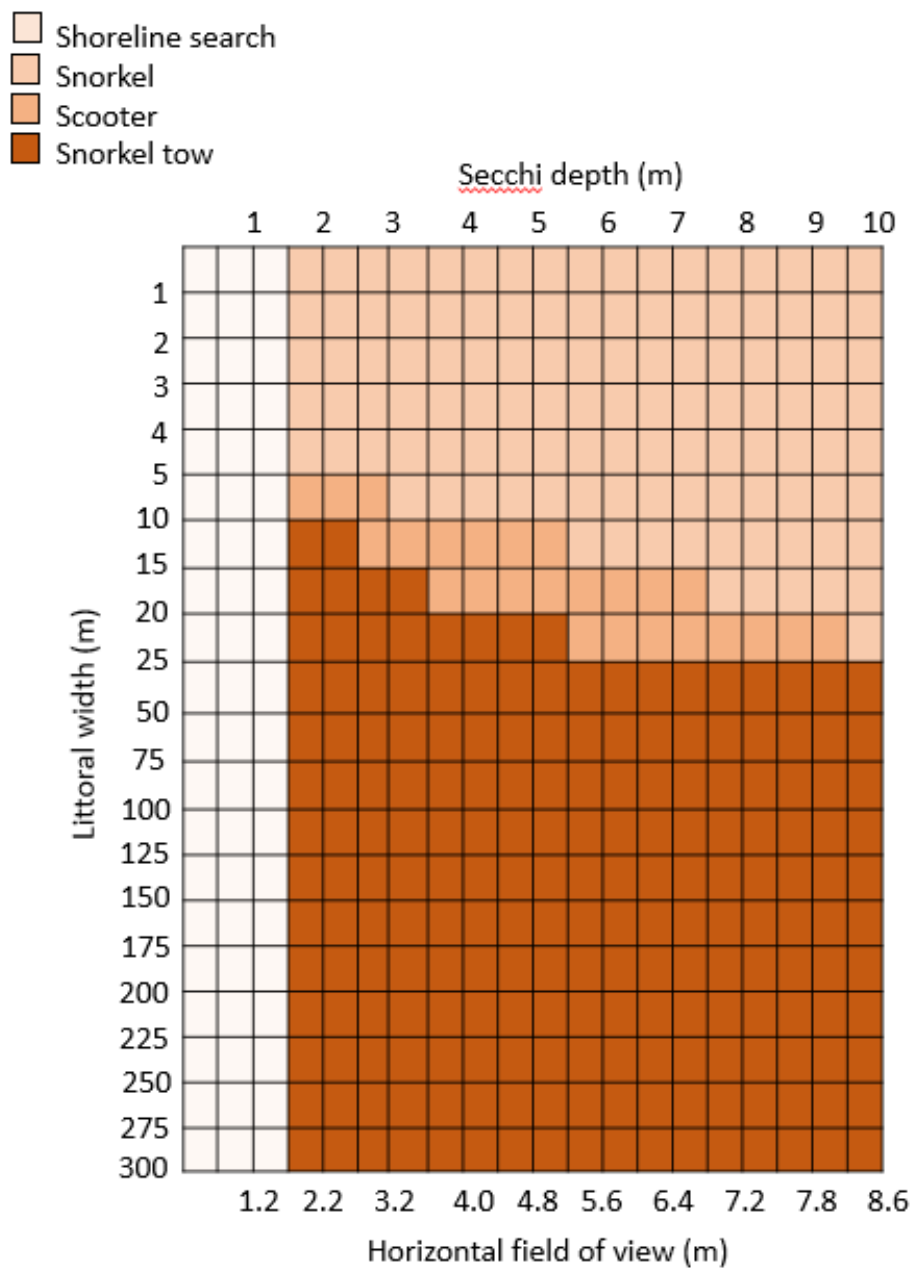
Figure 21:   Selection of surveillance method based on littoral width and water clarity in 3 m depth.
