Assessment of grass carp use for aquatic weed control:

Environmental impacts, management constraints and biosecurity risks in New Zealand waters

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Foreword

Grass carp are not a “silver bullet” for controlling problem aquatic weeds. However, they can be an effective tool for controlling weeds in stormwater or water storage ponds where they can be contained and managed, and where weed control is necessary for the function of the pond. They can also be effective in controlling and even eradicating highly invasive aquatic weeds in larger waterbodies.

Making decisions on applications to release grass carp into waterbodies for aquatic weed control is not easy given there are so many variables to consider. Both the Department of Conservation (DOC) and Ministry for Primary Industries (MPI) are required to make these decisions despite limited information on the risks and benefits of grass carp use in New Zealand.

This publication brings together the available current evidence and information from grass carp case studies in New Zealand. Along with *Grass Carp Effectiveness and Effects*, a companion document prepared for the Department of Conservation, these publications provide a set of operational guidelines and New Zealand-specific reference material. It is envisaged that the reference material and tools will assist applicants when preparing applications and agencies when assessing applications.

The publication should be treated as a living document and considered alongside new information as it arises. The Ministry will seek to review the information at an appropriate time in the future.

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Executive summary

The Ministry for Primary Industries (MPI) contracted NIWA to assess the use of grass carp (*Ctenopharyngodon idella*) in New Zealand, and develop a decision support system for their use. Grass carp are a species of herbivorous fish that were introduced to New Zealand for aquatic weed control. Grass carp have been deployed for weed control in a wide range of locations in New Zealand including lakes, ponds, drains and stormwater retention systems. MPI and the Department of Conservation (DOC) both have statutory roles in approving the use of grass carp; DOC for releases to new locations and MPI for locations where grass carp already exist. MPI (and DOC) require better information on grass carp and improved and up-to-date decision-making tools to best assess the risks of releasing grass carp.

The project included a literature review and field survey (Part One) and development of the decision support system (DSS) for grass carp use (Part Two). The literature review re-evaluated the risks of grass carp establishing a self-supporting population, of creating adverse ecological impacts and it reviewed methods for distinguishing escaped fish from suspected wild progeny. Information from the field survey was integrated into the assessment of environmental effects of grass carp and their effectiveness and contributed to the identification of management constraints for weed control across a representative range of New Zealand sites. Biosecurity risks associated with grass carp release, and options for their capture and removal were also reviewed.

The 1985 assessment of environmental effects (AEE) supporting the use of grass carp for weed control in New Zealand concluded that spawning was possible only in the Waikato River, but that the development of a large breeding population was improbable because river conditions would prevent the survival of most larvae. Even with higher flows and water temperatures expected under climate change scenarios, the low survival of larvae is still considered the major factor limiting the risk of a breeding population becoming established in the river. The risk of impacts from grass carp in the Waikato River is more likely to arise from massive widespread escapes into the river, than from natural reproduction. The most viable way of detecting any naturally bred grass carp in the Waikato River from hatchery-based fish would require micro-tagging all hatchery fish stocked into the catchment.

Effective weed control has been documented for a range of target weed species in New Zealand lakes, ponds and waterways. The potential for environmental effects as a consequence of grass carp controlling weeds, such as changes in water quality or clarity, is largely dependent on site-specific characteristics of the waterbody, and the grass carp stocking density. Turf-forming plants, are known to persist in lakes with grass carp, on gently shelving littoral zones where their low stature makes them inaccessible. Other accessible aquatic plants are consumed by grass carp in order of preference, with potential flow-on effects for fauna dependent on the plants, or weed free substrates.

A range of factors can influence the effectiveness of the weed control outcome including the appropriate use of grass carp relative to the management goals for the waterbody, achieving containment, accurately identifying plant species and the area of vegetation, determining an appropriate stocking density (and fish size) given the timeframe for weed removal, water temperatures (which reflect the plant growing, and fish grazing season), water quality or depth, and whether or not other plant species are present that the grass carp may prefer compared with the target plants. Where weed control has not been successful, there have

usually been one or a number of these contributing factors, that limit the effectiveness of grass carp.

Grass carp were initially quarantined in New Zealand in order to allow the removal of all ‘exotic’ parasites and disease organisms before they were released. However, the transfer of fish from one waterbody to another has the potential to spread resident aquatic plants and animals (e.g. plankton, molluscs, fish larvae), along with fish parasites and diseases, to waterbodies where they were previously absent. To minimise the risk of any new species being spread from grass carp hatcheries and rearing ponds, it will be necessary to identify the species, vector(s) and develop appropriate de-contamination measures and stocking protocols to reduce this risk.

Two major challenges in the use of grass carp for weed control are, the difficulty in determining the number of grass carp in a lake and the removal of grass carp after they have achieved the desired weed control. Both subjects are recognised as technology gaps, with no single method that is feasible for all waterbodies. Aerial counts (e.g. from a high viewing point, or via drones) are currently the most feasible methods (with limitations) for determining the number of grass carp present in lakes. Grass carp removal by angling, netting, electric fishing, herding, and the use of toxicants or attractants were all reviewed. Netting, herding and rotenone have been used successfully in New Zealand, however, all grass carp removal methods have limitations based on the size, shape and depth of the waterbody, the presence of non-target species and grass carp behaviour.

The DSS was informed by Part One of the project and provides a framework for decision making on the use of grass carp, by MPI, DOC and applicants. The DSS has nine over-arching themes, or levels that create a sequential structure to guide decision making. Key waterbody attributes that could trigger an immediate ‘No-go’ decision include the ability to contain grass carp, adverse impacts on threatened or at risk species, water temperature, water depth and quality, the target plant species and management goals for the waterbody. It is recommended that; (1) the DSS is made available to applicants wanting permits to introduce grass carp, (2) is used to guide the assessment of applications for grass carp releases, (3) that MPI (in consultation with DOC) takes a lead role in the development of a centralised electronic system where information on grass carp applications, releases and monitoring can be supplied, so that information can be readily tracked for waterbodies and catchments (by MPI and DOC), and (4) that a further review of the literature, and the DSS is undertaken in five to ten years.

1 Introduction

The Ministry for Primary Industries (MPI) works in conjunction with New Zealand's primary industries to grow and protect New Zealand's natural production, and has a role, in conjunction with Department of Conservation (DOC), in managing the release of freshwater aquatic life into the environment. MPI has a statutory role in assessing releases of the herbivorous fish grass carp (*Ctenopharyngodon idella*) into the wild for weed control. To achieve this, MPI have contracted NIWA to assess the use of grass carp in New Zealand. MPI require better information on grass carp and improved and up-to-date decision-making tools to best assess the risks of releasing grass carp into the many and varied waterbodies in which they are now used or may be used in the future (MPI 2013).

1.1 Project background

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 and Coffey 1971), and again in 1971 (Edwards and 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 waterbodies to assess their potential impacts. Sites included the small lakes, Parkinson's Lake and the Waihi Beach Reservoir (Mitchell 1980, Rowe 1984) and a drain off the Awaponga Canal on the Rangitaiki Plains (Edwards and Moore 1975) in the Bay of Plenty and the Mangawhero Stream (Schipper 1983) in the Waikato.

These 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 New Zealand lakes (Rowe and 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 (EIA) to formally address the use of this fish for weed control in New Zealand (Rowe and 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 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 (e.g. the use of sterile triploid fish) and control by the Department of Conservation and the Ministry of Fisheries (now MPI) (Conservation Act 1987). In 1993, the use of triploid grass carp was reviewed and public feedback on options for future management, including the use of diploid fish, were sought (Coffey 1993). Following this review and the feedback obtained, the use of diploid fish for weed control was approved.

Grass carp have been deployed in a wide range of locations throughout New Zealand to control excessive weed growth in lakes, ponds, streams, drains and storm-water retention systems. Releases of grass carp to a number of lakes and ponds have provided successful weed eradication outcomes (e.g. Elands Lake (Clayton et al. 1995); Lake Waingata (Rowe et al. 1999)), but releases to some waterways where escape was possible have resulted in grass carp entering rivers, such as the Waikato, raising the debate on the potential for grass carp breeding in natural ecosystems (Chisnall 1998). Concerns about the misuse of grass carp and the ability to accurately or adequately assess or predict the impacts they would have on some receiving environments led to the commissioning of reports on the cumulative impacts of multiple grass carp releases (Clayton et al. 1999) and the issues of risk assessment (Clayton and Wells 1999). These documents provided a critical review of the pros and cons of grass carp use, and suggested that a more conservative approach to their use should be adopted (Clayton and Wells 1999). They recommend that some areas be identified as exclusion zones where the use of grass carp would be prohibited (Clayton et al. 1999) and that where grass carp are released a number of parameters should be monitored including, aquatic vegetation, water quality, fish and waterfowl populations and containment structures (Clayton and Wells 1999).

Since 1988, there has been no systematic review or assessment of the effectiveness of using grass carp for weed control in New Zealand waters despite the large number of releases carried out. Consequently, there was little scientific information available to inform and improve the approval process and the management of this tool despite the increasing demand for its use throughout the country. As the conclusions of the 1985 EIA (Rowe and Schipper 1985) were based primarily on overseas research, and did not include the effects of climate change, it is now timely to review the use of grass carp in New Zealand to better inform and improve their future management.

This aim is implicit in the request for proposals (MPI 2013), which states that MPI and DOC continue to receive many applications to use grass carp to manage aquatic weed problems in waterbodies. "Over the last 18 years, many agencies (including MPI) have used grass carp for aquatic weed control in waterbodies. Over that time, larger and more diverse waterbodies have been stocked and consequently the conservation values of some of the systems are greater. Grass carp have now been released into waterbodies from Northland to Otago" (MPI 2013).

"The widespread use of grass carp has raised concerns over the potential effects of the release of these fish into sites that were not envisaged would be stocked in 1985 when the first and only report on the potential effects of grass carp was published" (MPI 2013).

The statutory roles of MPI and DOC in assessing releases of grass carp into the wild "need to consider the ecological, biosecurity and animal welfare effects of these releases. Both government departments and applicants require better information on grass carp and improved and up to date decision-making tools to better assess the risks of releasing carp into the many and varied waterbodies they are now used in" (MPI 2013).

DOC has already commissioned a research project to assess the effects and effectiveness of grass carp to improve future decision making (DOC 2012) that was recently completed by NIWA (Hofstra 2013a, 2014).

MPI seeks to complement the knowledge gained from the DOC project with this current project "Assessment of grass carp use" (MPI 2013).

1.2 Project scope

NIWA have been contracted to assess the use of grass carp in New Zealand with an emphasis on grass carp management, containment and biosecurity. The deliverables include an up-to-date collated resource for decision makers of the science and research on the use of grass carp in New Zealand, and a decision support framework to guide appropriate use of grass carp in New Zealand, both for applicants and decision makers.

The report is structured in two parts;

Part One includes the literature review with information from the field survey (Appendix B).

The literature review (Chapters 2 to 8) addresses the risk of grass carp establishing a self-supporting population, and methods for distinguishing escaped fish from suspected wild progeny; assesses the environmental effects of grass carp and their effectiveness and management constraints for weed control across a representative range of sites; and outlines biosecurity risks associated with grass carp release, and options for their potential capture and removal (Appendix A for detailed scope).

The field survey (Appendix B) was carried out to obtain better assessments of grass carp use. The focus was on sites that represent waterbodies typically stocked, or proposed for stocking with grass carp. Selection of the survey sites was informed by existing knowledge gaps, and the type and quality of information to be gained with a single site visit, to add value in the assessment of grass carp effectiveness and impacts in New Zealand. Insight gained from the field survey was used to update (where appropriate e.g., Chapter 4) the literature review.

To assist the reader, the location of lakes and ponds are shown on maps in Appendix C and plant names are recorded in Appendix D.

Part Two is the decision support system for grass carp use.

The literature review and the field survey informed the development of the DSS (Chapters 9 and 10). The purpose of the DSS is to provide a framework for decision making on the use of grass carp, by MPI, DOC and applicants.

PART ONE: Literature Review

2 Risk of grass carp breeding in the Waikato River

2.1 Introduction

The 1985 AEE supporting the use of grass carp for weed control in New Zealand concluded that spawning was possible in the Waikato River in New Zealand, but that the development of a large breeding population was improbable because river conditions would prevent the survival of most larvae (Rowe and Schipper 1985). This assessment was based on the scientific literature comparing conditions in the larger rivers of Europe and Asia where grass carp had been stocked and where breeding had or had not occurred.

Since 1985, grass carp have been released into many more waterways throughout the world and there is now more specific scientific information available on their breeding requirements. Furthermore, recent reports of grass carp and related species (i.e. silver carp and black head carp) breeding prolifically in the Mississippi River and of grass carp breeding in the Sandusky River of Lake Eire (USA) (Chapman et al. 2013) have raised concerns over breeding in smaller rivers previously considered non-viable for reproduction.

The minimum size and length of river required for grass carp breeding is dependent on surface water velocities and river water temperatures because the eggs must be carried downstream in the current while egg incubation, which is dependent on water temperature, occurs. Given the water velocities and water temperatures in the Waikato River in 1985, Rowe and Schipper (1985) indicated that, based on a precautionary approach, the minimum length of river required for hatching of the eggs in the Waikato River would be close to 80 km. In reviewing the minimum length of river required for grass carp breeding, Cassani et al. (2008) stated that a flow of 0.23-1.6 ms^{-1} and a river length of 50-180 km (depending on water temperature) was required. These lengths are much longer than the 15 km within which drift and hatching of eggs is thought to have occurred in the Sandusky River (Chapman et al. 2013). However, summer water temperatures in the Sandusky River are likely to be relatively high, ranging from 25-30ºC (Murphy and Jackson 2013), so incubation time would be much faster than in other rivers. Increases in water temperature would reduce the length of river required for breeding and climate change scenarios indicate that temperatures can be expected to increase in New Zealand (Mullan et al. 2001). As Rowe and Schipper (1985) did not consider the implications of climate change on water temperatures in the Waikato River, it is timely to re-examine the issue of grass carp breeding in this river.

Rowe and Schipper (1985) assessed the risk of a breeding population of grass carp establishing in the Waikato River by examining the probability that each stage in the reproductive cycle will be successfully completed. The various stages included:

(a) adults can mature and produce viable gametes;

(b) migrations of maturing fish upriver to spawning grounds are not impeded;

(c) river flows are high enough to stimulate spawning;

(d) spawning habitats (i.e. structures resulting in high turbulence, up-wellings or standing waves) occur in the Waikato River;

(e) water velocities are high enough down the river's entire length to keep eggs in suspension;

(f) water temperatures are high enough to allow eggs to hatch before they are carried out to sea;

(g) there is an 80 km length of river below the spawning grounds; and

(h) suitable rearing habitats for larvae and fry occur either in the floodplain, river-stem, or a freshwater estuarine area below the region where egg hatching takes place.

Should all these conditions occur, then a breeding population could theoretically establish, but the size of this would depend on factors influencing juvenile mortality rates and there is currently too little information available to assess this.

A further consideration is the effect that a large breeding population might have on the river's environment and more information on this risk can now be obtained from the international literature. The risk of all these stages being successfully completed in the Waikato River is re-examined below in the light of the international information and experience gained since 1985.

2.2 Adult maturation, migration and spawning

Rowe and Schipper (1985) reported that both male and female grass carp had matured in the wild in New Zealand waters and would readily do so in the Waikato River. Following the escape of 2,500 grass carp into the Waikato River (McDowall 1984), mature adult fish were sporadically captured in the river confirming that maturation of males and females will occur.

Water temperatures over 15ºC are required to help stimulate an upriver spawning migration (Stanley et al. 1978) and occur in the Waikato River during spring months. An upriver migration of maturing adults from the lower river up to the tailrace of the Karapiro Dam would therefore provide the necessary migratory stimulus for ovarian development to occur to the secondary stage (Aliyev 1976). There is little doubt that mature fish (males and females) could move upriver to the Karapiro Dam, which is 146 km above the river mouth. No impediments to the upstream migration of these fish occur in this region of the river.

Spawning habitat for the Asian carps, which include grass carp, has been recently examined in the Yangtze River and more explicitly characterised by Zhu et al. (2013). These carps are all pelagic spawners (i.e. they discharge floating eggs into the surface waters of rivers) and reproduction is stimulated by peak flood flows. A rise in water level over 1.2 m is reported to be required for spawning (Yi et al. 1988, Chilton and Muoneke 1992) but this may simply indicate the size of flows required to produce the right hydrological conditions over spawning grounds.

Spawning grounds for these fish are generally located in river reaches where complex channel morphology and/or river bed structures form rotary, 'vortex' flows that keep eggs in suspension while fertilisation occurs from sperm shed into the turbulent water by the males. Zhu et al. (2013) found that spawning occurred in river reaches where measures of rotary turbulence and vortex flows exceeded c. 27 $cmVs^{-1}$. These areas were characterised by relatively high water velocities (1.5 to 3.0 m s^{-1}) over complex riverbed morphologies. However, the characteristics of the riverbed morphologies that create these vortices and 'rotary' up-wellings are yet to be determined. Grass carp have been reported to spawn in river reaches where boulder substrates, river confluences or the tailraces of dams produce high water turbulence.

The high flows needed to create high water velocities can occur in the Waikato River during peak flood conditions in spring/summer months (Rowe and Schipper 1985) when rising water levels could stimulate grass carp to spawn. Furthermore, there are a number of reaches in the Waikato River below the Karapiro Dam and down to Hamilton (ca. 110 km above the river mouth) where the river is narrow and rocky, where islands and sharp bends occur, or where bridge pylons constrict and intercept the flow and could produce the riverbed morphologies needed to create hydrological spawning habitat. Such areas occur at distances of 53 km (Waipa confluence), 30 km (bridge pylons), 23 km (the Narrows), and at 13 km, 4 km, 2 km, 0.6 km (boulder substrates), and 0.2 km (dam tailrace) below the Karapiro Dam. Although it is not known whether high flow conditions at all or some of these locations would produce the required conditions for grass carp spawning, a precautionary approach to assessing spawning risk acknowledges that this possibility cannot be excluded. Therefore viable eggs could be shed by grass carp into the Waikato River and fertilised by the males.

2.3 Egg incubation and hatching

Eggs are carried downriver in the surface waters of rivers and there is a minimum velocity needed to keep them in suspension. If water velocity drops below this threshold the eggs settle on the river bed where abrasion and damage to the delicate membrane surrounding the egg results in death. Rowe and Schipper (1985) reviewed the literature on water velocities required for the continued suspension of grass carp eggs and adopted a threshold of 0.6 m s^{-1} as this characterised the surface waters of rivers where successful hatching had occurred. However, the suspension of semi-buoyant eggs in water is a complex process and depends on changes in egg density during development and the spatial distribution of water velocities in rivers. Water velocities are generally highest near the surface and in mid-channel, and decrease towards the river edge and river bed. Hence, eggs that are in this zone will continue downriver, whereas those that are on its periphery will drop out of the main flow and then slowly sink. If there are zones in the river where a wider river channel results in a general decrease in water velocities across the channel width, then this may result in all eggs sinking. Hence water velocities over the minimum threshold required to suspend eggs need to be maintained throughout the length of the river.

Leslie et al. (1987) examined the issue of egg buoyancy and water velocity for grass carp, and carried out trials to determine egg survival downriver. They found that 99% of eggs were lost after travelling 3.2 km downriver at a water velocity of 0.23 m/s. However, these losses were due to predation as well as settling. Murphy and Jackson (2013) recently investigated this issue in greater depth for the Asian carps in general (i.e. silver carp, bighead carp and grass carp). When eggs are released into the water by the females, they are small (2.0-2.5 mm in diameter) and relatively dense with a settling velocity close to 0.85 cm s^{-1}. The egg membrane rapidly absorbs water and as a consequence egg diameter increases to 5-6 mm. This 'water-hardening' process results in a semi-buoyant egg and occurs over a period of up to 20 hours during which the egg is fragile and requires turbulent surface water movements to keep it in suspension and transport it downriver. Once the egg is water hardened, lower water velocities can keep it in suspension, and these may be much lower than required for the initial stages of egg suspension. The settling velocity of grass carp eggs after they are hardened ranged from 0.67-0.77 cm s^{-1} (Tang et al. 1989) compared to 0.69 cm s^{-1} for silver carp and 0.80 cm s^{-1} for bighead carp (Murphy and Jackson 2013)[1]. Given the changes in density of eggs as they develop, Murphy and Jackson (2013) calculated that grass carp eggs could hatch ca. 15 km below the likely spawning site in the Sandusky River because water velocities were mostly over 10 cm s^{-1} in the lower reaches and travel time would range from 19-25 hours, which was within the time for hatching as determined by water temperature. Although water temperature in this river was not measured, air temperatures in July ranged from 25-35 ºC (Murphy and Jackson 2013) and Tsuchiya (1980) indicated that grass carp eggs would require 25 hours incubation at 25 ºC.

Garcia et al. (2013) has subsequently produced a Langrarian drift model for Asian carp eggs that simulates the effects of changes in egg buoyancy and calculates drift rates and egg dispersion at various water velocities. This model was tested using actual data on the drift rates of hardened grass carp eggs at a range of water velocities produced in a flume by Tang et al. (1989) and the results were used to simulate egg distribution down the Sandusky River. The results indicated that whereas some eggs were settling near the river bed by 6 km below their theoretical release point, most were still suspended even though water velocities were reduced from 80 cm s^{-1} near the expected spawning site to less than 20 cm s^{-1} in the hatching zone. Significant settling would only be expected to occur after the eggs had travelled more than 15 km downriver (Murphy and Jackson 2013).

Both these studies indicate that some water-hardened grass carp eggs can remain in suspension at water velocities much less than 60 cm s^{-1} and, while there will be some settling (and death) at water velocities less than 10 cm s^{-1}, many eggs will continue to be transported downriver. Significant settling is only expected as water velocities drop below c. 1.0 cm s^{-1}. The proportion of eggs remaining in suspension after a given time at such water velocities is not known, but in the Sandusky River, high water temperatures meant that hatching was possible after only 25 hours by which time the eggs would have travelled 15 km downstream. The risk of grass carp eggs hatching within a short reach of river is therefore greatly increased as water temperature rises.

Water temperatures over 20ºC are required for the hatching of non-deformed larvae of grass carp (Stott and Cross 1973, Shireman and Smith 1983) and incubation time reduces as water temperature rises. Murphy and Jackson (2013) reviewed the literature on the relationship between incubation time and temperature and found a curvilinear relationship. The data presented for grass carp (from Tsuchiya 1980) indicated that hatching times were slightly greater than for silver carp (i.e. 25 hr at 28ºC, 28 hr at 25ºC, and 47 hr at 20ºC). Rowe and Schipper (1985) also presented data on egg incubation times versus temperature from a range of studies on grass carp and noted that hatching times varied more at high than at low water temperatures (e.g. 36-48 hr at 20ºC, compared with 18-36 hr at 25ºC). Although

[1] Murphy & Jackson (2013) used a settling velocity of 0.75 cm s^{-1} for grass carp eggs based on the average for bighead and silver carp.

there is clearly variation in the time of hatching for a given water temperature, a conservative approach is required to produce a precautionary risk estimate.

River water temperatures in the lower Waikato River during summer months are typically over 20ºC and do not exceed 25ºC (Rowe and Boubee 1994). At 20ºC, the minimum hatching time for grass carp eggs would be 36 hrs. Given that some eggs could be travelling downstream at average velocities over 0.1 m s^{-1}, the travel distance required for these eggs to hatch would be 13 km. Travel distances will be longer at higher average water velocities (e.g. 65 km is required if mean water velocities are 0.5 m s^{-1}). These distances are less than the length of the Waikato River below the Karapiro Dam (146 km) and therefore incubation and hatching of grass carp eggs is possible before they are washed out to sea.

The drift model for grass carp eggs indicates that water velocities as low as 0.1 m s^{-1} could allow some grass carp eggs to remain in suspension and travel downriver, but the proportion of those that would do so is unknown. Giurca (1980) examined the breeding of grass carp in the Danube River and noted that it was successful only in years when suitable conditions occurred. These conditions were when water temperatures were over 22ºC and water velocities were over 0.5 m s^{-1} (Staras and Otel 1999). Hence, observations on the natural spawning of grass carp in the Danube River indicate that whereas some successful transport and hatching of larvae can be expected at low water velocities and temperatures, large numbers of larvae only occur when temperatures are over 22ºC and water velocities are over 0.5 m s^{-1}.

Climate change is predicted to increase the incidence and size of flood flows in the Waikato and can also be expected to increase average water temperatures in the river (Mullan et al. 2001). But there are insufficient data at present to indicate the magnitude or frequency of such changes. An increase in water temperature will reduce the time required for hatching and hence the length of river required, but increased flows can be expected to increase average water velocities and hence the length of river travelled during the incubation period. The risk of grass carp spawning would therefore be enhanced by higher river flows, but the effects of increased water temperature on the length of river required for egg incubation could be offset by faster mean water velocities in the river. Hence the role of climate change is difficult to predict. If water temperatures were increased by 2-4ºC, this would be expected to reduce the length of river required and hence increase the overall risk of successful incubation of grass carp eggs in the Waikato River.

2.4 Larval survival and rearing

The development of a naturally spawned grass carp population depends not only on the successful hatching of eggs within the river channel but also on the transport of larvae into suitable rearing areas (Rowe and Schipper 1985, Cassani et al. 2008). The larvae of grass carp go through two stages of development termed proto-larvae and meso-larvae. They are proto-larvae for approximately 3 days post-hatch and during this time have limited mobility (Rowe and Schipper 1985). They therefore continue to be transported downriver by the current. If spawning occurred at Karapiro and hatching occurred 13 km below Karapiro, then larvae would be transported a further 26 km downriver at an average water velocity of 0.1 m s^{-1} and the proto-larvae would transition to the meso-larval stage at about 39 km below the spawning site. However, if mean water velocity was 0.5 m s^{-1}, then the larvae would transition at approximately 194 km and would die as they would be carried out to sea. At a velocity of 0.4 m s^{-1} the total distance would be 154 km, which is also beyond the length of the river between Karapiro and the sea. The mean water velocity in the lower reaches of the Waikato River would therefore need to be less than 0.4 m s^{-1} to prevent the proto-larvae from being washed out to sea. This assumes that spawning would occur just below the Karapiro Dam, but if it occurred at one or more of the sites below the dam (see section 2.2), then mean water velocities over 0.3 m s^{-1} would wash most eggs out to sea. Rowe and Schipper (1985) examined water velocities at different flows in the various regions of the Waikato River below Hamilton. Although mean water velocity in the Waikato River declines with both discharge and distance downriver, it is still above 0.3 m s^{-1} at Mercer.

Meso-larvae are more developmentally advanced and are capable of greater movement, but are still subject to being carried downriver by currents. In their native rivers, these larvae are generally swept by the flood flows into shallow flood plains where water velocities are close to zero and the larvae can develop in the shallow, still and productive waters of lowland lakes. In large rivers where grass carp now breed, reservoirs, lakes or large deltas occur in the lower reaches (Stanley 1976) and take the place of flood plains as larval development habitats. Once these larvae become juvenile grass carp, they are capable of swimming against small currents and can then move to suitable habitats for feeding on the small invertebrates or plants along the river's edge. Meso-larvae are therefore dependent on river currents transporting them to suitable rearing habitat and, in the Waikato River, such habitat was historically provided by the floodplains and lowland lakes. These are now heavily stop-banked and protected by earthworks, weirs and flood gates such that flows are kept within the main river stem and channelled rapidly out to the sea, except when very high flood flows occur and flow diversion is required to channel some of the excess water into Lake Waikare. Hence, at present, most meso-larvae in the Waikato River would be constrained within the main river channel and swept out to sea (Rowe 1986, Clayton et al. 1999).

Rowe and Schipper (1985) concluded that whereas grass carp could spawn in the Waikato River and that some hatching of eggs was feasible, the survival of larvae would be much lower than in rivers where grass carp populations have become established. The escape of some 2,500 grass carp juveniles into the Waikato River in 1984 (McDowall 1984) did not result in the development of a breeding population, even though mature adult fish continued to be caught in the river over the following 13 years.

The recent investigations of grass carp spawning in North America indicate that some incubation and hatching could occur over shorter distances than indicated by Rowe and Schipper (1985) and Cassani et al. (2008), but that the major factor determining the risk of a breeding population becoming established in the lower Waikato River, even with the higher flows and water temperatures expected under climate change scenarios, is the low survival of larvae.

Recent studies on changes in larval densities of the Asian carps in rivers where breeding occurs provides some insight into the factors responsible for the survival of grass carp larvae. Because the fecundity of grass carp and silver carp is very similar, the proportion of grass carp to silver carp larvae produced from natural spawning in rivers where these two species are now naturalised can provide an indication of their relative reproductive success and its dependence on anthropogenic changes affecting rearing habitats. In 1975, Verigin et al. (1979) measured the proportions of carp larvae in the Syr-Dar'ya River where three species of Chinese carp (grass carp, big-head carp, silver carp) had been introduced and established breeding populations. They found that grass carp accounted for 10% of the larvae whereas silver carp were 85%. Hence conditions for grass carp larval survival were less suitable in this river than for silver carp. In 1956, the proportion of grass carp larvae in the Tone River (Japan), where both grass carp and silver carp had been introduced and established naturally breeding populations, was 79% compared with 21% for silver carp (Tsuchiya 1979). By 1960, following river modification and declining water quality, the proportion of grass carp larvae was reduced to 7% while silver carp accounted for 93%. The anthropogenic changes in the Tone River therefore reduced the survival of grass carp larvae relative to silver carp. Similarly, in the Yangtze River (China), where construction of the Three Gorges Dam affected the river, the proportion of grass carp larvae fell from 43% in 1964 to 25% by 2005 whereas over the same period the proportion of silver carp increased from 14% to 66% (Duan et al. 2009). The recent invasion of the Mississippi River primarily by silver carp and blackhead carp (Chick and Peg 2001, De Grandchamp et al. 2007, Lohmeyer and Garvey 2009) reflects the greater reproductive success of these species compared to grass carp) in this river system. Although grass carp also breed in this river, conditions for the survival of grass carp larvae are much less suitable than those for silver carp and black head carp. These species differences in the survival of carp larvae in modified rivers indicate that grass carp larvae have lower survival rates than silver or bighead carp larvae, and they indicate that conditions for the survival of grass carp larvae are more stringent than for the other Asian carps.

Rowe (2010) reviewed studies on the behaviour of silver carp and grass carp larvae and noted that there were key differences in the behaviour, habitat and feeding of these fish. Silver carp larvae are better adapted to open-water planktivory than grass carp larvae (Peirong 1989) and can thrive in plankton-rich habitats including the lower regions of large, slow-flowing rivers and reservoirs. In contrast, grass carp larvae require low water velocity habitats provided by flood plains, reservoirs (as in the Kara Kum canal), or lowland riverine lakes (Rowe and Schipper 1985). Hence, modification of river flows and river morphology to reduce flooding mitigates against successful grass carp reproduction while enhancing that of silver carp. In the Waikato River, the loss of connectivity between the flood flows and lowland lakes, combined with the construction of flood prevention works to prevent waters entering flood plains has largely eliminated grass carp larval rearing habitat. Because of this, the risk of a high density population developing in the lower Waikato River is low to negligible, and could only be contemplated if flood flows were to breach the protection works.

Although most grass carp larvae in the Waikato River would be washed out to sea and perish, it is acknowledged that not all larvae would be carried downriver by the current and that some could enter more sheltered backwaters on the rivers margin, where they could survive and mature. Hence, the rare occurrence of grass carp is possible in the Waikato River, but the development of a large population is improbable.

2.5 Consequences of natural breeding

The main concern with the naturalisation of grass carp in New Zealand is that densities high enough to reduce aquatic vegetation will occur (Rowe and Schipper 1985). While it is acknowledged that some breeding of grass carp could occur in the Waikato River, the risk that a high density population will develop and create impacts is negligible. Rowe and Schipper (1985) indicated that, in all the rivers where grass carp had been introduced and a natural breeding population had established, adult densities were generally low, and no adverse impacts had been recorded. Recent data on larval proportions and survival in rivers where the Asian carps now breed (see section 2.4) reinforce the likelihood that grass carp densities will be low and hence incapable of causing adverse impacts. In the Danube River, where annual changes in fish species composition were determined from 1960 to 1999, the proportion of all Asian carps was generally close to 1% or less, except in 1993 when it increased to 10% (Schiemer et al. 2005). This spike in density was likely to be due mainly to the breeding success of silver carp. Hence, grass carp were relatively rare in the Danube River despite the long-term presence of a breeding population. In rivers where Asian carp densities are reported as being high (e.g. in the Mississippi River), it is the silver carp and blackhead carp that are responsible for the high densities of carp and resultant problems (Chick and Peg 2001, De Grandchamp et al. 2007, Lohmeyer and Garvey 2009), not grass carp. Hence the official list of 'injurious fish species' in the USA includes silver and bighead carp but not grass carp (Short et al. 2004).

Pipalova (2006) and Cassani et al. (2008) noted that impacts of stocked populations of grass carp in lakes were dependent on high stocking densities and that the environmental effects of grass carp at low stocking densities were minimal. The environmental effects of grass carp in lakes were all indirect and related to the extent of macrophyte reduction. The same principal will apply to rivers. Environmental impacts in rivers would only occur if grass carp densities were high enough to remove most macrophytes. However, grass carp are not artificially constrained in rivers as they are in stocked lakes and so localised densities high enough to remove all macrophytes will be rare. Grass carp in rivers can be expected to move both up and downstream because they are strong swimmers and good jumpers. They will move to areas where macrophytes are most abundant and water velocities and temperatures are acceptable. Cold, spring-fed streams containing large amounts of macrophyte would be avoided because water temperatures are too low for grass carp feeding, as would areas that are too shallow for feeding (< 50 cm). Such areas aside, grass carp can be expected to spread rapidly throughout the river system to macrophyte containing areas in the main stem, tributary streams, as well as the lowland lakes. Grass carp escapees in the Waikato River were later reported from a wide range of habitats both above and below the stocking area and in riverine lakes. This movement and dispersion throughout the river minimises the risk of localised high fish densities occurring and removing all macrophytes in one part of the river.

There are no reports in the international literature of macrophytes disappearing or being reduced in rivers where grass carp reproduce and hence no reports of impacts. In 1976, grass carp had been stocked/released into 8 large rivers throughout the world where breeding and 'naturalisation' had been confirmed (Stanley 1976). At that time, breeding and 'naturalisation' of grass carp in the Danube had not occurred despite extensive stocking, but this has since been confirmed. Similarly, breeding in the Mississippi River Basin had not been confirmed but now has. More recent reviews and reports (Sutton et al. 1977, Stanley et al. 1978, Verigin et al. 1979, Shireman and Smith 1983, Opuszynski and Shireman 1995, Chick and Pegg 2001, Schmiemer et al. 2005) indicate that grass carp have now formed natural breeding populations in at least 10 large rivers including the Tone (Japan), the Pampangi River (Philippines), the Volga River (Europe), the Danube River (Europe), the Amu- and Syr-Darya Rivers (Asia), the Ili River (Asia), the Kuban River (Asia), the Terek River (Asia), the Rio Balsa (Mexico), and the Mississippi (USA). There are no known reports of grass carp causing environmental problems in any of these rivers.

Should some grass carp breeding occur intermittently in the Waikato River, and some juvenile survival occur, the resultant density of fish would be too low to adversely impact macrophytes in this river. The effects of a low density population of grass carp would be much less than the effects of the koi carp now present throughout the lower Waikato River, and the failure of grass carp to reproduce, or remove macrophytes throughout this river following the 1984 escape of ca 2,500 grass carp into the Waikato River, reinforces this conclusion. Impacts would only be expected if a large adult population were present and added to the overall browsing pressure of koi carp.

Clayton et al. (1999) estimated that 20,000 grass carp would be required to eliminate all vegetation in the Waikato River. Intermittent breeding and limited survival of larvae to adulthood together with the occasional escape of fish from treatment areas would not combine to result in such a high number of grass carp in this river. However, escape of large numbers of fish from a hatchery complex, or from most of the larger drains (assuming they were all stocked at 150/ha and all were breached at the same time) would be required for densities close to this level. Hence the risk of impacts from grass carp in the Waikato River is more likely to arise from massive widespread escapes from drains stocked with grass carp, or from a hatchery or juvenile rearing operation, than from natural reproduction.

