Memo

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To	Matthew Brady Freshwater Technical Advisor Department of Conservation
CC	Nigel Binks Freshwater Science Advisor Department of Conservation
Date	30 June 2022
Subject	Invasive macrophyte remote detection research: Memo update June 2022

1. Introduction

The development of a remote detection and mapping system for submerged invasive species is a multi-year research program initiated by NIWA in 2020/21. The project objectives are to develop tools for the automated detection of invasive submerged weeds using remote sensing data to enable more efficient survey methods.

Detection and monitoring populations of invasive submerged macrophytes using conventional methods (e.g., SCUBA divers) is expensive and time consuming. Remote detection, recognition and mapping software could greatly speed up the process, reduce the resources and costs involved and allow more water bodies and much larger areas to be assessed more frequently, by multiple freshwater management agencies.

This project aims to develop new tools and capability for the remote detection of submerged invasive weeds utilising advances in remote sensing, recognition software and machine learning, initially targeting one of New Zealand's worst aquatic weeds, *Lagarosiphon major*. This species is under active management programs in various lakes (e.g., Lake Wakatipu, Lake Wanaka, Lake Benmore, Lake Aviemore) by multiple agencies in New Zealand.

Developing the automated detection system to remotely detect lagarosiphon will guide development of the technology for other target high-risk freshwater species (e.g., *Ceratophyllum demersum, Egeria densa*, *Hydrilla verticillata*, pest fish), native species (e.g., taonga species, kōura and kākahi) and is also applicable in the marine environment.

Central and regional government have responsibilities to manage invasive species (National Policy Direction for Pest Management, NZ Government 2015). This research aligns with the Department of Conservation (DOC): Biodiversity Conservation Science Prospectus (DOC 2020), "Priority Area 2: Innovation in environmental monitoring, evaluation and reporting", specifically priority research to develop tools to enable "real time and remotely sensed data acquisition, complemented by automated processing and analysis using AI" and "Priority Area 9: Solving the freshwater pest problem", specifically priority research to develop "remote, automated and electronic monitoring technologies, enabling world leading technologies to be applied to help solve the freshwater pest problem".

The longer term (ca. 3 to 5 year) aim is to develop more efficient and effective survey methods for submerged species detection, that are not reliant exclusively on dive teams, with data more discoverable and readily integrated into reporting tools for invasive species management and predicting spread.

NIWA has developed (2020-2022) proof of concept for the automated detection of lagarosiphon from RGB video imagery using the object-based detection algorithm 'You Only Look Once' (YOLOv3) and developed a prototype detection module to collect near-real-time spatial location data of target detections (Bulleid and Clements 2021). This system is in an early stage of development and requires field development and testing to identify current limitations to progress towards operational use.

In 2021/22, DOC approached NIWA to help progress this research area and sought to field test the detection module for lagarosiphon and initiate development of the detection system for the high-risk target species hornwort (*Ceratophyllum demersum*). DOC specified that being able to differentiate between all invasive submerged macrophyte species in the future would contribute to being able to "solve the freshwater pest problem".

There are three parts to this research project that DOC sought to progress:

i. The initial field testing of the remote detection module and recognition software for detection and mapping of lagarosiphon in Lake Wakatipu and the Kawarau River. This should help determine what further development is required to progress towards operational use.

ii. Collection of initial video imagery of hornwort from Lake Rototoa (prior to control works being undertaken by Auckland Council) to initiate subsequent training of a hornwort detection algorithm (algorithm training not part of this contract).

iii. Collation of a database of previously collected NIWA video imagery to enable subsequent training for a hornwort detection algorithm.

