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Assessment of the Efficacy of Contained Grass Carp at Removing the Aquatic Weed Hornwort

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Abstract

NIWA were contracted by MPI to assess the efficacy of stocked grass carp (*Ctenopharyngodon idella)* in containment to eradicate the aquatic weed hornwort (*Ceratophyllum demersum*). Hornwort is an introduced invasive submerged weed that is already present in many regions in the North Island. As part of the National Interest Pest Response, MAF aims to exclude hornwort and eradicate any new incursions from the South Island. Grass carp are herbivorous fish recognised for their use in controlling excessive weed growth through plant consumption.

The purpose of this project was to contribute to the understanding of grass carp efficacy for aquatic weed control and specifically to develop the science around the potential use of grass carp as an incursion response tool, by determining the optimal stocking density required to remove the aquatic weed hornwort from artificial enclosures within a short (two month) timeframe.

After the necessary approvals were gained and support was received from iwi and stakeholders, artificial enclosures were installed in dense hornwort weed beds in Lake Karapiro downstream of Little Waipa domain in January 2012. The six enclosures included five different stocking densities of grass carp (1 to 5 grass carp per 6m diam. enclosure) and one enclosure without grass carp (the control). Nine weeks after the grass carp were introduced, the hornwort had been removed by the fish from the three highest stocking densities. During the next week the grass carp were recovered (except one) and the enclosures were deconstructed.

The results demonstrated that grass carp can be stocked at high density (>1000 grass carp per vegetated hectare) in a contained area for hornwort removal over summer and subsequently recovered.

Considerations for future use need to recognise that:

- Weed consumption by grass carp is slower at cooler water temperatures, which may require that the target stocking density is increased to achieve eradication within a short (two month) timeframe.
- Enclosure design is dependent on site, and grass carp recovery method is dependent on enclosure design.
- Approvals and stakeholder support are a necessary component of grass carp use. The timeframe for gaining support is not readily discernible, and different stakeholder perspectives can result in significant delays and logistical challenges.

Keywords: *Ctenopharyngodon idella, Ceratophyllum demersum,* incursion response

Introduction

Hornwort (*Ceratophyllum demersum* L) is a submerged aquatic weed that negatively alters freshwater ecosystems by smothering and shading native vegetation. It can form dense monospecific stands up to 7 m tall, occurring in water depths up to 15.5 m, and excludes native vegetation through smothering and shading.

Hornwort was first recorded in New Zealand in 1961 and has subsequently become widespread throughout the North Island (de Winton et al 2009). Whilst there are other tall growing non-indigenous weeds in New Zealand that displace native aquatic vegetation (e.g. *Egeria densa* and *Lagarosiphon major*), hornwort grows much deeper and also displaces characean meadows to depths that are not impacted by these other alien species. Dense hornwort growth can also impede water flow in irrigation and drainage channels.

Hornwort can also occur as floating mats or drifting fragments (Hofstra & Champion 2006) that can be driven into bays or against shorelines by wind, where it smothers and shades resident vegetation. Associated declines in habitat and water quality can have concomitant negative impacts on associated fauna. Buoyant rafts can also block intake screens and cause problems in the generation of hydroelectricity. Power-generation companies have experienced outages caused by hornwort in New Zealand. Such shut-downs can cost companies millions of dollars in repairs and lost generation, in addition to the costs of constructing booms and screens, and the on-going expense of removing and disposing of weed deposited in these areas (Hofstra & Champion 2006).

In the North Island, hornwort is present in many regions, with the Waikato River catchment, including Lakes Taupo, Rotoaira and the hydro-lakes, heavily impacted. The South Island, however, has no known established populations. As such, the National Interest Pest Response for hornwort aims to eradicate and exclude hornwort from the South Island (http://www.biosecurity.govt.nz/pests/surv-mgmt/mgmt/prog/nipr, viewed May 2012).

For aquatic weed control and/or eradication, the method is always dependent on a number of factors including the target plant species, the site and size of infestation and the management objectives (e.g. controlling plant biomass versus weed eradication) (Clayton and Wells 1999). Eradication success is most readily achieved for new incursions at an early stage of infestation within a small waterbody, or small defined area such as a single bay within a larger lake, and by matching the tool (or tools) from the weed control tool box with the target weed and site-specific requirements.

There are a range of tools available for the control of aquatic weeds, including hornwort, which can be placed in three broad categories: biological, chemical and physical. Examples of physical tools are mechanical harvesting, suction dredging, hand-weeding and habitat manipulation, such as weed matting (Clayton 1996). In New Zealand, chemical options are limited to a few herbicides that are registered for aquatic use, and there is currently only one biological control option, grass carp (*Ctenopharyngodon idella* Val).

Grass carp are a herbivorous fish, native to Asia, that derive their other common name, white amur, from the Amur River system that borders China and Russia (Cudmore and Mandrak 2004). They have been introduced to New Zealand and many other countries for aquatic weed control. The first consignments of grass carp arrived in New Zealand in 1966 (Chapman & Coffey 1971), and again in 1971 (Edwards & Hine 1974), with initial studies focussed on feeding preferences (Edwards 1973, 1974). Grass carp were subsequently released for a variety of field studies in small lakes, such as Parkinsons, Waihi Beach reservoir (Mitchell 1980, Rowe & Champion 1994), Elands farm lake (Clayton et al. 1995), Lake Waingata (Rowe et al. 1999) and drainage systems firstly on the Rangitaiki Plain (Edwards & Moore 1975), and then in the Mangawhero Stream (Schipper 1983) and Churchill Drain in the Waikato (Wells et al. 2003).