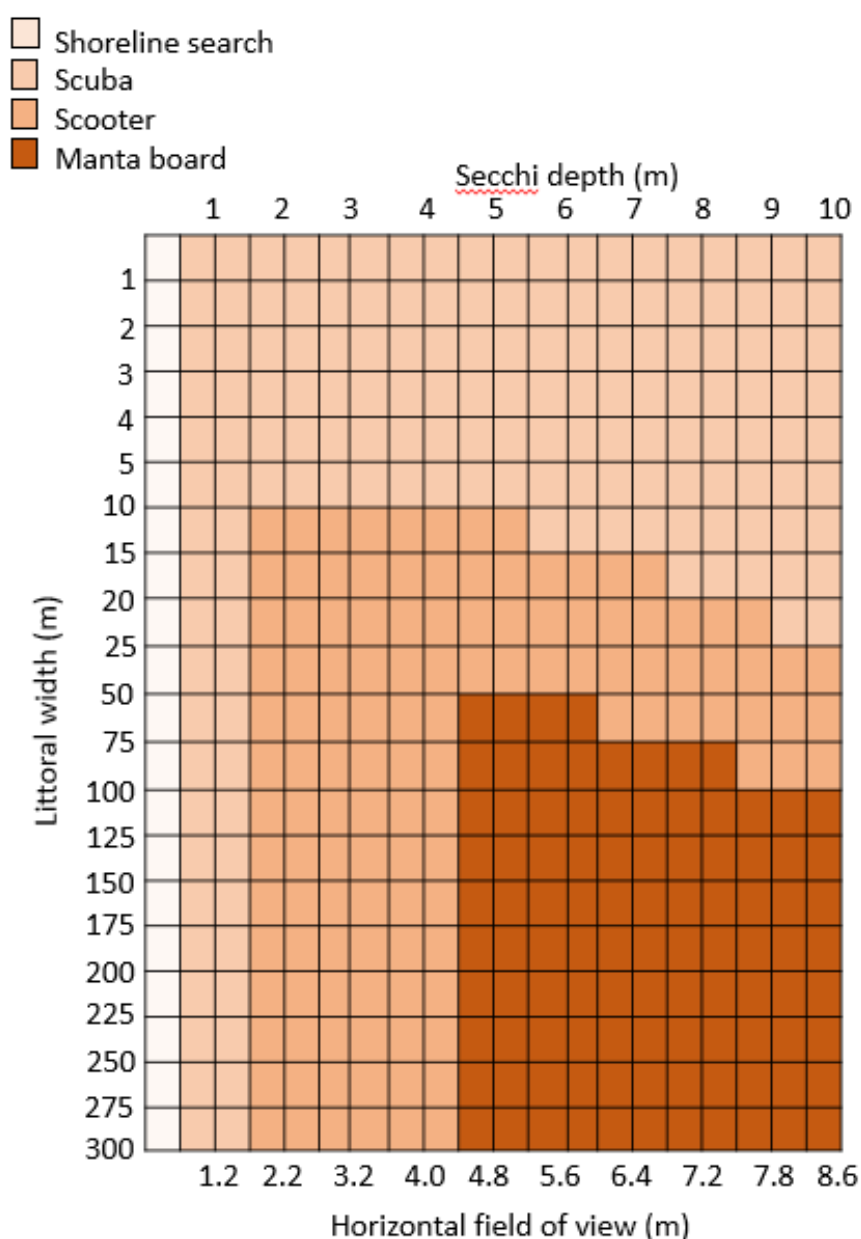
Figure 22: Selection of surveillance method based on littoral width and water clarity in 5 m depth.