Whereas the development of a large natural breeding population of grass carp in the Waikato River, capable of causing environmental impacts, is extremely unlikely, this depends on continuation of the status quo in terms of land use, flood protection works and river flows. The main bottleneck responsible for the current low risk of grass carp reproduction is the lack of adequate habitat for the larval development stage in the lower river. This habitat would be provided if one or more of the following occurred:

(a) flood protection works in the lower river were changed or breached (e.g. during a disaster) to allow flood waters to move directly to the lowland lakes of flood plains,

(b) land subsidence (e.g. via an earthquake) occurred such that the level of the existing plains dropped and allowed more frequent inundation,

(c) sea level rise and greater tidal inundation of the lower river resulted in the loss of pasture in the existing plains such that their use as pasture was not possible and they reverted to shallow swamps and wetlands,

(d) combinations of these factors occurred resulting in restoration of flood plains in the lower Waikato River.

Given the predictions for climate change, sea level rise and the recent global increase in large and more severe storms, scenarios (a) and (c) have to be considered as feasible and, in the long term, may even be inevitable. Should any of these events occur, then policies related to grass carp stocking in the lower Waikato River would need to be re-evaluated.

The bottleneck to the survival of larval grass carp that currently limits the development of a large population would be removed if large numbers of juvenile grass carp, such as occur in hatcheries or juvenile rearing ponds, escaped into the Waikato River. Even with high mortality (e.g. from shags), survival rates from the escape of very large numbers of fish (e.g. hundreds of thousands) would be sufficient to produce a relatively large population of adult grass carp in the river such that this species could become common.

Although such escape would not change the risk of grass carp breeding, many fish would be expected to congregate in the few areas where aquatic plants still persist. The increase in browsing pressure from grass carp would be expected to compound the effects of browsing by koi carp and would most likely further reduce waterfowl habitat in the lower Waikato River. Hence, an ecological impact would be expected should large numbers of stocked grass carp escape into the lower Waikato River. Similarly, the escape of large numbers of grass carp from a hatchery or juvenile rearing facility into another river could create an impact in connected wetlands and lakes containing macrophyte-based habitat in the catchment. Large populations of grass carp associated with hatcheries and juvenile rearing facilities are therefore best located in catchments where there are no valued macrophyte-based habitats downriver. This would ensure, that should a major disaster occur and result in the escape of large numbers of grass carp, there is little risk of a major ecological impact.

The risk of escape by large numbers of grass carp into the lower Waikato River is currently negligible because there are no large stocks of grass carp present in this catchment. Should large numbers of grass carp (e.g. > 10,000) occur in the future, the risk of escape would need to be carefully considered and minimised. This risk will increase as the more intense and prolonged rainfall events predicted by climate change scenarios occur. The risk that such events will result in catastrophic flooding that will inundate rearing ponds will also increase with distance downriver towards the river mouth because rising sea level and/or storm surges and spring tides could act together to increase flood height in the plains near the river mouth. In addition, the Waikato River catchment is vulnerable to the effects of volcanic eruptions and earthquakes. To avoid escape during such natural disasters, barriers and containment structures for large populations, such as occur in hatcheries and rearing ponds, would need to be constructed to withstand the likely effects of these natural disasters.

3 Methods for identifying escapees

3.1 Introduction

The ability to detect natural breeding by grass carp necessitates the ability to distinguish between those fish that may have resulted from natural breeding, and stocked hatchery fish that may have escaped containment.

3.2 Existing methods

Currently used methods for detecting the occurrence of natural breeding by grass carp in the Waikato River rely on the fact that most hatchery fish are stocked at a size over 200 mm to avoid predation by shags. Hence the presence of fish under this size in the river would indicate that natural spawning has occurred. Alternatively, small grass carp may occur in the river at a later date and raise concerns about natural spawning (e.g. Baker and Smith 2006). In practice, discrimination of hatchery reared from wild grass carp has proved problematic because the minimum stocking size is a guideline and some small grass carp (e.g. 150-200 mm TL) can be inadvertently stocked into a lake and then escape to the river. In addition, if a hatchery or juvenile rearing facility occurs in the river catchment, then escapees, from this could provide a plausible alternative to natural spawning (Baker and Smith 2006).

Examination of otoliths to determine early growth rates provides a potential way around this problem because hatchery fish, which are grown in high density ponds with a limited food supply, generally have a slower growth rate than wild reared fish. Determination of growth rate over the early years is possible because winter annuli are present (Baker and Smith 2006). In practice, this approach has also proved to be problematic because there are wide variations in the growth of hatchery fish. Some hatchery fish grow rapidly whereas the growth of others is stunted.

3.3 New methods for identifying sources of grass carp

An alternative to the otolith-based approach would be the marking or tagging of all hatchery fish. Fin-clipping is commonly used as a means to mark and hence identify hatchery-reared trout in order to distinguish them from wild fish. This works well, but requires the complete ablation of the pelvic fin rather than clipping it because complete re-growth of clipped fins occurs over a period of 2 or more years, depending on the age/size of fish. For example the right pelvic fin was clipped on grass carp that were released into Lake Hood in May 2005 (Decker 2007). Near complete regenerated of the right pelvic fin was observed on grass carp that were captured from the lake in November 2006 (Decker 2007). Ablation is more difficult and time consuming than clipping and its success-rate is dependent on the skill of the fin clipper. Hatchery-reared grass carp could also be identified by pelvic-fin ablation, but there is no reported practical experience of pelvic fin ablation in grass carp to indicate that it is viable and/or does not affect the ability of these fish to feed on macrophytes.

PIT (Passive Internal Transponder) tags have been used to individually tag grass carp stocked into Lake Wainamu (Auckland Council), but these tags have a cost and require a small surgical insertion in the abdomen of the fish, which increases stress, handling times and the risk of mortality. PIT tagging is feasible for fish over about 150 mm in length.

Wire tags (or nose tags) are much smaller and much less costly and can be readily inserted into very small fish (50-100 mm long). They were used routinely and successfully to mass tag large batches of salmon smolts in New Zealand. The 5 mm long x 1 mm diameter metal-wire nose tag is rapidly injected into the snout of small fish without the need for anaesthesia and can be detected in adults when their heads are placed into a metal tag detector. This tag lasts for the life of the fish and poses no threat to fish or human health or the environment. It would provide certainty in detecting hatchery-reared (i.e. tagged) grass carp from naturally reared ones (i.e. no tag), but it will increase the cost per fish because of the time needed to tag each fish.

More sophisticated techniques, based on the chemical composition of otoliths, are also now possible. The proportions of various metals in the water in which fish develop are incorporated into bony structures such as the otolith. The concentrations of these metals can now be detected with great accuracy near the core of the otolith and will reflect the respective concentrations in the rearing water. Hence, by identifying the metal concentrations in the otolith of a small grass carp, it is possible to determine where it was reared and, in particular, whether it came from a known hatchery rearing pond or not.

Various ratios of metals (e.g. the ratio of strontium to calcium) and the changes in these as fish grow have been successfully used to confirm that juvenile grass carp have developed naturally in the Sandusky River (USA) and not a hatchery (Chapman et al. 2013). This was possible because the water in the Sandusky River has a high concentration of strontium relative to hatchery waters. In New Zealand, analysis of the microchemistry of smelt otoliths revealed that different spawning stocks could be differentiated within the Waikato River because their otolith microchemistry showed different patterns. Hence otolith microchemistry is sensitive enough to identify where post-larval, juvenile grass carp have developed. The technology and expertise for such analyses (i.e. Inductively Coupled Plasma Mass Spectrography) is now well developed and available via the University of Waikato. It would be possible to sample juvenile grass carp from a hatchery (or rearing facility) and to identify the microchemical profiles of their otoliths. Should grass carp then occur in the Waikato River, their otoliths could be removed and checked to see whether their 'juvenile microchemical fingerprint' conforms to the hatchery profiles or not. However, the adoption of this method would require initial feasibility and calibration studies to confirm its reliability and repeatability. This is because the metal concentrations present in river/stream water may change between years depending on changes in catchment characteristics and landuse (e.g. topdressing patterns). It would be essential to confirm the reliability of the metal concentration patterns in hatchery water and fish otoliths over several years before adopting this method.

Genetic methods based on DNA analysis are also developing rapidly and may have a future role in the separation of hatchery from wild reared fish. Chen et al. (2012) used 21 microsatellite markers in the DNA of grass carp to distinguish stocks from various rivers. They also found reduced allelic richness and heterozygosity in the introduced stocks now breeding naturally in the Tone, Mississippi, and Danube Rivers, compared with grass carp in their native rivers (i.e. Yangtze, Amur, Pearl Rivers). However, such differences would not be expected between hatchery fish and the naturally spawned fish from recent escapes. Finer scale DNA analyses would be required to identify familial DNA links. Whereas this approach is technically possible, it would require preliminary investigation and study to determine the DNA profiles of all grass carp families raised in hatcheries to provide the necessary baseline for detecting ‘wild-reared’ grass carp. While polymorphic DNA fingerprinting has been developed for carp species, including grass carp (El-Zaheem et al. 2006), the ability to distinguish between families is in its infancy.

Currently, the most viable way of detecting any naturally bred grass carp in the Waikato River from hatchery-based fish would require micro-tagging all hatchery fish stocked into the catchment. However, the assumption that all nose tags will be retained by the tagged fish has not been tested, and some losses may occur due to errors in the insertion technique and tag expulsion over time in some fish. This assumption would require testing and the percentage loss rate determined.

4 Environmental effects of plant control by grass carp

4.1 Introduction

Rowe and Schipper (1985) assessed the environmental impacts that could result from the use of grass carp for weed control in New Zealand lakes and ponds. This assessment was based mainly on the research carried out in other countries up to that time, but it was adapted to a New Zealand context through the experimental trials with grass carp carried out mainly in Lake Parkinson (Auckland). Since 1985, grass carp have been introduced to many other waterbodies in New Zealand and there is now more information to draw upon to assess their environmental effects in lakes. In addition, the use of grass carp for plant control in lakes has increased internationally over the past decade and there is now a greater amount of information available in the international literature to draw upon. Much of this has been reviewed and periodically summarised in Chilton and Muoneke (1992), Bain (1993), Cassani (1995), Opuszynski and Shireman (1995), Cudmore and Mandrak (2004), Pipalova (2006), Cassani et al. (2008), Dibble and Kovalenko (2009) and Nico et al. (2012).

In New Zealand, the main concern with grass carp expressed in 1985 was its potential impact on rainbow trout and trout fisheries in lakes. However, the effects of grass carp on water quality and waterfowl were also of concern at that time. Experience with the use of grass carp in New Zealand over the past quarter century has indicated that whereas most of the predictions of Rowe and Schipper (1985) have been upheld, some changes were not predicted and now need to be addressed. In particular, there was little information available on the effects of weed removal by grass carp on turbidity levels in lakes and ponds and on the development of harmful algal blooms. Similarly, little attention was paid to the effects of grass carp on non-salmonid fish. Further, it is now apparent that the screens across lake outlets required to keep grass carp at high densities, could cause impacts by preventing downstream migrations of adult eels. These omissions are addressed in this section and new information collected over the past quarter century is presented on the risk profile of other potential environmental effects.

4.2 Water quality

Rowe and Schipper (1985) examined the results obtained by Mitchell et al. (1984) on the changes in lake water quality caused by grass carp browsing in Parkinson's Lake. In this lake, limnetic plant nutrients (nitrogen and phosphorus) increased during the summer after total weed control was effected by the grass carp. Phytoplankton biomass as measured by chlorophyll *a* increased and was accompanied by an increase in zooplankton and a spike in ammonia (from zooplankton excretion). As a consequence, secchi disc depth in this lake decreased in autumn-winter months after weed control (during the seasonal phytoplankton maxima) and increased in spring-summer months when zooplankton were most abundant (Mitchell et al. 1984). Rowe and Schipper (1985) concluded that in already nutrient-enriched (i.e. eutrophic) lakes, such as Parkinson's, a high stocking density of grass carp would produce an initial increase in limnetic plant nutrients after total weed control was achieved and that this would result in a short-term (1-2 year) increase in phytoplankton followed by an increase in zooplankton. In less nutrient enriched lakes, such limnological effects would be less marked to the point of not being detectable.

The limnological changes observed in Parkinson's Lake were in accord with the results of studies on grass carp browsing reported in the international literature since 1985 and the expected response of a small lake to rapid and total macrophyte removal. Pipalova (2006), Cudmore and Mandrak (2004) and Cassani et al. (2008) all noted that a number of studies had found evidence of an increase in nitrogen or phosphorus concentration and/or chlorophyll *a* in some lakes. However, they pointed out that a number of studies had also found no evidence of change in other lakes. Most of the major changes were reported in American lakes where all macrophytes were removed by high density grass carp stocking. Pipalova (2006) concluded that the effects of grass carp on water quality were greatest in small lakes (with no inlet or outlet) where the macrophytes contained a high proportion of the total nutrient load. Conversely, such water quality changes would be least in large waterbodies where there was some water flow through the system and where only a proportion of the plants was removed.

Pipalova (2006) also noted that the extent of plant removal and its rate of removal was crucial to changes in water quality. Hence, the stocking density of grass carp in relation to plant biomass is a major determinant of what water quality changes can be expected in lakes. It follows that the proportion of plant biomass in relation to lake volume is also a key determinant. Where plant biomass covers a major proportion of the lake area, effects of rapid removal by a high grass carp density will be greater than in lakes where macrophyte cover is minimal in relation to lake volume. Effects will also be greater in lakes with high stocking densities of grass carp than in those where plant removal occurs more slowly, over a period of several years, because of a lower grass carp stocking density. A density of 30 kg of grass carp per ha of lake surface was observed to have negligible effects on water quality (Pipalova 2006), with higher stocking densities having some effect, the magnitude of which depended on the stocking density in relation to the extent of macrophyte biomass in the lake. A high stocking density was generally over 100 kg ha^{-1}.

Cassani et al. (2008) also examined a number of studies on water quality effects and noted that these changes were associated with the rapid removal of large amounts of weed by grass carp, and were usually short term (1-2 years) such that limnological conditions then moved back towards the pre-treatment state.

These observations and limnological insights indicate some of the reasons why water quality changes can occur in some lakes stocked with grass carp but not in others. They indicate that risk assessments for the impact of grass carp on lake water quality need to be specific for a given lake and linked to the proportion of macrophyte biomass in relation to lake volume as well as to the stocking density of grass carp proposed. For example, Pipalova (2006) indicated that when the dry weight biomass of macrophytes in a lake is less than 1 g m^{-3} and it contains less than 25% of total phosphorus in the water column, there will be no effects of grass carp on water quality.

4.3 Water clarity

A more specific change in water quality that is of concern in New Zealand lakes is reduced water clarity. Pipalova (2006) noted that a number of North American studies had reported a decrease in clarity from increased phytoplankton in some lakes after macrophyte removal by grass carp, but that other studies in other lakes had found no detectable change in clarity. In New Zealand, Mitchell et al. (1984) recorded a reduction in water clarity in Parkinson's Lake following weed removal by grass carp, but this reduction was restricted to autumn/winter months and coincided with peak chlorophyll *a* levels reflecting a high phytoplankton biomass at that time. Water clarity returned to pre-grass carp levels during spring and summer when zooplankton density peaked and phytoplankton were heavily grazed. Water clarity in this lake was therefore affected mainly by phytoplankton density. After weed removal, water clarity remained similar to the pre-grass carp levels, but the later eradication of all fish in Parkinson's Lake resulted in a marked improvement in water clarity (Rowe and Champion 1994). Tench and rudd are both introduced species and such fish have been shown to reduce water clarity in small New Zealand lakes (Rowe 2007). These species were both abundant in Parkinson's Lake, so would have accounted for some of the low water clarity in the lake, both before and for several years after weed removal by grass carp. They were later eradicated (by rotenone treatment), but their presence was therefore a confounding effect for water clarity and it may have exacerbated the effects of weed removal by grass carp on water clarity. By reducing sediment stability through their browsing activities, these fish encourage the re-suspension of silt by wave action (Rowe 2007). This effect will have increased after weed removal when more of the shallow littoral zone was exposed to foraging.

Pipalova (2006) noted that wind action was reported in one investigation to increase turbidity in shallow lakes because wave action re-suspended silt after the protective macrophyte cover was removed by grass carp. It is likely that in shallow lakes with long fetches and shallow exposed shorelines with soft sediments, wind and wave action will increase turbidity from siltation after grass carp have removed all vegetation to a greater extent than deep, steep-sided, rocky, or sheltered lakes with short fetches. Lake Waingata (Northland) is a relatively shallow (maximum depth 7 m) elongated lake with its main axis lying parallel to the prevailing westerly winds. It is a dune lakes with soft shores and readily erodible banks. Hence it was vulnerable to sediment re-suspension after macrophyte removal by grass carp. Grass carp were introduced to this lake in 1995 and monitoring was carried out over a 6 year period from 1993 to 1998 (Rowe et al. 1999). The turbidity of this lake was observed to increase shortly after macrophyte removal, but the effects of wind and wave action on the soft substrate were highly dependent on the extent of strong westerly winds. The sediment settled rapidly once wind and wave action decreased and water clarity then increased. Several years after weed removal had occurred in this lake, low-growing turf species (e.g. *Glossostigma elatinoides, Elatine gratioloides*, *Lilaeopsis novae-zelandiae*) began to expand around the lake margin where it was too shallow (< 30 cm deep) for the large grass carp to feed (Rowe et al. 1999). These plants acted to consolidate and protect sediment in the shallow littoral zone from the effects of wave action, thereby reducing silt re-suspension. Similar observations of turf-forming species developing within the shallow littoral zone following macrophyte removal by grass carp have now occurred in other New Zealand lakes and will have acted to dampen silt re-suspension by wave action.

Cudmore and Mandrak (2004) noted that in some lakes, grass carp had eroded the lake and pond banks by consuming the roots of terrestrial plants. This would increase turbidity in lakes with soft and erodible banks, especially where rush beds are present on relatively steep sloping banks where grass carp are able to manoeuvre to feed on them (see section 4.7). Similar observations have been reported in some New Zealand ponds (near Waipu Cove) where rush beds grew on steeply sloping banks and the grass carp consumed the exposed root material. However such effects are less likely in lakes with rocky substrates and/or sandy shorelines.

These observations indicate that the removal of all macrophytes by grass carp can be expected to reduce lake water clarity at times and for variable periods in some (but not all) New Zealand lakes depending on the extent of macrophyte beds, the depth of the lake, the type of sediment (e.g. silt versus sand or rock), the lake's exposure to wind and the presence of other introduced fish. A reduction in water clarity is therefore not a typical response to weed removal by grass carp, but a conditional and sometimes temporary one. In the long term, increases in water clarity will occur as the spike in nutrient levels in the water column that can be caused by sudden and rapid macrophyte removal subsides, and as silt re-suspension is reduced by the spread of low-growing turf species that consolidate soft substrates in the shallows.

4.4 Harmful algal blooms

Pipalova (2006) noted that several studies had reported increases in cyanobacteria (blue-green algae) following weed removal by grass carp but others had not. Cassani et al. (2008) also reported cyanobacteria dominance in some Florida lakes following weed removal by grass carp. However, no cyanobacteria blooms occurred in oligotrophic lakes suggesting that the post weed control dominance by cyanobacteria species observed may be associated with eutrophic systems. Cyanobacteria species can result in the development of toxic algal blooms and so the risk that grass carp browsing will lead to cyanobacteria blooms needs to be more closely examined.

Rowe (2011) examined this issue in some detail in Lake Roto-otuauru (also known as Lake Swan), Northland, where a cyanobacterial bloom occurred in the autumn following weed removal by grass carp. Examination of the water quality changes preceding this bloom indicated that it arose as a consequence of a change in species dominance within a multi-species phytoplankton bloom caused by a spike in phosphorus concentration. The spike in phosphorus coincided with a prolonged period of calm weather in this lake caused by de-oxygenation of the hypolimnion. Hypolimnetic deoxygenation is known to release phosphorus into the water column when re-mixing occurs. The later change in species composition of the phytoplankton bloom from diatom to cyanobacteria species also coincided with a period of calm weather. As calm weather and lake stratification facilitated the sinking of relatively heavy diatom-based phytoplankton, species that are better able to cope with reduced water-mixing (i.e. flagellates and buoyant cyanobacteria species) replace the diatoms. It was concluded that while the cyanobacteria bloom occurred shortly after weed removal by grass carp, this was coincidental and the development of the bloom was not a direct consequence of weed removal. Weather conditions, specifically prolonged periods of calm weather were the more important and critical factors leading to its development.

A large cyanobacteria bloom also occurred in Lake Tutira (Hawkes Bay) several years after weed removal by grass carp. Grass carp were stocked into this lake in December 2008 and total weed bed control was achieved by April 2010 (Hofstra 2010). Cyanobacteria blooms have occurred in this lake during most summers over the past 30 years but the bloom in late 2012 was larger than usually encountered. The large peaks in cyanobacteria biomass (as measured by fluorescence in late 2012) were related to a prolonged rise in water level and a large increase in turbidity both of which were uncharacteristically uncoupled from rainfall (see data presented in Abell et al. 2013). Hence, the larger than usual cyanobacteria blooms in this lake in late 2012 were temporally correlated more with the prolonged inundation of the vegetated margin of the lake edge than with macrophyte removal. No such changes occurred in the nearby, but mesotrophic, Lake Opouahi, also stocked with grass carp in December 2008. Cyanobacteria blooms also occurred in Lake Omapere (Northland) both before and after weed removal by grass carp.

Whereas these observations and insights indicate that weed removal by grass carp has coincided with cyanobacteria blooms in some lakes, it has not resulted in blooms in a number of other lakes including eutrophic lakes such as Parkinson's Lake, Elands Lake, and Lake Waingata, nor in mesotrophic lakes including Lake Wainamu and Lake Opouahi. Nevertheless, the nutrient spike in lakes that follows rapid removal of macrophytes by a high density grass carp stocking could, under certain circumstances, be a pre-disposing risk factor for cyanobacteria blooms.

Rowe (2011) produced a risk assessment for cyanobacteria blooms in small New Zealand lakes based on an Australian model (Newcombe et al. 2010). This noted that while high total phosphorus concentration (>25 g m^{-3}) was a significant risk factor, high water temperature (>20ºC), the extent of thermal stratification during summer months (frequent), and a previous history of blooms (resulting in spore formation and re-seeding) were also high risk factors. Hence, the formation of cyanobacterial blooms requires much more than weed removal by grass carp. Other risk factors are more important, but weed control by grass carp should be considered more carefully in lakes that have a high risk profile for cyanobacteria blooms. Lower stocking densities of grass carp that remove weeds more gradually and which reduce the risk of a larger than usual nutrient spike are more suited to such lakes than high stocking densities.

4.5 Fish

One of the major concerns over the use of grass carp for weed control in New Zealand was their potential effect on trout fisheries in lakes. The trial in Parkinson's Lake indicated that direct impacts on trout (or other desirable fish) via the food chain did not occur (Rowe and Schipper 1985). This was because the removal of macrophytes by grass carp only affected littoral zone habitats and food webs, rather than pelagic zone food webs. Hence lakes with large pelagic zones would be less affected by weed removal than lakes with relatively large littoral zones. In Parkinson's Lake, weed removal resulted in the development of a high density of chironomid larvae in the exposed sediments of the littoral zone formerly covered by macrophytes. This resulted in a large increase in the density of common bullies, which are a primary prey species for other fish (Rowe and Schipper 1985). Hence, whereas some invertebrate prey species dependent on macrophytes will have declined, chironomid production in the littoral zone was increased and this enhanced common bully production such that predators of this small forage fish also increased.

This same response has now been recorded in Lake Waingata (Rowe et al. 1999), and in Lakes Tutira and Opouahi (Smith and Rowe 2011) indicating that it is a general consequence of weed removal and not restricted to Parkinson's Lake. Hence, weed removal increases the abundance of chironomids and raises production of common bullies for the benefit of piscivorous fish such as trout and eels along with birds such as herons, shags and kingfishers. The increase in chironomid larvae also provides a major food source for other small fish in lakes such as elvers, smelt and galaxiids. For example, the abundance of dwarf inanga (*Galaxias gracilis*) increased in Lake Waingata after removal of macrophytes by grass carp (Rowe et al. 1999). The risk of adverse effects from weed removal, for the growth of these fish, is therefore minimal and it may even be beneficial in that the limnetic zone is increased.

Littoral macrophyte beds may also provide protective cover for some fish species and the removal of all plants in the littoral zone by grass carp could therefore increase predation on these fish and reduce food and spawning habitat. This is the main concern with the use of grass carp for weed control on fish in North American lakes (Pipalova 2006, Cassani et al. 2008). There was no indication that a lack of macrophyte cover has affected common bullies because they have increased in density in all lakes after the removal of macrophytes. Similarly, more recent, long-term monitoring data on dwarf inanga in Lake Waingata (Rowe et al. 1999), on smelt and eels in Lake Opouahi, and on eels in Lake Tutira (Smith and Rowe 2011) indicates that weed removal by grass carp has had no adverse effect on the abundance of these native fish. In contrast, weed removal by grass carp did have an effect on rudd in Parkinson's Lake. The density of these fish as measured by mean catch per unit effort (CPUE) declined rapidly after weed removal, primarily because they became more vulnerable to predation by shags (Rowe 1984). Their main food supply (macrophytes) was also largely removed, resulting in reduced feeding (author's unpublished data). Although rudd use macrophytes as a spawning substrate, there was no apparent reduction in the number of juvenile fish after total weed control.

Similar results have been found in other countries. Cudmore and Mandrak (2004) noted that fish growth can be adversely affected when aquatic vegetation becomes too dense and spatially complex. Hence moderate removal results in improved growth for some fish species, whereas total removal can reduce growth. In general, phytophilous fish species dependent on aquatic vegetation for food or protective cover were affected by plant removal, whereas benthic and pelagic species were not and could benefit. Similarly, Pipalova (2006) reviewed the effects of weed removal by grass carp on other fish species, mainly in North America and Europe. She noted that whereas some fish species increased after weed control by grass carp in some lakes, other species and especially phytophilous species were often reduced. This was further reinforced by Dibble and Kovalenko (2009).

In particular, Pipalova (2006) noted that the abundance of phytophilous species including perch, crucian carp, roach, rudd and tench, declined because of a reduction in their spawning substrate and/or protective cover. Some of these species (rudd, tench and perch) are present in New Zealand lakes. Except in the few lakes set aside for coarse fishing enthusiasts, they are considered pest species because of their unchecked population growth and adverse effects on water quality and on indigenous biodiversity (Rowe 2007, Rowe and Wilding 2012). Hence, their decline would not be viewed as a negative impact of weed removal in most lakes.

In lakes where grass carp must be constrained by some sort of barrier to prevent emigration downstream, the natural movement of native fish (e.g. migratory species such as eels) could be affected. Such barriers are of no consequence to upstream migrant fish because the native species are all small and can easily pass through screens preventing the emigration of adult grass carp. However, the downstream emigration of large migrant eels does present a potential problem as longfin eels may be too large to pass through the mesh size of the screens. This potential problem has been resolved by the development of an adult eel pass designed to allow large-girthed migrant eels to readily pass over a barrier while preventing other fish from doing so. In essence, this consists of a large diameter (150 mm) PVC tube whose ends lie in the water above and below the barrier (Figure 1). Where this tube passes through or over the barrier, it has a U-shaped section that extends 20 cm or more above the water level. The U-shaped section above the water level prevents swimming fish from passing through the tube but allows adult eels to move over it. This design has been tested in a flume tank and found to work well. PIT tagged adult eels were placed on the upstream side of the pass and readily passed through it (Smith and Rowe 2014). Adult eel passes have been installed in the outlets of Lake Opouahi and Lake Tutira where mesh barriers and metal screens respectively prevent the emigration of grass carp and would have also prevented downstream passage of large migrant longfin eels.

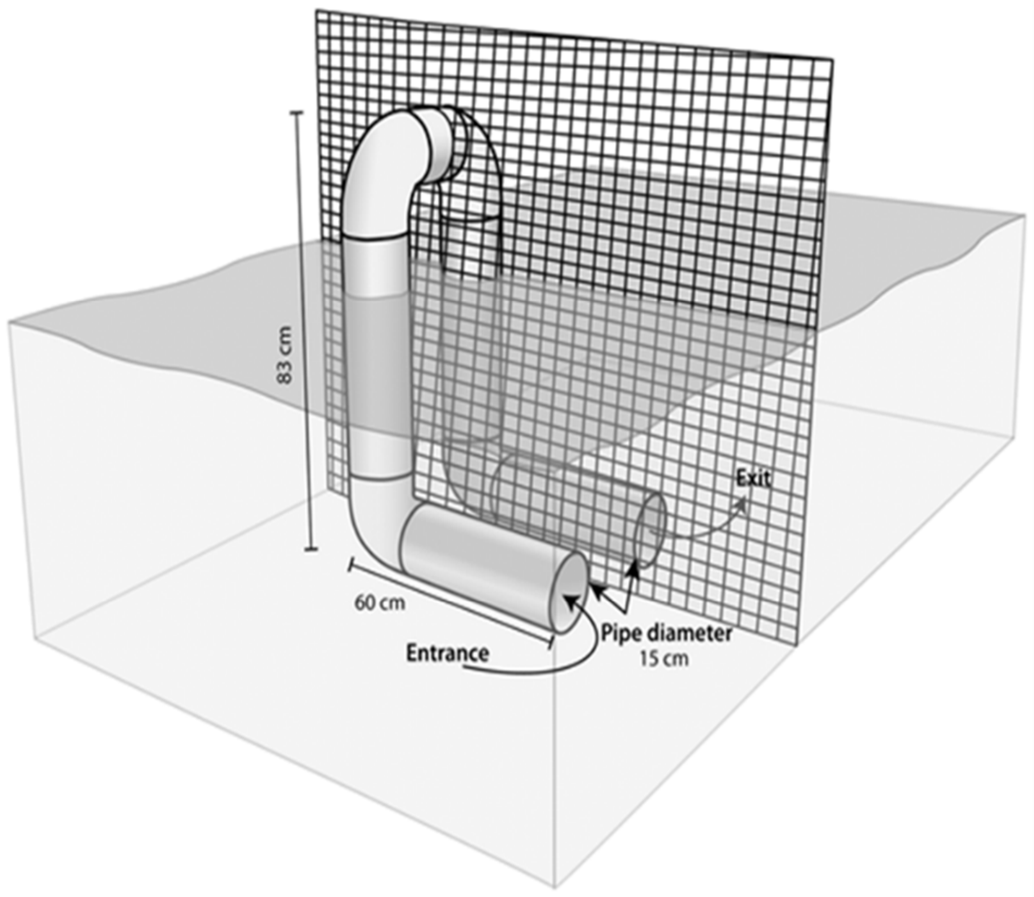

Figure 1: Design of eel pass for insertion in a fish screen.

4.6 Waterfowl

Concerns over the effects of weed removal by grass carp on waterfowl in New Zealand were addressed by Rowe and Schipper (1985). They concluded that, of all the species they considered, black swans in particular could be adversely affected because they depend on macrophytes in lakes as a food source. However, swan numbers did not show a decline in

Lake Waingata after weed removal by grass carp during the monitoring period 1993-1998 (author's pers. obs.). This was because, although the lake contained no macrophytes after 1996, it was close to other lakes that did, and after weed removal the swans used it mainly as a resting, roosting and breeding area, rather than as a feeding ground. In contrast, swan numbers declined in Lake Tutira following weed removal by grass carp (Hawkes Bay Fish and Game, pers comm). This was expected as Lake Tutira is one of the few lakes in the region and hence it is a major feeding ground on which the swans depend. The proximity of other lakes containing macrophytes is therefore a major factor affecting the impact of weed removal by grass carp on swans. However, it should be noted that swan grazing can result in the collapse of submerged aquatic plants, especially in low clarity shallow waterbodies. This was reported for several extensively vegetated Waikato lakes such as Waahi and Whangape (de Winton and Champion 1993).

The international literature on the indirect impact of weed control by grass carp on aquatic birds is relatively sparse. Cudmore and Mandrak (2004) cited Chilton and Muoneke (1992) who indicated that waterfowl species that utilise aquatic vegetation as habitat and food could be affected but provided no data on this. Similarly, Pipalova (2006) raised the possibility of indirect impacts through food competition and habitat reduction, but provided no evidence of it. Dibble and Kovalenko (2009) noted the sparse literature on the effects of weed removal on waterfowl, amphibia and other vertebrates and identified this as an information gap. Cassani et al. (2008) noted a study by Hoyer and Canfield (1994) showing that removal of macrophytes had no effect on overall bird abundance but did change the species composition. Species dependent on aquatic vegetation were replaced by those using open-water habitats.

4.7 Aquatic plants

Grass carp are selective or preferential browsers of the aquatic plants that are accessible to them (Rowe and Schipper 1985), which means that if non-target plants are preferred to target weed species then the non-target plants will be consumed first.

Feeding preferences of adult grass carp in New Zealand waters were described qualitatively by Rowe and Schipper (1985) as a preference for tender succulent plants, and an avoidance of fibrous species (such as *Typha orientalis*) or blister-raising species (for example, *Ranunculus*), with the latter only consumed when preferred species are no longer available. More specifically in New Zealand trials grass carp readily consumed a range of plants species including *Nitella* sp. aff. *cristata* (a charophyte), *Lemna disperma, Elodea canadensis, Callitriche stagnalis, Paspalum distichum*, *Nasturtium* spp. and *Potamogeton crispus,* while the native *Myriophyllum propinquum*, and weed species *Lagarosiphon major, Ceratophyllum demersum* (hornwort) and *Egeria densa* were less preferred (Edwards 1974). It was also noted that larger fish ate more parts of plants than smaller fish (Edwards 1974). In lakes and drains grass carp have been observed to browse preferred species first, then consume less preferred species until in some cases, all aquatic plants have been removed (Edwards and Moore 1975, Tanner et al 1990, Clayton et al. 1995). Overhanging, terrestrial grasses or fallen willow tree leaves were also consumed when they were in reach (Rowe and Schipper 1985, Clayton et al. 1999).

Non-target effects (perceived as positive and negative) have been seen in a number of New Zealand lakes or waterbodies; the same effect has usually been seen from more than one location. The examples (below) of environmental effects on non-target plants include: reduction of marginal emergent plants; a shift in plant species composition related to preferential grazing by grass carp; persistence or expansion of turf plants under long term grazing pressure; complete loss of plants or devegetation; the potential for native plant regeneration; and managed grass carp stocks to retain desired non-target species. These effects will be detailed in the sub-sections below.

(1) Reduction of marginal emergent plants.

Grass carp were released into Lake Tutira in December 2008 as part of a long term eradication response for the target weed hydrilla (*Hydrilla verticillata*) (Hofstra and Clayton 2014). By 2011 the marginal emergent species e.g., *Schoenoplectus tabernaemontani* and *T. orientalis* showed evidence of having been browsed by the grass carp. A year later change in abundance of these species was apparent, for example, *S. tabernaemontani* was not recorded, and *T. orientalis* stands were visibly reduced in size. Grazing of the *T. orientalis* was particularly related to water level, i.e. during periods of high water fish had access to emergent plants and during low water events the remnant stumps of *T. orientalis* were visible above the water. It was considered likely that the marginal emergent vegetation in Lake Tutira would continue to be consumed by the grass carp so long it was accessible to them, which is largely dependent on water level fluctuations (Hofstra and Clayton 2014).

(2) Shift in plant species composition related to preferential grazing by grass carp.

In Lake Tutira some aquatic plants (e.g. *Myriophyllum triphyllum, Ranunculus trichophyllus*) expanded both their distribution and cover following removal of the hydrilla weed beds by grass carp (Hofstra 2012). These non-target plant species appear to be less preferred by the grass carp compared to the target plant hydrilla and a range of other non-target native species including charophytes, and marginal emergent species (*S. tabernaemontanii* and *T. orientalis*). Over a period of two years the beds of native milfoil became locally abundant and dense, and also included a range of low growing turf plants (Hofstra and Clayton 2014). Whilst New Zealand native milfoil species have been described as palatable to grass carp (Rowe and Schipper, 1985), *M. triphyllum* appears to be less preferred within this lake. It is possible that chemical/nutritional properties of *M. triphyllum* in Lake Tutira, also contributed to its expansion. Such expansion or shift in the distribution of non-preferred plant species within mixed plant communities has been documented (Chilton and Magnelia 2008, Colle 2009) and *Myriophyllum spicatum* in the USA is an example (van Dyke et al. 1984). In the Lake Tutira example it was anticipated, (based on diver observations) that the grass carp would shift their feeding to the milfoil as alternative plants become more scarce (Hofstra 2012).