2. Methods

2.1 <u>Initial field test of the detection module in Lake Wakatipu and the Kawarau River in 2022</u>

The initial field test of the lagarosiphon detector module was carried out by NIWA in Lake Wakatipu (Kingston foreshore and Frankton Arm Marina) and the upper Kawarau River on 4-5 May 2022. Figure 1 illustrates the locations where the detector module was deployed. The detector module and submerged camera system was attached to a vessel and traversed along appropriate areas, ground-truthed by divers at each site, to demonstrate system capability and map locations of detected lagarosiphon. Real-time video was observed on the vessel (topside) to understand detection metrics, including if the module was collecting georeferenced location data, identifying lagarosiphon, misidentifying lagarosiphon or completely missing lagarosiphon. Post the field trial, the saved video data of detections from the module were visually assessed to evaluate the prototype module's detection performance.

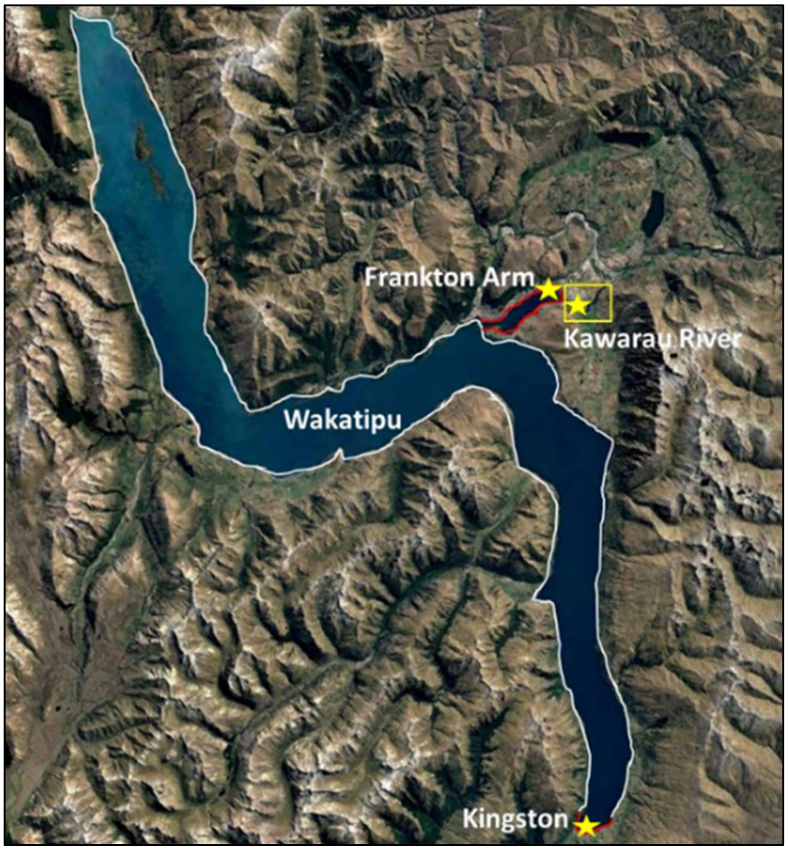

Figure 1: Map of Lake Wakatipu and Kawarau River showing the areas where the prototype detection module was deployed in May 2022 (yellow stars). Red lines delineate the shorelines of the Frankton Arm and Kingston foreshore and the yellow rectangle shows the area of the Upper Kawarau River.

2.2 Collection of initial video imagery of hornwort from Lake Rototoa in March 2022

Collection of video imagery of hornwort was undertaken by NIWA at Lake Rototoa on 17-18 March 2022. No herbicide control works had been carried out by Auckland Council prior to imagery collection. Video imagery of hornwort was collected using underwater cameras (i.e., GoPro's with specific video technical characteristics, described in Table 1) at five sites distributed throughout the lake (Table 2, Figure 2).

At each site a georeferenced waypoint was taken at the main hornwort infested area and a c. 100 m transect traversed by snorkelling along the shoreline length of each site while collecting video imagery of the lakebed and the submerged vegetation community present in each area.

Table 1: Submerged video camera technical characteristics used to collect hornwort imagery at Lake Rototoa in March 2022.