Initial studies provided data on the potential use of grass carp for weed control in temperate New Zealand environments and addressed the potential impacts of grass carp in lakes (Rowe & Hill 1989). Issues with respect to containment arose after some fish escaped into the Waikato River (McDowall 1984), and this event resulted in the production of an Environmental Impact Assessment to formally address the use of this fish for weed control in New Zealand (Rowe & Schipper 1985). The report analysed the potential impacts of grass carp, and uses, including their potential to eradicate certain problem weed species in lakes. It also confirmed the lack of suitable habitat for grass carp to breed and form a self-sustaining population in New Zealand waterways. It was followed by public consultation and an internal report (Rowe et al. 1985) seeking the formal release of these fish for weed control. This was subsequently granted by the New Zealand Government, subject to conditions and control by the Department of Conservation and the Ministry of Fisheries (Conservation Act 1987).

Since 1988, grass carp have been deployed in a wide range of locations throughout New Zealand to control excessive weed growth in lakes and ponds. In 2008 grass carp were used as the primary tool in the eradication response for hydrilla (*Hydrilla verticillata*), which is present in Lakes Tutira, Waikopiro and Opouahi in the Hawkes Bay. In Lake Opouahi, some grass carp were initially retained in a purpose-built enclosure within the lake until the enclosed hydrilla weed bed was consumed. The success of this approach for the hydrilla eradication response led to a Ministry for Primary Industries (MPI) initiative to assess the efficacy of containing grass carp for weed incursion response, which forms the basis of the present study on hornwort.

The MPI contracted NIWA to assess if grass carp in containment could be an effective eradication tool for aquatic weeds using hornwort as the target species. The aim of the current project was to develop the science for the localised control of aquatic weeds in lakes or reservoirs and to provide a tool for dealing with localised incursions before they spread. Specifically, the project aimed to determine the optimal stocking density of grass carp required to remove hornwort in a contained environment within a two month period.

Methods

LOCATION AND SITE SELECTION

Selection of the study site was based on the availability of hornwort weed beds, likely water level fluctuations, lake bed bathymetry, exposure to wind, boat access and accessibility by the public. Prior knowledge of hornwort weed beds was used to select candidate locations in Lakes Karapiro, Arapuni, Ohakuri, Maraetai and Atiamuri within the Waikato river system. Site reconnaissance undertaken in June 2011 included an assessment of candidate locations by divers at sites that had favourable sonar profiles (e.g. consistent water depth and lake bed bathymetry).

Relatively shallow embayments at the southern end of Lake Karapiro (downstream from Little Waipa Domain) were selected as the study location (Figure 1). The specific site for enclosure placement at this location (Site 1 in Figure 1) was determined following an on-site assessment in January 2012. At this assessment the hornwort was surface reaching allowing an assessment from the surface to ensure each enclosure would contain comparable hornwort weed beds.

Figure 1: Lake Karapiro study location with proposed sites marked. Site 1 was used for the trial.

PRE-REQUISITE APPROVALS AND STAKEHOLDER ENGAGEMENT

Statutory approvals are required for the introduction of grass carp into a new waterbody. For this research project, approvals were required from the Department of Conservation (DOC) under the Conservation Act (1987) section 26ZM, and the Auckland/Waikato Fish and Game Council under S59 of the Freshwater Fisheries Regulation to transfer and release grass carp into the enclosures within Lake Karapiro. To support these applications, an assessment of environmental effects (AEE) (Gear & Hofstra 2011) and an operational plan for grass carp transfer (Gear 2011) were prepared and presented with the applications. Freshwater Fisheries Regulations (1983) require that further releases of grass carp following the initial release are approved on a case-by-case basis by the Ministry of Fisheries. While such an approval was not anticipated, the Ministry of Fisheries was kept informed.

Containing the grass carp was considered to potentially restrict their natural behaviour. Animal Ethics Committee (NIWA) approval was therefore required and sought for the project.

Iwi consultation for the introduction of grass carp into Lake Karapiro was an essential component of the project. The Waikato River is of particular significance to Maori. The five river iwi, Ngāti Tūwharetoa, Raukawa, Te Arawa River Iwi Trust, Ngāti Maniapoto and Waikato-Tainui, recognise the river as a tūpuna (ancestor), a taonga (treasure), and for its mauri (life force). Waikato-Tainui, Raukawa and Te Arawa River Iwi Trust have agreements with the Crown in relation to the co-management of the Waikato River. Ngāti Korokī Kahukura is the hapū that has dominant manawhenua interest in the rohe around the Waikato River where Lake Karapiro lies, while Raukawa and Ngati Haua also have associations with the surrounding areas. The two marae, Maungatautari and Pōhara, are situated on the side of Maungatautari, a sacred mountain of the Ngāti Korokī Kahukura and Ngāti Hauā people. Support for the project was sought from Ngāti Korokī Kahukura, Raukawa and the Te Arawa River Iwi Trust.

Additional stakeholders were identified within the stakeholder engagement plan and communication strategy (Gear 2011) and included: Land Information New Zealand (LINZ); Mighty River Power (MRP); Waipa District Council and South Waikato District Council (DCs); the Harbour master; Environment Waikato (EW); and the Lake Karapiro Warden.

ENCLOSURE DESIGN AND INSTALLATION

The enclosure design was conceptually based on that successfully used to contain grass carp in Lake Opouahi (Hofstra & Smith 2009), and a prototype for the present study was developed. The prototype was constructed lakeside and its installation was tested at the study site (Figure 1, Site 1) in October 2011. With the exception of additional buoys, steel anchoring pegs and a fifth anchoring pole per enclosure the design remained unchanged (Figure 2).