For towing methods over large areas, GPS tracking of vessel trails together with depth sounding is an essential tool for navigating to achieve effective coverage at a site. Vessel runs should be parallel to shore and orientated for the greatest run distance before a turning manoeuvre is required.

We suggest the minimum water clarity for use of a manta board is equivalent to a 5 m Secchi disk depth (2 m for use of scooter). For faster coverage of large littoral areas, consideration should be given to towing dual divers on snorkel or with manta boards on scuba. If used, extra care should be taken with tight vessel manoeuvres, near obstacles and a dedicated observer on the vessel is an essential legal requirement.

5.1.4   Frequency of surveillance

Our trials clearly showed that height of the target plant is important with weed colonies becoming more detectable as they grow. However, as weed patches develop so does their potential to generate additional fragments for further spread. The frequency of surveillance should be considered for improving the chances of detection but also minimising the potential for spread. Here we consider the best frequency and timing for surveillance by factoring in likely plant growth in the Rotorua Te Arawa Lakes.

Previous growth trials for *Egeria densa* in Lake Tarawera over summer estimated an average of 3.5% per day growth (dry weight) for small (73 mm), viable shoot fragments that had rooted following 3 weeks of lower growth rates (NIWA unpublished data). If we assume height increase is proportional to dry weight accrual, a 2 m tall shoot could develop after 3.3 months in summer. Growth rates over winter would be significantly lower. Similar results were derived based on in situ growth trials using *Lagarosiphon major* in Lakes Rotorua and Taupo, where based on their respective measured growth rates 2 m tall shoots could develop after 3 - 4 months during summer (Rattray et al. 1994).

Based on the scenario above, it would be best to plan two surveillance operations per year timed for spring and late summer (c. 4 month summer interval). This provides two opportunities to detect a new colony during the critical growth phase. Increasing the frequency of surveillance can 'trade-off' somewhat against the need for complete coverage of an area by divers. It may be strategically beneficial to move to the more rapid methods of scooter or boat tows where the time savings allow for more frequent investigation of a site.

5.1.5   Herbicide clearance and defoliation

Diquat is the most cost-effective method for control of established or nuisance weed beds in the Rotorua Te Arawa Lakes. It has been used for over 50 years and one of the proven benefits is that native charophytes are not impaired and their abundance can considerably increase following control of the taller invasive weed species. When multiple invasive species have established in a lake (as for most of the Rotorua Lakes), it is common for an already established invasive weed species to provide a refuge for any new invasive submerged weed species. A potentially effective strategy for exposing a newly invasive weed species can be to treat an established weed bed with diquat so as to better expose potential habitat for any new invasive species. Removal of a weed bed canopy or partial defoliation of stems is possible with a low dose diquat treatment. Higher treatment rates or repetitive treatments can effectively 'reset the clock', resulting in native charophyte regeneration, greater native species diversity and improved habitat. Consequently, any potentially new invasive species can be more readily detected and removed than would otherwise be possible.

The above outcome has been effectively demonstrated in Lake Okataina were the majority of the northern shoreline (road access site) has been maintained in a native charophyte dominated condition for several years, through annual diquat treatment to control lagarosiphon and expose the presence of any recently invaded hornwort. A similar result has been achieved in Lake Okareka too where diquat treatment behind the cordon has largely eliminated any lagarosiphon and has made it much easier to survey for new invasive species such as hornwort. Furthermore, two bays in the north-western shore of Lake Okareka have reverted to predominantly native pondweed communities following diquat treatment during recent control of the new hornwort incursion in these bays. Although invasive species will regrow and displace the native milfoils, there is an opportunity through annual diquat treatment to rejuvenate native seed banks and strategically shift vegetation

dominance to a more enduring and desirable native condition as for regularly treated areas of Lake Okataina.

5.2   Targeted searches at sites

In addition to informed prioritisation of lakes and sites for surveillance as indicated in Champion et al. (2006), it is also possible to prioritise areas within sites to target searches in the most likely places for weed fragments to lodge and root. Areas or features to concentrate on are:

1. Species optimal depth range for establishment (see 5.1, Surveillance methods for detection).

2. Snags at the shoreline or in shallow water where weed fragments are likely to be intercepted or lodge (e.g., willows, reed beds, rocky promontories, fence lines, jetties).

3. High bed roughness or changes in roughness (e.g., variable sediment types, local depressions in substrates).

4. Bed topography, such as gradual slopes where fragments lodge with little further disturbance, and especially abrupt decreases in depth where a deposition zone develops.