Make and model	GoPro Hero 7 Black (GoPro Inc., San Mateo, CA)
Video resolution (pixels)	2.7 K
Frames per second	60 FPS
Field of view	Wide
Screen resolution (pixels)	2704 x 1520
Aspect ratio	16 : 9
HyperSmooth video stabilisation	Turned on

Table 2: Locations where video imagery of hornwort was collected in Lake Rototoa in March 2022.

Site number	Grid reference
1	36° 31.029'S, 174° 14.475'E
2	36° 30.891'S; 174° 14.609'E
3	36° 30.823'S, 174° 13.972'E
4	36° 30.605'S, 174° 13.983'E
5	36° 30.117'S, 174° 14.186'E

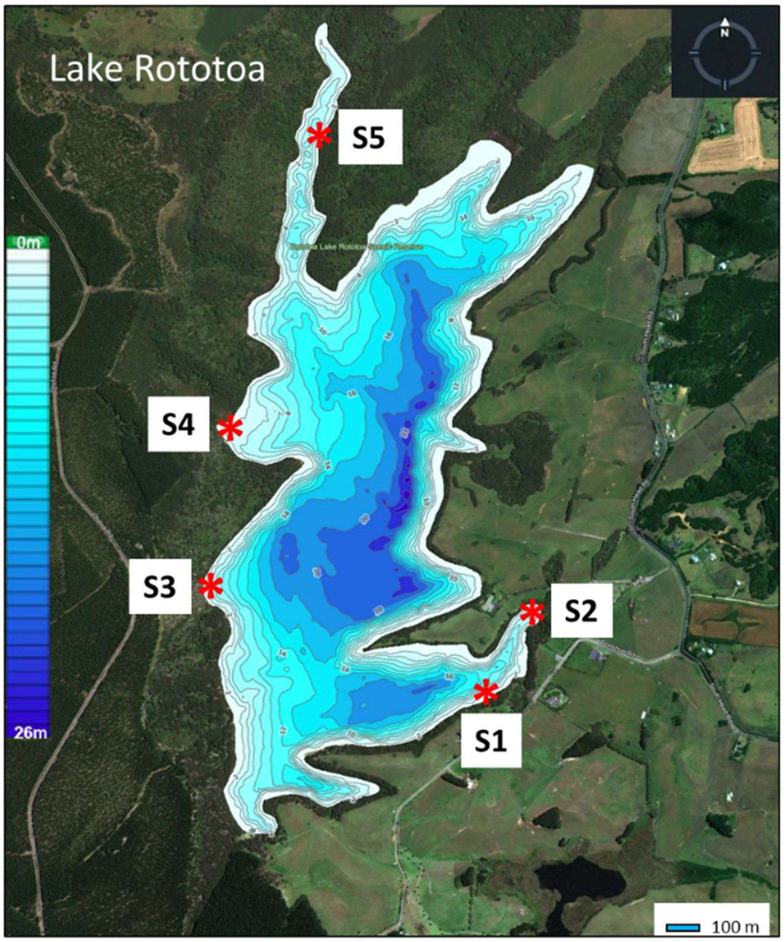

Figure 2: Locations where video imagery of hornwort was collected in Lake Rototoa in March 2022.

2.3 Collation of previously collected NIWA video imagery of hornwort

Video imagery of hornwort previously collected by NIWA at Lakes Rototoa (Auckland Region), Kuwakatai (Auckland Region), Karāpiro (Waikato) and Tutaki (Poutō Peninsula) was collated so that subsequent training of a hornwort detection algorithm could be initiated (training not part of this contract).

3. Results

3.1 Initial field test of the detection module in Lake Wakatipu and the Kawarau River in 2022

NIWA's first opportunity to carry out real-time field testing of the prototype detection module (Figure 3) occurred in May 2022 in Lake Wakatipu and the Upper Kawarau River, during inspections of lagarosiphon control works contracted by Land Information New Zealand (LINZ).