During the week commencing the 9th of January 2012 six enclosures frames were made by attaching lengths of PVC pipe (with glued t-joiners) to form a hoop approximately 6 m in diameter. The hoop was dissected (quartered) by additional PVC pipe, with buoys attached at each intersection, as well as midway along each pipe spoke. Along the rim of the enclosure frame, five PVC rings were attached to allow for the insertion of anchoring poles. Once installed on site, these rings would allow for guided movement of the buoyant net enclosure up and down the anchor poles as the water level fluctuated. On completion, the frame was floated onto the lake and anchored to a boat in readiness for being towed to the study location.

The sides/walls of the enclosure were made of mesh netting (5 m wide by 20 m long bird tex, RJ Reid Ltd). On shore the netting was laid out, stretched into shape, measured to confirm the required length, and the anchoring chain (37 mm link, 8 mm diameter) was laid along one edge. The chain was then rolled into the bottom edge of the net and secured with cable ties every 10 cm. The net with chain attached was then placed into a large bin and stowed in the boat.

At the study location, sites for each enclosure were selected within the embayment designated as site 1 (Figure 1). Selection was based on water depth (2.5 to 2.8 m), density of the hornwort (ca 100% cover of surface reaching weed) and accessibility to each enclosure site within the weed bed. The sites were out of the main channel and therefore not exposed to the main water currents, and not in the path of boats travelling along the river. Each site was marked by thrusting an anchoring pole (steel poles encased in a PVC sleeve) into the sediment. The enclosure frame that was to be installed first was secured to an anchoring pole, and successive poles were driven into the sediment through the guide rings on the perimeter of the enclosure frame. Once all five anchor poles were in place (securing the enclosure at the site), the net wall was attached.

Working from the boat moving around the enclosure frame, the top edge of the net was loosely attached to the frame, while the bottom edge with the chain was lowered into the water. The top edge of the net was then secured to the frame by rolling the top ca 15 cm of the net around the frame and attaching with cable ties. Where the two ends of the net wall met, they were attached to each other by rolling the net ends together and securing with cable ties every 10 cm. The last links on either end of the chain were also joined to each other by cable ties. SCUBA divers then embedded the bottom edge of the net (ca 50 cm) into the sediment and secured with steel pegs (ca 40 cm long) placed along its perimeter every 50 cm (Figure 2).

Two temperature loggers (Hobo® Pendant) were placed inside each enclosure. One was attached ca 60 cm below the water surface attached to the wall of the enclosure, and the other was free floating within the enclosure. The loggers recorded the water temperature hourly.

A roof for the enclosure was made from a pre-cut length (7 by 10 m) of netting (hailguard, RJ Reid Ltd). This was placed over the enclosure, pulled taut and secured to the enclosure frame (incorporating the side wall netting) with cable ties every 10 cm. Once secured, overhanging hailguard was trimmed to drape ca 30 cm below the top of the frame to reduce the potential for entanglement outside of the enclosure at future monitoring events. Successive enclosures were constructed and installed in the same manner.

Signs notifying the public of the trial were placed at either end of bay within which the enclosures were sited (Site 1 markers, Figure 1) for the duration of the study period.