5. Vegetation discontinuities, the maximum depth limit, abrupt changes in plant heights or cover and the edge of reed bed.

The design of targeted searches should be informed by lake bathymetry charts and if possible, by sonar survey of the sites of interest to establish spatial vegetation development and distribution patterns. Where lake water clarity is exceptional, satellite imagery from Google Earth has been effective for indicating background vegetation character and other features. Familiarity with sites should be built up over time and documented wherever possible.

5.3   Incursion delimitation methods

The purpose of surveillance for delimitation differs from surveillance for detection. The emphasis for delimitation is on determining the distribution and defining the edges of an infested site (i.e., GPS references). There is a need to document the nature of the infestation (weed covers, heights, biovolume) to inform control options and the feasibility of control outcomes. Also delimitation needs to determine containment risk accounting for proximity to boat ramps, jetties, access points and identify requirements for no-go zones for boats.

Delimitation surveillance needs to start at the known site of infestation and work outwards to establish if the initial detection point is a primary or a secondary incursion. It would be important to minimise the risk of inadvertent spread of weeds due to surveillance activities, therefore activities that may disturb the target weed and cause fragmentation should be carefully considered.

5.4   Diver training and experience level

Our trial results showed divers differ in their ability for target detection despite having similar qualifications. In our trials the target (totara branches) was familiar to all divers and they were introduced to the appearance of vegetation within the lake before trials began.

We recommend that divers used in surveillance operations are familiarised with the target species, in both diagnostic ID features and key characteristics of colonies and weed beds in the field. Divers should also be experienced with all forms of diver transport methods. For logistical reasons a common pool of trained/experienced divers should be used. Current eyesight tests and optical correction of any vision impairment is also important. To compensate for any diver differences in the field we suggest divers are rotated frequently and varied across the sites.

6 Recommendations

Our best practice guidelines above, combined with a review of the current practices of BOPRC for surveillance of submerged aquatic weeds indicate that the approaches currently used are sound. Here we make some recommendations for further consideration:

- Documentation of surveillance sites, the design of targeted search patterns, and description of methods used would be useful for continuity in the programme. For example, a surveillance strategy for the Waitaki lakes system is based on historical surveillance knowledge, and provides a structured, site-specific survey process appropriate for each lake and risk species (see http://www.niwa.co.nz/freshwater-and-estuaries/research-projects/waitaki-weed-surveillance-plan).

- We recommend that consideration is given to sonar mapping capability to provide background information for sites. For instance, use of depth sounders capable of recording .Sl2files (e.g., Lowrance or Simrad depth sounder) allows the use of processing services (e.g., Insight Genesis) to generate maps of bathymetry and vegetation biovolume. Sonar traces can be made during routine surveillance exercises and over time build up a more detailed resource for on-going surveillance.

- Diver training resources would be one potential way of addressing variations in diver abilities. Greater emphasis on recognition under variable conditions may assist performance. For instance recognition of weed targets under heavy algal growths can be difficult and the cues for recognition shift from diagnostic features to silhouette or architectural features. A range of visual resources (photographs video footage) should be collated for this purpose.

- The use of multiple divers is one solution to diver variations in detection ability although it has implications for resourcing. To address this we suggest the rotation of divers across sites between surveillance visits.

7 Acknowledgements

8 References

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Appendix A   Technical specifications of surveillance equipment

Deep Blue Pro Splash Cam specifications, colour, 3.6mm Lens, fixed 1 inch to focal infinity, 520 TV lines, 0.1 lux, 60m cable.

Sharp LCD colour TV specifications, Model LC-19A35X-BK.

Seadoo RS1 and Halcyon HDV-14 scooter models.

Lowrance HDS9 depth sounder/GPS/chart plotter used with a LSS-2 HD transducer and point 1 transducer.