Day 1 (4/5/22):

Our first trial, intended to set-up and check the operation of the detection module and associated equipment (Figure 3), involved a 14-minute duration sweep along the shoreline at Kingston, at the southern end of Lake Wakatipu (Figure 1, Figure 4). Control works (hand removal by divers) have been carried out in this area for several years with the aim of eradicating lagarosiphon from the lake. At Kingston, two snorkel tows behind a boat were conducted along c. 750 m of foreshore to ground-truth locations of lagarosiphon, however no lagarosiphon plants were found in amongst the submerged aquatic plant community (Figure 4). Therefore, it was a good opportunity to test the module for false-positive detections. Weather conditions at the time was sunny but windy and water conditions were choppy, so the boat and camera were rolling significantly. We tested at speeds of up to 4.5 knots (~2.3 m/s).

Post processing of the detection spreadsheet indicated that the model, with the threshold set at 70%, produced approximately 17 false-positive detections in every 100 frames. Further training of the lagarosiphon detection algorithm and modifying detection thresholds will reduce the number of false-positive detections.

Day 2 (5/5/22):

Detection testing occurred along a reach of the Upper Kawarau River (Figure 1, Figure 5) where lagarosiphon abundance ranged from minimal lagarosiphon cover upstream (<5% cover between 45° 1'45.80"S 168°43'59.24"E (WPT-1504) to 45° 1'58.01"S 168°44'30.42"E (WPT-1520)) to high cover (>76-95% cover downstream of 45° 2'0.24"S 168°44'36.80"E (WPT-1522)) (Figure 5).

Figure 6 shows a single frame from a detection video created in real-time in the area where high cover lagarosiphon occurred (WPT-1522, Figure 5). Multiple lagarosiphon tips and stalks were detected in this frame, along with the model's confidence-level (e.g., 0.840), which means the model is 84% confident that it has correctly predicted the relevant class. As the submerged camera (Figure 3, bottom) moves over an area the aspect changes, so different apical tips and stalks/stem material are detected and annotated (if the confidence level exceeds the 70% set detection threshold).

The system operates very rapidly with a single lagarosiphon plant detected in many frames as the vessel moves over a particular area. We will need to establish a meaningful metric to deal with multiple detections of the same target in the future. Data is typically incoming at a rate of 200-300 frames per second and there may be many detections in a single frame (e.g., Figure 6).

An output file is produced (.csv file) showing the date, time and georeferenced location data of each detection (Figure 7). This file becomes the input to mapping applications to enable control methods to be deployed and implemented at the sites where detections have occurred. This approach of geo-referencing detections in real-time avoids the problem of having to deal with post-processing of large video files, which has several advantages including minimal data storage requirements. Retaining still image frames for each detection has been identified as a requirement for process validation and will be incorporated into the system in the future.

Figure 3: (Top) Prototype lagarosiphon detection module (hardware) deployed for testing in Lake Wakatipu and the Kawarau River by NIWA in May 2022. (Bottom) Detection system setup and deployed on NIWA's jetboat in the Kawarau River showing the submerged camera system at the bow of the vessel. The detection module (top) is on-board the vessel.