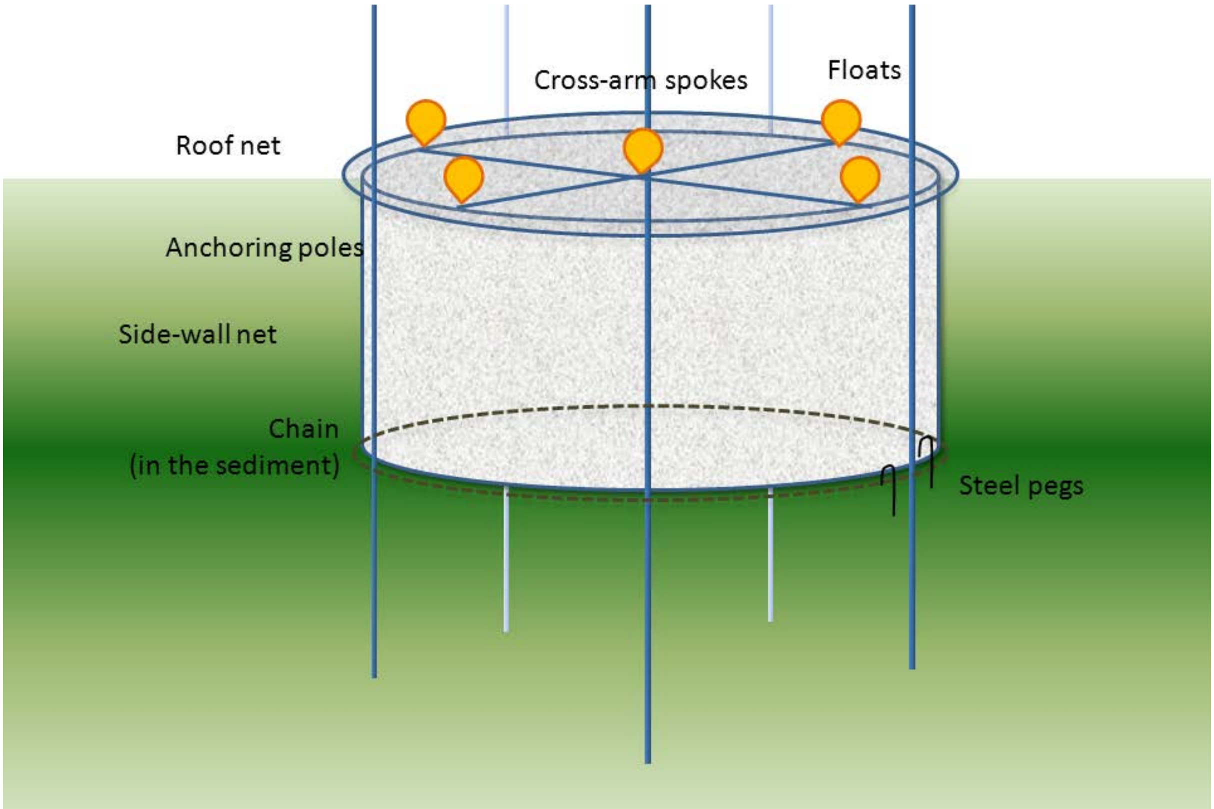

Figure 2: Diagram of an enclosure illustrating the essential design components (by M de Winton). NB: the buoys and steel pegs are placed to show the concept, not the precise detail.

GRASS CARP PROCUREMENT AND RELEASE

Grass carp (ca 30 cm in length) were procured from New Zealand Waterways Restoration Ltd, Orewa. Grass carp health checks, along with transfer and release protocols, were designed to prevent the transfer of any 'hitchhiker species' with the movement of the grass carp, as well as to ensure grass carp welfare (Gear 2011).

On delivery at the lakeside, grass carp were inspected by NIWA fisheries staff to ensure the fish were in good health and of appropriate size. A PIT tag was inserted into each grass carp using a syringe (Appendix, Table A1). Fish length and weight was recorded against the PIT tag number for each fish. The grass carp were then placed into plastic bins (filled with water) that were pre-labelled with their respective enclosure numbers. Lids were then secured in place for transport by boat to the appropriate enclosure.

There were a total of fifteen grass carp that were stocked into five of the enclosures, at stocking densities of 1, 2, 3, 4, and 5 fish in each of the respective enclosures. One enclosure, the control, did not have grass carp. Grass carp enclosure numbers referred to throughout the trial correspond directly to the number of grass carp stocked in that enclosure (Appendix, Table A2).

Prior to release of the grass carp, a final check of enclosure security was made by SCUBA divers. The fish transport boat was anchored to the enclosure, and the roof of the enclosure was opened sufficiently to allow the bin containing the grass carp to be lowered into the enclosure. With the roof flap lowered over the fish bin as much as practical to minimise any gaps, a second person opened the lid of the fish bin and released the grass carp into the enclosure. The bin was removed and the roof of the enclosure was secured with cable ties (every 10 cm).

The grass carp were released into the enclosures on the 13th of January 2012.

MONITORING

The enclosures were visited one week after the grass carp were released and fortnightly thereafter. At each monitoring visit, the integrity of the enclosures was assessed under water by SCUBA divers and on the surface from a kayak. Lake water level, weed in the enclosures (height and cover), and observations of grass carp (although rare) were also recorded. The enclosure walls were checked for fouling and periodically cleaned. Additional buoys were secured to the outside of those enclosures frequented by waterfowl to deter their access.

The timeframe for the study was two months over the summer (from January 2012). However the speed of hornwort removal by the grass carp was the critical factor for defining the end-point of the trial. Based on hornwort removal within the enclosures, the study was concluded after nine weeks, the grass carp were retrieved and the enclosures deconstructed.

GRASS CARP RECOVERY AND ENCLOSURE DECONSTRUCTION

The support boat was anchored (bow and stern) adjacent to the enclosure. Cable ties were removed from the perimeter of the enclosure roof to provide a narrow entry point for divers to enter the enclosure. Once divers were in the enclosure, the roof was secured to the perimeter frame using large bulldog clips. At all times, when not in active use, the entry point into the enclosure was secured. The temperature loggers were then removed from the enclosure and handed out to the support person on the boat.

Surface reaching hornwort in the water column was harvested in bundles (enclosures 0, 1 and 2), held with a rubber band at the base, and passed onto the diver at the exit/entry point of the enclosure. Weed was then carefully transferred from the enclosure to the support person. On the boat hornwort bundles were placed into a mesh frame and hung from the balance (Bonso Hanging Scale) until water ceased to run from the weed. When the weed was only dripping, the wet weight value was recorded for that bundle. Weed was then placed back into the lake on the far side of the boat, and the next bundle of weed retrieved from the diver. This action was repeated until the hornwort was removed from the water column.

Hornwort lying on and embedded in the sediment was removed from enclosures by a SCUBA diver using a large net bag. Once the net bag was full, this was transported to the surface diver who passed it out to the support boat. A sample of the net bags was weighed initially, but subsequently only estimated amounts were recorded, because the bags contained a significant portion of mud as well as moribund weed. However, removing this bottom layer of partially embedded moribund weed was necessary to establish a clean, unobstructed sediment surface to aid in the recovery of the grass carp.

Initial grass carp recovery in each enclosure was made by a SCUBA diver with a hand held net. Netted fish were secured on the boat in a lidded fish bin. As removal of all grass carp was not possible by this means, a staged deconstruction of each enclosure was subsequently required.

To provide a more flexible surface frame, deconstruction of each enclosure began with one spoke of the internal PVC pipe being cut next to the outer ring wall, and removed through the diver exit/entry point. Once the divers were no longer working in the enclosure, the roof netting was again secured to the PVC frame by cable ties. The buoys secured to the outside of the frame and the anchoring poles were then removed and stowed on the boat.