Appendix B   GLMM analysis results for proportion of detection

Table 1:   **Table of predicted means for method (Logit scale).**

Trial	Manta Board	Snorkel Tow	Snorkel	Scooter	SCUBA
1		0.503	1.543	1.078	1.078
2		0.991	3.246	2.398	2.152
3	-0.2271			1.0623	1.1987
4		0.993	1.968		2.232

Table 2:   **Table of standard errors of differences between pairs (Logit scale).**

Trial	Method	Snorkel Tow	Snorkel	Scooter
1	Snorkel	0.149		
	Scooter	0.138	0.156	
	SCUBA	0.138	0.156	0.145
2		Snorkel Tow	Snorkel	Scooter
	Snorkel	0.331		
	Scooter	0.247	0.37	
	SCUBA	0.23	0.359	0.283
		Manta Board	Scooter	
3	Scooter	0.2055		
	SCUBA	0.2093	0.2194	
4		Snorkel Tow	Snorkel	
	Snorkel	0.301		
	SCUBA	0.322	0.359	

Appendix C   Anova results for proportion detected

Table 3:   **Transformed data analysis results (arcsine square root transformed).**

Method	Surrogate height			
	Below canopy	**At canopy**	**Above canopy**	**Surrogate height sed**
Snorkel Tow	0.429	1.004	1.452	0.081
Snorkel	0.818	1.403	1.571	0.081
Scooter	0.68	1.215	1.517	0.081
SCUBA	0.739	1.171	1.437	0.081
Method sed	0.0765	0.0765	0.0765	

Appendix D   GLMM analysis results for diver differences

Table 4:   **Estimated variance components for diver for all Trials (Logit scale).**

Trial	Diver component	se
1	0.0595	0.0393
2	0.0132	0.0539
3	0.2548	0.1597
4	0.179	0.166

Table 5:   **Estimated variance component for diver for Trial 1, inclusive of surrogate height terms.**