Lake Rotomanu provides an example where *M. triphyllum* and a range of other aquatic plants re-established in the lake while grass carp were stocked, although the stocking density was uncertain (Hofstra 2014). From 2003 when no plants were recorded, aquatic vegetation re-established, comprised of pondweeds, charophytes and lesser amounts of egeria and lagarosiphon in 2004 (Aquaculture NZ 2004). Plant species composition changed to surface reaching growths of milfoils and some pondweeds in 2007 (Aquaculture NZ 2007) with *M. triphyllum* and lagarosiphon the most abundant species in 2009 (Aquaculture NZ 2009).

(3) Retention of turf plants in the presence of long term grazing pressure.

An aquatic plant survey in Elands lake in 1987 prior to grass carp release included; *T. orientalis, S. tabernaemontani, Juncus edgariae, Bolboschoenus fluviatilis, Eleocharis acuta, Persicaria decipiens*, *Ludwigia palustris, Lobelia perpusilla, C. stagnalis, Glossostigma diandrum, G. elatinoides, Lilaeopsis ruthiana, E. gratioloides, P. crispus, Potamogeton cheesemanii, Potamogeton ochreatus, Chara australis, N.* sp. aff. *cristata, M. propinquum,* elodea and hydrilla (Clayton et al. 1995). Although the native plants that were present in the lake had a limited distribution and abundance with hydrilla dominating the littoral zone of the lake bed (Neale unpublished report ca 1988a), they were further reduced by grass carp browsing. The grass carp eliminated the target weed hydrilla, a preferred species, and then consumed the marginal emergent aquatic plants. However, grass carp still remain in the lake, 20 years since their initial stocking and the low growing turf plant community persists in the presence of the grass carp (Hofstra and Rowe 2008). As described in earlier publications (Clayton et al. 1995, Clayton and Wells 1999) low growing aquatic plant species in gently shelving slopes with shallow (<0.2 m deep) water may not be grazed to a significant level. Lake Waingata provides another example where a low-growing turf plant community also remained following grass carp stocking (pers. obs. Rowe, Wells and Champion 2013).

(4) Complete plant removal or devegetation.

Lake Swan (also known as Lake Roto-otuauru, Northland) was given an ecological ranking of “moderate” as it had been highly degraded by aquatic weeds, and is currently in a largely de-vegetated state (NRC 2007-2011), following removal of the weed by grass carp. In this example, grass carp were introduced to remove the risk of weed spread to adjacent high value waterbodies, and with a longer term goal of native plant restoration in the lake (see point 5 below), however in other examples a permanent absence or large scale reduction of plants may be desirable long term (e.g. some ornamental ponds, drainage/irrigation systems, stormwater retention ponds).

For example Manuwai Lane Lake, which is a man-made privately owned lake in Drury, South Auckland, was stocked with grass carp in 1997. Even though the target was partial weed control and grass carp numbers were managed (local landowner, pers. comm.) all submerged plants have been consumed. The lake has remained free of submerged aquatic plants in the subsequent decades, and provides the local residents with the amenity values that were sought from their lake (Appendix B).

(5) The potential for native plant regeneration.

In Parkinson’s Lake grass carp eradicated the target plant egeria and removed most other aquatic vegetation (non-target species). However, following removal of the grass carp non-target native species regenerated from seed banks in the sediment and the lake was restored to its former state (Rowe and Champion 1994, Tanner et al. 1990).

Similarly the goal for two Northland lakes (Heather and Swan) that are currently stocked with grass carp, is to remove the grass carp post weed eradication, to enable restoration of native plant communities (Wells and Champion 2011).

(6) Managed grass carp stocks to retain desired non-target species.

Balancing stocking density to achieve partial plant control in the long term is rarely achieved in large natural lakes or deep water systems (Cassani et al. 2008), but has been demonstrated in smaller ornamental ponds or systems where the fish can be more readily captured and moved. An example is Ayrlies garden (Auckland) where grass carp numbers have been successfully managed. For example in a pond with a low stocking density of grass carp, water lilies which were non-target plants were also able to grow (Appendix B).

In general terms, the impacts or potential for impacts on non-target aquatic plants, including rare or endangered native plants that may be present at a site, are primarily dependent on what other plants are available to the grass carp and how preferred and accessible they are to the grass carp. However it has been noted that the presence or range of species consumed may change with the size and age of the grass carp (Edwards 1974, Bonar et al. 1993), and that preference is related to the chemical/nutritional properties of the plant and ease of mastication (Wiley et al. 1987, Bonar et al. 1993, Pipalova 2002). Further, there is some evidence that the same plant species from different locations (lake, or source) may not be as highly preferred (Chapman and Coffey 1971). However high stocking densities (section 5.6) result in consumption of all plants that are within reach or accessible to the grass carp (Rowe and Schipper 1985).

Also see Chapter 5 regarding additional factors that may determine plant consumption by grass carp and Chapter 6 for management constraints on grass carp use.

5 Effectiveness of grass carp for weed control

5.1 Introduction

Freshwater systems in New Zealand have been highly invaded, with a large number of alien aquatic plants now present (Champion et al. 2002a). Some alien plants are regarded as pests because of the problems they create, but others are regarded as having neutral (neither detrimental nor beneficial) impact, including various low-stature plants such as starwort (*C. stagnalis*). For management purposes, the species causing problems need to be distinguished from those that are not, and this decision can depend on the type of waterbody or waterway that is being managed, its functions and values, and its flora and fauna. Native species too, may be defined as weeds, or problems species depending on the perspective of those managing a waterbody or waterway (Champion et al. 2002a).

Grass carp were imported into New Zealand with the intent that they would be used to manage aquatic weeds (Rowe and Schipper 1985). They have been used successfully overseas and in New Zealand for the control and eradication of numerous aquatic plant species (see review by Rowe and Hill 1989, Cassani et al. 2008), and from a range of different aquatic systems including stormwater ponds, ornamental ponds, private dams or lakes and drainage/irrigation canals and waterways (see Appendix B).

Successful weed control is dependent on a number of factors including: the ability to contain the grass carp; achieving the appropriate stocking density and fish size; target plant preference; and that local conditions are suitable for grass carp welfare (e.g. DO, pH, water level) and promote feeding (e.g. temperature).

The extent to which grass carp have controlled weed problems in various types of waterbodies in New Zealand, are described below (section 5.2). For some of the waterbodies described below a more detailed review of grass carp effectivenss is provided in Hofstra (2014).

5.2 Effectiveness of weed control

In this section, the use of grass carp for controlling invasive aquatic plants is reviewed based on experience in different types of waterbodies and waterways and summarised for target weed species.

5.2.1 Lakes

Egeria, elodea, lagarosiphon and hornwort are all invasive submerged aquatic weeds that do not form seed or other long-lived propagules. They are also species that grass carp are known to consume (Chapman and Coffey 1971, Edwards 1974, Rowe and Schipper 1985, Tanner et al. 1990, Hofstra and Clayton 2012), and because they lack long-lived propagules they are species that could be eradicated by grass carp from waterbodies within relatively short timeframes. In New Zealand there are several lakes where grass carp have been introduced to control and/or eradicate one or more of these species. The earliest of these was Parkinson's Lake, a small (1.9 ha) shallow (9 m deep) dune lake southwest of Auckland. Half of the lake was covered in egeria when grass carp (44 per ha) were introduced (from May 1976 to November 1977) into the main body of the lake, and the successful eradication of egeria by grass carp was subsequently well documented (Mitchell 1980, Rowe 1984, Mitchell et al. 1984, Tanner et al. 1990, Rowe and Champion 1994).

In Lake Waingata, a small (12 ha) shallow (7 m deep) dune lake on the North Kaipara Head, plant records note the occurrence of the aquatic weed elodea and indicate that it was spreading through the lake as early as 1964 (Tanner et al. 1986, Rowe and Champion 1995, NIWA Aquatic Plant Database records). Continued expansion of elodea was reported (Tanner et al. 1986, Rowe and Champion 1995) and in the spring of 1995 and later in 1996 a total of 168 grass carp were introduced to eradicate the weed (Rowe et al. 1999). No elodea was recorded during vegetation assessments from March 1996 onwards (Rowe et al. 1999).

Lake Omapere is a large (1,206 ha) shallow (max depth 2.6m) lake in Northland. The lake was invaded by the introduced submerged plant egeria and since that time has undergone a phase where surface-reaching weed beds of the plant developed. The weed beds collapsed, and a turbid water algal dominated phase subsequently persisted, followed by the re-establishment of egeria. The historic weed bed occurrence and collapse (1985/6 and again in 2001), and changes in water quality, flora and fauna are well documented (e.g. Kokich 1986, The Lake Omapere Task Force 1986, Kokich1987, Champion et al. 1997, Champion and Burns 2001, Champion 2004, Lake Omapere Project Management Group 2006, Ray et al. 2006, and Gray 2012). Prior to the introduction of grass carp for egeria control, it was predicted that the lake was in an unstable state and the egeria would collapse, although the timeframe for the collapse was not certain (Correspondence, 15 June 2000 NIWA). A total of 40,643 grass carp were liberated into Lake Omapere between August (8000 grass carp) and December 2000 (32,643 grass carp on the 16th, the majority small i.e. less than 200mm). In such a compromised lake it is difficult to independently assess the effectiveness of the grass carp to remove the weed, with respect to changes that were already occurring in the lake (Hofstra 2013a). However, although the stocking of grass carp was too late to avoid the collapse of egeria in late 2001, the effective eradication of this weed has interrupted its boom-bust cycle of invasion alternating with an algal-dominated state (Schallenberg et al. 2013).

More recently, within the last six years, grass carp have been stocked into other North Island lakes for removal of invasive submerged aquatic plants; Lake Kereta for hornwort, Lake Wainamu for egeria and Lakes Heather and Swan for egeria and hornwort removal.

Lake Kereta is a shallow (max depth of 2.3 m, de Winton and Edwards 2012) sand dune lake of ca 26 ha on the South Kaipara Head (Wilcock and Kemp 2000, Leathwick et al. 2010). A survey in November 1999 found that the native vegetation had been displaced by hornwort, with the entire lake bottom dominated by hornwort apart from areas of planted waterlilies and southern marginal areas that had marginal emergent plant species (Gibbs et al. 1999). Lake Kereta was stocked with grass carp between March 2008 and April 2009 to eradicate the hornwort. Although a total of 14,799 grass carp were stocked, nearly a third of these were under 10 cm in length with the remainder between 15 and 20 cm in length (from G Jamieson, see de Winton 2012). Thus, the effective stocking density is uncertain because the lake was stocked with small fish, and the losses of fish in this size class from predation are unknown but suspected to be high (de Winton 2012). However there was a significant reduction in hornwort by February 2012, with few fragments noted (de Winton 2012) and no plants seen in 2014 (R Wells, NIWA, pers comm).

Lake Wainamu, on Auckland's West Coast, is a small (15 ha) dune lake of ca 12-15m water depth. Egeria was first recorded at the outflow from the lake in 1990, with colonisation noted within the lake over the next two years. By 1995, egeria occupied the entire perimeter within the lake, from the outside edge of the emergent vegetation to a water depth of 4m, with some plants found down to 5.5 m (Champion 1995). Subsequently the lake experienced a vegetation collapse, and during a survey in 1999, no submerged vegetation was found within the main body of the lake (Gibbs et al. 1999). Vegetation recovery occurred several years later. By November 2007, egeria had increased substantially in Lake Wainamu, with an estimated 2.2 ha of the lake being occupied by the weed. The weed bed in the lake was considered unstable, and at moderate to high risk of collapse with further reduction in lake conditions likely (de Winton et al. 2008). In March 2009 the Auckland Regional Council (Auckland Council, AC) released 270 grass carp in order to eradicate the egeria. This species had virtually displaced the lake's formerly abundant native aquatic vegetation and was also affecting recreational values for users (Surrey 2008). The target stocking rate was 100 fish per vegetated hectare. Egeria was not recorded in the lake four and a half years after stocking with grass carp (Correspondence 6th December 2013 NIWA) indicating successful control by grass carp.

Lake Swan is a 17.4 hectare shallow (max depth 5.5 m) dune lake, enclosed in old stabilised sand dunes, located on the North Kaipara Head (Pouto Peninsula) (Livingstone et al. 1986). Egeria was first recorded in the lake in 1992 (Champion et al. 1993), and by 2001 it had formed dense beds up to 2.5 m tall and occupied most of the lake from a depth of 0.6 m to 4.2 m (Champion et al. 2002b). Since its invasion, egeria dominated the lake, displacing native species to water less than 1 m in depth. The endangered *Trithuria inconspicua* (an endemic turf plant species, formerly known as *Hydatella*) was once found at this lake (Tanner et al. 1986) but has not been found during subsequent surveys (Champion et al. 2002b). Hornwort was later discovered in 2005 and at that time it had already taken over most of the lake including areas previously occupied by egeria. In parts of the lake, both species were surface reaching (NRC 2007). The release of 850 grass carp over 25cm in length was proposed in the EIA (Environmental Impact Assessment) (Mitchell 2008). With an estimated area of aquatic weeds comprising ca 12 ha of hornwort and 5 ha of egeria in the lake, the proposed application allowed for 50 large fish per vegetated hectare (Mitchell 2008). A Northland Regional Council media release reports over 800 grass carp were released (NRC (2009b). The goal of the grass carp introduction was 100% weed removal, meaning eradication. This would in the first instance reduce the risk of weed spread to adjacent high value lakes (NRC 2007-2011), and with subsequent capture of the grass carp, allow restoration of the native vegetation, and lake as a whole. Effective weed control has been achieved by grass carp, with a significant reduction in abundance of the target species by 2010, and no fragments found in 2013 (Wells and Champion 2013) or 2014 (P Champion, NIWA, pers comm).

Lake Heather is a small (8 ha), shallow lake (5.6 m max depth) enclosed in old stabilised sand dunes, located near Kaitaia in the far north of Northland. Between 1985 and 2001, the alien weed species, hornwort and egeria, established in the lake substantially displacing native submerged vegetation. Hornwort displaced native flora, particularly *C. australis*, and egeria was also distributed throughout the lake, although it had a lower density than hornwort (Champion et al. 2002b). Over the next decade, the exotic plant *Utricularia gibba*, was reported to have invaded Lake Heather and was assessed as common, and hornwort and egeria became well-established with surface-reaching beds throughout much of the lake. It was considered that the long term presence of these plants in the lake would alter the lake sediments making them (highly organic and flocculent) unsuitable in the future for submerged vegetation (Wells and Champion 2010). In addition, a heightened risk of lake-wide de-oxygenation was documented (Wells and Champion 2010). An approval to release grass carp to control the aquatic weed was obtained in 2010, with an expected release date of June for 400 grass carp (equating to a stocking density of ca. 50 fish per vegetated hectare). The initial goal was to control the weeds and reduce the risk of these species spreading into nearby pristine freshwater systems, and subsequently to eradicate the weeds, with a longer term goal of lake restoration (Wells and Champion 2011). Effective weed control has been achieved, with a significant reduction in abundance of the target species (egeria removed, 70% hornwort reduction, Wells and Champion 2013). It was noted in Champion and de Winton (2012) that the "biosecurity management initiative, to eradicate hornwort in Lake Heather using grass carp appears to be progressing towards its goal." In 2014 only fragments of hornwort were located during a lake survey (P Champion, NIWA, pers comm).

In contrast to the target weed species mentioned so far, hydrilla has long-lived propagules (tubers and turions) which has necessitated a longer term approach to control and eradication of the weed by grass carp.

Elands Lake was a grass carp trial site to determine their effectiveness to control and potential to eradicate hydrilla. Elands Lake is a 4 ha spring-fed dam on a privately owned farm in the Hawkes Bay region. In the 1980's hydrilla covered ca 1 ha of the lake down to ca 4.5 m of this shallow (max depth 7 m) lake (Clayton et al. 1995). As it has no inlet or outlet streams and is isolated from public access, Elands Lake was utilised for a grass carp trial which commenced in 1988 (Neale 1988b). Triploid grass carp were stocked by MAF Fish in December 1988. Initially 100 fish/ha (400 fish in total) of ca 270 mm in length were stocked (Clayton et al. 1995). An assessment of vegetation in April 1990 revealed a major reduction in hydrilla, 17 months after grass carp were released. In 1991, a further 200 grass carp were released to provide grazing pressure by smaller, younger fish amongst obstacles along the shoreline that may impede access by the now larger fish from the initial stocking (NIWA unpublished records). In November 1991 extensive searches at depths of 1-1.5 m revealed occasional hydrilla plants regrowing from tubers or buried stems, predominately in areas supporting low growing turf plants and amongst fallen tree branches (Clayton et al. 1995). Sediment sampling down to 3 m water depth also revealed viable tubers. However no plants or regrowth occurred in areas of the lake deeper than 1.5 m down to 4.5 m, the predominant depth range of hydrilla before grass carp (Clayton et al. 1995). Annual (April) vegetation survey of Elands lake has continued since then, with a hydrilla plant last found in 2003, and more recent surveys reporting only the continued presence of the turf plant community (Hofstra et al. 2008) and young raupo (Hofstra et al. 2004). The Elands Lake grass carp trial demonstrated the effectiveness of grass carp at removing hydrilla, providing proof of concept for the use of grass carp as a tool in the MPI hydrilla eradication response (MAF 2008).

Lakes Tutira, Waikōpiro and Opouahi were the remaining three lakes in the Hawkes Bay (and in New Zealand) that supported populations of hydrilla. Lake Tutira is 174 ha and ca 40 m deep, and joined by a culvert under a causeway to the smaller (11 ha, 18 m deep) Lake Waikōpiro (Hofstra and Rowe 2008). Lake Opouahi is smaller still (ca 6 ha, 24 m deep) and situated at a higher altitude to the north of Lakes Tutira and Waikōpiro. Grass carp were released into these lakes at a stocking density of 100 fish per vegetated hectare in 2008, as part of the MPI hydrilla eradication response (Hofstra and Rowe 2008). The hydrilla weed beds were removed from all three lakes by April 2010 (Hofstra 2010), and since then a small number of plants have still been recorded from Lake Tutira during annual surveys (Hofstra 2013b). Effective target weed control has been achieved, with progress toward the longer term eradication goal as anticipated based on results from Elands Lake.

Aside from invasive introduced aquatic plants, it is possible that native aquatic vegetation may be perceived as 'weedy' or requiring control. Midgley's Lake provides an example of a natural lake, in native condition that was stocked with grass carp to create more open water. Midgley's Lake is located north of Dargaville in a catchment of pasture and plantation pine. It is a small (2 ha) shallow (3 m) dune lake that had native submerged vegetation that included a large population of the critically endangered *Utricularia australis* in 2005 (Champion et al. 2005, de Lange et al. 2012). Subsequently grass carp were introduced in 2007 (62 fish per ha, AQTRANS 01/15) to create more open water. However, there was no requirement to report to DOC following stocking (Hofstra 2013a). A vegetation survey in 2011 shows that apart from the turf species and a few stunted charophytes, all submerged vegetation had been removed by the grass carp. Grass carp in this lake were considered incompatible with native lake values and an on-going threat to the native ecology of the lake without removal of sufficient numbers to allow vegetation recovery (Wells and Champion 2013).

5.2.2 Man-made lakes and ponds

As with the lake examples, egeria has frequently been the target of grass carp control in man-made waterbodies. Examples include, Western Springs Lake, Waiatarua Park ponds and channels, Tahuna Torea Reserve ponds (Appendix B) and other stormwater ponds (Appendix B). The aquatic plants elodea, hornwort and a range of native plants have also been targeted for weed control within the man-made waterbodies. Examples include, Lake Henley, Lake Rotomanu, Lake Hood, and Manuwai Lane Lake amongst others (Appendix B).

Western Springs Lake is a spring fed lake in an urban park that had expansive growths of egeria, with often large numbers of waterfowl and outbreaks of avian botulism. It is a small (ca 4 ha) and shallow (max. depth 2.9 m) lake that was constructed in 1875 by the Auckland Council to contain water discharged from an aquifer that had previously passed through swampy land and into Motions Creek (Decker 1995b). It has had a managed grass carp population since 1996 (AQTRANS0036) to control the egeria, with the aim to reduce the plants by 70% (Decker 1995b). Initial stocking of 3 large triploid fish in August 1996 (Correspondence 28th August Jamieson Holdings) was followed by an application to release 1000 juvenile diploid grass carp, which was subsequently approved (AK032/98, 1996). Monitoring reports, correspondence and file notes document the release (76 in winter 2000), removal (153 from 1998 to 1999), and escape (7 from 1996 in Motions Creek, released back in the lake in 2001) of grass carp during the subsequent years that make the effective stocking density difficult to discern. In particular the use of juvenile grass carp, which may be heavily predated (Decker 1995b) compounds the uncertainty in stocking density. However, although periodic growth of pondweed has been noted, egeria has not been recorded since 1999 (NZWM 2000, 2003, NZWR 2004, 2009).

The wetlands at Waiatarua were developed as a park, with boardwalks, viewing platforms and significant plantings of wetland species. The excavated ponds and channels are fed by stormwater from adjoining residential areas which result in significant water level fluctuation

(Correspondence 1st April 1996, DOC). An approval to release 200 grass carp was signed in May 1994 (AQTRANS0026), with subsequent authorisation to transfer another 30 fish in November 1995. Reference is also made to an earlier approval for triploid grass carp in May 1992 (Correspondence 1st April 1996, DOC). In April 1996, water levels were low, there was little water circulation within the wetland and the growth of submerged macrophytes, primarily egeria was very evident. In many areas there was 100% cover of egeria in the channels. The goal was to reduce the volume of egeria by 60%, however there was no requirement to report monitoring results to DOC (DOC 2010) and there appears to be little current information available. A site visit in February 2014, revealed channels choked with marginal and submerged aquatic plants (including egeria), although the water in the main pond was free of submerged plants and inhabited by a large population of waterfowl (Appendix B). The lack of drain weed control indicated that there were unlikely to be any fish present. The absence of grass carp was corroborated (G Jamieson, NZWR, pers comm) with fish having been removed ca 10 years ago when further development of the site as a wetland was undertaken.

Grass carp were introduced into Lake Henley to control nuisance growth of aquatic plants comprising several species, but primarily *P. crispus* and elodea (Buchannan 1991). The establishment of Lake Henley in 1988 provided the region with a high valued recreational amenity (Buchanan 1991). This artificial lake is 11 ha lake size, and includes a number of small islands, and it is shallow, ca 1.5 m for much of its area, with a maximum depth of 3m. By 1990 aquatic plants and floating algal blooms were considered a threat to the continued recreational use of the lake (Buchanan 1991). In 1993 grass carp (triploid) were released at a stocking density of ca 20 fish/ha (250 grass carp) (AQTRANS0019, Miller 1994) however the target reduction of vegetation (ca 50%) was not achieved, with no indication of grass carp activity after the first two years (Miller 1995). In 1997 approval for a further 1000 grass carp was obtained (MFish). The objective was to maintain the weed at intermediate levels so that the beneficial functions of the submerged vegetation on the lake were maintained (Dugdale and Wells 2001) along with amenity values (Buchannan 1991). In November 2000 the submerged vegetation of Lake Henley was surveyed and found to be of low abundance. The native nitella (*N.* sp. aff. *cristata*) was the most common species present with an average cover of 15-20%. The exotic weeds elodea and *P. crispus* were sparse with covers of less than 5%. Because of the positive effect of submerged vegetation on water clarity, weed control methods that target specified areas of weed were considered more suitable than a whole of lake treatment, and grass carp were not recommended (Dugdale and Wells 2001). It was considered unlikely, that partial weed control could be achieved by grass carp in a small lake, such as Henley, for an extended period of time (Dugdale and Wells 2001). In addition containment issues were highlighted, that may have compromised the effective stocking density of grass carp in Lake Henley (Dix 1998). Weed spraying was undertaken in the intervening years, yet surface reaching weed beds were still recorded in summer (Correspondence Bayley 2007 and 2008), and in May 2009 the Masterton District Council obtained approval for a further release of grass carp (up to 500) into Lake Henley.

Similarly, in Lake Rotomanu, the weed control by grass carp was ineffective relative to the recreational uses of the lake and the need to maintain weed free areas. Lake Rotomanu is a 9.8 ha lake, that was formed by diverting water from the Waiwhakaiho River to an old quarry. The lake is used for a range of recreational activities including swimming, trout fishing, water skiing, jet skiing, boating and model boating, and as a walking and picnicking area

(Aquaculture NZ 1998a). Approval to release 147 grass carp was obtained (AQTRANS07/03, 1999) for partial weed removal (ca 30%) with lagarosiphon and egeria listed as the target weeds, initially. However a collapse of the weed beds in 2001, attributed primarily to herbicide (A Stancliff, Fish and Game, pers comm), resulted in no macrophytes for the next two years (Aquaculture NZ 2002a, 2003) and the removal of eight grass carp (Aquaculture NZ 2003). In 2004 the pondweeds, *P. ochreatus* and *P. crispus,* along with charophytes were recorded as most abundant from the survey transects, with lesser amounts of lagarosiphon and egeria (Aquaculture NZ 2004). In the following surveys, August 2005 (Aquaculture NZ 2005) and June 2006 increases in *P. ochreatus* and plant biomass in general were reported (Aquaculture NZ 2007), despite the introduction of more grass carp in 2005 (50 grass carp (CA050), 50 grass carp (CA063). By May 2007 the most abundant plants were *P. ochreatus,* elodea and species of milfoil (*M. triphyllum* and *M. propinquum*), with surface reaching growths of the milfoils and some pondweeds (Aquaculture NZ 2007). Grass carp appeared to have been grazing on the deeper beds of charophyte, which were largely absent in 2007 (Aquaculture NZ 2007). The release of further fish was approved in 2007 (500 in September 2007 (CA090), and in 2009 (500 in May 2009 (CA112)) (Aquaculture NZ 2009). Elodea, lagarosiphon*, M. triphyllum* and charophytes were recorded as the most abundant plants in January 2009, and later in the same year *M. triphyllum* and lagarosiphon were the most abundant species (Aquaculture NZ 2009). At that time weed harvesting was recommended to reduce the plant biomass (Aquaculture NZ 2009). By 2012 a request had been made to remove the grass carp from Lake Rotomanu (Jamieson pers. comm. NZWR, pers. comm. Oct 2012). Initial weeds were reportedly consumed, but there was a “shift in the dominant plant species to a native milfoil that was still regarded as a weed, but is less preferred by the grass carp, and resulted in inadequate control” (G Jamieson, NZWR, pers. comm. Oct 2012). In addition, stocking density appears uncertain, with questions having been raised about minimum fish size relative to the gap size in the security screens (Correspondence 31st August 2007 DOC) and the potential for fish to have escaped, and whether or not all screens remained in place (Correspondence 5th May 2009 Fish and Game). Although, no grass carp have been reported from the adjacent river or the wetland (A. Stancliff, Fish and Game pers comm). Furthermore, some grass carp have been captured from Lake Rotomanu (A. Stancliff, Fish and Game pers comm). In general, the balance between stocking density and weed growth was not achieved, and grass carp consumption of weeds tended to result in patchy control which was not conducive to recreational uses of the lake. Weed control is achieved now with targeted herbicide application (S McGill, New Plymouth District Council (NPDC) pers comm).

Multiple plant species were targeted for control in Lake Hood. In this example, both introduced and native plants are causing nuisance growths, however the level of control achieved with grass carp has been less than desired (Sutherland et al. 2013). Lake Hood is an artificial lake (filled in 2002) of ca 72 ha in size with an average water depth of ca 2.5m. The lake is managed for recreation including, water-skiing, kayaking, sailing and swimming, and along with the surrounding park has high aesthetic values. There is also a purpose built community on the water edge and along the canals from the lake. The lake and surroundings are managed by the Ashburton Aquatic Park Charitable Trust (AAPCT). The presence of dense growth of aquatic vegetation was considered to adversely impact on the values, use and function of the lake, and in 2005 grass carp were introduced at a stocking density of ca 34 fish/ha to control the plants (AQTRANS11/01). The target species were identified as *P. crispus, P. cheesemanii,* charophytes and elodea. Although some of the initial monitoring reported a reduction in plants at some sites (Decker 2005, 2006), a subsequent survey indicated that initial declines may have been due to seasonal change that had been interpreted as grass carp impacts (Clayton 2012). Since 2012, there has been a shift in the dominant aquatic weed from *P. crispus* to elodea in the main body of the lake. This was most likely attributed to seasonal dieback of *P. crispus* allowing elodea to rapidly colonise the lakebed (Sutherland et al. 2013). However, a change in species dominance from *P. crispus* to elodea (the latter a supposedly preferred species) indicates that grass carp survival from stocking (of large and small fish) may have been too low to be effective and/or that feeding activity was not sufficient for the plant growth rate (Sutherland et al. 2013, 2014).

Manuwai Lane Lake is potentially an example of hornwort removal. Effective weed control was achieved, however a discrepancy in the identification of the dominant submerged aquatic plant that was present in the lake prior to the introduction of grass carp, casts some doubt over what species was removed. The lake at Manuwai Lane is a small (ca 1 ha and 7m deep) man-made pond that originally supplied water for orchards and irrigation (Decker 1996). In the past the pond was regularly pumped dry every summer until about 1987 (Correspondence October 1996, Hoffman) which prevented macrophytes becoming established. In the 1990's, the adjacent landowners wished to keep the pond full of water for its aesthetic values (Decker 1996), however by the mid 1990's submerged aquatic plants formed surface-reaching growths in the shallows, on and amongst which grew azolla (*Azolla* spp.) and algae. The risk assessment report describes large beds of hornwort in all of the shallow reaches (Decker 1996). A site visit by MPI staff in November 1996 records milfoil present in large quantities (Correspondence November 1996, Pullan), with no mention of hornwort. Recent discussion confirms the reference to a milfoil most likely indicated a native milfoil rather than parrot's feather (S Pullan, MPI, pers comm January 2014). Although it cannot be verified, it seems possible that the hornwort identification by Decker (1996) and the milfoil identification by Pullan (1996) may in fact have been the same plant, since these two species are often confused. Irrespective of the species identification, grass carp were introduced to control the aquatic weeds, with the intention to reduce macrophytes to a level of about 60% of the current level (Decker 1996). All submerged weed beds have been removed (NZWR 2006de), and the lake has remained in a largely de-vegetated state that supports the amenity values of the local residents (Appendix B).

Grass carp were used to control native plant species in Waihi Reservoir when other control methods were considered less feasible. Waihi Reservoir was constructed in 1963 (Mitchell 1980) and the "encroachment of *T. orientalis* and *Eleocharis sphacelata* had been controlled by herbicide spraying, but the difficulties inherent in spraying or draglining a water supply reservoir led to the stocking of grass carp to control the macrophytes". Within the lake *P. ochreatus* was the dominant species covering about 60% of the water surface in water up to 1.5m deep, with an understorey of *Nitella* spp. to a depth of 4m. Along the margins, as well as *T. orientalis* and *E. sphacelata* there were scattered clumps of *Carex* spp. *M. propinquum, P. cheesemanii, P. decipiens, L. palustris* and *Ranunculus* spp. In the spring of 1975 grass carp were stocked at a density of 55.3kg fish per hectare, followed two years later by the stocking of 50 grass carp (additional ca 58 kg fish/ha). The grass carp exhibited a preference for the *P. ochreatus*, with the *Nitella* not controlled until after the additional stocking of grass carp. By April 1979 few plants remained in the reservoir (Mitchell 1980).

5.2.3 Flowing water, drainage and irrigation canals

There is little international information on the use of grass carp for weed control in water channels used for irrigation or drainage. However Rowe and Schipper (1985) raised the possibility of using grass carp for weed control in the numerous lowland waterways used to drain flat land and maintain pasture in New Zealand. Rowe and Hill (1989) later reviewed the use of grass carp for weed control in drains in New Zealand. Although Edwards and Moore (1975) had carried out a small, short-term trial in a Rangitaiki plains (Bay of Plenty) drain that showed significant weed reduction and promise, a later and larger trial in the Mangawhero Drain (lower Waikato) resulted in total weed control being maintained for many years (Schipper 1983). The grass carp removed all vegetation in the treatment section and maintained this state for at least 5 years, whereas routine draglining was required in the control section (without grass carp) to periodically remove the weed and maintain water drainage. Although grass carp were successfully used to maintain continuous total weed control in a long section of the Mangawhero, other drainage trials failed either because of high mortality caused by poor water quality, or because of escape during floods (Rowe and Hill 1989). Later, a further trial was carried out in Churchill Drain (Waikato) and this too showed that grass carp could be used to remove all weed and maintain this state for a prolonged period, but that such control could also be compromised by poor water quality (Wells et al. 2003). The more recent field surveys carried out in summer 2014 highlighted that a common theme for a successful weed control in the drains was a spring-water inflow (Appendix B). Spring-water inflows appear to reduce the impacts of high temperatures and low dissolved oxygen which may result in fish mortality. In contrast, drains that do not have any spring-water influence have now been abandoned for further grass carp stocking (Appendix B).

In summary, although weed control in drainage channels (and irrigation channels) is feasible, there are some constraints on this related to site suitability.

6 Constraints on grass carp use for weed control

Constraints on the use of grass carp as a weed control solution and on the management issues related to their effective use for this purpose are largely determined by the type of waterbody, the management goals, and the weed species present. For example, some waterbody types are unsuitable for grass carp because of the risk of escape, and/or because they are too cold, or too shallow, or are flood prone, or contain poor water quality that would limit grass carp survival. In addition, the function, values and uses of the waterbody will influence the need for and extent of weed control and whether the goal is weed eradication or control all of which will influence the range of control methods that could be used and hence the use of grass carp. Finally, the type and distribution of the target weed species and whether it is a preferred species for grass carp will influence stocking density. This section discusses factors that need to be considered and issues that have arisen and may constrain the effective use of grass carp.

6.1 Waterbody and plant management goals

Grass carp are non-selective herbivores and will consume a wide range of plant species. In general, they result in the removal of all macrophyte species in waters over ca 40 cm deep, including some emergent rush species (see sections 4.7 and 5 above). Such 'total' control may be desirable in some waterbodies but not in others where it could cause other environmental problems (e.g. lake shore erosion, increased turbidity, reduced waterfowl habitat). In these waterbodies, weed control by grass carp could replace one problem with another. Hence the use of grass carp as a weed control tool should be influenced by lake and river management goals and plans. Unfortunately, such plans are currently lacking for most waterbodies in New Zealand, but they can be expected to develop in the near future as a consequence of the new National Water Policy Statement on Freshwater which will require Councils and the community to develop acceptable environmental limits for all major waterbodies. This should help address shortcomings relating to many (particularly larger) natural lakes, while many artificial waterbodies and drainage systems already have clearly defined management objectives.

The nature of grass carp browsing means that it is not feasible to achieve weed control in targeted regions of lakes, unless the carp are constrained within a barrier net specifically for localised 'spot' control. Hence grass carp are not suitable for weed control in waterbodies where the goal of macrophyte management requires the removal of introduced weeds in some areas but the retention of more valued macrophytes (e.g. native plants) in others. This would include waterbodies where problem plant species occur, along with rare and/or threatened native species vulnerable to grass carp browsing.

The high level of control exerted by grass carp on macrophytes can result in the eradication of many of the introduced problem plant species in New Zealand because they only reproduce vegetatively (i.e. they do not set seed). But grass carp will not eradicate plant species that set seeds which can be dispersed by wind or wildlife. As a consequence, grass carp browsing can be expected to eradicate some problem species in a waterbody but only control others. Furthermore, where introduced plant species occur in tributary streams or ponds above the waterbody and are hydrologically connected to it, continual re-infestation can occur and prevent eradication. Where eradication is the goal and is achievable, then grass carp can be used for this and then removed (or allowed to die out). But on-going, low-level browsing (and hence stocking) will be required where eradication is not possible and long-term control is required.

In summary the suitability and methodology of grass carp use should be consistent with the management goals of the waterbody.

6.2 Grass carp containment

Grass carp containment is an essential component of their effective use, not only from a management perspective, but also to minimise the potential for off-target effects outside of the designated control zone. Effective weed management, requires a stocking density of grass carp that can achieve a desired level of weed control. Escape of large numbers of fish reduces browsing pressure and effective control of aquatic vegetation may not be achieved (Sanders et al. 1991). Where grass carp are used for weed control, containment structures to ensure that the grass carp remain within the waterbody are often required (Rowe and Schipper 1985, Sadlon 1994, Hofstra and Rowe 2008).