The sides of the enclosure were then pursed by divers removing the pegs from the base chain and gradually advancing the chain into the centre. To ensure integrity of the containment a small section of chain (ca 30 cm) was carefully lifted to just below the surface of the mud and pushed forward through the mud (30 to 40 cm at a time) towards the centre point of the enclosure then rested again in the mud. Divers worked systematically along the length of the chain until all of the chain was located in a central bunch in the mud.

Once the chain was centrally located, a rope was secured around the bottom of the net walls, above the chain, and tied tightly to choke the net. Two lift bags were then attached to raise the chain free of the sediment. With the chain still secured to the enclosure, excess mud was removed as far as possible by divers shaking the net wall. The chain was then tied off to the support boat.

Working the netting in sections, the entire enclosure was then pulled across the deck of the boat. When the last section of the enclosure containing the grass carp was in the confines of the boat the net was cut and the grass carp transferred to a partially lidded fish bin while enclosed in a damp towel. Once all grass carp from the enclosure were in the fish bin, the lid was secured with cable ties. The fish bin, which had fine mesh panels in the sides (to allow water circulation) and buoyancy support, was then placed back into the lake and secured to the boat. The fish bin was then placed in the boat in a larger bin full of water for transport back to shore. Back on shore, the grass carp were sedated in preparation for transport (Gear 2011). Sedated fish then had their PIT tag number, length and weight recorded before being placed in a bin for transport. Fish recovered on day 1 were returned to NZ Waterways Restoration staff on-site. Fish recovered on subsequent days were transported by vehicle (in fish bins with portable aerators) back to NIWA Ruakura and held in a secure aerated tank until collected from NIWA Ruakura by NZ Waterways Restoration staff for transport back to Warkworth.

All construction materials for the enclosures, including signage were removed and transported back to shore. The enclosures were fully deconstructed on land, for transport back to NIWA Ruakura at the end of each day.

Results

By December 2011 statutory approval for the introduction of grass carp into a new waterbody was received from Fish and Game, as was Animal Ethics Committee (NIWA) approval. Iwi support for the project was received from Ngāti Korokī Kahukura, Raukawa and the Te Arawa River Iwi Trust. Stakeholder support from LINZ, MRP, Waipa District Council, South Waikato District Council, Environment Waikato was also received.

Approval from DOC was received at the end of December 2011, subject to requirements in addition to the operational plan including, the insertion of a PIT tag in each grass carp released, the addition of a fifth anchor pole to the enclosure design, the use of pegs along the basal edge of each enclosure and signage to advise the public to stay clear of the site.

Enclosure integrity was maintained throughout the study. Water level fluctuations of up to ca 50 cm were recorded during monitoring visits and were well within the design specification of the enclosures.

Relatively inaccessible enclosure sites amongst the weed were seen as important to minimising the risk of accidental damage to the enclosures by curious members of the public. There was no evidence that the enclosures had been visited by members of the public.

Mallard ducks, swans and herons were all observed on the enclosures during monitoring visits. The addition of buoys to enclosures where the waterfowl frequently visited (based on faeces), in an attempt to raise the frame and make it less accessible to the wading birds, appeared to provide a temporary improvement.

Temperature data was recorded for all enclosures for the duration of the study. The data were consistent between enclosures, with surface temperatures fluctuating more than the relatively stable 20°C recorded subsurface (ca 60 cm below the water surface) (Figure 3).

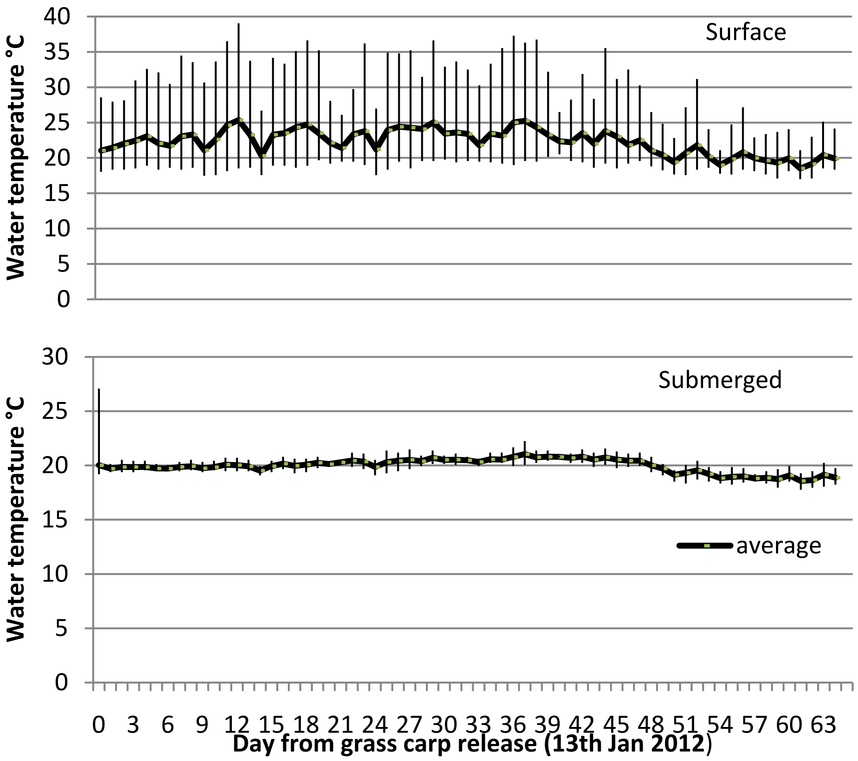

Figure 3: Average daily water temperature in the grass carp enclosures during the study period. Bars represent the daily minimum and maximum values from all enclosures.