Diver component	se
0.135	0.086

Early detection using surveillance for aquatic weeds

Appendix E   Sonar side-scan images

Trial 1

Chart 50
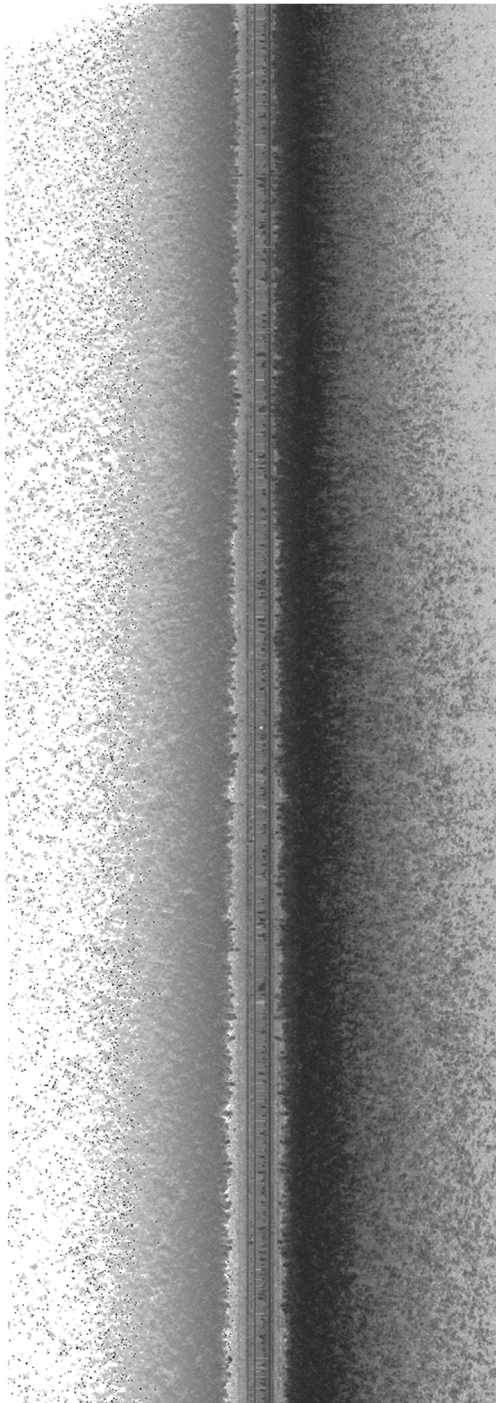
Chart 152
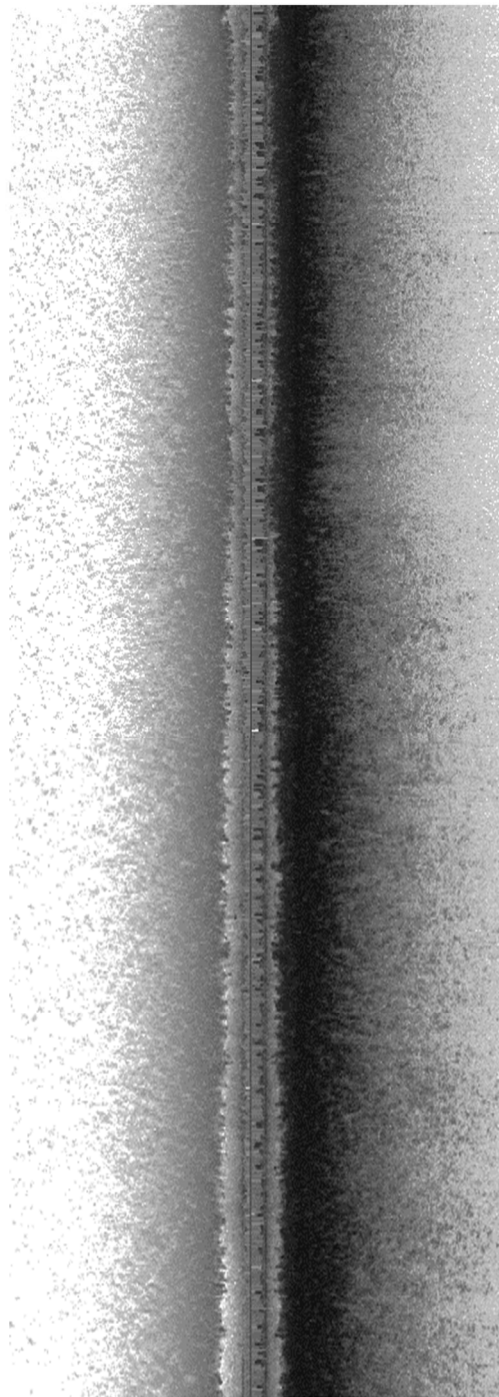
Trial 2