The size and type of barrier or containment device is dependent on the type of waterbody or waterway in which the grass carp are being released, from barriers within or between lakes (Pine and Anderson 1991b), to screens preventing access to outlet or inlet streams of lakes, which are similar to those described for placement in canals and drainage systems (Mitchell 1980, Schipper 1983, Cassani and Maloney 1991, Masser 2002, Wells et al. 2003, Belal 2007).

Examples include welded steel bars, with a gap size small enough to ensure that the stocked fish cannot pass (e.g., 32 mm apart in Edwards and Moore (1975), Mitchell (1980), Slack (1992); and 40 mm apart in Rowe (2004) where adult fish were stocked). Masser (2002) used horizontal bars 5 cm apart. The screen must be high enough to extend above the maximum water level (Mitchell 1980, Schipper 1983). Other similar structures may also provide effective barriers (Wells et al. 2003, Belal 2007, Hofstra and Rowe 2008). For example, the existing pump station in a drainage canal was relied upon to contain the grass carp (Wells et al. 2003), and Belal (2007) used metal frames (2 cm wide bars that were 18 cm apart) that were covered from both sides with plastic mesh screens (1.25 cm mesh). The spacing of bars on screens depends on the size of fish stocked and their minimum head width.

In practice, barrier screens have been breached when unexpectedly high floods occurred and water levels overtopped the barriers, or when vegetation accumulates on the screens and results in increased water levels, or damages the screen and its footings resulting in water flow around it (author’s pers. obs.; McDowall 1984). These issues aside, bar screens (vertical metal rods embedded in a frame with gaps between each bar) have proved effective at preventing escape, but require periodic maintenance to clear floating vegetation from the screen face. Minor problems have arisen in the past because the gap size between just two bars has been accidently enlarged during installation or as a consequence of damage from floating logs. If a bent bar results in a gap of 30 mm or more, even at one location, grass carp will find this ‘hole’ and readily move downriver. Routine inspection is required, especially during the first 12 months, to ensure that each rod in the screen is intact and in place, and that the screen is properly maintained to keep water flowing through it. Screens also need to be constructed (in terms of width, height and footing) such that a flood flow and/or elevated water level will not allow water movement around the screen.

Floating barrier nets (mesh size 20-25 mm) are also effective at preventing the escape of grass carp in some circumstances. They can prevent movement between areas within a lake/pond, or down lake outlets where there is a small and stable flow. But they are not as effective as metal screens. Care is required in the siting and construction of such nets to ensure that grass carp cannot jump over them. Experience in New Zealand has found that these fish are excellent jumpers, with adults capable of leaping half a metre high or horizontally over a 1.5 m distance when disturbed (author's observations). Siting barrier nets in shallow waters (< 0.4 m), particularly those frequented by people, can prevent adult fish from jumping them because grass carp usually avoid shallow waters and disturbed areas. If escape is to be prevented, the net should extend at least 0.5 m above the water line. Care is also required in the installation of barrier nets to ensure that they are properly weighted and/or staked to the lake/stream bed by divers so that grass carp cannot swim under or around them. Purpose built net enclosures were used successfully to contain grass carp for short periods of time (months), to achieve targeted control of hornwort in Lake Karapiro (Hofstra and Clayton 2012) and hydrilla in Lake Opouahi (Hofstra and Smith 2009). A barrier net was used to constrain grass carp to one side of Lake Parkinson during trials to determine their effectiveness. A barrier net installed across the outlet stream was also successfully used to prevent grass carp emigrating from Lake Wainamu. However, barrier nets across streams may trap floating vegetation and are vulnerable to being blown out during high flow events.

Some non-physical barriers, such as behavioural systems (e.g., strobe lights, air bubble curtains, acoustics, electrical fields, hydrodynamic louver screens) have been documented with partial success (Cassani et al. 2008). However, in the majority of cases physical structures are required to contain the grass carp at the outlet of the waterbody (Bonar et al. 1993). Professional advice should be sought on the risk of grass carp escape and the most appropriate barrier design because each location will have specific characteristics influencing optimal design.

Screens that prevent the emigration of grass carp will not reduce the upstream migrations of native fish species because the juvenile migrants are all small enough to pass through the screen slots. However, upstream migrations by adult lamprey and grey mullet could potentially be affected by screens, but only if these species occur above the stocked site and the screen slots are too small for them. In these situations, larger screen slots may be required and hence larger grass carp. Downstream migrations of adult eels could also be prevented by screens unless an eel pass is installed (see section 4.5). Adult eel passes have been installed in the outlets of Lake Opouahi and Lake Tutira where mesh barriers and metal screens respectively prevent the emigration of grass carp and would have also prevented downstream passage of large migrant longfin eels.

In summary, the feasibility of using grass carp for weed control in a given waterbody or waterway must consider the ability to contain the grass carp at a high enough density to control the weed. Containment may be inherent in the nature of the site, i.e., a pond with no inlets or outlets, or it could take the form of a constructed barrier. Grass carp cannot be considered for macrophyte control in aquatic environments where it is not feasible to contain them or where their containment results in other unacceptable environmental effects.

6.3 Plant species palatability and density

Another potential constraint on the use of grass carp is the presence of unpalatable plant species. Although grass carp prefer certain plant species over others, there are few plants in New Zealand that are not palatable when no other species are present. The least preferred plant species (and hence the last to go) include species of water lilies (*Nymphaea*), water fern (*Azolla* spp.), *Acorus, Phragmites*, *R. trichophyllus*, and *M. triphyllum*. In addition, grass carp preferences are related to the chemical/nutritional properties of the plant, the ease of mastication (Wiley et al. 1987, Bonar et al. 1993, Pipalova 2002) and the lake from which the plants were sourced. For example Chapman and Coffey (1971) noted that egeria from the Waikato River was consumed, while plants of the same species from Western Springs were rejected. Despite the large number of grass carp releases in New Zealand that have occurred to date, there are no known instances of unpalatable plant species completely replacing palatable species. This aside, where less palatable species dominate, higher stocking densities of grass carp may be required to achieve rapid control.

Weed density may be high in some shallow waterbodies (e.g. small drains and ponds where 100% weed cover can occur) such that the movement of grass carp is impeded. Stocking these waters is not advisable as high mortalities of grass carp can occur. For example, when a borrow pit (in the Hauraki Plains) was stocked with juvenile grass carp, a high mortality occurred following the development of 100% surface water cover by the water fern (azolla (*Azolla* spp.)). The cause of this mortality was attributed to the depletion of oxygen entering the water via the surface because of the dense cover of azolla (author's observation). This constraint could be removed by pre-treatment (mechanical or chemical) to create some open-water areas for the grass carp. Partial removal of azolla was carried out in a pond at Ayrlies Garden prior to stocking with grass carp, and subsequent successful weed control by the grass carp was achieved (Appendix B).

6.4 Water temperature

Water temperature, which is affected by latitude and altitude, is the main factor limiting grass carp feeding (Spenser 1994, Swanson and Bergerson 1988). Hence the length of the growing season may influence the feasibility of using grass carp and the stocking rate required to achieve control.

Grass carp are a warm water, herbivorous fish and feeding on macrophytes begins at water temperatures over ca. 15°C, increasing up to at least 30°C (reviewed in Rowe and Schipper 1985). Consumption rates at optimal temperatures also vary with fish size, such that there is an increase in consumption with increasing size up to the point where fish mature. For example, juveniles (6 to 15 cm) consume 6 to 10% of their body weight in vegetation each day (wet weight basis). Fish weighing 1 to 1.2 kg can consume more than their body weight each day (Masser 2002), with larger mature fish exhibiting a decline in consumption relative to their body weight with age (Chapman and Coffey 1971, Colle 2009).

Irrespective of the plant species, grass carp consume vegetation intermittently at temperatures as low as 3-5°C (Chapman and Coffey 1971, Masser 2002), they feed more steadily at 10° to 16°C, with optimal consumption at temperatures between 21°C and 30°C (Wiley and Wike 1986, Osborne and Riddle 1999, Masser 2002). Mitchell (1980) state that low water temperature (below 13°C) reduced grass carp browsing to maintenance levels, and some recolonisation of plants was observed. Likewise, Kilambi and Robison (1979) recognised a temperature threshold of ca 13°C, with temperatures above this (18 to 29°C) resulting in plants consumption rates by grass carp that were more than four times higher. Chapman and Coffey (1971) report a change to active feeding occurring at 7 to 8°C, which is lower than that reported in other studies (above), although they used juvenile fish and observed the most intensive utilisation of food at water temperatures of 24° to 26°C.

Given that other water quality parameters are acceptable to freshwater fish in general, grass carp feeding and growth are driven by water temperature (Spencer 1994), and more specifically the duration of temperatures over the threshold for active feeding (Swanson and Bergerson 1988). Understanding this relationship is essential to predicting whether grass carp can achieve plant control, and in adjusting their stocking densities to local climate conditions (Wiley and Wike 1986).

Simulation scenarios for irrigation canals with warmer or cooler water temperature have shown that using triploid grass carp (e.g. in northern California irrigation systems that typically have cool water temperatures (12 to 24°C)) would require more fish than in warmer waters (Spencer 1994). Similarly, grass carp feeding in New Zealand water is maximal during summer months and minimal during winter with the feeding season being largely determined by water temperatures.

These results indicate that environments with low water temperatures will be unsuitable for vegetation control by grass carp. For example, high altitude lakes and tarns in New Zealand where water temperatures are low for most of the year and rarely exceed 20°C would not be suitable for grass carp. Similarly, some streams in New Zealand are fed primarily by cold spring water such that year-round water temperatures are less than 20°C (Mosely 1982). For example, many of the larger streams entering Lake Rotorua (e.g. Ngongotaha, Utahina, Awahoua, Hamurana) are spring fed, have water temperatures below 15°C for most of the year, and yet contain large beds of introduced macrophytes. The Te Waikoropupū Springs near Takaka has cold water and supports a diverse macrophyte community. Because the water temperatures in these environments are too low to support grass carp feeding, the use of these fish for vegetation control could not be considered practical in these environments.

In addition, a number of mid-altitude South Island lakes/reservoirs are fed by the cold water melt from glaciers and so during spring are cooler than lakes fed by rainfall and whose water temperatures are influenced primarily by air temperature. Water temperatures are also moderated in large, deep, glacial lakes which take longer to heat. Such cooler lakes/reservoirs would not be suitable for grass carp if their water temperatures failed to exceed 20°C during summer or only exceeded this threshold for a short period. Identification of these will depend on the availability of seasonal temperature data, which is currently lacking for many of these waters.

Apart from such ‘cool’ water environments, there is unlikely to be any temperature restriction on the use of grass carp in lowland New Zealand lakes and waterways, including those on the east coast of the South Island, where summer air temperatures are often hotter than in northern North Island. Even at higher inland altitudes, such as in the McKenzie Basin, where there are greater variations in temperature than elsewhere in New Zealand, summer air temperatures are over 20°C for much of the summer, so lake temperatures would be suitable.

In summary, given that other key water quality parameters (e.g. pH and oxygen) are acceptable, grass carp feeding and growth are driven primarily by water temperature (Spencer 1994), and more specifically by the duration of temperatures over the threshold for active feeding (Swanson and Bergerson 1988). Understanding this relationship is essential to predicting whether grass carp can achieve plant control, and in adjusting their stocking densities to local climate conditions (Wiley and Wike 1986). In general, water temperatures would need to be over 20°C for at least a month to enable weed control by grass carp. Control may be achieved in cooler environments by using very high stocking densities but, at present, this has not been trialled in New Zealand and so there is limited data to support this possibility.

6.5 Water depth and quality

Water depth is also an important constraint on the use of grass carp. Adult fish tend to avoid the shallow margins of lakes despite the presence of edible vegetation and they do not enter streams much shallower than ca 0.5 m deep, preferring deeper (>1.0 m) waters. In addition, grass carp avoid shallow lake areas subject to frequent disturbance by humans (e.g. jetties, launching ramps). The use of grass carp for weed control could be problematic in lakes or drains where a large proportion of the littoral zone is shallower than 0.5 m. Other vegetation control methods may be required to complement grass carp in such shallow environments, or the water level would need to be artificially raised.

Low oxygen concentrations, high ammonia levels and/or low pH (acid conditions) will also limit the use of grass carp for weed control. These fish are generally tolerant of low water quality conditions but their survival is reduced by low oxygen concentrations (< 2 ppm), high ammonia levels and low pH (<4) acid conditions. In addition, food consumption studies show that grass carp feeding can be reduced by low dissolved oxygen (<4 ppm), increased salinity, and low water temperature (Stewart and Boyd 1999, Pipalova 2006, Colle 2009). For example, dissolved oxygen (DO) levels influenced their feeding activity with reduced consumption below 4 ppm and fish stop feeding if DO falls below 2 ppm (Colle 2009).

The stocking of carp in tertiary oxidation ponds (near Napier) where nocturnal oxygen levels can fall below 2 ppm just before dawn failed because of high fish mortalities (A. Carruthers, pers. com.). Consequently grass carp would not be suitable in these environments. Similarly, grass carp have failed to survive in lowland drains experiencing low pH levels (<4) following heavy rain and the likely influx of acidic ground-water present in adjacent peat swamps (author's unpubl. data).

6.6 Stocking rates

The use of grass carp for weed control has been described as resulting in one of three outcomes based on stocking density: high stocking resulting in the removal of all aquatic vegetation; intermediate stocking resulting in a selective reduction of vegetation, with preferred species grazed first (Blackwell and Murphy 1996, Bonar et al. 1993, Chilton and Magnelia 2008); or low stocking with little or no control at all and some change in species composition (Cassani 1995).

Within the literature there is huge variation in the stocking density of grass carp reported for successful aquatic weed control programmes over the last 50 years, with effective stocking rates ranging from 5 to 500 grass carp per hectare of lake surface area, although 25 to 60 fish were more commonly used (e.g. Allen and Wattendorf 1987, Sutton and Vandiver 1986, Leslie et al. 1987, Wiley et al. 1987, Schramm and Brice 1998, Stewart and Boyd 1999). Some of this variation can be attributed to the different management goals of stocking programmes, (e.g. maintaining a low level of, or removing all vegetation), how the stocking density is reported (e.g. size of the waterbody, or the vegetated area within the waterbody), the desired timeframes in which control is achieved, the plant species present, differing fish responses to regional temperature ranges, but also differences due to a lack of certainty as to how many fish have stayed in the stocked area (i.e. the effective density, including losses from mortality) (van Dyke et al. 1984, Swanson and Bergersen 1988, Blackwell and Murphy 1996, Schramm and Brice 1998, Stewart and Boyd 1999) (see section 6.2 on containment).

Grass carp stocking rates may be varyingly described as the number of fish per area of lake, or per vegetated area, or weight of fish per area. In shallow waterbodies, that have submerged vegetation throughout, these first two stocking density numbers vary little, but there is greater variation between these rates in deeper lakes where the vegetation is confined to the littoral margin. Furthermore, some publications also attribute the "all or none" result in weed control from grass carp (Cassani 1995) to stocking density calculations based on waterbody area not vegetation (Wiley et al. 1987, Leslie et al. 1996, Schramm and Brice 1998).

To illustrate with a New Zealand example, the reported stocking of grass carp in two small lakes was 54 kg/ha and 58 kg/ha in two consecutive introductions two years apart in Waihi Beach Reservoir, and 115-161 kg/ha (incrementally stocked over winter) in Parkinson's Lake (Mitchell 1980). In Waihi Beach Reservoir, preferential consumption of plants occurred at the low stocking density but no long term reduction in standing crop occurred. A higher stocking density resulted in significantly reduced vegetation after two summers. In Waihi Beach Reservoir *P. ochreatus* and *Nitella* sp. aff. *cristata* were preferentially consumed. In Parkinson's Lake the incremental grass carp stocking rate reached 161 kg/ha and was sufficient to eliminate all vegetation (dominated by *E. sphacelata* and egeria) by mid-summer in the year after the final stocking. Given that the different stocking densities used here to heavily reduce or eliminate the aquatic vegetation were not directly comparable, Mitchell (1980) suggested that stocking density based on surface area would not yield consistent results, and that calculations were best based on the littoral zone size (which limits macrophytes) or a measure of the plant standing crop.

An approach where vegetation estimates are used to calculate stocking density has been supported elsewhere (e.g. percent cover (Schramm and Brice 1988) and macrophyte biomass (Cassani et al. 2008)) and is advocated in this present report.

Although the calculation of total macrophyte biomass would be the most accurate approach, it requires multiple transects to estimate cover and height (and so is expensive to determine), and the density of plant shoots can vary with species, and time of year. A more realistic approach would be to assess the macrophyte biomass present from the measured percent cover of the lake area. Where accurate measurement of percent cover is not possible (e.g. because the lake is deep and hence the maximum depth of weed beds cannot be observed), the percent of the lake bed that is shallower than 10 m would provide a practical substitute, as little growth of problem weeds is found in deeper water (Champion et al 2002a).

Aside from the goal of stocking grass carp for a weed control outcome such as eradication versus plant reduction, the target species and presence of preferred plants is also an important factor in determining the result. In the two examples above (Waihi Reservoir and Parkinson's Lake), the target plants also differed, not just the stocking density (Mitchell 1980). The influence of plant species on daily plant consumption by grass carp has been documented and modelled (AMUR/STOCK model, Stewart and Boyd (1999)). But this refinement depends on grass carp plant preferences and these can vary. There are examples where the same species is reported as preferred in one study and not in another (e.g. hornwort was 'not consumed' in Pine and Anderson 1991a, Spencer 1994, Stewart and Boyd 1999, Masser 2002, compared with 'preferred' in Mehta and Sharma 1972, Cassani 1981, Swanson and Bergersen 1988, Kirkagac and Demir 2006). The challenge here is that no two studies offer the same selection of plants to the grass carp, and 'preferred' is a relative term, and may be related to plant source (section 6.3).

Although the lack of standardisation in the terminology of grass carp stocking prevents direct comparisons between many reports in the literature, an additional challenge is that the stocking rates generally reported do not account for the increase in size of fish related to their growth rate. This is also very important as the browsing pressure of grass carp increases as the fish grow. Hence, stocking rates should ideally be recommended with the growth and hence total biomass of grass carp in mind after 3-4 summers.

6.6.1 Development of a standard stocking rate

To overcome some of these issues, Stewart and Boyd (1999) produced a stocking rate model that calculates the number of fish required per vegetated hectare. This allows managers to identify stocking rates given data or assumptions about lake size, seasonal water temperature, plant biomass and production rates and fish size, mortality and growth rate. This is a sophisticated model and it illustrates many of the factors that influence the stocking rate for grass carp noted above. As it was produced for North America, it would need to be calibrated for New Zealand use, however, its value over a more simplified version would also need to be determined.

To reduce some of the variability in stocking rate terminology, in New Zealand waters it is recommended that:

- Stocking rates are based on a standard fish size (i.e. 25 cm fork length);
- Rates are expressed in terms of number of fish per vegetated hectare (vha);
- Different rates are used depending on the requirements for weed control (e.g. rapid versus slow, where there are ecological risks from rapid control).

In New Zealand, grass carp will generally be stocked at the smallest size needed to avoid excessive production and transportation costs while reducing the likelihood of high mortality from predation (see section 5.2.1). Hence the minimum stocking size proposed for a 'standard fish' in New Zealand is 25 cm long (measured from the tip of the snout to the fork in the tail fin). This equates to a weight of about 200 g (Figure 2).

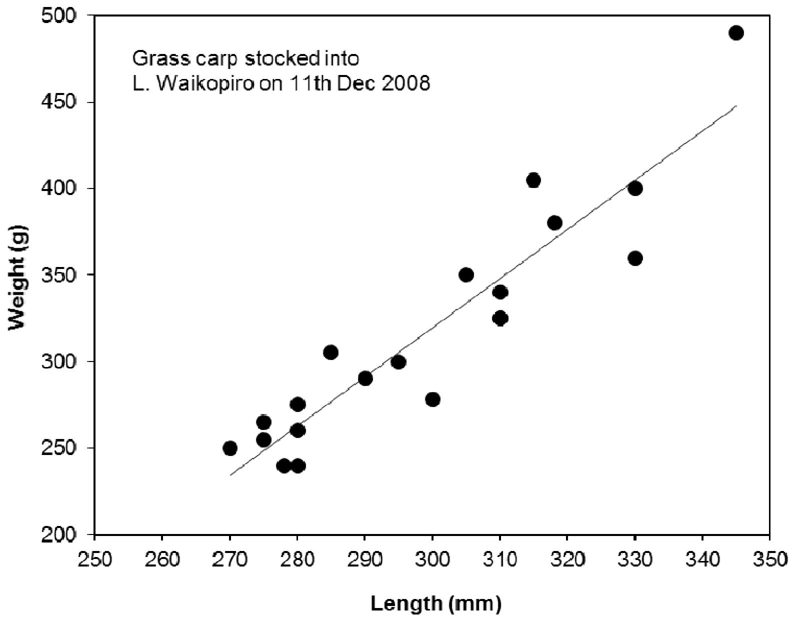

Figure 2: Length-weight relationship for juvenile grass carp (supplied by NZ Waterways Restoration Ltd).

Given the typical summer water temperatures in New Zealand, grass carp stocked at this size can be expected to grow from the stockable weight of ca 200 g up to 6 kg after 3 years and reach weights over 15 kg after 7 years (based on a growth rate for grass carp reported in Chisnall (1998)).

A rapid reduction of macrophytes occurred in Parkinson's Lake at a stocking rate of only 22 fish/vha, even though the stocking rate was later increased to 44 fish/vha (Mitchell 1980). These fish were all stocked at a relatively large size (i.e. close to 500 mm long and > 2 kg in weight) and so browsing pressure was greater than for an equivalent number of smaller fish. In Lake Waingata (Northland), where the weed occupied 7 ha, total removal occurred after two summers following the stocking of 153 grass carp averaging 1.5 kg in weight (also at a density of 22 fish/vha). Thus, relatively rapid removal (>90%) can be achieved in lowland New Zealand lakes after 2 years at stocking densities of 22 fish per vegetated ha, provided large fish (>1.5 kg) are used.

A rate of 22 fish/vha, but using smaller, standard-sized fish, can be expected to also achieve removal of all vegetation in New Zealand waters, but over a longer time scale (i.e. 3-4 years versus the 2 years for larger fish). This is because the total browsing pressure related to an initial stock of 22 standard-sized fish/vha would increase over time such that after 4 years the total biomass of the fish would achieve the 100 kg/vha recommended for total vegetation control in temperate European (Pipalova 2006) and New Zealand lakes (Rowe and Schipper 1985). A stocking rate of 22 fish/vha is therefore a useful baseline for identifying high and low stocking rates appropriate for New Zealand waters.

6.6.2 High stocking rates

High stocking rates are required to achieve control when the main plant species are unpalatable and/or when water temperatures are cooler than in lowland lakes because of high altitude or large inflows from cold-water springs. Examples from the literature, for less preferred plant species (e.g. milfoil and hornwort), consider it may be necessary to increase the stocking rates by up to four times (Wiley et al. 1987, Spencer 1994), or more (Masser 2002).

The stocking rate used in the cooler Devil Lake, Oregon (180 fish v/ha) was much higher than rates used in most other US states for control (not elimination) of submerged macrophytes, and was closer to densities that have been successful in Europe (Bonar et al. 1993). But this lake was colder than those typically stocked with grass carp in the USA. During the two year study period in Devil Lake, surface water temperatures ranged from 7°C in winter to spring-summer temperatures of 17 to 21°C, and with the exception of the hornwort which remained constant, the vegetation only declined by 30% (Bonar et al. 1993).

A stocking model was developed for coldwater lakes by Swanson and Bergersen (1988) that included key factors (e.g. water temperature, density, distribution, aquatic plant species and human disturbance). Grass carp densities were increased as temperature decreased based on Daily Temperature Units (DTUs). These were defined as the annual sum of mean daily air temperatures above 12.7°C to reflect changes in grass carp feeding rates with temperature. Grass carp stocking densities in this model were also adjusted according to the standing crop (biomass) of aquatic vegetation. Standing crop was estimated by multiplying plant area by average plant density; therefore, the higher the vegetation biomass the higher the required stocking rate. Stocking densities were conservatively designed to achieve the desired density and distribution of vegetation within three to four years after the introduction of grass carp. Based on these factors, and a grass carp size of 20 to 28 cm, baseline stocking rates ranged from 20-30 fish/ha for low-elevation lakes with low plant biomass, up to 90-100 fish/ha for high-elevation lakes with high vegetation biomass (Swanson and Bergerson 1988).

Simulations of grass carp feeding in canals with cool water temperatures (Spencer 1994) yielded generally higher stocking rates. For example, simulations showed that using triploid grass carp in northern California irrigation systems that typically have cool water temperatures (12 to 24°C) would require 50 to 250 kg of grass carp biomass per vegetated hectare depending on the management objectives. However, in the initial simulations consumption rate was recalculated every hour based on the estimates of water temperature and consumption. Literature reports indicate that grass carp do not show strong temporal patterns of feeding behaviour (Shireman and Smith 1983), but simulations were also run to test the notion that grass carp feeding was restricted to the warmest part of the day, which correspondingly altered the impact on plant biomass (Spencer 1994). Stocking rates obtained in simulations for cool water Californian canals were similar to those reported from some European studies that demonstrated weed reduction, e.g. 29 to 250 kg of grass carp biomass per hectare (in Pipalova 2002, Fowler and Robson 1978, and van Zon 1977, respectively across the range), with a higher value (ca 343 kg of grass carp biomass) reported in Stott and Robson (1970).

High stocking rates of adult grass carp are also required when rapid control of a target weed species is required (e.g., an unwanted species that poses a high biosecurity risk). High stocking rates generally result in the rapid removal (i.e. within 1-2 years) of all aquatic vegetation in lakes that contain palatable plant species. Comparatively high grass carp stocking rates have been used in this context in New Zealand lakes to remove hydrilla weed beds. A rapid reduction of the submerged weed hydrilla was required in Lakes Tutira, Waikōpiro and Opouahi to mitigate the national biosecurity risk of it being spread elsewhere. Grass carp over 25 cm long were stocked into these lakes at a relatively high density of 100 fish/vha of weed cover (Hofstra and Rowe 2008). Fifteen months (including two summers) after stocking, hydrilla was reduced by 99% in all lakes (Clayton and Champion 2011).

- It is recommended that a stocking rate of 100 grass carp/vha be adopted as a high stocking rate for New Zealand waters as this can be expected to achieve rapid removal of palatable submerged aquatic vegetation.

6.6.3 Low and medium stocking rates

Because rapid removal of aquatic vegetation can amplify some of the adverse environmental effects of weed control (Pipalova 2002), it would be more desirable for some sites if weed reduction or removal was spread over 4-5 instead of 1-2 summers. The development of a lower stocking rate for a more gradual control of aquatic vegetation depends on the size of grass carp used as well as the thermal properties of the lake. It also depends on the palatability of the main plant species and plant growth rates. Stocking rates as low as 3-10 fish tonne per dry weight of weed were trialled in Florida lakes to achieve a partial level of hydrilla control (Wiley at al. 1987, Leslie et al. 1987, Cassani 1995). Unfortunately, the data provided in those reports do not allow stocking rates to be calculated in terms of numbers of fish per vha. Nevertheless, these low densities resulted in a slower level of control with some plants still remaining after 4-5 years. Hence lower stocking rates can produce a slower rate of control even though total control (weed removal) will be achieved in the long term.

These rates would have less effect in the colder waters of New Zealand. In New Zealand, stocking rates of 22 'large' (i.e. > 1.5kg) grass carp per vegetated hectare achieved control over 2-3 summers (see section 6.6.1). A 'standard' stocking rate of 22 'standard-sized' fish/vha would therefore be expected to achieve total control over longer periods (e.g. ca. 3-4 years) in most New Zealand waters containing palatable plant species. This slow rate of removal would help reduce the risk of short-term adverse changes in water quality.

- It is recommended that 22 standard-sized grass carp/vha is adopted as a slow stocking rate for New Zealand waters.
- Given that 100 standard-sized grass carp per vha is a high rate, 50 standard-sized grass carp per vha is recommended as a medium rate for use in situations where control is required but where the rate of control is not an issue and where the stocking rate does not need to be high.

6.6.4 Grass carp welfare

There are several factors that require consideration for successfully stocking grass carp. Of these containment (section 6.2), plant preferences (section 6.3), water temperature (section 6.4) and water quality (section 6.5) have already been described earlier. This section covers other aspects of sites as related to grass carp welfare such as the risk of mortality from handling and predation.

The loss of grass carp from mortality can be a challenge in maintaining an effective stocking density. In particular, at low densities the loss of even a few fish could significantly reduce the total biomass of grass carp within the impoundment and affect the control outcome (Osborne and Sassic 1979, Blackwell and Murphy 1996). Hence it is important to maintain the survival of grass carp during transport to the site and following their release.

Mortalities and stress of grass carp during transport can be avoided by ensuring the water in holding tanks is as cool as possible (<15ºC) and is always well-oxygenated (>5 ppm). High densities of fish will rapidly deplete oxygen concentrations, so continuous aeration (or oxygenation) may be required and the maintenance of cool water (e.g. using ice) will reduce metabolism and hence oxygen demand. In addition, the use of fish sedatives such as Aqui-S to reduce stress during transport is now increasing and can be considered ‘good practice’.

Handling of fish during loading and release can also induce stress and cause delayed reactions including greater susceptibility to disease organisms. Care is required during this process to ensure physical contact with fish is minimised. Transfer into water differing greatly from that experienced by grass carp just prior to release can also be stressful. It is considered good practice to acclimatise fish to the water quality (including temperature) of the receiving environment before their release. This is achieved through a gradual replacement of container water with water from the receiving environment.

Predation risk should also be considered. For example, small grass carp were introduced into the hydrilla-infested Lake Baldwin but no control was achieved so a selective rotenone treatment was undertaken to estimate the population. A loss of grass carp (94% mortality) was established, and predation considered the likely cause for the reduction in grass carp density (Shireman et al. 1985). Similarly, the stocking of high densities of small grass carp has occurred in New Zealand lakes and water ways (e.g. Lake Omapere, Lake Kereta (section 4.2.1), also see Appendix B) with likely high mortality. This is undesirable because it introduces uncertainty over stocking density and results in unnecessary mortality of fish. It is readily averted by stocking fish over the minimum size for predation. There are no large piscivorous fish in New Zealand lakes, apart from trout and eels, and neither of these species can consume grass carp over 25 cm in length. The main avian predator is the black shag (*Phalocrocorax carbo*) but if grass carp are stocked at a size at or over 25 cm, then mortality from shags can also be largely avoided.

7 Biosecurity risks from the use of grass carp

7.1 Introduction

The transfer of fish from one waterbody to another by deliberate stocking has the potential to spread aquatic plants and animals (e.g. plankton, molluscs, fish larvae), along with fish parasites and diseases, to waterbodies where they were previously absent. There is now a wealth of international experience indicating that fish transfers from one waterbody to another are one of the main vectors responsible for the spread of aquatic invasive species.

This is of particular concern in New Zealand because freshwater aquatic ecosystems are particularly vulnerable to invasions by plants (e.g. the algae water net, didymo), planktonic species (e.g. hydromedusae and crustacea), molluscs (e.g. lymnaeid snails, apple snail) and fish (e.g. koi carp, catfish, gambusia). Furthermore, the transfer of live fish from one waterbody to another has contributed to the spread of gambusia in the North Island and resulted in the historic but temporary (as no longer present) contamination of a number of South Island east coast rivers with *Myxobolus cerebralis* (whirling disease) (McDowall 1990).

Grass carp were initially quarantined in New Zealand in order to allow the removal of all 'exotic' parasites and disease organisms before they were released for experimental trials (Edwards and Hine 1974). The risk of such novel 'exotic' parasites and diseases being introduced to New Zealand and spread internally was therefore addressed during this quarantine.

However, some indigenous and new disease and parasite species could now be spread in the future as a result of grass carp stocking. In addition, species of algae and some small fish and molluscs could also be spread via grass carp stocking. The categories of organisms of most concern include;

(a) any existing disease or parasite that could infest hatchery stocks of grass carp and adversely affect other fish species,

(b) any introduced planktonic organism that is present in grass carp rearing ponds that could be spread to waters where it is not present and create environmental problems,

(c) any introduced species of mollusc or other invertebrate present in grass carp rearing ponds that could be spread to waters where it is not present and pose a risk to, indigenous species,

(d) any introduced species of fish present in grass carp rearing ponds that could be introduced to waters where it is not present and pose a risk to other species, and

(e) any introduced species in water added to the transportation tanks during transfer from a hatchery or rearing area to a stocking site.

To minimise the risk of introduced and/or unwanted species being spread from grass carp hatcheries and rearing ponds, it is necessary to identify such species, to determine the main vector(s) involved in their spread from the hatchery and to develop appropriate de-contamination measures and stocking protocols to reduce this risk. This task is beyond the scope of this report, but provided grass carp hatcheries and rearing ponds are pest and disease free (as determined by monitoring), biosecurity issues would need to be considered in transfers of grass carp from one release site to another. Such issues would also need to be considered if the hatchery or rearing pond water used to transfer grass carp is replenished or topped up from any other water source (apart from treated town supply) en route to the stocking site.

7.2 Pest species and vectors

At present, information on the identity and status of disease organisms infecting grass carp (i.e., pathogenic bacteria and viruses) and being transferred to other fish species in New Zealand is sparse. The disease organisms known to infect grass carp in other countries are listed in Shireman and Smith (1983) and more recently by the Food and Agriculture Organisation (FAO) http://www.fao.org/fishery/culturedspecies/Ctenopharyngodon_idella/en

The main threat to grass carp is haemorrhagic disease (GCRV reovirus), but it is also susceptible to infection from common bacterial pathogens such as *Aeromonas, Yersina, Vibrio,* and *Pseudomonas* which infect a range of fish species, especially species within the Genus Cyprinidae.

Corfield et al. (2008) reviewed the risks associated with the spread of pathogens by exotic freshwater fish in Australia and noted that koi herpes virus has been spread via introductions of koi carp from Japan to North America and Europe with devastating effects. Koi carp and grass carp are different species, but are related and in the family Cyprinidae so there is likely to be a risk of pathogenic transfer associated with the stocking of species such as grass carp. Corfield et al. (2008) produced a list of the pathogenic organisms known to be associated with the culture and transfer of goldfish. As goldfish and carp are also both cyprinids, their disease profiles may be similar and the pathogens infecting goldfish maybe similar to those infecting grass carp. However, there is little known about the pathogens of Asian carps let alone grass carp and the effects these may have on other fish species in New Zealand, especially the native Galaxiids and Eleotrids. As a consequence, the biosecurity risk of transfer of pathogenic bacteria and virus by grass carp in New Zealand cannot be addressed at present and constitutes a global ‘knowledge gap’. Until this risk is better quantified, grass carp should be isolated from other cyprinid species to ensure hatchery stocks are disease free.

In general, introduced species of fish, plankton, plants and molluscs present in hatchery ponds containing grass carp, could be readily transferred via the water on nets into tanks for transport of grass carp to a new location. If the water in the transport tanks containing the grass carp is drained directly into the treatment lake/pond, then any ‘hitch-hikers’ present will enter that lake/pond and colonise it. The species posing most risk will be those that are small (or which have a small larval stage) and which thrive in grass carp hatchery ponds. In addition, some fish diseases and/or parasites could be spread by transfers of grass carp.

Whereas ponds used to rear juvenile grass carp would be the main source for the spread of these introduced species to waters where they are currently absent, transfers of live adult grass carp from one treatment site to another also needs to be considered. The biosecurity risks associated with transfers of adult fish from one waterbody to another waterbody that is not hydrologically connected with the first, are just as important as those involving the transfer of juvenile fish from a hatchery to a treatment site. Avoidance of the potential biosecurity problems associated with such inter-site transfers requires knowledge of (or an assessment of) the introduced species present in each environment to ensure that no new species are transferred with the grass carp. In addition, when grass carp are transferred from a treatment site back to a hatchery, then the risk of introducing new species to hatchery ponds needs to be considered and avoided.

Hatchery ponds where grass carp are reared currently occur mainly in the North Island, but rearing sites, where juveniles are grown to a stockable size have included sites in Northland, Upper Hutt and Nelson. Rearing ponds for juvenile grass carp at these sites will be the main source of potential introduced species, and the species present will depend mainly on the source water for the ponds. Where the rearing pond water is sourced from a nearby river/stream, then the larvae of introduced fish, or other species present in that stream can enter the ponds and colonise them. Surveillance (via routine monitoring) is therefore required in these ponds to identify any introduced species that may be inadvertently transferred to a new waterbody through the stocking of grass carp.