When the enclosures were installed, the weed beds were between 2.3 to 2.8 m in height (the depth of the water column) and had ca 100% surface cover for all enclosure sites. Few other plant species were present and were sparse in both density and distribution. For example, there were a few stems of the submerged weed *Egeria densa* in enclosure 5 and 3, and two small patches (ca 50 cm diameter) of the floating plant *Lemna minor* in enclosure 2 amongst the surface reaching hornwort.

Change in the density of hornwort was first noted three weeks after grass carp release, when the surface cover of weed in the highest density stocked enclosures (4 and 5) was an estimated 75%, compared with 100% in the control and low density enclosures. By five weeks after grass carp release there was a trend in the reduction of surface weed within the enclosures, which was consistent with the stocking density of the grass carp (i.e. less weed where there were more grass carp) and became more distinct over the next two monitoring events (Figure 4). Divers also noted more open space amongst the hornwort, in the water column and at the sediment level, in enclosures 4 and 5 after seven weeks.

Nine weeks after grass carp were released there were no surface reaching plants and no healthy, free-standing upright hornwort in the water column in enclosures 3, 4 and 5. Most of the water column was open, with bare areas of sediment conspicuous. Some ‘mounds’ of accumulated detrital weed remained in the sediment where hornwort was collapsed and partially embedded within the sediment. In enclosure 2 there was a 75% reduction in hornwort and a dense canopy of hornwort remained in enclosure 1 and the control enclosure (Figure 4).

The percent cover values for surface reaching hornwort corresponded to a similar trend in wet weight of hornwort in the water column when the trial was concluded. For example, there was greater hornwort biomass remaining in the enclosure without grass carp and with a single grass carp than in the enclosures with two or more grass carp. In all enclosures, moribund and old hornwort remained entangled in the sediment.

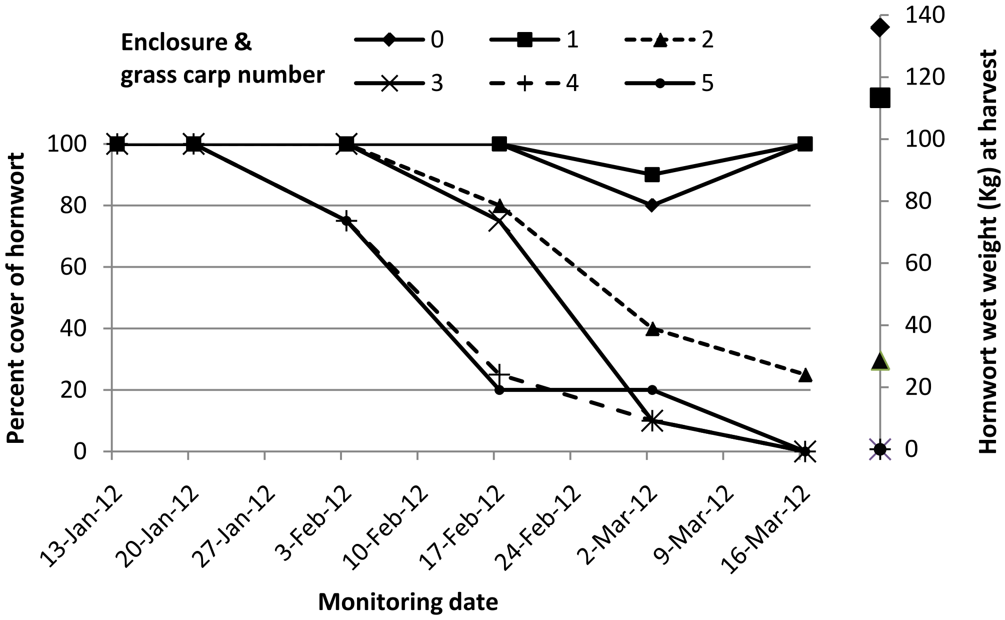

Figure 4: Hornwort cover during monitoring and biomass at harvest in the enclosures.

Fifteen grass carp were released in total, all of which were over 30 cm long and around 0.4 kg in weight. When released, grass carp swam into the weed within their enclosure. However, one fish appeared ‘sleepy’ on release and slipped, rather than swam into the weed bed.

During monitoring events, movement was observed occasionally in enclosures, but no grass carp were seen until week nine. At that time, enclosures 3, 4 and 5 were free of surface reaching weed in the water column and with quiet observation by divers grass carp were seen swimming in pairs or more.

When the fish were recovered after nine weeks, one fish was unaccounted for (Appendix, Table A1). It is possible that this grass carp died during the study and was consumed by eels. Eels, as well as catfish and goldfish were recovered from enclosures along with the grass carp. Alternatively, it is possible that the missing grass carp escaped under the chain while it was being pushed through the mud during the recovery process. MPI and DOC (as required) were notified at the time. Between their release and recovery, the grass carp in all enclosures increased in length and doubled in the weight (Figure 5).