Chart 151   Chart 153

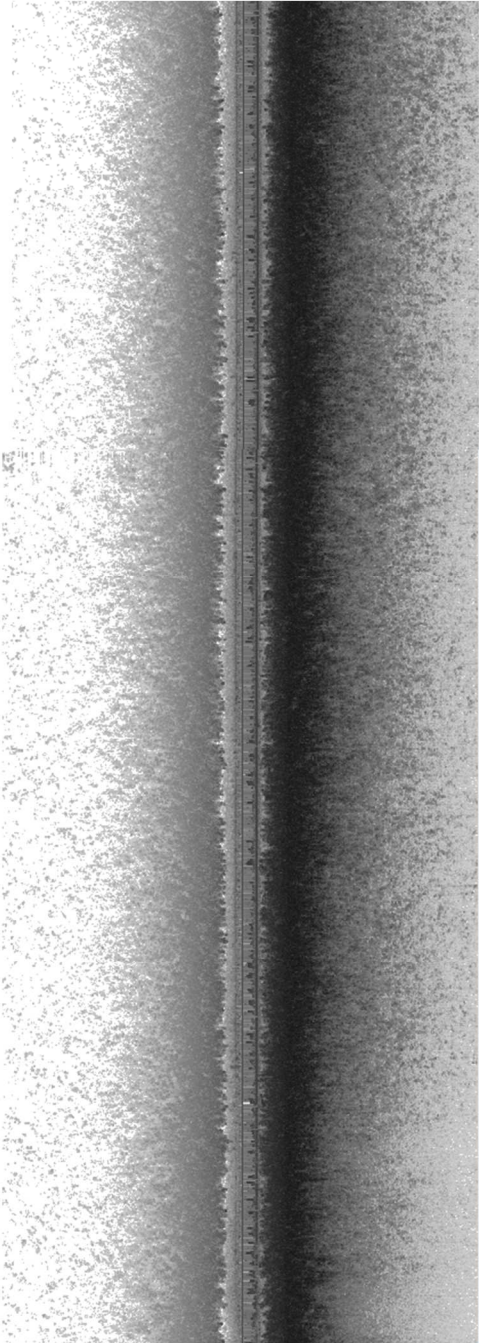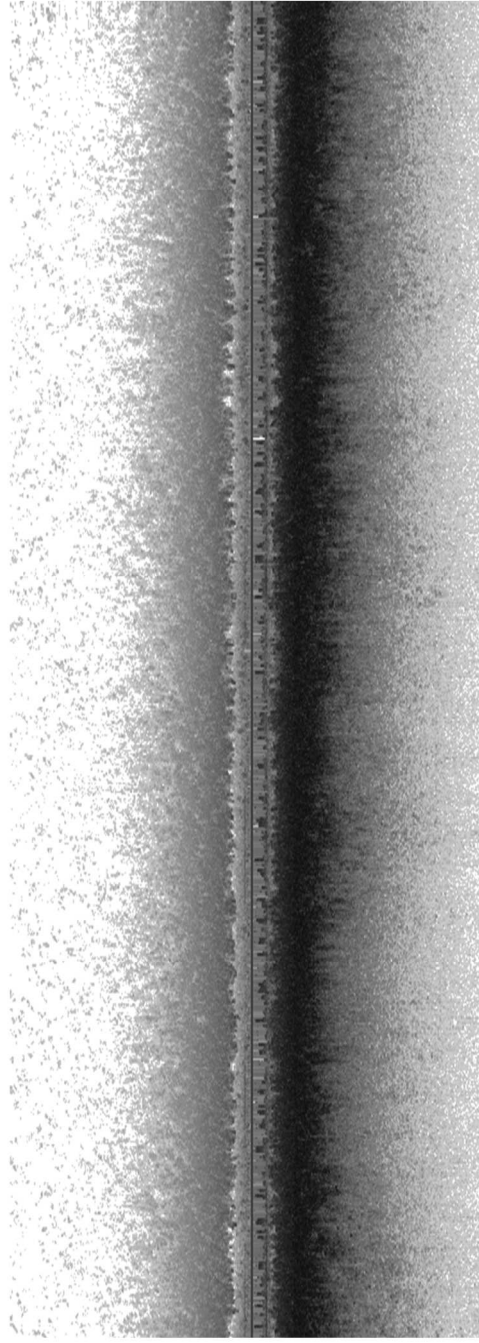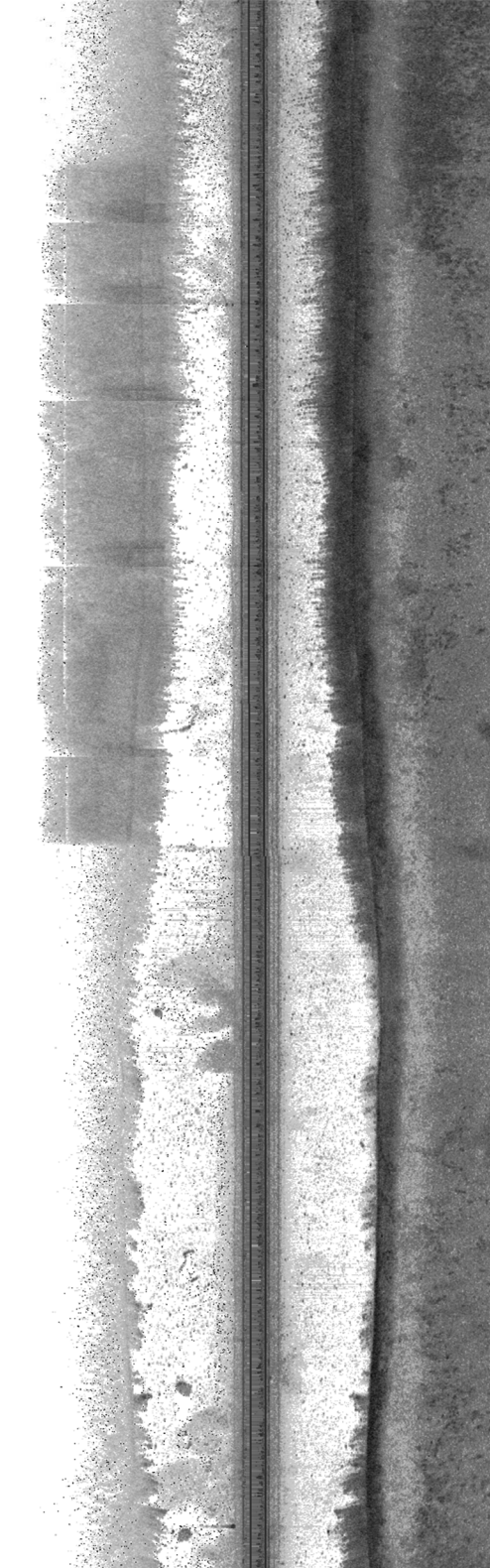# Trial 3