The species of introduced fish in New Zealand that are most likely to pose a biosecurity risk through their transfer (via shipments of grass carp) to locations where they are not currently present include gambusia and goldfish. Both species are common in many North Island waters and can be expected to occur in the rearing ponds of fish hatcheries, especially if water for the ponds is sourced from rivers/streams where these species are present. The New Zealand Fish Risk Assessment Model (Rowe and Wilding 2012) scores introduced fish species on the basis of their overall threat status to New Zealand freshwater ecosystems. Gambusia scored 28 (high risk) whereas goldfish scored 17 (moderate risk).

Although both species are present in many waters throughout the North Island, with goldfish also present in the South Island, there are also many ponds and lakes where these species do not occur. The small size of gambusia and potential presence of small goldfish larvae in hatchery ponds means that they could be readily introduced into the grass carp transport containers and then accidentally transferred to sites where they do not currently occur through the stocking of grass carp. As their transfer to new locations could create unwanted ecological problems and compromise ecosystem services, surveillance and monitoring of hatchery ponds would be required by the hatchery staff (as required by MPI) to ensure their continued absence.

Parasites and disease organisms associated with fish also need to be considered. *Ligula intestinalis* is a fish tapeworm that is currently confined to several west coast lakes north of Auckland (Weekes and Penlington 1986). Although it favours cyprinid fish as its primary host, it readily infests common bullies in these lakes (Weekes and Penlington 1986) and bullies are a key prey species for more valued fish including eels and trout. As *Ligula* has readily infested common bullies it can be expected to be spread to other indigenous fish in time, including possibly galaxiids and eels. Secondary hosts include fish-eating birds such as shags, herons and kingfishers. These can spread *Ligula* to new waterbodies but it is currently confined to few lakes in the North and South Kaipara Head and has not been spread beyond these, despite the presence and likely extensive movements of both small and large black shags in this region. If *Ligula* entered a fish hatchery (either via the return of an infested grass carp, or via a secondary host) it could infest the grass carp present in the hatchery. Its spread to other waters via transfers of grass carp would then follow unless it could be treated and eradicated from the hatchery ponds. Hence, infestation of grass carp stocks with *Ligula* needs to be avoided as this could result in more rapid spread of this parasite.

Planktonic species (e.g. algae and zooplankton) and small unattached plants such as bladderwort (*Utricularia gibba*) could also be spread by transfers of fish from hatcheries. In New Zealand, the North American calanoid copepod, *Skistodiaptomus pallidus*, has been recently found in several lakes stocked with grass carp (I Duggan, University of Waikato pers. comm.) and, although its spread through New Zealand waters could occur naturally over time via bird movements, it may be accelerated and long-distance dispersal facilitated by fish stocking. The stocking of grass carp has the potential to accelerate the spread of introduced zooplankton species along with any new plankton algae and/or other aquatic microorganisms.

7.3 Sanitation and decontamination measures

Preventing the introduction of species posing a biosecurity threat into grass carp hatchery environments requires fine (<1 mm) filtration of river/stream water before it enters the ponds. Where water for the rearing ponds is sourced solely from rainfall, springs, or bores then the risk of contamination by introduced species is minimised. However, some very small invasive species (e.g. zooplankton) could be introduced to rearing ponds via aquatic birds such as shags, which are attracted to hatchery ponds containing small fish. Netting placed over such ponds to prevent predation on fish will minimise this risk.

At present, MPI protocols/regulations govern the transfer of freshwater fish from the South Island to the North Island to prevent the spread of whirling disease and more recently didymo to the North. These regulations would prevent the transfer of all live fish, including grass carp, from the South Island back to the North Island. However, the transfer of grass carp from the North Island to the South Island and other Islands is currently possible.

These regulations aside, the risk of introducing legally ‘unwanted’ species, such as gambusia and *Utricularia gibba*, to the South Island needs to be prevented as these species are currently absent from the South Island, except for several populations of gambusia near Nelson which are the subject of DOC eradication programmes. The voluntary protocols described below would help achieve this, but all transfers of grass carp from the North to South Island should also be subject to MPI approval to ensure that there is no transfer of ‘new organisms’ to waterbodies where they are not already present.

Internal transfers of grass carp within the South or North Island, either from a hatchery to a treatment site, or between treatment sites, will need to avoid the risk of introducing invasive and/or nuisance species to waters where they are not present. Avoidance of this risk requires vigilance in the loading of grass carp into transport containers, and the adoption of protocols for ensuring hatchery water does not enter the treatment lake or pond into which the grass carp are being stocked. Protocols used successfully to date include the transfer of grass carp (by hand net) from their transport container(s) into temporarily constructed pools/containers (e.g. parapool) placed alongside the treatment lake/pond. These temporary pools/containers are filled with water from the lake/pond and the grass carp are netted out from the transport containers and placed into the temporary pools/containers, where they can acclimatise to the lake/pond water conditions. Once acclimatised, they are then netted out (by hand net) and stocked into the treatment pond/lake. Such double-handling increases stocking costs and stress, but ensures that grass carp are properly acclimatised to the treatment lake/pond water and that any ‘hitchhikers’ are either not introduced into it, or are too few to establish a self-reproducing population (i.e. propagule pressure is minimised). Water from the transport container(s) and temporary pool(s) is then drained to land so that it does not enter the treatment environment. Such stocking protocols will avoid the risk of transferring other introduced fish species (e.g. gambuia, goldfish, koi carp, catfish) and should be part of management plans for stocking grass carp.

Prevention of the biosecurity risk posed by smaller organisms is problematic because zooplankton, phytoplankton and aquatic microorganisms are all much smaller than fish larvae. Reduction rather than avoidance of this risk is more appropriate as the spread of these organisms is also likely via aquatic birds. Reduction could be achieved through the use of protocols for preventing the introduction of small fish as described above.

Prevention of hatchery and rearing pond contamination by fish parasites and diseases will require vigilance by hatchery managers to ensure that no live grass carp are returned to the hatchery from sites already infested with parasites such as *L. intestinalis*, and/or disease organisms. In addition, periodic (e.g. annual) checks of grass carp reared in hatchery ponds would be advisable to ensure that they are free of exotic diseases and parasites. These measures will not only protect the stocks of grass carp present, but will also reduce the risk of parasitic or disease organisms being spread more widely.

8 Removal of grass carp

8.1 Introduction

Two of the major constraints on the efficient use of grass carp for weed control are;

(a) the ability of managers to determine the size of the stock especially after an event such as a flood occurs that may result in escape or mortality, and

(b) the ability to remove all grass carp or significantly reduce the stocking density after they have achieved the desired weed control outcome.

These limitations are becoming more important as the number of sites stocked with grass carp increases in New Zealand and as experience indicates that, without intervention, grass carp can maintain browsing pressure and hence a weed free condition for up to 20+ years. While this may be an advantage at some locations, it is a major limitation in others, especially where grass carp are used as a tool in lake restoration (as in New Zealand).

Restoration of lakes in New Zealand is possible following removal of introduced weeds, because the majority of the most invasive aquatic weeds do not produce seed, which facilitates their eradication. Without a seed bank these plants can only spread via vegetative growth. Once all vegetation is removed from a lake by grass carp, these species are effectively eradicated and will not re-occur unless they are re-introduced by humans. Removal of problem plant species is an important step in restoring native biodiversity and hence natural food-webs in lakes. But regeneration of native plants depends on the removal of grass carp. Whereas removal of grass carp is not a major issue in other countries, it is important for the use of grass carp in many New Zealand waters.

8.2 Assessing stock size

Methods for assessing grass carp stock size in treatment lakes/ponds have not been investigated in a formal sense to date. Consequently there is little guidance on this subject in the international literature apart from acknowledgement that it is a significant technological gap that constrains the use of grass carp for weed control.

Experience obtained in New Zealand to date indicates that grass carp density can only be coarsely assessed by monitoring the rate of weed removal. High stocking densities are deliberately set and used to produce total weed removal within two summers of stocking. If this is not achieved by this time, then it is likely that the density of grass carp was too low and that supplementary stocking is required. However, the number of fish that need to be added to achieve total weed removal is likely to be unknown.

Attempts to obtain estimates of grass carp numbers present in a lake after weed control was achieved were initially tested in Lake Waingata (Northland). It was known that grass carp could be readily observed on the surface of lakes during calm, cold winter mornings when the sun warms the surface waters. Grass carp seek the warmer waters at the lake surface during such times and can be observed swimming on and near the surface from a high vantage point. Water clarity was not an issue because these fish can only be seen at the surface and those that are >10 cm below it are generally not visible. Photographs were taken of groups of fish at the surface in Lake Waingata (using a polarised lens) at various times, and were later examined to count the maximum number of fish observed. It was assumed that all grass carp would adopt this behaviour but that not all would be visible on the surface of the lake at the same time. Hence a series of photographs taken over a period of hours resulted in a maximum count providing an estimate of the minimum number of grass carp present. This process was possible at Lake Waingata because of the presence of a high vantage point. But it is not possible in lakes lacking such high points. Lake Waingata was small and oval in shape such that the entire lake surface could be seen from the vantage point. However, this method has not been applied to other lakes because they lack a vantage point, or local topography only allows part of the lake to be scanned.

An ‘aerial count’ method is now more feasible because of the ready availability and low cost of small radio-controlled aerial drones or quad-copters fitted with video and/or time-lapse camera capabilities. This technology provides a way of readily obtaining aerial counts of grass carp over the entire lake in a relatively short time frame during calm, autumn or spring mornings. However, the estimates of grass carp obtained by this method will be minimum counts. A more accurate census would require such counts to be calibrated against known stock size, which would be more problematic.

Other methods of stock assessment trialled in New Zealand include PIT tagging of all stocked fish coupled with a floating attractant device fixed with an aerial to detect grass carp passing underneath it. This method was trialled in Lake Wainamu (Auckland) using a feeding station as the attractant device. The feeding station periodically broadcast floating food pellets into the water within a 2 m diameter floating hoop from which the PIT aerial was suspended. The feeding station proved to be a highly effective attractant device for grass carp in Lake Waingata and was expected to also work in Lake Wainamu. In practice, it failed to attract grass carp in Lake Wainamu, because other species of fish present in Wainamu (i.e. eels, rudd, perch) were highly attracted to the pellets and ate them before grass carp. Hence a species-specific attractant device will need to be developed before PIT tagging can be used for grass carp stock assessment purposes.

Other tags that can be detected at greater distances (e.g. acoustic tags) would overcome the problem of finding an attractant device because the acoustic receivers can be placed at various points around the lake and over time will record the presence and movement patterns of all the grass carp present. However the size and cost of acoustic tags is currently prohibitive and they need to be surgically implanted. In addition, unlike PIT tags, their power source means that they have a limited life span (6-12 months) and so a population census would not be possible after they have been stocked for 1 year. This is too soon for effective weed control to have been achieved, hence aerial counts (using drones) is currently the most feasible method for determining the number of grass carp present in a lake.

One indirect method for assessing total grass carp browsing pressure has been noted but not pursued to date. Cassani et al. (2008) observed that several studies had reported a large increase in potassium concentration in lake water as aquatic macrophytes were progressively removed by grass carp. They suggested that potassium levels may provide an indication of grass carp feeding activity in lakes. If so, potassium concentration in summer months may also provide an alternative means for assessing grass carp abundance.

8.3 Removing grass carp

Problems of assessing the stock size of grass carp aside, there have been a number of studies in New Zealand and in other countries to identify suitable methods for removing grass carp from lakes after weed control is achieved. Schramm and Jirka (1986) tested eleven methods of grass carp removal in large canals. Seven methods were later evaluated in lakes by Bonar et al. (1993), and Hestand (1996) later reviewed a wide range of methods trialled for use in North American waters. In 2008, Cassani et al. (2008) reviewed those reports as well as a range of more recently tested control methods.

Bonar et al. (1993) investigated angling, pop-nets, lift-nets, baited traps, water heating (to attract fish) and herding. The trapping systems (e.g. pop-nets, box nets with a net curtain on one side) utilised baits to attract grass carp into an area where a net could then be rapidly raised around them. These methods were less successful than herding or angling because only a few grass carp entered the areas at any one time, and those that did jumped over the nets when their escape was blocked.

8.3.1 Herding

Herding was regarded as the most successful method followed by angling, but herding was only applicable to small, relatively elongated and shallow lakes (< 10 ha). Herding involved the use of noise and disturbance to scare grass carp away from an area and then successive placement of back-stop nets across the lake to herd the grass carp into a progressively smaller area where gill nets were used to trap them.

Herding was also the most successful method in Parkinson’s Lake as this small lake had a shallow (<2 m deep) narrow arm, and grass carp were readily herded into it by boats and loud noises. A net across the arm was then raised blocking the escape of grass carp. However, entanglement of grass carp in gill and trammel nets as they attempted to leave this arm failed when the water was clear (secchi disc of >1 m) because the carp could easily see the net and they either avoided it or jumped over it. Netting only worked well in this lake when the turbidity of the water was artificially increased so that the vision of grass carp was compromised. These fish were then readily 'panicked' into swimming into the net.

Bonar et al. (1993) noted that herding techniques were successfully used to harvest grass carp in China, and that several studies had reported better results when electroshocking was used to herd these fish. Specific sound frequencies could also potentially be used to herd grass carp (Curtin 1994). Whereas this method is useful in shallow, elongated lakes, it is not possible in deep lakes because of the cost and difficulty of constructing and operating deepwater (>4 m) nets. Although it may be technically feasible in large, shallow lakes, again the cost of net preparation and deployment would be high.

8.3.2 Angling

Hestand (1996) evaluated a wide range of methods and concluded that electric fishing (confined to shallow lakes), haul seining by commercial fishing boats, angling and rotenone were the best methods, but each had limitations. Angling was the most cost-effective method. It removed 61% of the grass carp in 8 days in one 3.6 ha lake indicating that this method can be useful and cost-effective (Hestand 1996). In another trial reported by Hestand (1996), 12 permitted anglers used dough balls and worms as baits to remove 242 grass carp over 16 months, with 3 of the anglers responsible for 70% of the catch (Mallison et al. 1994). Angling can therefore be achievable and cost effective, but it takes time and needs to be controlled through fishing permits. Over time, catch rates tend to drop, because the fish become more aware of the danger and avoid the baits. Hence it is useful for reducing grass carp density but not for removing all fish.

8.3.3 Electric fishing

Hestand (1996) found that electric fishing also produced high catch rates but was limited to shallow lakes. He concluded that whereas catch rates were initially high, it was not suitable for large-scale removal because avoidance increased. Seine-hauling using commercial seining boats was also successful but costly because of the gear and time involved. Hestand (1996) had more success with lift nets using baits (floating fish pellets) to attract grass carp than Bonar et al. (1993). The lift nets worked well but daily baiting over 6 days was required to attract grass carp into the nets.

8.3.4 Fish toxicants

The use of the fish toxicant rotenone for removing grass carp was also reviewed by Hestand (1996). Because grass carp are more sensitive to rotenone than many other fish species, a low concentration can result in selective removal of grass carp as demonstrated in an 80 ha lake by Colle et al. (1978). It has also been used successfully to obtain 98% removal of grass carp in a Florida lake (Hestand 1996). Whereas this method is best at water temperatures over 20ºC (Cassani et al. 2008), Cumming et al. (1975) obtained 100% mortality of grass carp in shallow 1.4 ha ponds exposed to 1 mg/l Noxfish (containing 5% rotenone) over 50 hours at water temperatures of 0-9ºC. Cumming et al. (1975) also found that antimycin at 6 µg/l resulted in 100% mortality at such temperatures. The sedative thanite (obornyl- thiocyano-acetate) was less successful.

Rotenone (Noxfish formulation) was successfully used in Parkinson's Lake to remove all grass carp present (Rowe and Champion 1994). For this exercise to be successful, full mixing of the rotenone into the water column was essential down to 7 m (maximum depth). Hence its application could only be carried out in spring before thermal stratification occurred and as water temperatures increased over 20ºC. Full mixing of rotenone throughout the water column was successful (as determined by the mortality of caged goldfish placed on the bottom), and all of the grass carp were recovered alive because the effects of rotenone were readily reversed by placing them in a tank of water containing methylene blue.

The application of piscicides such as rotenone are currently controlled in New Zealand by the Environmental Protection Authority (EPA). DOC has obtained approval for the use of 'cube root powder' and 'cube root powder in aqueous slurry' under the Hazardous Substances and New Organisms (HSNO) Act. However, only 'cube root powder in aqueous slurry' is registered for use in New Zealand under the Animal Control and Veterinary Medicines (ACVM) Act. At present, an Approved Handler certificate is required to use this product and only DOC staff have such a certificate. . No commercial preparations (e.g. Noxfish) can be imported and used as these may contain emulsifiers and synergists not approved under the HSNO Act.

The use of low concentrations of rotenone for selective removal of grass carp has not been widely applied to date, and this may be related to the fact that the use of chemicals in lakes is increasingly problematic because of public opposition, despite its low toxicity to other animals, including humans and its rapid degradation. In New Zealand, resource consents are required under the Resource Management Act (RMA), except in Motueka where it is a permitted activity under the RMA. Where consents are required, objections may result in a formal hearing process, which can be costly to all participants. Hence the cost of obtaining approvals adds to the cost of application and mitigates against the use of this method as a routine control option in New Zealand. Nevertheless, it remains the only effective and humane way of removing all grass carp from a lake at present.

The success of rotenone as a fish toxicant for grass carp in the USA led to the development of rotenone impregnated baits now referred to as the Fish Management Bait (FMB) (Mallison et al. 1995). This method requires a feeding station to be placed in the lake. Floating fish pellets (containing alfalfa) are broadcast onto the water surface at a given time each day for a period of weeks. This process trains the grass carp to aggregate around the station during feeding times and to eat the floating pellets. The pellets in the food hopper are then substituted for rotenone impregnated ones. Grass carp consuming several impregnated pellets acquire a toxic dose and die. Trials in the USA indicated that this was a successful method on its first application. It removed 78% of grass carp present in hatchery ponds, and 13% in Live Oak Lake (Mallison et al. 1995; Hestand 1996). However secondary applications were much less effective and Hestand (1996) concluded that it has limited potential in large systems.

The FMB system was also trialled in New Zealand in Lake Waingata and very similar results were obtained (Rowe 1999). The secondary application was much less successful than the first because while the grass carp readily consumed the trainer fish pellets, they rapidly learned to avoid the rotenone impregnated ones. They were observed to initially ingest these pellets but then spat them out and ignored all others, presumably because they differed from the trainer pellets in terms of taste or texture. There were no effects on other fish (e.g.

common bullies, dwarf inanga) or waterfowl. The ability of grass carp to detect rotenone in the FMB pellets prevents secondary applications from being effective and is therefore a major limiting factor.

Ways around this problem are technically possible. Micro-encapsulation of rotenone may be possible without destroying its toxicity. If so, then this would prevent grass carp detection of the rotenone. Alternatively, another toxicant (e.g. antimycin) maybe more effective than rotenone because it is relatively tasteless (Rach et al. 1994). Kroon et al. (2005) tested antimycin impregnated pellets (coated with algin) on 12 grass carp in tanks at a New Zealand hatchery and obtained 100% mortality. However, antimycin is an antibiotic and there are concerns about the widespread use of antibiotics that would need to be resolved with this approach. Such pellet-based approaches may only be useful in lakes lacking eels and other fish such as rudd and perch. Time-lapse photography was used to see if a feeding station broadcasting floating pellets onto the lake surface would attract PIT tagged grass carp in Lake Wainamu. Eels and rudd were more rapidly attracted to the floating pellets than grass carp and rapid consumption of the pellets by these other fish prevented grass carp from approaching the feeding station. The presence of other fish species may therefore compromise the use of this technology.

Other more recent methods proposed include the implantation of capsules containing a toxicant into grass carp (Thomas et al. 2006). Biodegradable capsules would result in the release of the toxicant after a certain time had elapsed and euthanize the fish (Cassani et al. 2008). Thomas et al. (2006) examined potential implant sites, toxicant formulations and polymer-based capsules and concluded that development of such a technology was feasible. They considered public health issues related to the accidental consumption of such implants and noted a number of ways of reducing this risk. The major uncertainty with this method is the variable time for biodegradation of the capsule and the possibility that the toxicant will be degraded and/or released slowly over time, rather than abruptly in a lethal dose. The consequences of toxicity degradation and/ or slow release will need to be considered, as will the effects of this on the well-being of the fish. Other time-based release mechanisms (e.g. those activated by a radio signal) may prove more effective and provide more flexibility in timing. As some people may catch and consume grass carp, care would be required to ensure that any such implants do not pose a danger to human health. There is also a possibility that a non-lethal, time-delayed implant could be developed that resulted in fish being ‘abdominally inflated’ and forced to the surface for collection.

Clearwater et al. (2008) and, more recently, Nico and Walsh (2011) have both reviewed a wider range of potential chemical toxicants for use on fish, and they considered that Aqui-S and several plant-derived saponins or triterpene glycosides, along with squoxin, could be useful. However, none of these have been formally tested to date either experimentally or in the field, nor compared against rotenone and antimycin. The time and cost of research required to test such alternative piscicides is likely to preclude their use in the near future.

8.3.5 Other methods

Other removal methods for grass carp not attempted to date but which have been used on other species of carp include the targeting of winter aggregations of grass carp (reportedly present in the deeper waters of large lakes) through the use of radio-tagged ‘judas’ fish.

Once the ‘key’ overwintering locations for carp aggregations are known, methods could be developed to net the fish within them at a time when they are relatively quiescent.

Other attraction technologies tested on grass carp include warm water (Bonar et al. 1993), water flow to stimulate a positive rheotaxis (Hestand 1996) and sound (Cassani et al. 2008). Neither warm water nor an artificial flow could be produced in a large enough volume to test these two measures. However, Duncan (2002) used food-based operant conditioning as established by Willis (2002) to attract grass carp to a site using a low frequency sound. This resulted in the aggregation of grass carp at the site and permitted the capture of 61% of the population (Cassani et al. 2008). Hence sound appears to provide a promising attractant cue when combined with feeding.

In places where grass carp are used to eradicate invasive plant species so that the return of native plants is possible, the removal of all grass carp may not be required. Removal of a large proportion may be acceptable. In theory, plant regrowth at a lake scale can be expected when the total daily browsing pressure of grass carp in terms of plant biomass is exceeded by the daily growth in plant biomass. Hence an alternative to complete grass carp removal is the establishment of plant biomass in sufficient density to overcome total browsing pressure. This would involve the creation of areas within a lake where grass carp are excluded (e.g. by nets) and hence where plants can re-establish and grow in the absence of browsing pressure by grass carp. Once the total biomass and growth of all plants exceeds the limit of browsing pressure, the barriers can be removed in the expectation that total grass carp browsing will not reduce the existing biomass, thereby allowing more widespread development of macrophytes in other areas of the lake. This approach would be possible in lakes that contain large shallow arms and/or areas that can be easily netted off to prevent access by grass carp. However, calculation of the minimum area required is difficult and would need to be determined empirically after trials based on ‘large’ exclosures have been carried out to test the feasibility of this approach.

PART TWO: Decision Support System

9 Introduction to the DSS

The purpose of the DSS is to provide a guide for the preparation of proposals to stock grass carp by applicants and to provide a framework to guide decision-making by MPI and DOC on applications to stock grass carp. The aim of the DSS is to provide objective and consistent information on the main issues that require consideration and are associated with using grass carp for weed control in New Zealand waters. The development of the DSS was informed by the information that is presented in the literature review (Part One) and the field survey (Appendix B). Common themes in assessing the effectiveness of grass carp for weed control were the effects of weed removal on the environment, the management objectives for a waterbody and whether or not grass carp are an appropriate weed control option (e.g. can they be contained and what level of weed control is required) (Hofstra 2014). Those themes have been addressed in the DSS. The DSS is not intended to provide a decision-making tool with legal status because each potential stocking site is different and such individual characteristics cannot all be encompassed within a generalised DSS model. In this sense, the DSS is a tool that is based on the most up-to-date scientific information and experience, and that is designed to assist rather than to make decisions on stocking grass carp. Applicants would benefit from having developed a management plan for the lake or waterbody of interest at the outset of the process, that (at a minimum) clearly articulates the weed issues, any native or conservation values (if applicable) and the long term goals for the site.

The DSS has nine over-arching themes or levels that create a sequential structure for decision making extending down from viability or not, to the need for a comprehensive AEE, to a more-specific environmental risk analysis, and to key fish management considerations, including containment and biosecurity considerations. Within each level, detailed questions, coupled with additional information (notes or boxes) lead the user to the next appropriate question and level based on previous answers.

Level 1 identifies waterbody attributes that would exclude grass carp use (i.e. No-go decisions as shown in the red boxes). Level 2 deals with site specific considerations that may require an AEE to be prepared, or require more information to be provided to supplement that provided in an existing AEE. The scores that are assigned in Level 3 determine the need for, and focus for an AEE. The remaining overarching themes (Levels 4-9) address the management constraints on using grass carp at a given site and are designed to assist in the identification of fish management requirements that should be adhered to, including stocking rate, minimum fish size, fish welfare, biosecurity considerations, containment, monitoring and restocking and/or fish removal.

10 DSS for grass carp use in NZ

Level 1: No-go criteria		QUESTIONS	YES	NO	DON'T KNOW
Waterbody attributes that could trigger an immediate NO for grass carp because they would not be an appropriate long-term control method.	1	Will grass carp be contained in this waterbody by natural structures, or can they be effectively and economically contained, long-term, by a man-made barrier?	Go to question 2.	Grass carp are not suitable for this site.	Identify all potential inlets/outlets and assess feasibility of installing barriers. See Note 1.
	2	Could the escape of most grass carp result in macrophyte reduction in other waterbodies in the catchment, and/or result in significant adverse impacts on rare, threatened or at risk species in the catchment?	Grass carp are not suitable for this site.	Go to question 3.	Identify all hydrologically connected waterbodies and assess whether, if all grass carp escaped, a density of grass carp in the smallest could exceed 10 fish/ha and therefore potentially reduce macrophytes. Consult with DOC and waterbody managers.
	3	Would grass carp containment be lost during a 1 in 100 year flood event and/or failure of flood control measures during such an event?	Grass carp are not suitable for this site.	Go to question 4.	Identify maximum historic water level, or estimate flow and water level from a 100 mm rainfall over 2 hours.
	4	Will water depth be greater than 50 cm over 75% of the weeded area at all times to allow widespread movement, and browsing by adult grass carp?	Go to question 5.	Grass carp are not suitable for this site.	Determine area of waterbody deeper than 50 cm at the lowest water level.
	5	Will daily mean water temperatures be over 20ºC for at least 4 weeks during summer?	Go to question 6.	If water temperatures do not exceed 17°C, grass carp will not be effective. High stocking density may be needed if temperatures are only 20°C for 4 weeks or less.	Measure water temperatures at the same time of day as often as possible in January to March.
	6	Could grass carp survival be severely reduced because of a high risk of deoxygenation from 100% cover of the water surface by floating weeds, or hyper-eutrophication, or a pollution or emergency discharge event?	Grass carp are not suitable for this site.	Go to question 7.	Identify whether the waterbody will be prone to water fern/lily/duck weed colonisation, is hyper-eutrophic, or receives discharges.

	7	Would grass carp survival be severely reduced because of acid water inflow from peatland?	Grass carp are not suitable for this site.	Go to question 8.	Determine whether peat is present within the catchment (e.g. from soil maps and/or FENZ wetland maps).
	8	Are the plant species causing problems in the waterbody all eaten by grass carp (i.e. are they all palatable species, irrespective of grass carp preferences)?	Go to question 9.	Grass carp are not suitable for this site.	Identify plant species present and check against lists of grass carp food preferences and non-palatable species. See sections 4.7 and 6.3.
	9	Is the proposed extent of weed removal (i.e., total versus only in blocked off sections) by grass carp compatible with the waterbody's long-term management goals?	Go to question 10.	Grass carp are not suitable for this site.	Consultation with managers/owners (including iwi where required).
	10	Are there any rare, threatened or at risk native aquatic plant species (or vegetation communities) present, and/or rare, threatened, or at risk animal species that are dependent on the plants present?	Grass carp may not be suitable for this site.	Go to question 11 in Level 2.	Consultation with DOC and lake managers is required. See Note 10.

Level 2: Provisional Go	**QUESTION**		**YES**	**NO**	**DON'T KNOW**
Site-specific environmental considerations resulting in a provisional go, or a need for more data via consultation including preparation of a comprehensive AEE.	11	Does the target weed have a national or regional biosecurity status (i.e. is it listed in a national or regional pest management plan) requiring its eradication/control?	Go to question 24 in level 4.	Go to question 12.	Check with MPI and/or Regional Council.
	12	Is the waterbody artificial (i.e. man-made) and either an excavated farm pond, a dammed pond, a constructed irrigation pond or raceway, a constructed drain, an ornamental pond, or a private constructed waterbody less than 2 ha in surface area?	Go to question 24 in level 4.	Go to question 13.	Determine construction history and size and consult the DOC grass carp EIA policy.
	13	Is it certain that widespread weed removal will not result in any more-than-minor adverse effects on water quality, waterfowl, fish, native species biodiversity, and cultural or iwi values?	Go to question 14.	AEE is required. Go to question 15 in level 3.	Consultation with DOC, Fish and Game, and local iwi required.
	14	Would the use of grass carp be more economically costly than other weed control methods?	Grass carp may not be the best method. Decision required by managers/owners.	Go to question 24 in level 4.	Carry out an economic assessment of control options (including compliance costs and containment feasibility).

Level 3: Preliminary AEE	QUESTION		YES	NO	DON'T KNOW
Checklist to ensure that the main environmental effects associated with grass carp are either unlikely, or are adequately assessed. It should be noted that there is a need to evaluate the impacts on native biodiversity and cultural values, and for a first release of grass carp DOC will decide if an AEE is required.	15	Is the stocking of grass carp intended to be short-term in order to eradicate one or more introduced plant species (after which grass carp can be removed), as opposed to providing ongoing weed removal or maintenance control of plants because eradication is not possible?	Go to question 18	Go to question 16.	
	16	Are the problem plant species widespread in this waterbody (i.e. they cover or could cover > 25% of the total length of the littoral zone, or 10% of the waterbody's surface area)?	Go to question 18.	Go to question 17.	Identify species and survey plant distribution, and/or seek expert advice.
	17	Could other weed control methods be used to spot control problem areas and would spot control or weed removal be more suited to the overall management goal?	Grass carp may not be the best method. Decision required by managers/owners.	Go to question 18.	Consult with independent weed control experts with experience in using a range of control methods (eg., NIWA), and with the managers of the waterbody (i.e. those with statutory ownership rights and/or responsibility for funding and approving weed control).
	18	Would complete weed removal (including all aquatic plants in water deeper than 30cm) increase the risk of permanent water clarity decline?	Add 1 to overall score for potential environmental damage and go to next question.	Go to question 19.	Risk of water clarity decline is high if lake is eutrophic or hypertrophic, if it is mostly shallow (>30% of area < 3 m deep) with a large fetch (longest axis > 100 m) and is exposed to wind, if its inflows are turbid, or if it contains 2 or more of introduced species (viz. rudd, tench, koi carp, perch, catfish, gambusia, goldfish).
	19	Would weed removal increase the risk of cyanobacterial blooms occurring?	Add 1 to overall score for potential environmental damage and go to question 20.	Go to question 20.	Risk of cyanobacterial bloom is high if the waterbody is eutrophic or hypertrophic, has a history of algal or cyanobacterial blooms, contains perch, experiences prolonged calms during summer, or has a high

					phosphorus concentration. Risk assessment is provided in Rowe (2011).
	20	Would weed removal potentially reduce any native fish, or any introduced fish species supporting a commercial, recreational or cultural fishery in the waterbody?	Add 1 to overall score for potential environmental impacts and go to question 21.	Go to question 21.	Herbivores and phytophilous species could be reduced (i.e. rudd, koi carp, tench, goldfish, perch) but these are generally regarded as pests and would only be of concern if they supported a coarse fishery managed by Fish & Game.
	21	Would removal of submerged aquatic plants potentially reduce swan numbers in the region, or diminish desirable bird habitat?	Add 1 to overall score for potential environmental damage and go to question 22.	Go to question 22	Food for herbivorous waterbirds such as swans will be reduced, but swans will only decline regionally if there are no other local feeding areas.
	22	Would screens used to prevent the escape of grass carp prevent the upstream movement of adult migratory species such as flounder, mullet, lamprey?	Add 1 to overall score for potential environmental damage and go to question 23.	Go to question 23.	Determine whether flounder, mullet or lamprey would be present at or above the site. Contact DOC or NIWA (Fish Database).
	23	Is the total score for potential environmental damage 1 or more?	An AEE is required that addresses the specific issues contributing to the score of 1 or more.	Grass carp could be a weed control option at this site. Go to question 24 in Level 4.	

Level 4: Management requirements	QUESTION		YES	NO	DON'T KNOW
Constraints on grass carp use at the site requiring specific management actions to be included in planning, and subsequent approval/ permits	24	Will grass carp need to be contained by constructed barriers?	Go to question 25.	Go to question 30.	Determine if the waterbody has surface water inlets or outlets, or groundwater conduits through which grass carp over 25 cm long could move.
	25	Will bar screens be required?	Install as per design criteria in Box4A and specify in application for inclusion as a condition to the approval/permit. Go to question 26.	Go to question 26.	
	26	Will net or mesh barriers be required?	Install as per design criteria in Box 4B and specify in application, for inclusion as a condition in the approval/permit. Go to question 27.	Go to question 27.	
	27	Will a rock weir barrier across the water channel be required?	Install as per design criteria in Box 4C and specify in application, for inclusion as a condition in the approval/permit. Go to question 28.	Go to question 28.	
	28	Will barriers be required across low lying areas?	Install as per design criteria in Box 4D and specify in application, for inclusion as a condition in the approval/permit.	Go to question 29.	
	29	Will a downstream eel pass be required on any containment structure?	Install eel pass as per design criteria in Box 4E and specify in application, for inclusion as a condition to the approval/permit.	Go to question 30.	Required if long or shortfin eels occur in the waterbody. NB. It is not possible with existing technology to provide downstream passage for adult salmonids and also constrain grass carp.
	30	Will supplementary weed control be required?	Go to question 31.	Go to question 33 in level 5.	
	31	Will pre-stocking spraying/mechanical control be required?	Carry out as per Box 4F and specify in application, for inclusion as a condition to the approval/permit.	Go to question 32.	
	32	Will post-stocking spraying/mechanical control be required?	Carry out as per Box 4F and specify in application, for inclusion as a condition to the approval/permit.	Go to question 33 in level 5.	

Level 5: Fish stocking	QUESTION		YES	NO	DON'T KNOW
Management constraints on fish stocking to be specified in the management/operational plan, and approval/permit.	33	Is proposed control site in North Island?	Only source fish from a licensed North Island fish farm. Name the fish farm in the application, for inclusion as a condition to the approval/permit.	Go to question 34.	Add source as a condition to any relevant approval/permit.
	34	Is proposed control site in the South Island?	Source fish from a licensed NI fish farm where gambusia are absent, or from a licensed South Island fish farm. Name the fish farm in application, for inclusion as a condition to the approval/ permit.	Go to question 35.	Add source as a condition to any relevant approval/permit.
	35	Will any grass carp be below the standard minimum length of 25 cm fork length?	This will result in high mortality and unknown density. Not recommended.	Go to question 36.	
	36	Is a rapid rate of control required (e.g. within 2 years for a biosecurity response)?	Specify stocking rate (SR) of 100 std fish/veg ha in the application, for inclusion as a condition to the approval/ permit. Go to question 40.	Go to question 37.	
	37	Is a slow rate of control required (e.g. over 4-5 years to reduce environmental risks)?	Specify SR of 22 std fish/veg ha in application, for inclusion as a condition to the approval/ permit. Go to question 40.	Go to question 38.	
	38	Is a standard stocking density required (e.g. for control over 3-4 year)?	Specify SR of 50 std fish/veg ha in application, for inclusion as a condition to the approval/permit. Go to question 40.	Go to question 39.	
	39	Is a high stocking density required (e.g. for cooler waters, less preferred plant species, drains etc.)?	Specify SR of 100 std fish/veg ha in application, for inclusion as a condition to the approval/permit. Go to question 40.	Go to question 40.	
	40	Is the area of the waterbody that is affected by weed known?	Multiply area by SR to determine fish numbers required and specify in application, for inclusion as a condition to the approval/permit. Go to question 41 in level 6.	Estimate vegetated area as per Box 5A and multiply area by SR to determine fish numbers required. Go to question 41 in level 6.	