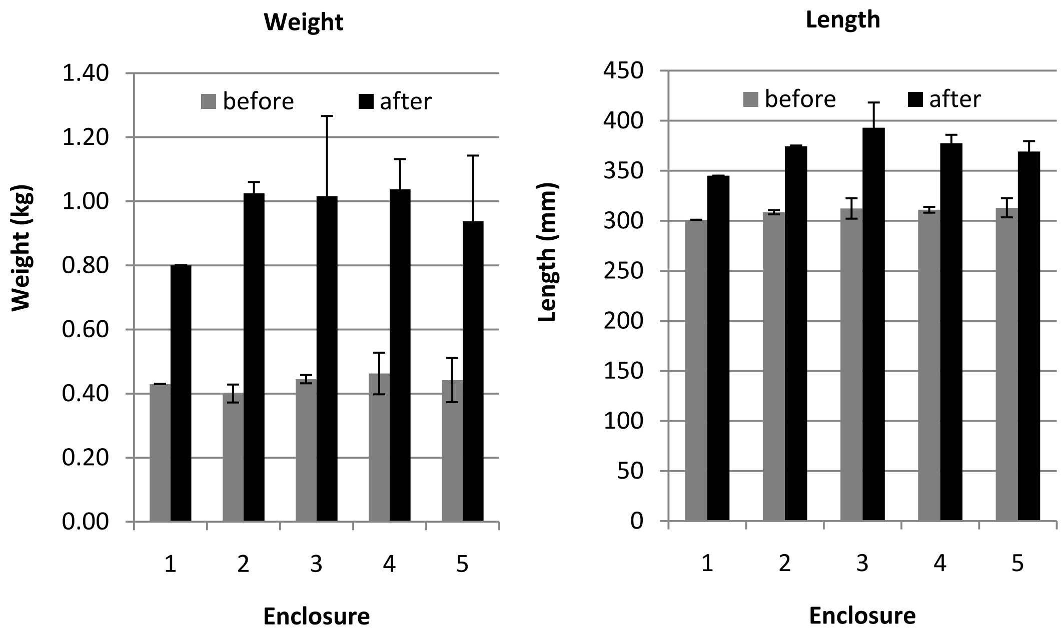

Figure 5: Grass carp weights and lengths before release and after recovery from the enclosures. Data are average values for each enclosure with associated standard deviation.

Discussion

The purpose of this trial was to assess the potential use of grass carp in containment as an incursion response tool. The optimal stocking density required to remove hornwort from artificial enclosures within a two month timeframe was determined. This result allows managers to consider contained grass carp as an effective tool for the control and/or eradication of aquatic weeds. In determining if the method is likely to be useful thought needs to be given to the physical characteristics of the site (in particular weed density, temperature and water fluctuations) which will influence cage design, stocking density, and the method of introduction and removal of fish.

Artificial enclosures must be able to securely contain the grass carp around existing hornwort weed beds. Grass carp containment can be challenging, as they are known to jump over barriers (Cudmore & Mandrak 2004, Ellis 1974) including a New Zealand example where grass carp escaped from containment (Rowe & Schipper 1985). However, in these examples, grass carp were being contained within a lake, or parts of a drain or waterway, rather than an artificial enclosure. Few examples of grass carp being contained within an artificial enclosure in a lake for weed control have been published (Santha et al 1994, Osbourne & Riddle 1999, Hofstra 2011). Even so, in all these cases the scale of the barrier or containment device was dependent on the physical characteristics of the waterbody in which the grass carp were being contained. Similarly, the design of the enclosure in the present study was dependent on the water body where the trial occurred.

In Lake Karapiro the enclosure design prototype was based on that used in Lake Opouahi (Hofstra & Smith 2009), which included net walls, a weighted chain base, and anchoring poles in the sediment. However, in the Lake Opouahi example, the net walls extended above the water to create a wall that would prevent jumping grass carp landing in the main body of the lake. A similar design had previously been used to exclude grass carp in the USA (Bonar et al 1993). Such a design was not possible at the Lake Karapiro site as it was more wind exposed and likely to have greater water level fluctuations. In addition, the walls of the Lake Opouahi enclosure had been supported by submerged guy lines. In Lake Karapiro such a design would have posed a navigation hazard due to the likelihood of curious members of the public approaching the cages. The final design for the Lake Karapiro enclosures met the physical characteristics of the site by incorporating sides that would rise and fall with fluctuating water levels and a roof over the enclosure for containing the grass carp while minimising potential wind stress and public hazard risk.

To support the welfare of the fish the enclosure was designed with a roof that allowed sufficient space under it for the grass carp to surface, should they need to. Dense beds of weed, like hornwort, have the potential to become oxygen depleted. Grass carp are able to cope with such conditions by gulping air at the surface. To provide an adequate space for this behaviour buoys were used to maintain the roof netting approximately 20 cm out of the water. However, it was noted during monitoring that when wading birds had been sitting on the enclosure roof the roof netting could be depressed into the water. This was remedied in this trial by adding extra buoys to the perimeter of the enclosure and increasing the tension on the netting. At no time did this pose a significant hazard to the grass carp, as it only impacted a section (quarter) of the roof that was most frequented.

Apart from that unplanned and aesthetically negative impact on the enclosures, the design was a success at installation and during the trial, with structural integrity and grass carp security maintained. Anchorage by heavy chain, with diver assisted embedding, was sufficient to tension and secure the side wall, and it was noted that the use of pegs at the base of the walls was unnecessary.

The timeframe that was established at the outset for the study was two months during summer. Given that the purpose was to develop the science for use as an incursion response tool, the ability to achieve weed removal within a relatively short timeframe was critical. In addition, the generally warmer water temperature in summer would promote grass carp feeding activity, which is temperature dependent (Hofstra 2011). Although January to March 2012 was relatively cool, with water temperatures around 20°C, this was well above the 15°C below which grass carp feeding activity diminishes (Rowe &Schipper 1985, Wiley & Wike 1986, Osbourne & Riddle 1999, Masser 2002, Hofstra 2011).