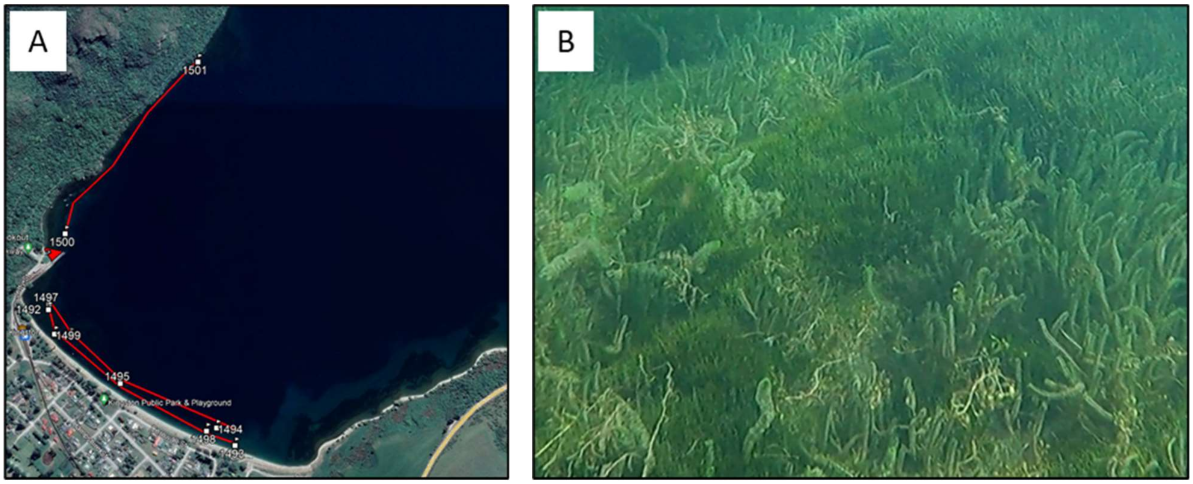

Figure 4: (A) NIWA's snorkel tow inspections (red lines) conducted at Kingston in May 2022. (B) No lagarosiphon was detected by divers at Kingston in May 2022 in amongst the submerged vegetation community (e.g., *Elodea*, *Myriophyllum*, *Isoetes*).

Figure 5: GPS locations of lagarosiphon plants identified by divers in the Upper Kawarau River in May 2022. Red line indicates upstream area where individual lagarosiphon plants occurred at low cover (estimated 5% cover by NIWA divers). The area indicated by the orange polygon (c. 100 m of river shoreline) indicates where hessian benthic barrier has been laid to control lagarosiphon (<5% lagarosiphon cover). Lagarosiphon was present at high cover (>76-95%) downstream of the orange polygon.

Figure 6: Multiple lagarosiphon shoot tips and stalks/stems detected by the prototype detection module in real-time along the Upper Kawarau River in May 2022.

1	Date	Time	Lat	Long	Detection Class
2	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Stalk
3	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Stalk
4	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Stalk
5	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Stalk
6	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Stalk
7	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Stalk
8	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Tip
9	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Tip
10	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Tip
11	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Tip
12	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Tip
13	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Tip
14	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Tip
15	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Tip
16	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Tip
17	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Tip
18	5/05/2022	2:38:37	45°02'0.92"S	168°44'37.5"E	Tip
19	5/05/2022	2:38:38	45°02'0.92"S	168°44'37.6"E	Stalk
20	5/05/2022	2:38:38	45°02'0.92"S	168°44'37.6"E	Stalk
21	5/05/2022	2:38:38	45°02'0.92"S	168°44'37.6"E	Stalk

Figure 7: A section of the output spreadsheet (one frame per row) derived from the .csv file generated in real-time in the same area represented by the image in Figure 6.

Figure 8: ArcGIS mapping of the module detections in the .csv file. The detections are raw, unvalidated, and contain false-positive and false-negative detections. While the detection model requires further training to improve detection accuracy, the image helps demonstrate end-to-end functionality.

Figure 9: A single lagarosiphon plant was detected in real-time by the module in a berth at Frankton Marina (Queenstown), even with significant shadows created by the marina pontoons.

3.2 Collection of initial video imagery of hornwort from Lake Rototoa in March 2022

In March 2022, 11.03 GB of video data was recorded of the submerged vegetation community across the five hornwort sampling sites at Lake Rototoa (Table 2, Figure 2) using a GoPro Hero 7 Black (Figure 10). This equates to 25.5 minutes of video data across the five sampling sites (Table 3). A further 28.6 GB of video data was recorded outside of the sampling sites at Lake Rototoa in March 2022 using a GoPro Hero 9 Black. This video imagery could be used as training data to develop an initial hornwort detection algorithm in the future (training not part of this contract). This data is stored on NIWA's secure project drive: O:\DOC22213\RawData\Task 2 - Lake Rototoa hornwort Imagery collection - March 2022\Lake Rototoa_17-18.3.22\Lake Rototoa Imagery-16-18.3.22.