Level 6: Fish welfare	QUESTION		YES	NO	DON'T KNOW
Checklist to ensure fish welfare and survival is covered in the management/operational plan, and approval/permit.	41	Will grass carp which are to be transported to the weed control site be held in a hatchery pond/tank without food for 24 hours to reduce faecal contamination of transport water?	Add to application, for addition as a condition to the approval/permit. Go to question 42.	Confirm reason for this (e.g. short duration trip) and go to question 42.	Add as a requirement to the management plan, and to the approval/permit.
	42	Will all grass carp be tagged before stocking in order to identify any escapees?	Add to application, for addition as a condition to the approval/permit. Go to question 43.	Confirm reason for not tagging (e.g. escape not possible) and go to question 43.	Add tagging as a requirement to the management plan and to the approval/permit, if grass carp are to be stocked into any part of the Waikato River catchment.
	43	Will fish be transported in at least 2 litres of water per each standard-size fish, or more than 2 litres water if mean size of fish is larger?	Add to application, for addition as a condition to the approval/permit. Go to question 44.	Confirm there is a valid reason for this (e.g. adequate aeration and/or oxygenation) and go to question 44.	Add as a requirement to management plan, and to the approval/permit.
	44	Will water in transport container be continuously aerated by bubbler or oxygenated to maintain a concentration over 5 ppm?	Add to application, for addition as a condition to the approval/permit. Go to question 45.	Confirm there is a valid reason for this and go to question 45.	Add as a requirement to management plan, and to the approval/permit.
	45	Will water temperature during transit be maintained below 18°C by periodic addition of ice, or replacement with cold water?	Add to application, for addition as a condition to the approval/permit. Go to question 46.	Confirm there is a valid reason for this in the application for a permit and go to question 46.	Add as a requirement to management plan, and to the approval/permit.
	46	Will stress on fish be reduced by addition of Aqui-S or similar?	Add to application, for addition as a condition to the approval/ permit. Go to question 47.	Confirm there is a valid reason for this and go to question 47.	Add as a requirement to management plan, and to the approval/permit.
	47	Will fish be acclimated at the release site by staged (over 1-2 hours) replacement of container water with water from the site?	Add to application, for addition as a condition to the approval/permit. Go to question 48 in level 7.	Confirm there is a valid reason for this and go to question 48 in level 7.	Add as a requirement to management plan, and to the approval/permit.

Level 7: Biosecurity	QUESTION		YES	NO	DON'T KNOW
Checklist to ensure there is no introduction of new species to the release site	48	Are there any unwanted or introduced species in the grass carp hatchery/on-growing ponds, or in the catchment above these ponds that are not in the control site or the waterbodies feeding into it?	Go to question 49.	Go to question 50.	Assume yes and add biosecurity protocols (Questions 49 and 50) below to management plan and approval/permit.
	49	Will all fish be hand netted into the release site?	Note this in the application for inclusion as a condition of the approval/permit. Go to question 50.	High risk of spread for invasive species. Explain why this is not required in the application, or add a protocol to the application for inclusion as a condition of the approval/permit.	Assume no and add protocol to management plan, and approval/permit to minimise risk.
	50	Following release of all grass carp, will all water used for transportation of grass carp be discharged to land soakage so that it cannot enter the stocked or any other surface waterbody?	Note this in the application for inclusion as a condition of the approval/permit. Go to question 51 in level 8.	High risk of spread for invasive planktonic species. Explain why this is not required in the application, or add a protocol to the application for inclusion as a condition of the approval/permit.	Assume no and add protocol to management plan, and approval/permit to minimise risk.

Level 8: Post-stocking monitoring	**QUESTION**		**YES**	**NO**	**DON'T KNOW**
Monitoring requirements for consideration.	51	Will weed cover be assessed between March-May of each year after grass carp release?	Include proposed assessment method and schedule in application, for addition to the approval/permit as a condition. Go to question 52.	State why this is not required in the application, or add plan based on Box 5A to the application for addition as a condition to the approval or permit.	Add requirement to management plan, approval/permit based on Box 5A.
	52	Will all screens/barriers be inspected monthly after installation until 80% weed removal has occurred, and then annually to detect any maintenance requirements?	Include proposed inspection schedule in application, for addition to approval/permit as a condition. Go to question 53.	State why this is not required in the application.	Add requirement to management plan, approval/permit.
	53	Will all screens/barriers be inspected as soon as possible after major rainfall events (> 50 mm over 24 hours in the catchment) and after regional earthquakes that could compromise these structures?	Include proposed inspection schedule in application, for addition to approval/permit as a condition. Go to question 54.	Add requirement to management plan, approval or permit.	Add requirement to management plan, approval/permit.
	54	Will grass carp abundance be monitored to assist in determining any escape and or high mortality that may prevent weed control and require restocking?	Add proposed monitoring as per Box 8A to the application, for inclusion as a condition to the approval/permit. Go to question 55.	Confirm that monitoring is not required, or is not feasible as per Box 8A, in the application and state reason why.	Add monitoring as per Box 8A to management plan, approval/permit.
	55	Is any environmental monitoring required?	Include in application, for addition as a condition to the approval/permit.	Go to question 56 in Level 9.	DOC, Fish & Game, local iwi, and/or lake managers may specify monitoring and environmental data collection related to potential impacts identified in the AEE.

Level 9: Restocking		**QUESTION**	**YES**	**NO**	**DON'T KNOW**
Identifying a need for restocking and/or post-control removal of grass carp	56	Have grass carp ever been stocked in this waterbody?	Go to question 57.	Go to question 1 in Level 1.	If written proof of a previous stocking (as opposed to an illegal release or escape) cannot be provided, then decision-making should proceed on the basis that grass carp are not present (i.e. go to question 1 Level 1).
	57	Does the data from weed monitoring indicate that control is now not occurring?	Go to question 58.	Go to question 60.	Carry out survey to determine extent of control as per Box 4A.
	58	Is there a likelihood of grass carp loss from escape, mortality or theft?	Determine other likely causes of mortality (eg. water quality). Go to question 59.	Go to question 59.	Confirm the integrity of any containment structure(s).
	59	Does the grass carp abundance monitoring data indicate a decline in numbers?	Estimate numbers of grass carp required based on escape or monitoring data and submit application for restocking to MPI.	Identify factors other than grass carp abundance that could account for lack of weed control.	Obtain estimate of fish remaining as per Box 8A.
	60	Does weed monitoring data indicate that control has been completed?	Go to question 61.	Wait until weed monitoring indicates control has been achieved.	Carry out survey to determine extent of control as per Box 4A.
	61	Has eradication of target species been confirmed?	Implement grass carp reduction/removal plans as per Box 9A. Go to question 62.	Wait until weed monitoring confirms absence of target species.	Carry out survey to determine whether target species are still present.
	62	Can grass carp be excluded from large shallow areas by exclosures, or barrier nets to allow regeneration of native plant community in these areas?	Develop plans for grass carp exclusion.	Removal may only be possible by gill netting, trammel netting, angling, toxicants, or natural mortality (over 20 years?).	

Additional Information **Notes**. Note numbers are aligned with question numbers.
Note 1. Use Topo50 map series and/or Google earth, and a site inspection.
Note 10. Will the lack of weed control lead to the eventual extinction of the threatened plant, whereas grass carp may remove the weed and rare plant, but then the rare plant could re-establish from seed bank? See section 4.7 (point 5).

Boxes. Numbering is as indicated in the DSS.
BOX 4A. Design criteria; vertical slots (for cleaning), bar diameter > 10 mm, max. gap < 35 mm, height above max. water level (if not in culvert) >30cm, footing and side insets (if not culvert screen). Civil engineer best practice.
BOX 4B. Design criteria; UV proof mesh, mesh size > 20 mm < 30 mm, supported by plastic floats, 40 cm extension above water or 1 m wide anti-jump floating apron, weighted by continuous chain, staked side and bottom at 2 m intervals.
BOX 4C. Design criteria; cobbles > 80 mm diameter if upstream fish passage required, height > 20 cm above max. water level.
BOX 4D. Design criteria; 1m high wire mesh, > 35 mm gaps, supported by waratahs at 3 m intervals, staked to ground every 2 m, extended to where ground level is 20cm above max. water level.
BOX4E. Refer to report by Smith & Rowe (2014) for design specifications.
BOX 4F. Check with local authority, consent may be required for chemical control. Spray application is generally < 25% vegetated area at any one time.
BOX 5A. Obtain estimates of the area of vegetation via one or more of; visual observation by boat (plus grab samples), diver transects, high frequency echosounder transects, aerial photos (polaroid lens), or estimate area of lake < 10 m deep. For larger lakes there are often bathymetry maps for accurate determination of areas.
Box 8A. Monitor grass carp abundance over time by direct observation from a high bank or a high vantage point, or by drone (eg., quad-copter) based video surveys during fine calm mornings. NB: Visual counts from observation or video-analysis provide a measure of minimum relative abundance (not actual). Counts are expected to be similar over time if there is no loss or mortality of fish and fish always congregate near the surface in the same areas.
Box 9A. Obtain a permit from MPI to remove grass carp (defined as aquatic life) by gill netting, trammel netting and/or angling. Fish toxicants may be applicable where rapid removal is required but will require approval from DOC/MPI and a consent from the Regional Council.

11 Project Summary

Grass carp have been used for aquatic weed control in many diverse types of waterbodies. The use of grass carp has raised concerns over the potential effects of the release of these fish into sites that were not envisaged would be stocked in 1985 when the first report by Rowe and Schipper on the potential effects of grass carp was published (MPI 2013).

The statutory roles of MPI and DOC in assessing releases of grass carp into the wild need to consider the ecological, biosecurity and animal welfare effects of these releases. MPI, DOC and applicants require better information on grass carp and improved and up to date decision-making tools to assess the risks of releasing grass carp into the many and varied waterbodies in which they are now used (MPI 2013). NIWA was contracted by MPI to assess the use of grass carp in New Zealand (Part One) and to provide a decision support system for grass carp use (Part Two).

In assessing the use of grass carp the risk of grass carp establishing a self-supporting population was re-evaluated as were methods for distinguishing escaped fish from suspected wild progeny. The environmental effects of grass carp and the effectiveness of grass carp (along with the field survey) and management constraints for weed control across a representative range of sites was assessed, along with biosecurity risks associated with grass carp release, and the options for their potential capture and removal.

Re-evaluating the risk of grass carp establishing a self-supporting population

The 1985 assessment of environmental effects (AEE) supporting the use of grass carp for weed control in New Zealand concluded that spawning was possible in the Waikato River, but that the development of a large breeding population was improbable because river conditions would prevent the survival of most larvae (Rowe and Schipper 1985). Although recent investigations of grass carp spawning in North America indicate that some incubation and hatching could occur over shorter distances than previously indicated, the key factor minimising the risk of a breeding population becoming established in the lower Waikato River is the low survival potential of larvae, even with the higher flows and water temperatures expected under climate change scenarios. The rare occurrence of grass carp is possible in the Waikato River, but the development of a large population is improbable. Hence the risk of impacts from grass carp in the Waikato River is more likely to arise from massive widespread escapes from drains stocked with grass carp, or from a hatchery or juvenile rearing operation, than from natural reproduction.

Identifying escapees

The ability to detect natural breeding by grass carp necessitates the ability to distinguish between those fish that may have resulted from natural breeding, and stocked hatchery fish that may have escaped containment. The examination of otoliths to determine early growth rates provides a potential method because, hatchery fish generally have slower growth rates than wild reared fish. In practice, however the approach is problematic because there are wide variations in the growth of hatchery fish. More sophisticated techniques, based on the chemical composition of otoliths, which are derived from the water the fish were reared in, are also possible. But, because the metal concentrations present in river/stream water may change between years depending on changes in catchment characteristics and landuse (e.g. topdressing patterns), feasibility and calibration studies would be required to confirm reliability and repeatability. DNA based methods are developing rapidly and may have a future role in the separation of hatchery from wild reared fish. At present, polymorphic DNA fingerprinting has been developed for carp species, including grass carp (El-Zaheem et al. 2006), but the ability to distinguish familial linkages is in its infancy.

PIT tags have been used to individually tag all grass carp stocked into Lake Wainamu (Auckland Council) but these tags have a cost and require a small surgical insertion in the abdomen which increases stress and handling times. Wire tags (or nose tags) are much smaller and much less costly. This tag lasts for the life of the fish and poses no threat to fish or human health or the environment. It would provide certainty in detecting hatchery-reared (i.e., tagged) grass carp from naturally reared ones (i.e., no tag), but would increase the cost per fish because of the time needed to tag each fish.

Assessing environmental effects

The potential for environmental effects as a consequence of the release of grass carp for weed control is largely dependent on site-specific characteristics of the waterbody, and the grass carp stocking density. For example, Rowe and Schipper (1985) concluded that in already nutrient-enriched (i.e. eutrophic) lakes, a high stocking density of grass carp could result in a short-term increase in phytoplankton followed by an increase in zooplankton. In less nutrient enriched lakes, such limnological effects would not be detectable. In addition, the potential for water quality changes would be least in large waterbodies where there was some water flow through the system and where only a proportion of the plants was removed. Similarly the potential for water clarity changes is linked to waterbody size, shape, bathymetry and substrate type. For example, removal of plants can lead to increased turbidity through re-suspension of sediments in the wave-wash zone. However, the effects of wind and wave action on substrate is highly dependent on lake bathymetry and prevailing winds. The presence of pest fish (e.g. tench and rudd) that are known to reduce sediment stability through their browsing activities, also has an effect on water clarity and may exacerbate the effects of weed removal by grass carp on water clarity. The presence of low growing turf forming plants species in shallow water (<30 cm) consolidate and protect sediment from the effects of wave action, thereby reducing silt re-suspension. Turf forming plants are known to persist in lakes with grass carp on gently shelving littoral zones.

Weed removal by grass carp has had a positive effect on common bullies, with increases in their density recorded from a number of lakes. As a primary prey species for other fish, increases in the number of common bullies has a positive flow-on effect for the predators (e.g. eels, trout). It has been noted that the abundance of phytophilous species including perch, crucian carp, roach, rudd and tench, may decline because of a reduction in their spawning substrate and/or protective cover following weed removal. Some of these species (rudd, tench and perch) are present in New Zealand lakes, and generally considered pest species because of their adverse effects on water quality and on indigenous biodiversity (Rowe 2007, Rowe and Wilding 2012). Their decline would not be viewed as a negative impact of weed removal in most lakes. In contrast, adverse impacts on swan numbers could occur following weed removal, depending also on the proximity of other lakes containing macrophytes; although it should be noted that swan grazing alone can result in the collapse of submerged aquatic plants, especially in shallow, low clarity waterbodies (e.g. Lakes Waahi and Whangape).

In lakes where grass carp must be constrained by some sort of barrier to prevent emigration downstream, the natural movement of native fish (e.g. migratory species such as eels) could be affected. This potential problem has been resolved by the development of an adult eel pass designed to allow large-girthed migrant eels to readily pass over a barrier while preventing other fish from doing so (Smith and Rowe 2014).

Grass carp are selective or preferential browsers of aquatic plants that are accessible to them (Rowe and Schipper 1985), which means that if non-target plants are preferred to target weed species then the non-target plants will be consumed first. In general terms, the impacts or potential for impacts on non-target aquatic plants, including rare or endangered native plants that may be present at a site, are primarily dependent on what other plants are available to the grass carp and how preferred and accessible they are to the grass carp. However it has been noted that the presence or range of species consumed may change with the size and age of the grass carp (Edwards 1974, Bonar et al. 1993), and that preference is related to the chemical/nutritional properties of the plant and ease of mastication (Wiley et al. 1987, Bonar et al. 1993, Pipalova 2002). Further, there is some evidence that the same plant species from different locations (lake, or source) may not be as highly preferred (Chapman and Coffey 1971). The consumption of non-target plant species is also determined by the stocking density of the grass carp. At low density it is possible that those plants that are highly preferred, may alone be consumed, and where there are mixed plant communities, low grass carp stocking may result in a species shift to plants that are preferred less (Pipalova 2002, Chilton and Magnelia 2008, Colle 2009). However high stocking densities (section 6) result in consumption of all plants that are within reach or accessible to the grass carp (Rowe and Schipper 1985). Following weed removal, restoration of aquatic plants is possible from the seed bank (Rowe and Champion 1994).

Effectiveness of grass carp

Grass carp have successfully controlled a number of target weed species in a range of different lakes and waterways. Successful lake examples include, the eradication of egeria from Lake Parkinson, and elodea from Lake Waingata. More recently, grass carp have been successfully stocked into further lakes for removal of invasive submerged aquatic plants; Lake Kereta for hornwort, Lake Wainamu for egeria and Lakes Heather and Swan for egeria and hornwort removal. In contrast to the target weed species mentioned so far, hydrilla has long-lived propagules which has necessitated a longer term approach to control and eradication of the weed by grass carp. The Elands Lake grass carp trial demonstrated the effectiveness of grass carp at removing hydrilla, providing proof of concept for the use of grass carp as a tool in the MPI hydrilla eradication response (MAF 2008). Lakes Tutira, Waikōpiro and Opouahi were the remaining three lakes in the Hawkes Bay (and in New Zealand) that supported populations of hydrilla. To date, effective target weed control has been achieved, with progress toward the longer term eradication goal as anticipated based on results from Elands Lake.

Where weed control has not been successful, there have usually been one or a number of contributing factors. Examples include; issues with regard to stocking density and containment of grass carp (e.g. Lake Henley); the appropriateness of grass carp relative to the management outcomes such as partial weed control in the lake, or in specific areas (e.g. Lakes Henley and Rotomanu); balancing stocking density with feeding preferences (e.g.

Lakes Rotomanu), and that grass carp survival from stocking (of large and small fish) may have been too low to be effective (e.g. Lake Hood) or that feeding activity was not sufficient for the plant growth rate (e.g. Lake Hood).

Stormwater ponds and drainage systems were the focus of the field survey, because there were recognised knowledge gaps for these systems in terms of grass carp effectiveness. Generally there was less information available for these sites than for natural lakes or man-made lakes with high recreational values. At several sites, control methods other than grass carp were utilised, which clouds interpretation of the relative effectiveness of the grass carp for reduction in the volume of weed. However, in the majority of ponds, target weed control was regarded as successful, in that perceived weed issues no longer existed, but complete (rather than partial) weed removal was the outcome, even though partial weed removal was usually described as the goal.

Although weed control in drainage channels (and irrigation channels) is feasible, there are some constraints on this related to site suitability. This was highlighted in the field survey where drains with spring-water inflows were regarded as successful. The influence of spring-water appears to reduce the impacts of high temperatures and low dissolved oxygen which may result in fish mortality.

<u>Management constraints for weed control</u>

Management constraints for weed control using grass carp are described for containment (i.e. the need to prevent escape), the goal of weed removal and the outcome sought for the waterbody, plant species present, water temperature, depth and quality, and stocking rates.

Containment is essential to maintain stocking density and efficacy, and prevent non-target (off site) impacts. The feasibility of using grass carp for weed control in a given waterbody or waterway must consider the ability to contain the grass carp at a high enough density to control the weed. Containment may be inherent in the nature of the site, i.e., a pond with no inlets or outlets, or it could take the form of a constructed barrier. Grass carp cannot be considered for macrophyte control in aquatic environments where it is not feasible to contain them or where their containment results in other unacceptable environmental effects.

It is important to recognise whether or not grass carp are the most appropriate tool for weed control, given the outcomes that were sought with respect to the functions and values of the waterbody and the management goals (Clayton and Wells 1999). For example, if the primary goal is to keep water ski or rowing lanes weed free, that goal is not likely to be consistent with partial (i.e. non-site specific) weed removal in the lake by grass carp. Such targeted plant removal is best achieved by other methods (e.g. Lake Henley (Dugdale and Wells 2001)).

The presence of unpalatable plant species may constrain the effective use of grass carp. Although grass carp prefer certain plant species over others, there are few plants in New Zealand that are not palatable when no other species are present. However where less palatable species dominate, higher stocking densities of grass carp may be required to achieve rapid control.

Given that other key water quality parameters (e.g. pH and oxygen) are acceptable, grass carp feeding and growth are driven primarily by water temperature (Spencer 1994), and more specifically by the duration of temperatures over the threshold for active feeding (Swanson and Bergerson 1988). In general, water temperatures would need to be over 20°C for at least a month to enable weed control by grass carp. Control may be achieved in cooler environments by using very high stocking densities but, there is limited data on thresholds. Low oxygen concentrations, high ammonia levels and/or low pH (acid conditions) will also limit the use of grass carp for weed control. Grass carp are generally tolerant of low water quality conditions but their survival is reduced by low oxygen concentrations (< 2 ppm), high ammonia levels and low pH (<4) acid conditions.

The use of grass carp for weed control has been described as resulting in one of three outcomes based on stocking density: high stocking resulting in the removal of all aquatic vegetation; intermediate stocking resulting in a selective reduction of vegetation, with preferred species grazed first (Blackwell and Murphy 1996, Bonar et al. 1993, Chilton and Magnelia 2008); or low stocking with little or no control at all and some change in species composition (Cassani 1995). However there are challenges in comparing stocking densities within the literature due to the different terminology used (e.g. the number, or weight of grass carp, per hectare, per vegetated hectare (vha), per weed bio-volume or weed weight (which differs between species)). The use of a standard fish size (25 cm fork length) and terminology is advocated. Rates of 20-30 fish per vegetated hectare have achieved control over 3-5 summers and are considered 'slow-rates', with fast-rates of 50-100 fish/ha achieving rapid control (i.e. after 2 summers). The successful stocking of grass carp is contingent on mitigating stress during transport so the fish arrive in good condition. Stress can be avoided by ensuring the water in holding tanks is as cool as possible (<15ºC) and is always well-oxygenated (>5 ppm), and handling is minimised. If grass carp are stocked at a size at or over 25 cm, then mortality from shags can be largely avoided.

Biosecurity

The transfer of fish from one waterbody to another has the potential to spread aquatic plants and animals (e.g. plankton, molluscs, fish larvae), along with fish parasites and diseases, to waterbodies where they were previously absent. Grass carp were initially quarantined in New Zealand in order to allow the removal of all 'exotic' parasites and disease organisms before they were released for experimental trials (Edwards and Hine 1974). The risk of such novel 'exotic' parasites and diseases being spread internally was therefore addressed. To minimise the risk of any new species being spread from grass carp hatcheries and rearing ponds, it is necessary to identify such species, to determine the main vector(s) involved in their spread from the hatchery and to develop appropriate de-contamination measures and stocking protocols to reduce this risk. The disease risk associated with grass carp can be expected to be very similar to that posed by goldfish, which is produced in hatcheries and distributed throughout the country. Hence, protocols for grass carp stocking should be the same as those that are already applied to other freshwater fish movements within New Zealand (e.g. salmonid hatcheries and stocking, goldfish aquaculture and sales).

Removal of grass carp

Two major challenges in the use of grass carp for weed control are, (i) the difficulty in determining the number of grass carp present and (ii) removal of grass carp after they have achieved the desired weed control. There are few accurate methods for assessing grass carp stock size in lakes and ponds, and the subject is recognised as a significant technological gap. Aerial counts (e.g. using drones, quad-copters) are currently the most feasible method for determining the number of grass carp present in a lake. If/when stock and weed assessment indicates that the removal of grass carp is necessitated, there is no single method available that can remove all of the grass carp that is suitable for all sites. Methods that have been reviewed include; angling, pop-nets, lift-nets, baited traps, water heating (to attract fish) and herding. All methods have limitations to their effectiveness such as lake size and bathymetry for herding and netting, and/or because the fish learn to avoid anglers and poisoned bait. Electric fishing produced high catch rates but was limited to shallow lakes, and the use of rotenone which was successfully used in Parkinson's Lake to remove all grass carp present (Rowe and Champion 1994), also has limited utility (e.g. lake size, bathymetry) and only DOC is currently permitted to use it.

Decision Support System

The development of the DSS (Part Two) was informed by the literature review, and integrated experiences of the authors to discern and prioritise overarching themes (i.e. levels) and questions to guide decision making. Key waterbody attributes that could trigger an immediate No-go include containment, adverse impacts on rare, threatened or at risk species, water temperature, depth and quality, the target plant species and management goals for the waterbody.

12 Recommendations

MPI has a statutory role in assessing releases of the herbivorous fish grass carp (*Ctenopharyngodon idella*) into the wild for weed control. However, it is recognised that approving the first release of grass carp (to a new location) is the role of DOC, with subsequent release decisions the role of MPI.

NIWA was contracted by MPI to assess the use of grass carp in New Zealand and develop a decision support system for grass carp use for MPI, DOC and applicants alike. In reviewing information on where grass carp had been used in New Zealand waters to date it was apparent that the roles of the two government departments provide challenges for record keeping, and access to information. Accurate information on grass carp use is important for assessing individual applications, and for assessment on a catchment basis when there may be the potential for more widespread impacts from cumulative releases or escapes. With this in mind the following recommendations are made.

1. That the DSS is made available to applicants wanting permits to introduce grass carp so that the content of their proposals can be guided by the DSS and allow better informed decision making.

2. That the DSS is incorporated into the assessment of applications for grass carp introductions (into new waterbodies and waters where they have been stocked previously) by both DOC and MPI, with particular attention being given to 'not approving' applications that trigger the 'No-go' recommendations in Level 1.

3. That MPI (because it is required to make decisions on subsequent, and potentially multiple, releases at a designated location) takes a lead role (in consultation with DOC) in the development of a centralised electronic system where information on grass carp applications, releases, monitoring and fish removal can be logged (by the applicant) and tracked. This would ideally be accessible to appropriate MPI and DOC staff, and enable tracking of information on stocking density, effects and effectiveness for individual sites, and that can be utilised for future risk assessment and for potential cumulative impacts in catchments. Access to the centralised system via a web portal or phone app may facilitate uptake by applicants, and linking the information to a mapping tool would benefit catchment level impact assessments.

4. It is recommended that a further review of the literature, and the DSS is undertaken in five to ten years.

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Appendix A Literature review scope

The literature review was described in the MPI RFP16829 by the following points (a) to (g). For clarity the table below highlights the section numbers in the current report where this information is discussed.

Section number (this report)	Content description from MPI RFP16829.
2	(a). Re-evaluate the risk of grass carp establishing self-supporting populations in New Zealand as outlined in the 1985 report and consider the implications of climate change on establishment risk. This would be a desktop analysis and focus on the lower Waikato River, as this is the system most likely to provide suitable conditions for grass carp to breed.
4	(b). Identify a representative range of sites where grass carp have been released and collate available data on flora, fauna and water quality for these sites and assess the effects grass carp have had at these sites.
7	(c). Evaluate any associated biosecurity risks from stocking grass carp, such as inadvertent release of pest species (e.g., weeds, algae and diseases), and impacts on native aquatic vegetation.
5 and 6	(d). Review literature on grass carp use for weed control, reassess and update the conclusions in the 1985 report and present them in the final report. Assess the extent to which grass carp have controlled weed problems in various types of waterbodies in New Zealand, how effective grass carp have been in controlling invasive aquatic plants and identify and document management issues that have arisen and been solved or require further resolution.
6	(e). Assess factors that may limit browsing of grass carp in some parts of the country, for example, in some parts of the South Island.
8	(f). One chapter should outline options and strategies for potential methods for removing most grass carp from various types of waterbodies where it may be desirable. This chapter needs to address ecological, biosecurity and animal welfare risks posed by the methods evaluated.
3	(g). Develop guidelines and procedures that can be employed to assess whether small grass carp caught in the wild are escapees of farm-raised fish from a weed control site or progeny from naturally spawning grass carp.

Appendix B. Field Survey

Purpose

The purpose was to survey a limited number of sites (as agreed with MPI) to obtain better assessments, particularly waterbodies that represent sites typically stocked, or proposed for stocking with grass carp.

Selection of the survey sites was informed by existing knowledge gaps, and the type and quality of information to be gained with a single site visit, to add value in the assessment of grass carp effectiveness and impacts in New Zealand.

In discussion with MPI, it was recognised that there was comparatively little information on grass carp efficacy for weed control and impacts in man-made and modified systems. Two broad categories of typically stocked waterbody types were identified as, (1) those in which water is moved (drains or irrigation systems) and, (2) those in which water is retained (e.g. ponds). The aim was to collate existing information (including contacting the managers or owners) of the waterbodies, to develop a group of sites within each category for further assessment. A third category (3), of proposed grass carp release sites included a fish farm at Waiuku and Quarry Lake that were also identified for a site visit and survey.

To obtain a better assessment of grass carp use, records on the selected sites were sought (from MPI, DOC, Council and landowners) to provide a background perspective and grass carp stocking information, the selected sites were visited in January to March of 2014 and the aquatic vegetation was surveyed.

1. Drainage Sites on the Rangitaiki Plains

There is an extensive drainage system on the Rangitaiki Plains, Bay of Plenty that covers a broad area of flat, low-lying farmland between the Tarawera River and the Whakatane River. A network of ca 350 km of drains and canals services an area of ca 27,000 hectares, managing the stormwater via a series of pump stations, flap gates and culverts in the plains. Extensive beds of invasive weeds, such as *Myriophyllum aquaticum* and *Ceratophyllum demersum* impede water flow and seriously reduce the ability of the pump stations and control mechanisms to manage stormwater. In addition, weeds that blocks pump station screens inhibit the water flow when the pumps are operating (Aquaculture NZ 1997, Decker 2004).

The drains and canals are maintained in a weed free condition primarily by mechanical harvesting. Saltwater intrusion, aquatic herbicides and grass carp are used in a small portion of drains (Aquaculture NZ 1997). Amongst those drains that have been stocked with grass carp (Appendix C, Figure C6), and based on discussion with Bruce Crabbe and Roger Waugh (BOPRC, Bay of Plenty Regional Council, formerly Environment Bay of Plenty (EBOP)) several drains (listed below) were identified that differ in their weed issues, size, history of stocking and weed control outcomes. A site visit was carried out by NIWA in March 2014 with Andrew Pawson (BOPRC Works Coordinator) to assess aquatic vegetation in these drains, as well as upstream and/or downstream reaches that could provide a comparative estimate of weed condition and to assess the use of grass carp for drain weed control.

Section 72

This drain (the section 72 outlet, Nicholas Pump station) is ca 2.23 km long and about 2 m wide (ca 0.4 ha) that is pumped into the Kopeopeo East canal and then the Whakatane River (Aquaculture NZ 1999). The target weed species was primarily *C. demersum*, and the drain was considered to have few natural values and no uses other than drainage (Aquaculture NZ 1997).

An Operational Plan (Aquaculture NZ 1999) was developed and stated that grass carp would be 37.5 cm in length and maximum stocking density, if required in the future, was 110 grass carp in Section 72. The grass carp would be contained in the Section 72 drain by the pump station at the Kopeopeo East canal, and a screen at the other end of the drain. The drain has three culverts that the grass carp can pass through, and has a spring-water inflow (A. Pawson, BOPRC pers comm).

Section 72 was one of the first drains in the area to be stocked with grass carp (AQTRANS0075 BOP), with the initial stocking of 70 fish in April 2000. Since then, MFish approved further releases of grass carp into the drain, including 35 in December 2000, and 110 in December 2001 (Correspondence 13th December 2001 MFish).

Grass carp losses from the drain reported by Aquaculture NZ (2002) included 58 fish in August 2000, 29 fish in February 2001, 31 fish in December 2001 and a further 19 in January 2002. However, there is a discrepancy between the numbers reported by Aquaculture NZ (2002) and those reported in correspondence (12th December 2001 NZWR) where 60 grass carp deaths were reported in August 2000, but also 75 fish deaths were reported approximately four months earlier, with a further 35 grass carp in December 2000, and 29 in February 2001.

Despite these losses, the initial releases from 2000 to 2001 were described as having controlled the aquatic weed (70% weed free), and the drain was functioning well (Correspondence 28th March 2003 EBOP). Although Aquaculture NZ (2002) reported that a digger was used to control the *C. demersum* in December 2000, October 2001 and January 2002. Snapshot measurements (i.e. at a single point in time) of water quality parameters indicated that the habitat was suitable for grass carp (pH 6 (at ca 8 am), DO ca 50% saturation, secchi 1.2 m (i.e. clear to bottom)) in April 2002, although the water temperature (15.7°C, (Aquaculture NZ 2002b)) was unlikely to promote vigorous feeding behaviour from grass carp.

In July 2004 there were serious floods on the Rangitaiki plains, but although the drain was flooded the 100-year stop-banks were not overtopped, so it is unlikely that any grass carp reached the main river. Nevertheless, there were escapes of grass carp from Section 72, which was in the centre of the flooded area. Grass carp were recorded as having reached other nearby drains or they became stranded on farmland, and only three grass carp were found in the drain once the flood water receded (Correspondence 23rd November 2004 MFish). In November 2004 the release of a further 80 fish was requested, and approved (CA051).

A monitoring report in 2006 by NZWR (New Zealand Waterways Restoration Ltd), again provided a snapshot of measurements on water quality parameters (pH 6.57, DO 5.7 mg/l, temperature 16°C) the water was clear to the bottom and weed growth over the previous months exceeded the weed consumption rate by the grass carp. By March 2007 the release of 332 grass carp was requested, as drain weeds were having to be controlled by the use of diggers and herbicide applications, twice and three times, respectively, in the preceding twelve months (Correspondence 27th March 2007 MFish).

During a site visit in March 2014, Section 72 was described as an example of successful weed control by grass carp (A. Pawson, BOPRC pers comm). The drain water was dark in colour (stained, rather than suspended sediments), but is reportedly clear at times. Prior to stocking with grass carp the weed extended across the drain, compared with the almost complete absence of weed in March 2014 (Figure B1). The water is generally warm in summer (ca 20°C) and grass carp are replaced annually based on an attrition rate of 10% (A. Pawson, BOPRC pers comm).

Figure B1. Section 72 drain without aquatic weeds, and showing dark stained water.

Pearce and Mahy

There are two main parts to this site, the Pearce outlet and the Mahy which are 4.5 km long and an estimated 1.66 ha. Grass carp screens are in place on the drain, which receives water from a large catchment and is spring fed (A. Pawson, BOPRC pers comm). The drain water is pumped into Awaiti canal, and then discharges into the Tarawera River.

The operational plan states that grass carp would be 37.5 cm and a maximum stocking density, if required, would be 400 grass carp in the Pearce and Mahy drain (Aquaculture NZ 1999).

The initial approval for grass carp was in 1998 (AQTRANS0075 BOP), an operational plan was agreed in 1999 and 170 fish were released (Correspondence 2nd April 2003 MFish). MFish approved the release of a further 115 grass carp (Correspondence 2nd April 2003 MFish). In addition, the Aquaculture NZ report (2002) states that 85 grass carp were released on 20th December 2000, and 115 in December 2001. Grass carp losses of 35 in November 1999 and 26 in January 2002 were also reported by Aquaculture NZ (2002).

In March 2003 the weed cover within the drain was described as being 60% (Correspondence 28th March 2003, EBOP). With a target weed level of 30% and 70% clear water, the release of an additional 60 grass carp was approved in April 2003 (CA033). In 2006 release of a further 68 grass carp was requested based on natural attrition (Correspondence 21st September 2006 NZWR). The November 2006 monitoring attributes the excellent weed control to the recent release of additional grass carp (NZWR 2006a). However by March 2007 further grass carp were requested as it had been necessary to control weed with herbicide over the previous summer (Correspondence 27th March 2007, MFish). The release of 332 grass carp was approved in March 2007 (CA083).

The Pearce and Mahy drain is another example of managed grass carp stocking that has provided successful weed control for BOPRC. During the 2014 field visit there were few submerged plants (*C. demersum*), some sprawling marginal plants (*M. aquaticum* and *Persicaria decipiens*) and it was evident that the margins had recently been sprayed with herbicide (glyphosate) (Figure B2). In contrast the Awaiti canal into which this drain discharges has significant weed growth that has been managed using the cutter boat and herbicide applications to keep it free of aquatic plants (A. Pawson, BOPRC pers comm).

Figure B2. Pearce Mahy drain showing only small patches of aquatic plants (front left corner with *C. demersum*) and recently sprayed margins.

Awakeri

The Awakeri drainage scheme pumps water into the Orini canal and then the Whakatane River. The drain is approximately 3.5 km long (ca 2.33 ha), 5 to 8 m wide and 0.6 to 1.3 m deep and consists of one main drain with several bends (Decker 2004). The grass carp are contained by the pump station at the seaward end, and by insufficient water at the other (Decker 2004). The water in the drain was described as turbid by Decker (2004). Water records include temperatures of 12 and 17.2°C, pH of 6.8 and DO of 2.65mg/l at 8am with good water clarity such that the bottom sediments were visible (Decker 2004, NZWR 2006a). The dominant weed was *C. demersum*, but *Potamogeton crispus* and duckweed could also be abundant (Decker 2004).