The stocking densities to be assessed were based on those used in the Lake Opouahi enclosure and those generally used for long term control of aquatic weeds (Rowe & Schipper 1985, Hofstra & Smith 2009).In the Lake Opouahi enclosure grass carp removed the target weed hydrilla within two months at a stocking density of 1600 per vegetated hectare. Given that grass carp prefer hydrilla over hornwort as a food, it was considered likely that hornwort removal would require higher densities of grass carp and/or a longer period of time to achieve a grazing rate equivalent to the Lake Opouahi example. Hence the highest stocking density assessed in the present study (1785 fish per vegetated Ha) exceeded that used in the Lake Opouahi enclosure.

A high grass carp stocking density to achieve weed control (and eradication long term) is 100 grass carp per vegetated hectare (Rowe & Schipper 1985, Rowe & Champion 1994, Rowe et al. 1999). At that target stocking density hydrilla was removed from Hawkes Bay lakes over several growing seasons (Clayton et al 1995, Hofstra 2010). This grazing rate would be too slow for a response tool so that stocking density became the lower limit for the present study. The final design meant the lowest stocking density trialled was actually 350 fish per vegetated hectare.

The grass carp in the higher stocked enclosures (3, 4 and 5) removed the hornwort from the water column within nine weeks of their introduction, with a comparable reduction in hornwort in the enclosure with two grass carp. Some old and moribund hornwort remained amongst the sediment in the bottom of all of the enclosures. Had the study continued for another two weeks, it is expected that the grass carp would have consumed this too (e.g. demonstrated most recently in Lake Kereta (de Winton 2012). However, extending the study would have exposed the fish at the highest stocking density to the likelihood of being food deprived. A new incursion of hornwort by definition has new or young growth, and is less likely to have old stems in the sediment as found in this study. Thus as an incursion tool it is unlikely that fish would be forced to consume old and decaying plant material entangled in the sediment.

In comparing the result achieved in the present study with the literature on stocking density, plant preference and feeding activity (at 20°C) (Hofstra 2011), the results are consistent with expectations and demonstrate that grass carp can be stocked at a very high density in a contained area for weed removal over summer, and subsequently recovered.

For future use as an incursion response tool, particularly in the South Island, consideration needs to be given to water temperatures and the reduction in feeding activity caused by lower temperatures. This may mean a tight seasonal window of opportunity and/or stocking at higher densities to obtain adequate grazing rates.

The design of enclosures or containment barriers and the necessary approvals for the introduction of grass carp must also be considered when using this tool. The enclosure design is dependent on the site, and the subsequent recovery of the grass carp is dependent on the enclosure design (and site). New weed incursions are most likely to be associated with human activities (e.g. boat ramps, anchoring spots) and, as such, public activity needs to be considered in the design of the enclosure or containment barrier.

The multiple stakeholders and permissions required for the use of grass carp (introduction to a new waterbody) can result in a number of potentially conflicting perspectives on the fate of the grass carp that, in conjunction with the enclosure design, can make recovery challenging and potentially hazardous for divers. In this study the requirements were, 1) the negotiated procurement meant that the grass carp were to be returned to the supplier alive, 2) the animal ethics committee approval required humane recovery of the grass carp, and 3) DOC required that live grass carp did not enter into the main body of Lake Karapiro. To balance these differing perspectives the grass carp had to be recovered from a net enclosure, surrounded by dense weed beds, in two to three metres of murky (low to zero visibility) water. For future use of grass carp for incursion response, it would be advantageous if all stakeholders had the same expectations of the fate of the fish, if not the same perspectives. This would likely require further consultation (and time) for stakeholder engagement prior to the response.

CONCLUSIONS

The scope of this study was to assess the efficacy of contained grass carp (*Ctenopharyngodon idella)* to eradicate the aquatic weed hornwort (*Ceratophyllum demersum*) within an enclosure over a short timeframe. This was achieved and contributes to the understanding of grass carp efficacy for aquatic weed control and specifically the science around the potential use of grass carp as an incursion response tool.

The results demonstrated that grass carp can be stocked at high density (>1000 grass carp per vegetated hectare) in a contained area for hornwort removal over summer and subsequently recovered.

Considerations for future use need to recognise that:

- Weed consumption by grass carp is slower at cooler water temperatures, which may require that the target stocking density is increased to achieve eradication within a short (two month) timeframe.
- Enclosure design is dependent on site, and grass carp recovery method is dependent on enclosure design.
- Approvals and stakeholder support are a necessary component of grass carp use. The timeframe for gaining support is not readily discernible, and different stakeholder perspectives can result in significant delays and logistical challenges.

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Appendices

Table A1: Grass carp data

PIT tag number		Before release		At recovery	
Prefix	Suffix	Fork length (mm)	Weight (kg)	Fork length (mm)	Weight (kg)
03790911	66898201	330	0.56	Not recovered*	
03790911	66890028	310	0.44	377	1.2
03790911	66899539	308	0.405	372	0.8
03790911	66899482	310	0.38	354	0.75
03801809	14265412	307	0.425	374	1
03801809	14267749	311	0.46	375	1.05
03801809	14262585	310	0.405	390	1.1
03801809	14263564	315	0.555	372	1.1
03790911	66899763	308	0.43	373	0.9
03790911	66895453	324	0.45	420	1.25
03801809	14261063	305	0.455	370	0.75
03801809	14262340	308	0.43	390	1.05
03801809	14261007	307	0.42	375	1
03801809	14261313	310	0.38	374	1.05
03801809	14265134	301	0.43	345	0.8

* Grass carp that was unaccounted for during the recovery and enclosure deconstruction process.

Table A2: Enclosure number and grass carp stocking density

Enclosure Number	Number of grass carp	Stocking density per vegetated hectare
0	0	0
1	1	350
2	2	714
3	3	1071
4	4	1428
5	5	1785