Table 3: Video imagery collected of hornwort in Lake Rototoa in March 2022 at five sampling sites.

Site number	Megabytes [MB]	Minutes of video
1	1724	3.95
2	2443	5.77
3	2090	4.82
4	3563	8.18
5	1206	2.78

Figure 10: Example of video imagery collected of hornwort at Lake Rototoa in March 2022. Hornwort was covered in algae at many sites, however clean new growth (apical shoots) was also present.

3.3 Collation of previously collected NIWA video imagery of hornwort

NIWA has collated ~942.3 GB of previously collected video data associated with four hornwort infested lakes including Lakes Rototoa, Kuwakatai, Karāpiro and Tutaki. This data could be evaluated and used to train a hornwort detection algorithm (training not part of this contract).

At Lake Rototoa (36°30'47.59"S 174°14'12.54"E), ~45.7 GB of video data was collected using a GoPro Hero 7 Black (Table 1) on two previous occasions (July 2019 and November 2020).

A further 862 GB of video data was also collected around the margin of Lake Rototoa on two previous occasions (September 2020 and April 2021) using a towable georeferenced underwater camera system (modified from: https://www.splashcam.com/product/delta-vision-industrial-hdtvi/). Camera Specifications include: Video Output: HDTVI / HDMI; Imaging Device: 1/3" 1080 High Sensitivity CCD; Video Format: 30hz or 25hz 30fps; Resolution: 1920 x 1080; Sensitivity: 0.1 lux. The imagery collected from this system is of lower quality compared to the GoPro Hero 7 Black system. This footage needs to be evaluated by NIWA's Instrument System team to determine if it is appropriate to be used in the development of an automated hornwort detection system.

At Lake Kuwakatai, near Lake Rototoa (850 m south), ~3.30 GB of video data was recorded of the hornwort infestation in March 2022 (16/3/22) between (36°31'56.83"S 174°13'57.81"E and 36°31'53.58"S 174°14'1.74"E) using a GoPro Hero 7 Black (Table 1).

At Lake Karāpiro in the Waikato (37°56'19.25"S 175°33'8.66"E), ~23.9 GB of video data has been recorded across the hornwort beds on four previous dates (23/2/2021, 6/1/22, 1/2/22 and 3/3/22) using a GoPro Hero 7 Black.

At Lake Tutaki (36° 17.512'S; 174° 1.611'E), 6.54 GB of video data associated with the hornwort infestation was recorded in January 2020 using a GoPro Hero 7 Black.

This data is stored on NIWA's secure project drive: O:\DOC22213\RawData\Task 3 - Hornwort video - collation of previous imagery by lake.

4. Discussion

4.1 <u>Initial field test of the detection module in Lake Wakatipu and the Kawarau River</u>

From the initial field test of the detection module in Lake Wakatipu and the Kawarau River in May 2022, we have demonstrated that automated 'detection-to-map' is practical and achievable. While the detection model requires further training to improve detection accuracy, we have demonstrated end-to-end functionality and have identified several improvements that can be made to the automated detection system.

i. <u>Detection accuracy</u>: From our initial field test the system detection accuracy is limited. We have not been able to train the prediction model effectively to date due to a lack of lagarosiphon training material from the field (e.g., good-quality, relevant video from diverse habitats) with subsequent insufficient algorithm training time. We require a specific project to collect suitable lagarosiphon training material, enable detection algorithm training and importantly evaluate detection efficacy. We plan to collect the suitable training material to improve the lagarosiphon detection algorithms and evaluate detection efficacy under NIWA's Freshwater Biosecurity Research programme (Strategic Science Investment Fund) over the next two years (project currently being evaluated by NIWA). The most important factor to enable accurate and robust detection is quality training data. We can continue to train the model until the detection accuracy and robustness required is achieved.