Grass carp release dates reported in NZWR (2006) include 238 fish on 13th May 2005, 109 fish on 28th September 2006 and 55 fish on 4th October 2006. The release of 536 grass carp on the 5th of April 2005 was reported in correspondence (27th March 2007 MFish) along with an application for stocking an additional 30 grass carp in September of 2006 (Correspondence 21st September 2006 NZWR). In 2007 there was also an approval (CA084) for the release of 932 small grass carp (65 mm or longer). Prior to the 2007 approval, alternative methods to grass carp had been utilized to control the drain weeds (e.g., weed cutter boat, digger and herbicide applications) (Correspondence 27th March 2007 MFish).

There have been some issues with this drain with regard to achieving the desired stocking density and weed control outcome. For example, the small grass carp that were stocked appeared not to provide sufficient control of *P. crispus*. Every year there has been some *P. crispus* which at times required control with herbicide (Aquathol K) to enable the plant consumption rate of the grass carp to keep up with the weed growth rate. Generally stocking of grass carp over 30 cm in length, has provided better weed control outcomes. There have also been fish kills within the drain, which have been attributed to low DO or other water quality issues (although there has been no testing) following high rainfall events. Unlike this drain, fish kills do not appear to be a problem in drains that have spring-water inflows (A. Pawson, BOPRC pers comm). In March 2014 there were no submerged aquatic plants, only small areas of algae adjacent to the margins of the drain (Figure B3).

Figure B3. Awakeri drain showing small patches of algae adjacent to the margins.

Omeheu east

Water from the Omeheu east drain is pumped into the Omeheu canal and then into the Tarawera River. The drain is ca 6.4 km long, 3 to 5 m wide (ca 2.56 ha) and has an average depth of 1.1 m. Drain water records include temperature 13 and 17°C, pH 6.9 and 7.4 and DO of 8mg/l (Decker 2004, NZWR 2006a). The dominant weed was *C. demersum*, but duckweed and *M. aquaticum* were also present (Decker 2004).

Approval to release grass carp (Correspondence 14th March 2011 MFish), and subsequent releases included 589 fish in April 2005 (Correspondence 27th March 2007 MFish), 215 fish on 13th of May 2005, and 26 fish on the 22nd of September 2006 (NZWR 2006a). By November 2006 the release of further grass carp was requested (NZWR 2006a) and approved on 28th March 2007 (CA084, 1024 grass carp). In 2011 a subsequent approval for 100 grass carp was obtained to restock replacements for natural losses (CA159).

Even though no escapes have been reported from this site (Correspondence 14th March 2011 MFish), several stockings of grass carp had been undertaken, along with a drain aeration trial to improve fish habitat (A. Pawson, BOPRC pers comm). The Omeheu East drain has now been abandoned as a grass carp control site. This means that although the fish are still contained, weed control is now being achieved by other methods (Aquathol K for *C. demersum*), and grass carp are no longer being re-stocked (A. Pawson, BOPRC pers comm). During the 2014 survey there were no submerged plants in the drain, but some large areas algae on the water surface (Figure B4). In contrast the downstream canal (without grass carp) had large patches of *M. aquaticum*.

Figure B4. Omeheu East drain showing weed free areas (left), and stretches of the drain covered in algae (right).

Massey

The Massey drain is 6.4 km long, 7 to 10 m wide (ca 5.75 ha) with an average depth of 1.1 m. Drain water records include a temperature of 12.2°C and pH of 7.4 (Decker 2004). It was dominated by *C. demersum* and duckweed with *Egeria densa*, *Azolla* spp. and *P. crispus* also abundant (Decker 2004). Approval to release grass carp (1323) for weed control was gained in April 2005 (Correspondence 27th March 2007, MFish).

Grass carp releases documented in NZWR (2006) include 515 fish on 13 May 2005, 104 fish on 28th of September 2006 and 31 fish on the 4th of October 2006. However, reports in 2007 detail the number of times in the preceding 12 months that other control methods were utilised to remove the aquatic weeds indicating that numbers of grass carp were not sufficient to manage these weeds and an application was made for further grass carp releases, including smaller fish (Correspondence 27th March 2007 MFish). The release of 2300 (small fish 65 mm or longer) was approved (CA084).

Despite nearly six years managing stocking densities, this site was abandoned as a grass carp control site 3 years ago. During the field visit in 2014 the drain was largely free of weed, with herbicide (Aquathol K) application used approximately 8 weeks previously to remove the *C. demersum*, and the *P. crispus* (Figure B5). Although there are no supporting data, water quality in the drain is suspected to be the reason that weed control by the grass carp was not always adequate, and difficult to maintain. The low lying adjacent paddocks are fertilised, the drain receives runoff, and there has been die-off of grass carp. Of note, there is no spring-water inlet to this drain that could provide a refuge for the grass carp during periods of poor water quality as has become evident in other successful grass carp drains (A. Pawson, BOPRC pers comm).

Figure B5. Massey drain approximately eight weeks post spray with herbicide. The drain is largely weed free but there were some patches of dense weed growth (in the distance).

Crystall and Seacombes drain

Crystall (ca 1.4 km) and Seacombes (ca 1.5 km) are two drains (the first primarily across farmland, the latter adjacent to Greig Rd), that have continuous water flow and unrestricted grass carp access between them through a culvert under Greig Rd (A. Pawson, BOPRC pers comm). There are spring-water inflows to both the Seacombes and Crystall drains. A pump station pumps water from the drain into the Old Rangitaiki channel that discharges into the estuary area of the Tarawera River.

Grass carp were approved for use in Crystall drain in September 2006 (EBOP 2006, Correspondence 26th September 2012 MPI), the drain is unusual in that the initial approval was for 2000 small grass carp (65 mm or larger). Since their release in 2006, grass carp numbers gradually declined, and were insufficient to control the *C. demersum*. MFish subsequently approved the release of further grass carp to the drain (Correspondence 26th September 2012 MPI).

Prior to the release of grass carp, *C. demersum* covered the width of Seacombes drain and diggers were used to clear the drain. Following the release of grass carp it was ca 18 months before the target weed control was achieved (A. Pawson, BOPRC pers comm).

During the 2014 site survey of Seacombes drain, there was no *C. demersum*, *P. decipiens* was present on the margins, along with a small patch of *Isolepis prolifera* that apparently the grass carp do not like to consume (Figure B6). Crystalls drain also had some *I. prolifera* on the margins, but no submerged weeds other than small patches near the confluence with Seacombes drain (Figure B6). Since the introduction of grass carp, the drains do not require de-silting as frequently (due to the removal of weed beds that trap sediment) which has a flow on effect for bank stability, and maintaining marginal habitat for water fowl (A. Pawson, BOPRC pers comm).

Figure B6. Seacombes drain showing sprawling marginal plants near the spring-water inflow (left) and Crystalls drain with *C. demersum* (right).

Awaiti East

The Awaiti East drain (ca 1.3 km) is separated from Crystall drain by an earth bund, such that there is no water connection between the two sections of drain (A Pawson, BOPRC pers comm). However, the Awaiti East drain was described as an extension to Crystall drain in the application for fish transfer (CA195). Grass carp (ca 100) were released into the drain ca 20 months ago, with a subsequent release of ca 60 fish (A. Pawson, BOPRC pers comm). Before grass carp were put in the drain there was dense growth of *C. demersum* in this 1 to 1.5 m deep drain. During the 2014 site visit the only *C. demersum* present was fragmented drift material that had collected at the pump screen (Figure B7). Awaiti East is the most recent drain on the Rangitaiki plains to be stocked with grass carp for weed control and is regarded as another successful example.

Figure B7. Awaiti East drain showing fragmented *C. demersum* that had collected at the screen.

Summary – Rangitaiki drains

The purpose of the field surveys was to add value in the assessment of grass carp effectiveness and impacts in New Zealand. Of the eleven drains on the Rangitaiki Plains with grass carp (Pullan 2013), the seven that were selected for a site visit included a range of sizes, and varied in the length of time they had been stocked, and in their weed control outcomes. Section 72 and Pearce Mahy drains were initially set up as pilot sites to assess whether grass carp could be an effective and environmentally friendly method of controlling macrophytes (Aquaculture NZ 1997). Grass carp releases were approved in these first two drains over a decade ago, with the remainder of the field survey sites having had more recent first releases. Of these seven drains the majority are considered a success, with a common factor between them being a spring-water inflow. Spring-water inflows appear to reduce the impacts of high temperatures and low dissolved oxygen which may result in fish mortality. In contrast, drains that do not have any spring-water influence have now been abandoned for further grass carp stocking.

Less readily comparable are the stocking densities within the drains, where there have been some losses (flood events, escapes, natural attrition and poaching) and also increased predation losses where small grass carp were stocked in three drains. Although target stocking densities (200 or more large grass carp per ha) were stated in the operational plans and on approvals, it is difficult to discern over what periods of time these stocking densities were achieved. There was a lack of information as to whether or not all the fish approved, were released (and when), and where approval and/or actual release numbers do not align with proposed stocking densities, particularly in regard to grass carp numbers per vegetated hectare. This may be a consequence of not having adequate mortality data, and/or accurate vegetation assessments. In general, the best weed control outcomes have been achieved in drains stocked with larger grass carp (over 30 cm in length), that are re-stocked based on a natural attrition ca 10% per annum (to maintain stocking density) and where there is a spring-water influence and site security can be achieved.

The expertise of drainage staff managing the drains stocked with grass carp provides a useful assessment of control effectiveness, where council staff regularly inspect these drains and can assess whether acceptable control occurs.

2. Stormwater and Ornamental Pond Sites

There are a large number of ponds throughout the country that have weed issues that limit their function or utility as perceived by the pond manager or owner. For any given weed issue there are a number of different tools that can be used to control or remove the weeds, the use of which is largely site and species dependent. Within the Auckland region there are a comparatively large number of sites in which grass carp have been stocked for weed control (Appendix C), some which date back two decades. The majority of the selected sites in the Auckland/Waikato region are ponds that are used for stormwater retention, although some are purely ornamental, and others have multiple uses. Generally, they are highly compromised shallow waterbodies with high nutrient loads, suspended sediments and few natural (native biodiversity) values. The weed issues have primarily been submerged aquatic plants that are readily accessible to grass carp, and although there is generally little monitoring data available (for water quality, flora or fauna), the fundamental knowledge gap is the weed control outcome. Was the target weed control achieved by the grass carp?

Chelsea Sugar ponds

The Chelsea sugar refinery is located in Birkenhead, Auckland (Appendix C, Figure C4). Artificial ponds (4) were created from 1884 to 1917 to retain water from Duck Creek to provide a cooling water reservoir for the refinery (Kanz et al. 2012). Later the ponds were also used for stormwater retention when the area upstream became an urban subdivision. A decline in water quality was noted since the catchment was subdivided (Kanz et al. 2102) and aquatic weed issues have been noted since the 1970s (Tanner 1981).

Grass carp (an unspecified number) were first approved for use in 1992 (AQTRANS0017, 1992). The purpose of the introduction of grass carp was for the biological control of nuisance aquatic plants. However the site suffered from pollution events and fish deaths were reported (eels and carp) about a year after release of the grass carp (correspondence 27th August 2010 MFish), all of the grass carp were believed to have died (Kanz et al. 2012).

In 1995 the ponds were described as suffering from the presence of beds of *E. densa* (Decker 1995a). The area of weed cover was estimated at 50% in ponds 3 and 4, 20% in pond 2, while pond 1 was almost barren (possibly due to being dredged in 1988) (Decker 1995a). Subsequent applications to release silver carp and juvenile grass carp were made in 1996. Approvals were granted for silver carp, although stocking numbers were not stated (AQTRANS0038, 1996) and up to 500 juvenile grass carp (AK015, 1996).

In 2010, correspondence (5th February 2010 NZ Sugar) reveals that submerged macrophytes were again at nuisance levels, with the abstraction pond (pond 3) “90% full of oxygen weed and pond 4 is rapidly becoming choked with the same”.

A further approval was granted to release grass carp and silver carp into the Chelsea ponds in 2010 (CA126). The numbers of fish approved for the ponds were as follows; 395 grass carp (>25 cm), 720 juvenile grass carp and 50 silver carp (>35 cm) for pond 4, 395 grass carp (>25 cm) and 720 juvenile grass carp for pond 3, and 100 grass carp (>20 cm) for pond 2 (CA126). The fish were released into the ponds on 31st of August 2010 (Correspondence 31st August 2010 NSCC), with additional fish in 2011 (Kanz et al. 2012). Stocking numbers were recorded as 400 grass carp and 40 silver carp in pond 4, 270 grass carp in pond 3, 220 grass carp in pond 2 and 50 grass carp in pond 1. The stocked fish numbers equated to densities from ca 100 to 200 grass carp per hectare, with the highest density in pond 3 (Kanz et al. 2012). The target was a 60% reduction in the volume of *E. densa* (DOC unpublished records, 2010).

The macrophyte community in the Chelsea ponds is considered unstable (Kanz et al. 2012). Reportedly dense mats of aquatic plants (in particularly *Lagarosiphon major)* dominated and experienced seasonal dieback (Kanz et al. 2012). In addition to the use of grass carp, aquatic vegetation had been managed by cutting and removal. A weed cutter boat was used in the ponds during the summer 2010/11 to control significant macrophyte growths and assist in restoring water circulation in pond 4 (Kanz et al. 2012). In conjunction with the grass carp, effective weed control was achieved over the 2011/2012 summer period (Kanz et al. 2012). However, the possibility of varying plant growth rates in different years was also considered when explaining successful weed control outcomes (or not), and long term monitoring was considered necessary to verify the effectiveness of the grass carp in Chelsea ponds (Kanz et al. 2012).

February 2014, three ponds were surveyed (ponds 2, 3 and 4, i.e. the most upstream pond (pond 1) was not surveyed). The fourth pond (closest to the sea) had water visibility of ca 0.4 m and the water appeared turbid from a declining algal bloom (despite the strawbales) (Figure B8). Mallard ducks, black swans, black-backed gulls were all present on the water and there was a black shag rookery in an adjacent tree. No submerged aquatic plants were present. Small patches of marginal aquatic plants on the water edge included *Myosotis laxa, Lycopus europaeus* and *Ludwigia palustris*. Three grass carp (up to 60 cm long) were observed swimming in the shallow water of the littoral zone.

The third pond was more turbid than the fourth (i.e. lower water clarity). However this was not due to algae but rather suspended sediments. The second pond (further upstream) had emergent beds of *Typha orientalis* and *L. palustris*.

In summary, the Chelsea ponds are highly compromised in terms of historic use and impacts, with significant challenges ahead for management if water quality improvements are sought. Fish deaths (including grass carp) and the stocking of juvenile grass carp (which may be highly preyed on e.g. by shags) leaves considerable uncertainty over stocking density. During the more recent stocking events (from 2010) other control measures have been implemented that cloud the interpretation of grass carp effectiveness for weed control such that further monitoring was considered necessary by the managers (now AC) (Kanz et al. 2012).

Figure B8. Chelsea pond 4 showing resident ducks and the strawbales anchored in the lake and floating just at the surface (right).

Tahuna Torea Reserve Pond

The Tahuna Torea Reserve is located in Glen Innes, Auckland (Appendix C, Figure C4). The lake in the reserve had problems with macrophytes (*E. densa*) and grass carp were introduced to control the plants (AQTRANS0022, 1993). The goal was to reduce the volume of weed by 60% (DOC unpublished records, 2010). The council were reportedly (Decker 1995b) impressed by the success of the carp in this lake and the resultant cost savings.

Subsequent monitoring reports record die off of the raupo (*T. orientalis*), with largely open water (85%) with algae, and pond margins with swamp willow weed (*Persicaria*) (NZWR September and November 2009a).

Herbarium records from 1982 listed Tahuna Torea as one of the first sites with *C. demersum* in Auckland (de Winton 2010). In February 2010 the pond was surveyed for *C. demersum,* and none was found (de Winton 2010). The ephemeral habitats were choked with marginal plants (e.g. *Persicaria* spp.) and water lilies, and the main lagoon had compromised water quality with extensive filamentous algal cover (de Winton 2010).

The lake water was murky in February 2014, and presumably the strawbales that were present in the lake were to minimise the algal bloom. There were no submerged aquatic plants, but marginal species were represented by *P. decipiens, Paspalum distichum, T. orientalis* and *Bolboschoenus fluviatilis*. There was a large population of mallard ducks and pukekos, and mosquito fish were also present.

The target weed species, egeria, was no longer present. However there is a lack of information since stocking with grass carp to determine whether or not the weed removal can be attributed solely to the grass carp, or if other control methods have been employed. Drag-lining was reportedly used to remove the egeria prior to the stocking of grass carp (ca 100) in 1994 (Local resident, pers comm). Egeria removal and current areas of open water were attributed to the stocking of grass carp, and it was commented that large fish are still seen on occasion (Local resident, pers comm). Only a few grass carp remain in Tahuna Torea with the majority having been removed in March 2013 (G Jamieson, NZWR, pers comm).

Figure B9. Tahuna Torea reserve pond showing strawbales in the water (left) and murky water in the foreground with lawn mowing clippings on the surface water and *P. decipiens* on the margin (right).

Waiatarua Wetland Reserve Lake

The Waiatarua Wetland Reserve is located in Meadowbank, Auckland (Appendix C, Figure C4). The reserve has a wetland with boardwalks and paths, excavated pond and channels fed by stormwater, and a restoration project was opened in September 2004.

Grass carp were approved for release into the Waiatarua wetland reserve in 1994, to control *E. densa*, with target reduction of 60% (AQTRANS0026, 1994). Subsequent correspondence details the intended release of 200 grass carp to the site (Correspondence 22nd August 1995 Jamieson Holdings Ltd). However by 1995 additional grass carp stocks (ca 25) were requested (Correspondence 16th November 1995 DOC), and subsequently approved for 30 fish (Correspondence 16th November 1995 MFish).

By April 1996 Auckland City Council had applied to restock the ponds and channels within Waiatarua reserve with 200 grass carp. It was noted that the excavated ponds and channels that receive stormwater from the surrounding area had significant ponding, water level fluctuations, and little water circulation with dense growths of submerged macrophytes. The dominant submerged species was *E. densa* and many of the channels had 100% cover of the plant (Correspondence 1st April 1996 DOC). In the past ACC had attempted manual and chemical (herbicide) control of the aquatic weeds with limited success. The continued use of grass carp was seen as providing longer term plant control, with little or no change or impact on the water bird and fish communities present (Correspondence 1st April 1996 DOC).

The February 2014 site visit revealed drains clogged with aquatic plants including *Ottelia ovalifolia, E. densa, P. decipiens, Glyceria declinata, Alisma plantago-aquatica, Juncus articulatus* and *P. distichum.* The lake in the wetland had a diverse and large number of water fowl, but no submerged aquatic plants (Figure B10).

The target weed species, *E. densa*, was no longer present in the main waterbody. There was no requirement to report monitoring results as part of the grass carp approval (DOC unpublished records, 2010), and there is a lack of available information since stocking to determine whether or not the weed removal can be attributed to the grass carp. The lack of drain weed control indicated that grass carp were not present. The absence of grass carp was corroborated (G Jamieson, NZWR, pers comm) with fish having been removed ca 10 years ago when further development of the site as a wetland was undertaken.

Figure B10. Wetland channels choked with aquatic plants (top) and the open water of the pond with resident waterfowl (bottom).

Ayrlies Garden Ponds

Ayrlies garden is located in Whitford, Auckland, and has been developed from bare paddocks since 1964 (www.ayrlies.co.nz). The garden is 4.5 ha and includes five ornamental ponds in a landscaped garden, with the more recent addition of a larger wetland area and lake. The ornamental ponds have had blooms of algae, and extensive growth of the floating plant *Azolla pinnata*. Grass carp were introduced to control the aquatic weed azolla (AQTRANS0046, 1997).

The site was visited on 23 March 2010 by Department of Conservation staff (DOC unpublished records, 2010). It was noted that the ponds were not connected to natural waterways, and the grass carp were still present in four of the five ponds, Cypress, Log Pond, Ollies and the New pond. Very large fish were observed feeding in one pond. Several grass carp died when they were put into a pond with complete cover of azolla possibly from low dissolved oxygen in pond. It was noted that azolla was not a preferred plant for the grass carp (DOC unpublished records, 2010).

In 2014 grass carp were present in the same four ponds as in 2010, as well as in the Native pond. Grass carp (12) were released into the native pond in 2008. The lake was partly cleared of weed prior to their release, to improve fish habitat and to reduce the initial plant biomass for consumption. Only a small patch of the sprawling marginal plant, *P. decipiens,* was present during the site visit. Current stocking in this pond is six grass carp, with two having been taken by shags, and four that had been moved to other ponds on the property. Amongst the remaining four ponds grass carp numbers are managed to control submerged and floating aquatic plants, while enabling water lilies which were non-target plants to grow (see section 3.7). There were small amounts of azolla and duckweed on the margins of some of the ponds, and isolated plants of *P. ochreatus* and *P. cheesemanii* (Figure B11). Grass carp have been seen to browse the water lilies, and bite marks were evident on the leaves of some plants (Figure B12). Marginal aquatic plant species were also present on the edges of Cypress, Log and Ollies pond. Species included *M. aquaticum, L. palustris* and *Pontederia cordata.*

In summary, Arylies garden is an example of a grass carp stocking site where fish numbers have been managed successfully to achieve the desired weed control outcome of azolla removal while maintaining non-target plants of waterlilies and marginal aquatic species.

Figure B11. A selection of aquatic plants found in the ponds at Ayrlies garden. Azolla and duckweed (top left), *P. ochreatus* (top right), *P. cheesemanii* (bottom left) and *M. aquaticum* and *L. palustris* (bottom right).


Figure B12. Water lilies in the shallow New pond with a single grass carp in the foreground (left) and lily leaves with bite sized pieces removed by grass carp in Cypress pond (right).

Wattle Farm Park Pond

There are two ponds on the Wattle Farm reserve, the most southern pond has saline water, and the northern pond (ca 3ha) has one stream inlet and acts as a storm water retention pond (correspondence 21st February 2003, MFish). Grass carp (up to 100) were approved for release in the northern pond (AQTRANS02/22, 2005) to control 60% of the nuisance plants in the pond (Decker 2002). Fish were release on the 4th of April 2005 (Aquaculture NZ 2008). Plant species listed as present include, *E. densa, L. major, P. crispus* and *Ruppia* spp. (Decker 2002).

Despite problems with screen security and the potential for grass carp escape (DOC unpublished records 2010), monitoring in 2006 describes a decrease in the level of pest plants (NZWR 2006bc). In February 2007 an increase in *P. crispus, M. aquaticum* and filamentous algae were reported (NZWR 2007a), and 100 grass carp were released on 25th February 2007 (NZWR 2007b). By March 2009 marginal plants of raupo and willow weed were reported as common, and submerged plants were not present (NZWR 2009b, Aquaculture NZ 2009a). In November 2009 there was extensive modification of the north pond (DOC unpublished records 2010).

There were no submerged macrophyte beds in the most southern pond in February 2014, only small fragments of *Ruppia* spp. In the most northern pond the water was clear (ca 2 m) with localised patches of the submerged plant *P. crispus* (Figure B13). On the pond margins there were a range of species including *Alternanthera philoxeroides, Persicaria hydropiper, P. decipiens, M. aquaticum, L. europaeus, M. laxa, Nasturtium officinale, Alternanthera nahui* and *Phragmites karka* (a newly recognised pest plant reported to the biosecurity sections of MPI and AC) (Figure B13). The *A. philoxeroides* plants were in poor condition with a large number of the flea beetles (*Agascicles hygrophila*, a biocontrol agent) evident on the plants (Figure B13). At the inlet on the upstream side of the screen there was also *O. ovalifolia*.

The ponds were largely free of aquatic plants compared with the inlet stream.

Figure B13. Aquatic and marginal plants from Wattle farm pond. *P. decipiens* and *P. crispus* (top left and right) *A. philoxeroides* and *P. karka* (bottom left and right).

Hayman Park Ponds

Hayman Park is located in urban Manukau, Auckland (Appendix C, Figure C4). The man-made ponds in the park were created for aesthetic purposes, and receive run-off water from the surrounding park (Decker 2003). Grass carp (50, larger than 25 cm) were approved for release to control nuisance aquatic weeds (AQTRANS02/21, 2005) primarily *E. densa,* filamentous algae and *P. decipiens* with a target weed removal goal of 70% (NZWR 2006b). The fish were released on the 11th of April 2005 (Aquaculture NZ 2008). Manual weed removal was undertaken in 2006 which cleared weed from the surface water, leaving about 65% of the bottom of the pond with plants (May 2006), and by November 2006 the lake was clear of weed (DOC unpublished records 2010). Subsequently it was suggested that the stocking density should be reduced by removing 30 to 40 grass carp (NZWR 2006b), and in November 2006 the addition of a further 10 grass carp to the lower pond was recommended (NZWR 2006c). In 2007 no *E. densa* was present in the upper pond, and there was a further reduction of the plant in the lower pond (2007ab). By 2008 estimated fish numbers were 4 grass carp in each of the ponds (Aquaculture NZ 2008), and weeds were all recorded as sparse through to 2009 (NZWR 2009b, Aquaculture NZ 2009a). However in September and November 2009 monitoring records show ca 10% open water (weed free) in the lower pond and 98% open water in the upper pond, (Aquaculture NZ 2009b). A further five grass carp (ca 25 cm long and 2 years of age) were released in August 2010 (CA143, 2010). By January 2011 no *E. densa* was reported from the ponds (NZWR 2011a).

In February 2014, the water had ca 40 cm visibility and no *E. densa* was recorded. There were only marginal aquatic plants including *L. palustris, M. laxa, P. decipiens, Persicaria lapathifolium, Carex secta, P. distichum* and *Ranunculus flammula* (Figure B14).

Control of the target species appears to have been successful in conjunction with manual weed removal.

Figure B14. The edge of the lower Hayman park pond showing marginal aquatic plants (primarily *P. decipiens* and *L. palustris* in the water).

Montgomerie Ponds

The Montgomerie ponds are two small (0.2 ha each), shallow (max depth ca 2m) stormwater ponds (Decker 2006d) located off Richard Pearse Drive, Mangere, Auckland in the Oruarangi Creek catchment (Appendix C, Figure C4). Grass carp (44 fish, >350 mm) were approved for release in November 2007 (AQTRANS02/52) to control nuisance aquatic plants, primarily *Ottelia* and *Ludwigia* spp (Decker 2006d). Releases took place in April 2008 with 44 grass carp into each pond (Aquaculture NZ 2008). Monitoring reports from 2008 and 2009 show a decline in the amount of plant cover in both ponds. In January 2009 there were few plants and no emergent species in one pond, with large beds of emergent species and sedges in the other pond (DOC unpublished records 2010). In 2011 *L. palustris* was the most abundant plant in the south pond and *P. decipiens* was considered common in the north pond (NZWR 2011a).

In February 2014 the water was relatively clear (visibility greater than 0.5 m) and no submerged aquatic plants were present (Figure B15). The marginal species included *P. decipiens, L. europaeus, I. prolifera, P. distichum, Ludwigia peploides* and *A. nahui*. Gambusia (mosquito fish) were also seen in the southern of the two ponds.

Control of target weeds has been achieved, only a small bed of *L. peploides* was present.

Figure B15. Montgomerie stormwater ponds North (left) and South (right) showing a small patch of *L. peploides* in the South pond (distant right) and otherwise weed free water.

Puhinui Reserve Pond

The Puhinui Reserve pond is situated in the reserve in South Auckland (Appendix C, Figure C4), and in the Puhinui Stream catchment (Correspondence 14th November 2007 DOC). This small (0.3ha) shallow (max depth ca 1m) pond receives water from its immediate catchment and from springs within the pond (Decker 2006b, Aquaculture NZ 2008). Grass carp (24 fish, >250mm) were approved for release to control 70% of the nuisance aquatic plants (AQTRANS02/42, 2007). Species included were *P. decipiens, E. densa, Callitriche stagnalis, Azolla* spp., *Lemna disperma* and *P. distichum* (Decker 2006b). In March 2008 24 grass carp were released (Aquaculture NZ 2008). A further grass carp release was granted by MPI in February 2011 for 20 grass carp (CA161 Site 62, (Correspondence 18th March 2011 MFish)).

Monitoring reports show large changes in the amount of open water and the abundance of *E. densa*, from 20% open water with abundant *E. densa* in March 2008 to 75% open water and common *E. densa* in March 2009 (NZWR 2009a, Aquaculture NZ 2009a). In 2011 the *E. densa* was reported with 80% cover (Correspondence 18th March 2011 MFish).

In February 2014 the wetland margins of the pond had a variety of species including; *R. flammula, I. prolifera, L. palustris, L. peploides, P. decipiens, P. distichum, M. propinquum, C. secta, Eleocharis acuta,* and *J. articulatus* (Figure B16). The pond water was dark (peaty) and there were no submerged macrophytes.

Target weed control appears to have been achieved*, E. densa* declined significantly in the first year after stocking with grass carp, and no *E. densa* was recorded in 2014. The *P. decipiens* and *P. distichum* did not extend beyond the wetland margins.

Figure B16. Puhinui reserve pond showing a range of marginal aquatic plants species.

Whaka Maumahara Reserve pond

The Whaka Maumahara Reserve is located in Botany Downs, Auckland (Appendix C, Figure C4), and is in the Pakuranga Stream catchment. The stormwater retention pond (0.66 ha) in the reserve is shallow (max depth 0.5 m) and was dominated by *E. densa* (Decker 2006c). Approval to release 66 grass carp was obtained in 2007 (AQTRANS02/46). Two releases occurred in 2008 of 10 and 56 grass carp in March and April respectively (Aquaculture NZ 2008). Further releases include 10 grass carp on 28th April 2009 (CA105, Aquaculture NZ 2009a), 10 grass carp were approved in August 2010 (CA148), 30 grass carp were applied for in November 2010 (Pullan 2013) and 30 grass carp approved in March 2011 (CA165) (Correspondence 18th March 2011 MFish).

The goal was 70% weed removal of the target species *E. densa* and *P. distichum* (DOC unpublished records, 2010). Monitoring reports described a reduction in *E. densa* from 99% cover in March 2008 (Aquaculture NZ 2008) to only marginal patches of willow weed recorded March 2009 (NZWR 2009b). By November 2009 there had been an increase in the abundance of *E. densa* and *P. crispus,* and the introduction of further grass carp was recommended (Aquaculture NZ 2009b). In January 2011 *E. densa* was described as abundant along with filamentous algae, and vegetation covered 80% of the water surface (NZWR 2011a).

In February 2014 ducks and pukekos were common on and around the pond. No submerged macrophytes were present in the pond, however both *E. densa* and *P. crispus* were present in the outflow (Figure B17).

Figure B17. The stormwater pond in the Whaka Maumahara reserve showing resident waterfowl (left) and *E. densa* downstream of the pond (right).

Wiri Stream Ponds

The Wiri Stream ponds are in the Wiri Stream Reserve in Manukau, Auckland (Appendix C, Figure C4), and in the Puhinui Stream Catchment. The two ponds are shallow (max depth 1m) and formed within a natural stream that flows through the ponds out of the reserve (Decker 2006b). The ponds function is to manage water flows during heavy rainfall, as well as aesthetic values within the reserve (Decker 2006b). Grass carp (78 fish, >350 mm) were approved for release in 2007 (AQTRANS02/36) for the control of aquatic weeds primarily *E. densa,* with a target of 70% plant removal (DOC unpublished records 2010). In March 2008 41 grass carp were released followed by a further 37 grass carp in April 2008 (Aquaculture NZ 2008), and 21 in December (NZWR 2009b). In April 2009 70 grass carp were approved for release (CA106), and a further approval was processed for the lower pond by MPI in 2011 for 20 grass carp (CA172) (Correspondence 31st October 2011 MFish). NB: Aquaculture NZ (2009a) lists 72 grass carp >35 cm as released on 28th April 2009; CA74 states 191 grass carp were approved by DOC (Correspondence 31st October 2011 MFish).

Monitoring reports from 2008 and 2009 indicate some increased open water, although there was still a large volume of weed (e.g. 60% congestion) in March 2009, with *E. densa* and *Glyceria maxima* recorded as the dominant species (NZWR 2009b). *E. densa* and filamentous algae were still described as abundant in the upper pond in January 2011 (NZWR 2011a). By September 2011 submerged aquatic plants were recorded as sparse, with the upper pond also having reduced weed levels, however it was noted that grass carp may have been lost in a flood event (NZWR 2011b).

In February 2014, there were pukekos, mallard ducks and black shags on the downstream pond. There were no submerged plants in the downstream pond and the water had ca 40 cm visibility. The marginal plants included *G. maxima, P. decipiens, P. hydropiper, Veronica anagallis-aquatica* and *N. officinale*. The stream (culvert) water between the two ponds had *P. crispus* and *C. stagnalis*, along with smaller amounts of *Apium nodiflorum* and *P. lapathifolium*. The upstream pond was choked with predominately *E. densa* and smaller amounts of *P. decipiens* (Figure B18). The downstream outlet had relatively small amounts (compared with upstream) of *E. densa, P. crispus*, and *Nitella* sp. aff. *cristata*.

Control of target weeds has been successful in the downstream pond. The scale of weed infestation in the upstream pond indicates that there are unlikely to be any grass carp present in that pond.

Figure B18. Wiri stream ponds showing the weed free water in the downstream pond (left) and the upstream pond (right) choked with *E. densa*.

Cyril French Pond

Cyril French pond is a stormwater retention pond in Flat Bush (Chapel and Baverstock Roads), Auckland (Appendix C, Figure C4). Grass carp (15 fish, >500mm) were approved for release in December 2007 (AQTRANS02/32, 2007) primarily to control *C. demersum* (Decker 2006a) (Correspondence 31st October 2011 MFish)). Ten grass carp were released on 27th March 2008 (DOC unpublished records 2010), 5 more grass carp were released in August 2010 (CA147 (NB: states 6 grass carp for approval CA147 in Correspondence 31st October 2011 MFish), 20 were approved in March 2011 (CA164) and 50 grass carp were approved (CA171) and released in October 2011 (Pullan 2013).

The goal was to achieve 70% weed removal of *C. demersum,* with *P. decipiens* and *P. distichum* also identified as target species (DOC unpublished records 2010). An estimated 40% of the pond was covered in weed (*C. demersum* was not quite surface reaching) in March 2008 (Aquaculture NZ 2008). Monitoring shows an increase in open water to 95% in

September 2009 and *C. demersum* is not recorded (Aquaculture NZ 2009a). However *C. demersum* was recorded as common in 2011 (NZWR 2011ab), having increased significantly, and the release of further grass carp was sought (Correspondence 31st October 2011 MFish).

In February 2014 no submerged aquatic plants were present (Figure B19). The marginal species included *P. decipiens, L. europaeus, M. aquaticum, L. palustris and Schoenoplectus californicus* (Figure B19). There were also about 60 mallard ducks on the pond.

Control of the target weed *C. demersum* has been achieved.

Figure B19. Cyril French stormwater pond showing weed free water with ducks (left) and marginal aquatic plants (right).

Manuwai Lane Lake

The Manuwai Lane lake is a small (ca 1 ha and 7m deep) man-made pond that originally supplied water for orchards and irrigation (Decker 1996). The pond was formed in 1965 by damming a small stream and water was used for irrigating. In the past the pond was regularly pumped dry every summer until about 1987 (Correspondence October 1996, Hoffman) which prevented macrophytes becoming established. The water level in the lake is controlled by rainfall and two short streams, the outflow (culvert) flows ca 500m before reaching the tidal Whangapouri Creek (Manukau Harbour). A screen was placed over the outflow to prevent grass carp escape downstream (Aquaculture NZ 1996). The lake is surrounded by six properties (lifestyle blocks) in a rural catchment (Decker 1996).

Grass carp were introduced to the lake to control nuisance aquatic macrophytes, the target was a 60% reduction in plants (Decker 1996). The aquatic transfer (AQTRANS0051, FIS0041) for grass carp and silver carp into the lake at Manuwai Lane for weed and algal control was dated May 1997. Copies of the risk assessment report (RAR) (Decker 1996), operational plan (Aquaculture NZ 1996) and monitoring reports (NZWR 2006d, 2006e, 2009) were obtained from MPI. Stocking rates of up to 200 grass carp and 100 silver carp were recommended (Decker 1996).