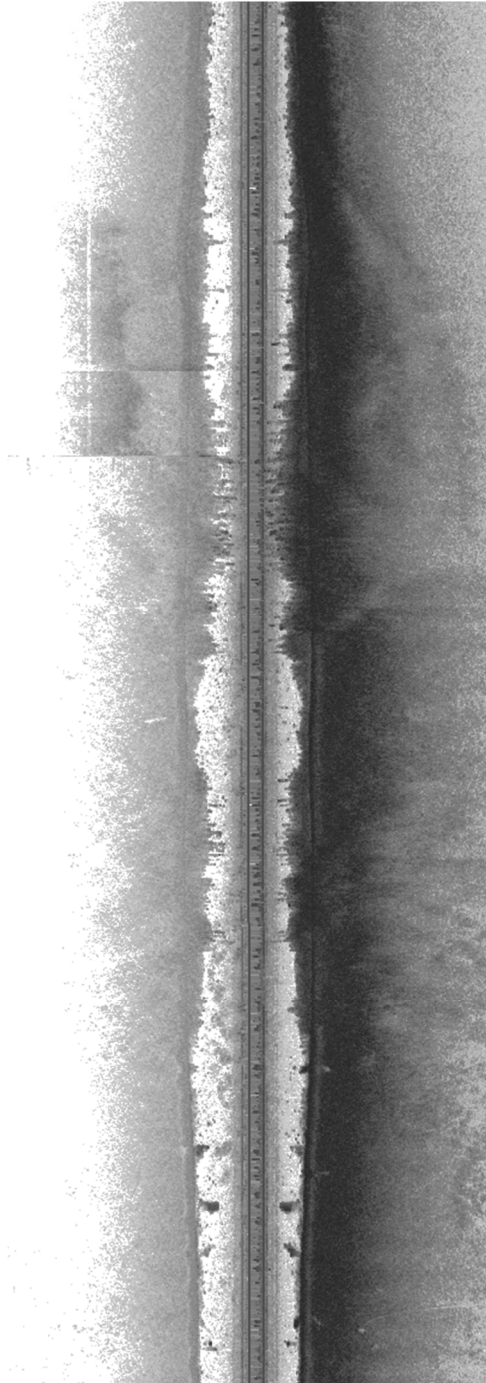## Chart 154   Chart 155

Trial 4

Chart 156   ## Chart 157