ii. <u>Detection threshold adjustment:</u> During the field trial we were unable to adjust the threshold level where a 'hit' is deemed to be a detection. This had been fixed at 70% confidence level and the software does not yet include capability to adjust sensitivity. Setting the threshold too low tends to increase the number of false-positive detections. Setting it too high tends to increase the number of false-negative detections.

iii. <u>Camera height adjustment:</u> To reduce risk of damage to camera equipment on a moving boat it would be desirable to be able to automatically raise the camera system (Figure 3, bottom) if it is likely to intercept the lakebed or weed canopy when moving. An acoustic sounder, or lasers, may be suitable as an input to inform the pole's motor drive to take avoidance action.

iv. GPS to map: We will change the module's GPS export data to better match input to mapping applications (i.e., ArcGIS).

v. Adapt for use with multiple cameras: We will adapt the software to enable deployment of 1-3 cameras mounted on a submersible boom. This will enable scans of wider swath areas.

vi. Multiple GPS co-ordinates for each detected target: The system operates very rapidly and a single lagarosiphon plant is detected in many frames as the vessel moves over a particular area, we need to establish a meaningful metric to deal with multiple detections of the same target.

4.2 Collection of initial video imagery of hornwort from Lake Rototoa and collation of previously collected NIWA video imagery.

Over 950 GB of video data associated with hornwort infested lakes has been collected and collated as part of this project. Before collecting any more video data to develop a hornwort detection algorithm, this imagery should be used to develop an initial hornwort detection algorithm and tested to determine the efficacy of developing an automated detection system for hornwort.

The next phase of the project to develop an automated detection system for hornwort could include:

i. Develop detection algorithms for hornwort from databased imagery.

ii. Apply the detection algorithms to independent imagery datasets (not used in algorithm training).

iii. Evaluate (statistical performance testing) developed detection algorithms with independent data.

iv. Operationalise the automated detection system with end-users, including finalising detection module software and hardware and preparing for system field testing.

v. Field test the automated detection system for hornwort with end-users, ground-truth with diver surveys and further refine algorithms if required.

Other potential additions:

- Partner with external agencies (e.g., DOC) to collect training imagery and hydroacoustic datasets for their species of interest from their priority lakes to optimise detection algorithms for priority waterbodies.
- Combine the detection module with self-navigating (autonomous) field ready surface craft, to enable flexible monitoring at large spatial scales.

5. Conclusion

From the initial field test of the detection module in Lake Wakatipu and the Kawarau River we have demonstrated that automated 'detection-to-map' is practical and achievable.

During the field testing the prototype equipment generally worked as expected and, from this experience we have generated a list of required improvements. We primarily need to focus on improving detection precision by developing and evaluating field detection algorithms and detection rates. This is a known and achievable task.

As we continue to develop these modules, they will enable faster, more cost-effective, and extensive surveillance, and provide early warning of existing and emerging threats to freshwater ecosystems.

The modules will be replicable and deployable on a wide range of surface craft. The module has a high-tech inner core, but with a low-tech outer shell it will require only minimal skills to set up and may be potentially operated by different agencies, weed removal contractors or, perhaps, citizen scientists.

While we have primarily developed the detection module to target invasive submerged weeds in New Zealand waterways, in principle, the system could be used for recognising other relevant target species including pest fish, native species (e.g., taonga species, kōura and kākahi) and is also applicable in the marine environment.

6. Acknowledgements

Thanks to Inigo Zabarte-Maeztu and Hayden McDermott (NIWA) for their assistance in the field at Lake Wakatipu and the Kawarau River. Thanks also to Aleki Taumoepeau, Mary de Winton (NIWA) and Dirk Immenga for their assistance in the field at Lake Rototoa.

7. References

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