In the RAR it was recognised that the pond receives nutrient from surrounding farmland, and it was considered that once the macrophytes were removed, these nutrients may promote algal blooms. The silver carp were introduced to control these blooms (Decker 1996). Large beds of *C. demersum* (hornwort) were reported in all of the shallow reaches, with azolla covering a large part of the surface of the pond. Other aquatic and marginal species included duckweed, *Nymphaea* spp, *T. orientalis, P. decipiens* and filamentous algae (Decker 1996).

However it is interesting to note that in the same year 1996, a visit by MFish (now MPI) staff does not record *C. demersum* but records milfoil (Correspondence November 1996, Pullan). Although it cannot be verified, it seems possible that the *C. demersum* identification by Decker (1996) and the milfoil identification by Pullan (1996) may in fact have been the same plant. The native milfoil (*Myriophyllum triphyllum*) can be mistaken for *C. demersum.* In 2014, Mr Pullan could confirm that, his reference to milfoil was not the introduced marginal aquatic weed *M. aquaticum,* which he refers to as parrot's feather (Pullan, MPI pers comm). *M. aquaticum* was recorded from the lake some 10 years later (NZWR 2006d). It is worth noting that both species (*C. demersum* (or hornwort) and milfoil) may have been present, although only a single submerged species is mentioned as abundant in each report (e.g. "Hornwort which occupies most of the shallow areas of the pond" (Decker 1996), and "Azolla and milfoil are present in large quantities" (Correspondence 6th November 1996, Pullan)).

The implications for the lake are, that the continued development of large beds of *C. demersum*, (as reported by Decker (1996)) would likely have led to a deterioration in water quality and provided only poor habitat quality for a limited range of aquatic species. However if *M. triphyllum* was present, it may have already colonised (given the lake depth) the area of the lake available to it, and a comparatively large area of open water would have remained.

Although few monitoring reports were available since the release of the grass carp, there is agreement that the pond was largely free of aquatic weed (NZWR 2006de), and that *C. demersum* was not seen for over two years (2006d), although *Azolla* spp. was abundant (NZWR 2009c).

In February 2014 there were no submerged macrophytes. Marginal aquatic plants included *M. aquaticum, A. pinnata, T. orientalis, C. stagnalis, P. decipiens, L. disperma, A. nodiflorum, Iris pseudacorus* and *P. distichum* (Figure B20).

In summary, even though the target was partial weed control and grass carp numbers were managed (local landowner, pers. comm.) all submerged plants have been consumed. The lake has remained free of submerged aquatic plants in the subsequent decades, and provides the local residents with the amenity values that were sought from their lake. However, correct plant identification is key to predicting the likely outcomes of a perceived weed invasion, and the need to intervene with weed control.

Figure B20. Manuwai lane lake showing open water and a stand of the marginal emergent species *T. orientalis* (left) and the foreshore with *M. aquaticum* with a single stem of *P. decipiens* (right).

Waitakaruru Arboretum Ponds

The Waitakaruru Arboretum and sculpture park in the Waikato (Appendix C, Figure C5) is a former quarry that has been transformed into a 17.5 hectare garden and arboretum. The rehabilitation started in 1991 to enhance the existing features of rocky outcrops, ponds, flowing water and broad vistas (www.sculpturepark.co.nz). The two largest ponds were constructed as settling ponds prior to water flowing into the Waitakaruru Stream (Wakeling and Wakeling 2009). The catchment of the ponds is solely from runoff and underground seepage from the quarry property. The ponds flow into the Waitakaruru Stream via an overflow pipe that maintains the water level at ca 700 mm below the lowest bank (Wakeling and Wakeling 2009). Water depth is ca 3m, and the ponds are ca 0.2 and 0.26 ha in area (Rowe 2009).

In December 2009 approval was sought to release grass carp into the two largest of the ornamental ponds on the property (Correspondence 9th December 2009, Sculpture Park) to eradicate *E. densa* and other macrophytes (Wakeling and Wakeling 2009). Although Rowe (2009) records the dominant species as *Elodea canadensis* and *P. ochreatus*. The proposed stocking density was 12 grass carp (larger than 300mm) in each pond (50 per ha) (Wakeling and Wakeling 2009), to achieve gradual weed control over one summer (Rowe 2009).

The grass carp were approved (AQTRANS03/18, 2010) and released on 30th of July 2010 (Correspondence 4th August 2010, DOC).

In 2014 there were no longer any submerged macrophytes in the ponds, although marginal aquatic plants were still present (Rowe, observations) (Figure B21). The grass carp have achieved the desired level of weed control (eradication). However, water clarity has been reduced (at least in summer months) by a dense diatom bloom, related to a lack of zooplankton caused by heavy predation from gambusia.

Figure B21. Ornamental pond in the Waitakaruru arboretum and sculpture park, showing marginal emergent plants (photo by J Clayton).

Summary – Stormwater and ornamental ponds

Amongst the twelve sites in this field survey, the initial release dates for weed control by grass carp range from less than 4 years to over 20 years. For some of the sites, the amount of information that could be collated, and supported by a field survey to assess the use of grass carp, was limited. For others, more complete records were available, which enabled weed control outcomes to be better assessed. As with the drainage sites, there was a general lack of clarity as to whether or not the fish approved for release, were released and when.

Target plant species varied, and discrepancies between some reports highlighted the need for accurate identification at the outset, and during subsequent monitoring. Target weed control goals were usually defined in the assessment of environmental effects and/or operational plans, as partial weed removal. At several sites, control methods other than grass carp were utilised, which clouds interpretation of the relative effectiveness of the grass carp for reduction in the volume of weed. In the majority of ponds, target weed control has been regarded as successful, in that perceived weed issues no longer exist, but complete (rather than partial) weed removal was the outcome.

3. Proposed sites

Waiuku goldfish farm

The goldfish farm (NZ Goldfish Limited) is situated between the Waiuku-Otaua Road and the Otaua Stream (Appendix C, figure C5). It is approximately 6 km from Waiuku on flat farming land to the north of the Waikato River (Jackson and Jamieson 2013). The facility was purpose built to farm fish and has a number of rectangular earthen outdoor ponds, as well as raised concrete and galvanised tanks (Figure B22). Because the ponds were designed for fish farming, the water flow and levels can be managed depending on fish farming requirements (Pullan 2013). Water is pumped from the adjacent Otaua Stream and each pond can be filled independently (without water passing through another pond). Water discharges from the ponds and passes through a coarse filtration unit, and is then recirculated through the ponds. Discharges of water from the site if/when necessary are through a seepage pond at the south end of the property (Jackson and Jamieson 2013). There are no natural inlets into the ponds (Pullan 2013).

Figure B22. Waiuku goldfish farm showing the general layout of outdoor ponds and tanks (source, Google Earth September 2013).

The initial proposal was to stock the site for the purposes of farming the grass carp and the applicant was intending to apply for a fish-farm licence (Pullan 2013). However, the application was changed so that the release of grass carp was for weed control purposes only, and as such DOC did not require an EIA (environmental impact assessment) (Pullan 2013).

The focus of the field survey was the rectangular earthen ponds, as these were the ponds intended for the release of the grass carp for weed control (Pullan 2013) (Figure B22). These ponds range in size from 0.04 to 0.08 ha, and are from 0.75 m to just over 1 m deep (Jackson and Jamieson 2013). The site visit and vegetation survey was carried out on the 5th of March with Mr Michael Jackson, the owner of the NZ Goldfish Ltd.

Amongst the ponds there were a range of aquatic plant species including, *P. crispus, P. cheesemanii, E. canadensis, M. aquaticum, L. palustris*, *Nymphaea* spp. and *A. plantago-aquatica*. The surface area occupied by the plants and the combination of species varied between the ponds (Figures B23 to B27), and while some ponds were full of plants with surface reaching plant growth, others had areas of open water (e.g. Figure B23).

In the grass carp application, *E. canadensis, P. crispus,* and *Glyceria fluitans* were described as present in every outdoor pond on site, with a few ponds having scarce amounts of filamentous algae, *M. aquaticum*, and *C. stagnalis*. The weed control target, was removal of all of the vegetation (Jackson and Jamieson 2013).

Figure B23. Rectangular outdoor ponds proposed for stocking with grass carp (photo by J Clayton). Plants on the margin of this pond are *M. aquaticum* and *L. palustris*.

Figure B24. The aquatic plants *P. crispus* and *P. cheesemanii* are in the foreground of this pond (left, with a close-up image of the plants on the right) the pond is dominated by *E. canadensis* (Photo by J Clayton).

Figure B25. The marginal plants *M. aquaticum* (left) and *L. palustris* (right) (photo by J Clayton).

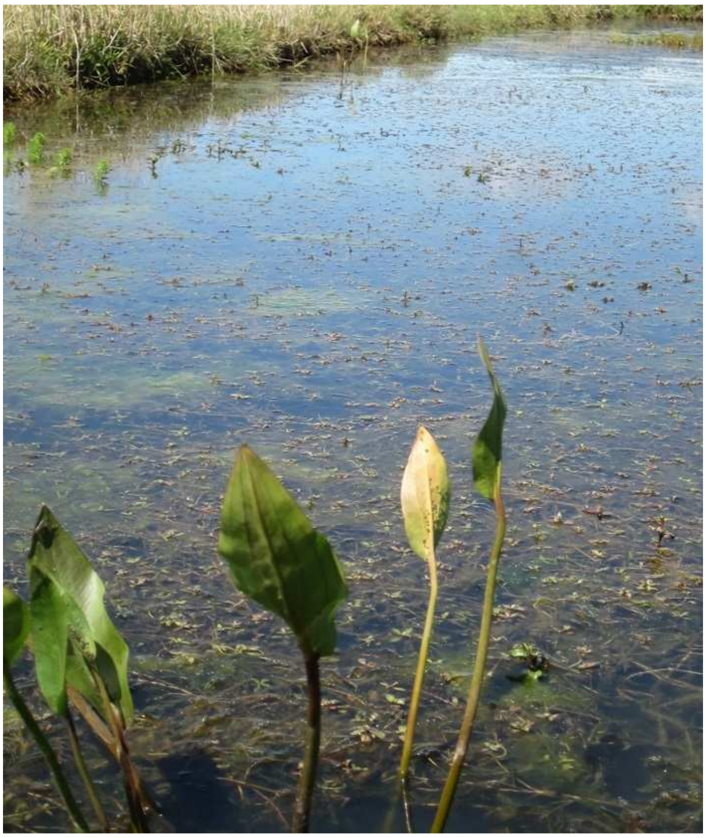

Figure B26. ***Alisma plantago-aquatica*** **in the foreground of a pond that is covered with submerged aquatic plants.**

Figure B27. Water lilies and *E. canadensis* in a pond adjacent to the bamboo hedge (photo by D. Rowe).

Stocking density for weed control was proposed at 85 grass carp (Pullan 2013) for the 19 rectangular ponds with an estimated area of 0.85 ha (Jackson and Jamieson 2013), which equates to a stocking density of 100 grass carp per hectare. A high stocking density for weed control (and eradication) is 100 grass carp per vegetated hectare (Rowe & Schipper 1985, Rowe & Champion 1994, Rowe et al. 1999), and most of these ponds were covered in vegetation in March 2014. However Pullan (2013) notes that although the stocking density does not appear to be excessive to control the types of aquatic weeds present, it was unclear what size these fish would be.

A key component to achieving effective weed control with grass carp is maintaining stocking density. Here the size of the fish at socking makes a difference with regards to a higher risk from predation for smaller fish, as does site security and the ability to ensure the grass carp are contained.

In the application it is stated that "there is no risk of the grass carp escaping once in the ponds except by way of a catastrophic natural disaster" (Jackson and Jamieson 2013). All water entering the site is by way of a pump that is screened with 500 micron mesh and fish cannot presently pass out of the inlets and outlets of the ponds (Jackson and Jamieson 2013). There is an artificial barrier that follows the eastern border of the property (stream side) in the way of fine bird mesh (with gaps no greater than 10mm), and a thick bamboo fence (ca 1.5 m depth) which would provide a barrier in a catastrophic natural disaster - although flooding has never occurred on the farm (Figure B28) (Jackson and Jamieson 2013).

In addition to the mesh fence on the stream (eastern) side of the property, there is also a small earth bund between the property and the stream (Figure B29). However the ponds are low-lying and the earth bund and mesh fence only forms a partial perimeter to the site. On the western side of the property there is neither a bund nor a fence, only a bamboo hedge between the ponds and a drain. The drain could provide fish access to the canal (Figures B30 and B31), which flows to the Waikato River. Although the bamboo hedge may provide an adequate barrier to large grass carp, used for weed control, it is less likely to do so for small/juvenile grass carp. Given the size of the site, the ponds could hold in in excess of 250,000 juvenile grass carp (authors observations). Escape of a large number of juvenile grass carp to the canal and downstream to the Waikato River could overcome a population bottleneck and would likely result in impacts, with a residual population for ca 20+ years. If juvenile grass carp were to be approved for stocking or rearing on the property in the future, the possibility and consequences of a large number of small/juvenile grass carp gaining access to the Waikato River would need to be addressed.

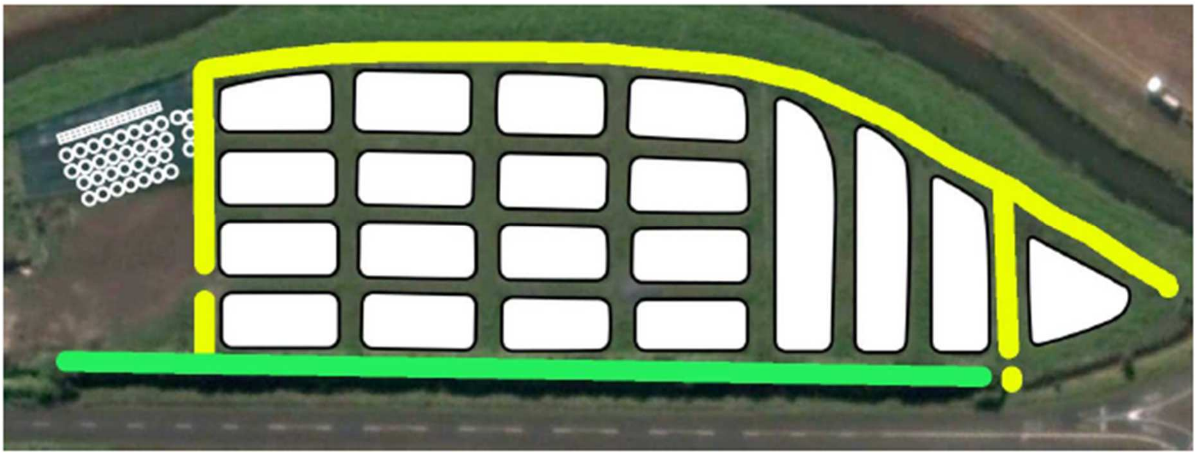

Figure B28. Diagram from Jackson and Jamison (2013) showing the rectangular ponds proposed for stocking with grass carp. The yellow line indicates the mesh fencing, and the green line indicates the bamboo hedge.

Figure B29. The eastern boundary of the site showing the mesh fence on the earth bund beside the canal (Left, photo by S Pullan, August 2013), and a close-up of the mesh fence (right, photo by J Clayton, March 2014).

Figure B30. The southern boundary of the property where the drain from the western boundary converges with the canal (photo by S Pullan, August 2013).

In February 2014 DOC approved the release of grass carp into ponds at the fish farm for the purposes of weed management (AQTRANS 02/84, 2014). The approval stated that; the inlets and outlets of the ponds must be screened with 35mm mesh prior to release, the size of the grass carp must be greater than 250 mm fork length, and the total number of fish that can be stocked is 85 (4 fish per pond in 16 ponds, 8 fish in 1 pond, 7 fish in 1 pond, 6 fish in 1 pond) (AQTRANS 02/84). The grass carp were released on the 14th of March 2014 (S Pullan, MPI, pers comm).

Quarry Lake

Quarry Lake, is as its name suggests a former quarry site. It is a small (ca 1.4 ha, 8.5 m deep) man-made lake (James 2011) directly adjacent to Lake Pupuke located in Takapuna, Auckland (Appendix C, Figure C4). The two lakes are separated by a low and narrow strip of reclaimed land (Figure B31). At times of heavy rainfall there is some discharge of water from Quarry Lake to Lake Pupuke through two small pipes and a small channel across the reclaimed land (Aquaculture NZ 2009c). Anecdotal evidence reported in the EIA also indicates that Quarry Lake overflows to Lake Pupuke during periods of heavy rainfall (ca 5cm depth on the causeway) (Aquaculture NZ 2009c).

The lake is used by model yacht enthusiasts, canoeists, kayakers, divers and to a lesser extent swimmers. In addition the surrounding land area is used by people walking, picnicking and socialising (James 2011).

Quarry Lake supports primarily introduced fish species including tench, rudd, goldfish and koi carp, although native shortfinned eels have also been reported (Aquaculture NZ 2009d). The aquatic plant community is dominated by the introduced species *Vallisneria australis* and to a lesser extent *E. densa* (author observations) and form surface reaching growths in the shallower regions of this otherwise steep sided lake.

In the past, aquatic weed growth in the lake has reportedly limited its use. For example, the North Shore Radio Yacht Squadron described weeds on Quarry Lake as having made the yacht course unusable for three months (Hallahan 2013). The release of grass carp was proposed for weed control, and an application was made by The North Shore Radio Yacht Squadron Inc to release up to 121 grass carp into Quarry Lake (Correspondence 5th September 2009 NZWR). In the EIA it was stated that the "number of fish to be released will be determined on the basis of 100 fish per vegetated hectare of the lake. With 85% of the area being vegetated that is 121 fish in total for the application" (Aquaculture NZ 2009c).

However, "there were a number of issues that led to the original application being declined" which were outlined in correspondence referring to a subsequent application to release grass carp into Quarry Lake by NZWR on behalf of the North Shore City Council (NSCC) on 23rd September 2010 (Correspondence 4th November 2010 DOC).

In 2014, an application was again made to DOC for approval to release grass carp into Quarry Lake (Jamieson 2014). The stocking of 166 grass carp greater than 25 cm fork length is proposed (Jamieson 2014).

Quarry Lake was a proposed site at the outset of the present project, and it was visited in February 2014. The species present in the water included, the submerged plants *V. australis, E. densa*, with small patches of *P. distichum* along the margins. With the exception of larger patches of weed in the southwestern corner of the lake and in the northeastern end of the lake (Figure B32), the submerged plants (primarily *V. australis)* were restricted to a narrow (ca 1 m) littoral band of this steep sided lake (Figure B33). The majority of the lake was open water, on which coots, mallards and black swans were present.

Given the relatively small area of water in which the public may come in contact with aquatic plants, compared with open water, the proposed stocking of 166 grass carp seems high. However the application (Jamieson 2014) does not refer to the vegetated area of the lake that requires control, although transect surveys are mentioned the data are not provided (page 6, Jamieson 2014).

A monitoring report from 2009 (Aquaculture NZ 2009d) listed plants from one transect in Quarry Lake, which runs parallel to the causeway at the north end of the lake. Based on observation of surface reaching weeds (from February 2104), the area in that one transect (Aquaculture NZ 2009d) may not be indicative of the lake as a whole, or of the volume of weed in the lake.

In addition to consideration of the stocking density relative to the area of vegetation, containment needs to be ensured to maintain stocking density and grazing pressure. Without adequate containment the consequences of not achieving stocking density, and the grazing pressure for targeted weed control need to be addressed as well as environmental impacts outside of Quarry Lake (e.g. Lake Pupuke as the likely destination for any escaped fish). Furthermore, if there were a large scale escape event or events, subsequent or cumulative risks from multiple stockings may require consideration. For example, fish escapes from Quarry Lake would reduce the stocking density in that lake and lessen the level of vegetation control. Would the applicant then seek to restock Quarry Lake, and if security were not improved subsequent escapes could ensue, adding to the numbers in the receiving waters. Alternatively could weed management tools other than grass carp be sought for Quarry Lake, and have these been considered by the lake managers in the first instance, given the small volume of weed and the challenge posed by the site to maintain security?

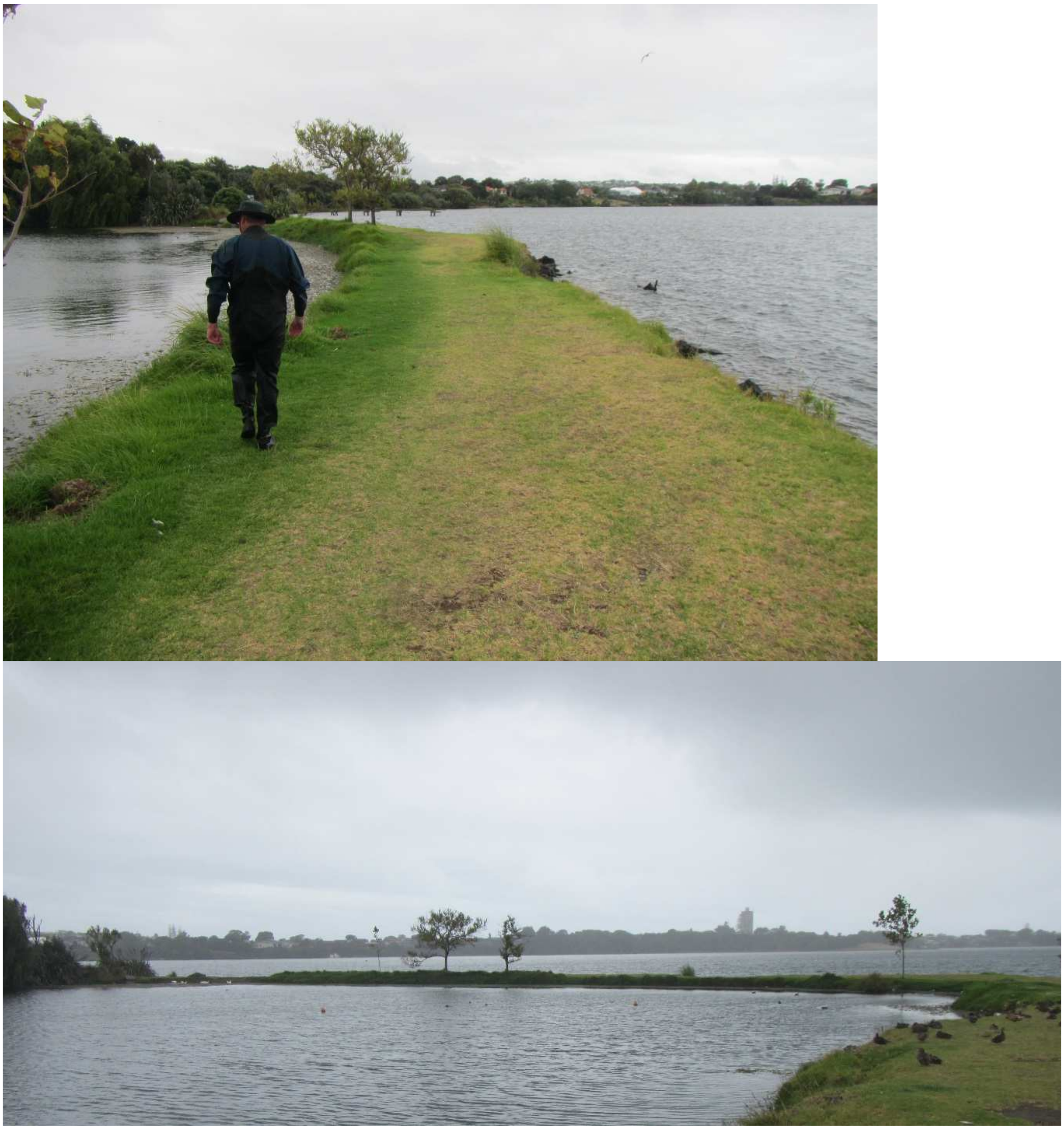

Figure B31. Quarry Lake and Lake Pupuke separated by a narrow (top image) and low (bottom image) strip of land. Quarry Lake is on the left (top image) and in the foreground (bottom image).

Figure B32. Wide patches of aquatic plants forming surface reahcing growth at the southwest end (top) and the northeast (bottom) of the lake.

Figure B33. Quarry Lake view toward the south west alongside Northcote Rd, showing a narrow band of submerged plants (*V. australis*) at the surface of the water.

Appendix C. Site location maps

Figure C1. North Island showing the distribution, and relatively large number of grass carp approval sites in the North (Source: Google map adapted from Pullan 2013). Individual sites are best located in maps C3 to C7. Sites with red markers are from Pullan (2013), sites with blue markers are single release sites or sites that pre-date the original map image by Pullan (2013). Named sites, as opposed to numbered sites are referred to in the body of the report or Appendix B, or the regional maps C3-C7.

Figure C2. South Island showing Lake Hood and other grass carp approval sites (Source: Google map adapted from Pullan 2013).

Figure C3. Northland region of the North Island showing sites approved for grass carp release (Source: Google map adapted from Pullan 2013). Sites with red markers were from Pullan (2013), sites with blue markers were added and are referred to in the body of the report, as are named sites (as opposed to numbered sites). State highway one has been added to provide a reference point.

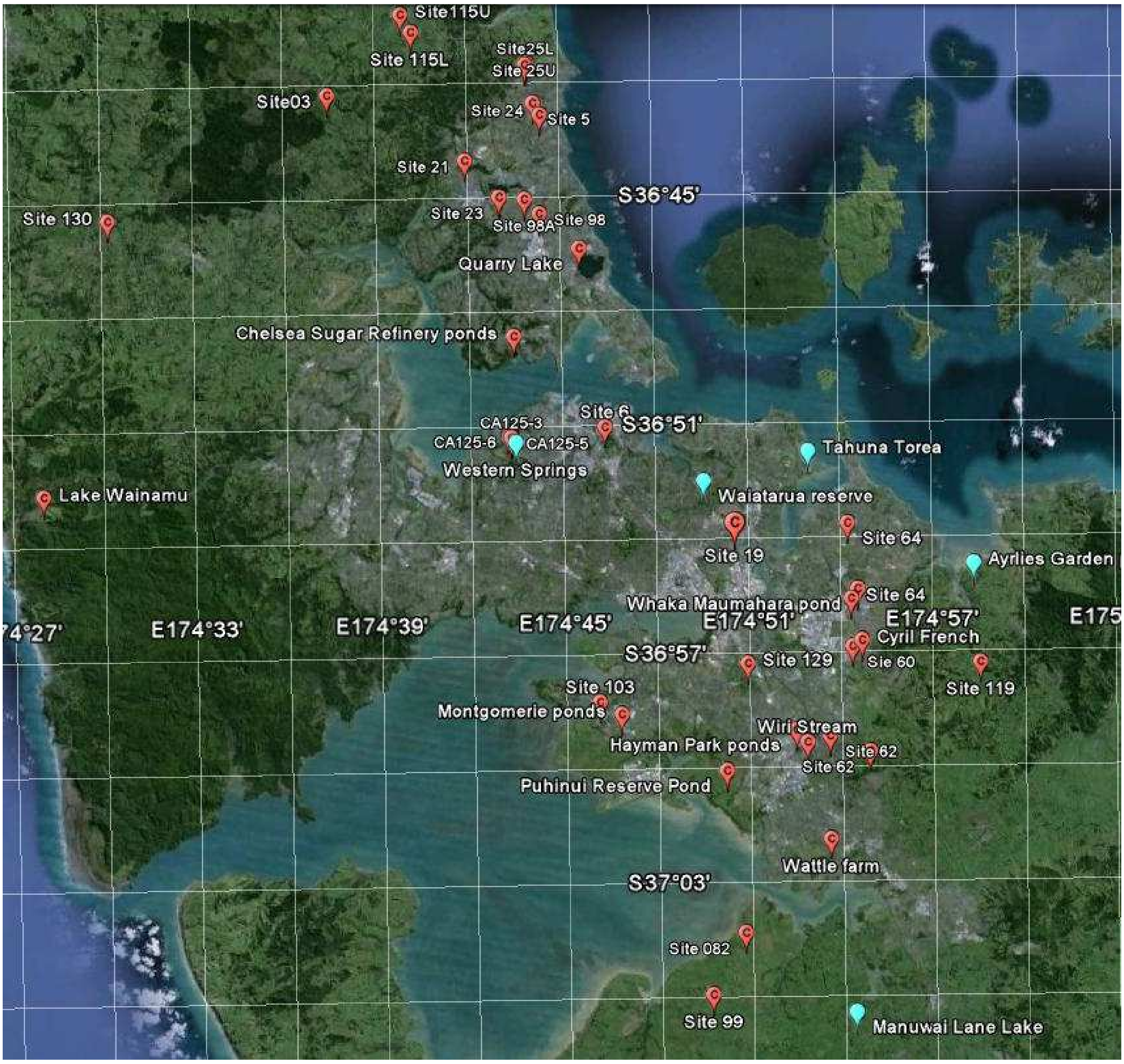

Figure C4. Auckland region of the North Island showing sites approved for grass carp release (Source: Google map adapted from Pullan 2013). Sites with red markers were from Pullan (2013), sites with blue markers were added and are referred to in the body of the report, as are named sites (as opposed to numbered sites).

Figure C5. Waikato region of the North Island showing sites approved for grass carp release (Source: Google map adapted from Pullan 2013). Sites with red markers were from Pullan (2013), sites with blue markers were added and are referred to in the body of the report, as are named sites (as opposed to numbered sites).

Figure C6. Rangitaiki plains showing grass carp release sites (red markers) and surveyed drains (red markers and lines). Sites with red markers were from Pullan (2013), the site with the blue marker is referred to in the body of the report (Source: Google map adapted from Pullan 2013).

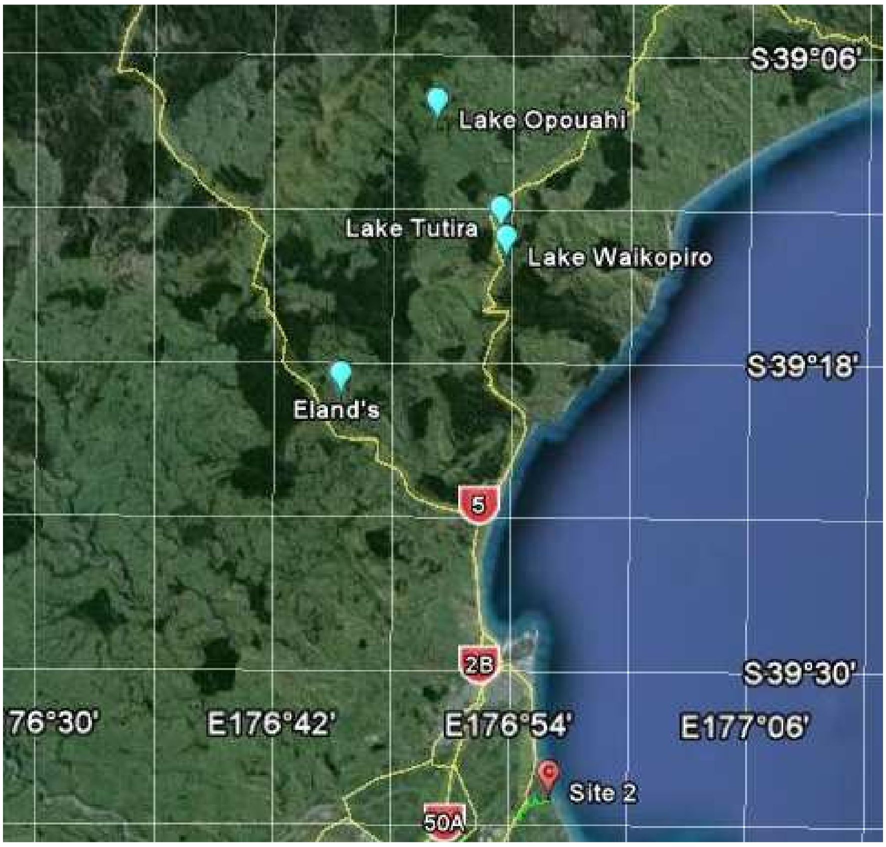

Figure C7. Hawkes Bay region of the North Island showing sites approved for grass carp release (Source: Google map adapted from Pullan 2013). The site with the red marker was from Pullan (2013), sites with blue markers were added and are referred to in the body of the report. Major roads have been added to provide reference points.

Appendix D. Plant Species List

Table D1. List of plant species referred to in this report.

Species	Common name	Life form type, habitat
Alisma plantago-aquatica	Water plantain	Marginal aquatic plant
Alternanthera nahui	Nahui	Marginal aquatic plant
Alternanthera philoxeroides	Alligator weed	Marginal aquatic plant
Apium nodiflorum	Water celery	Marginal aquatic plant
Azolla spp.	Azolla, water fern	Floating plant
Bolboschoenus fluviatilis	Purua grass	Marginal aquatic plant
Callitriche stagnalis	Starwort	
Carex secta	Purei	Marginal aquatic plant
Ceratophyllum demersum	Hornwort	Submerged weed
Chara australis	Charophyte	Submerged
Egeria densa	Egeria	Submerged weed
Elatine gratioloides		Turf forming, shallow water
Eleocharis acuta	Spike sedge	Marginal
Eleocharis sphacelata	Kuta, bamboo spike sedge	Marginal
Elodea canadensis	Elodea	Submerged weed
Glossostigma elatinoides		Turf forming, shallow water
Glossostigma diandrum		Turf forming, shallow water
Glyceria declinata	Floating sweet grass	Marginal
Glyceria fluitans	Floating sweet grass	Marginal aquatic plant
Glyceria maxima	Reed sweet grass	Marginal aquatic plant
Hydrilla verticillata	Hydrilla	Submerged weed
Iris pseudacorus	Yellow flag	Marginal aquatic plant
Isolepis prolifera	Jumping rush	Marginal aquatic plant
Juncus articulatus	Jointed rush	Marginal aquatic plant
Juncus edgariae		Marginal aquatic plant
Lagarosiphon major	Lagarosiphon	Submerged weed
Landoltia punctata	Duckweed	Floating
Lemna disperma	Duckweed	Floating
Lilaeopsis novae-zelandiae		Turf forming
Lilaeopsis ruthiana		Turf forming
Lobelia perpusilla		Marginal, shallow water
Ludwigia palustris	Water purslane	Marginal aquatic plant
Ludwigia peploides subsp. *montevidensis*	Primrose willow	Marginal aquatic plant

Species	Common name	Life form type, habitat
Lycopus europaeus	Gypsywort	Marginal aquatic plant
Myosotis laxa	Water forget-me-not	Marginal aquatic plant
Myriophyllum aquaticum	Parrots feather	Marginal aquatic plant
Myriophyllum propinquum	Water milfoil	Submerged, shallow
Myriophyllum triphyllum	Water milfoil	Submerged
Nasturtium officinale	Water cress	Marginal aquatic plant
Nasturtium spp	Water cress	Marginal aquatic plant
Nitella sp. aff. *cristata*	Nitella	Submerged
Nymphaea spp.	Water lily	Floating leaved aquatic
Ottelia ovalifolia	Swamp lily	Floating leaved aquatic
Paspalum distichum	Mercer grass	Marginal aquatic plant
Persicaria decipiens	Swamp willow weed	Marginal aquatic plant
Persicaria hydropiper	Water pepper	Marginal aquatic plant
Persicaria lapathifolium	Pale willow weed	Marginal aquatic plant
Phragmites karka		Marginal aquatic plant
Pontederia cordata	Pickerelweed	Marginal aquatic plant
Potamogeton cheesemanii	Pondweed	Submerged
Potamogeton crispus	Pondweed, curly leaved	Submerged
Potamogeton ochreatus	Pondweed	Submerged
Ranunculus spp.	Buttercup	
Ranunculus flammula	Spearwort	Marginal aquatic plant
Ranunculus trichophyllus	Water buttercup	Submerged
Ruppia spp.	Horses-mane weed	Submerged aquatic plant
Schoenoplectus californicus	Californian bulrush	Marginal aquatic plant
Schoenoplectus tabernaemontani	Lake clubrush	Marginal emergent
Trithuria inconspicua (formerly *Hydatella*)		Endemic turf plant
Typha orientalis	Raupo	Marginal emergent
Utricularia australis	Bladderwort	
Utricularia gibba	Bladderwort	
Vallisneria australis	Eelgrass	Submerged aquatic
Veronica anagallis-aquatica	Water plantain	Marginal aquatic plant
Myriophyllum spicatum L. (Eurasian watermilfoil) is present in the USA and was referred to in the review. This species is not present in New Zealand.		