NIWA
Taihoro Nukurangi

Grass carp Effectiveness and Effects

Stage 2: Knowledge review

Prepared for the Department of Conservation

May 2014

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NIWA Client Report No:	HAM2014-060
Report date:	May 2014
NIWA Project:	DOC13214

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Executive summary

Department of Conservation (DOC) contracted NIWA to prepare a report that collated the existing knowledge on the effectiveness and effects of using grass carp (*Ctenopharyngodon idella*) for weed control in New Zealand, drawing on published, unpublished and other information for the lakes of interest. The information was used to review the effectiveness of grass carp in terms of the weed control and/or eradication outcomes for which they were stocked and the effects of the grass carp on water quality, habitat quality and flora and fauna at the transfer locations.

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. DOC have a statutory role in the approval of grass carp release to a new location (where grass carp do not already exist). However DOC consider that insufficient information is available regarding the effects of grass carp on the ecosystems that they have been transferred into. The purpose of this review of the effects and effectiveness of grass carp is to improve future decision making.

A total of 24 lakes and ponds were selected by DOC. Information for those waterbodies was sourced primarily from NIWA, DOC, MPI (Ministry for Primary Industries) and regional councils. Amongst the sites, grass carp had not been released into two of the lakes, nine were natural lakes and fifteen were man-made lakes, the majority of which are used for storm water retention. NIWA visited 15 of the sites within the summer to early autumn field season (2013/2014) and updated the vegetation records.

Although some significant data sets on vegetation and water quality were readily available, there were information gaps in other aspects of the lake ecology, such as adequate pre-release baseline information, actual grass carp stocking density, and post-stocking monitoring. Information, and lake records were generally more complete for natural lakes, and recent stocking events (i.e., within the last six years).

Grass carp can be effective weed control agents for submerged aquatic plants. Total removal of all submerged vegetation is normally the long-term outcome, and partial weed control is rarely achieved. Grass carp are preferential browsers of plants, consuming both target and non-target species in order of their relative palatability and their accessibility to the grass carp. Impacts on non-target plant species, effects on fauna, water and habitat quality were reported for some sites and were largely dependent on waterbody characteristics.

In making recommendations for future decision making it was recognised that DOC only approves releases to new locations (MPI approves subsequent releases), and that DOC procedures already reflect some aspects of the recommendations.

It is recommended that;

1. Assessment of an application to release grass carp, takes in to account the ecological functions, the weed issues, and the appropriateness of using grass carp in the waterbody.

2. Applications are assessed on the basis that there will be complete removal of submerged aquatic plants.

3. The approval includes (i) the grass carp stocking density and containment measures, (ii) monitoring requirements for the aquatic plants, (iii) environmental monitoring that aligns with the risks and consequences of adverse effects to that waterbody, and (iv) submission of monitoring reports to DOC and MPI (ideally in a centralised repository, see point 4).

4. Environmental impact assessments, applications for stocking grass carp, actual stocking records, and monitoring reports are supplied and maintained, through a centralised system with DOC and MPI so that information can be readily tracked for waterbodies and catchments.

1 Introduction

1.1 Grass carp

Grass carp (*Ctenopharyngodon idella*) are a herbivorous fish, native to Asia, that derive their other common name, white amur, from the Amur River system that borders China and Russia (Cudmore and Mandrak 2004). They have been introduced to New Zealand and many other countries for aquatic weed control. The first consignments of grass carp arrived in New Zealand in 1966 (Chapman & Coffey 1971), and again in 1971 (Edwards & Hine 1974) with initial studies focussed on feeding preferences (Edwards 1973, 1974). Grass carp were subsequently released for a variety of field studies in small lakes to assess their potential impacts, such as Parkinsons and the Waihi Beach reservoir (Mitchell 1980, Rowe 1984) and drainage systems on the Rangitaiki Plain (Edwards & Moore 1975) 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 lakes (Rowe and Hill 1989). Issues with respect to containment arose after fish escaped into the Waikato River (McDowall 1984), and this event resulted in the production of an Environmental Impact Assessment to formally address the use of this fish for weed control in New Zealand (Rowe & Schipper 1985). The report analysed the potential impacts of grass carp, and uses, including their potential to eradicate certain problem weed species in lakes. It also confirmed the lack of suitable habitat for grass carp to breed and form a self-sustaining population in New Zealand waterways. It was followed by public consultation and an internal report (Rowe et al. 1985) seeking the formal release of these fish for weed control. This was subsequently granted by the New Zealand Government subject to conditions and control by the Department of Conservation and the Ministry of Fisheries (Conservation Act 1987).

The Conservation Act 1987 (Sections 26ZM, 26ZQA) requires Ministerial approval to possess, transfer and release new fish, including grass carp to environments where they have not been recorded before. An application must be made to the Department of Conservation (DOC) for the transfer of grass carp to a new location and DOC may require an impact assessment. Until late 2012, DOC also required operational plans but the conditions covered by them are now incorporated in the actual approval. Under the Freshwater Fisheries Regulations (1983) consent is also sometimes required from the Fish and Game Council with local jurisdiction before fish are liberated (part 8 r59), and releases of grass carp following the initial release need to be approved by Ministry for Primary Industries (MPI), (formerly the Ministry of Agriculture and Fisheries (MAF), and Ministry of Fisheries (MFish)).

Since 1988, grass carp have been deployed in a wide range of locations throughout New Zealand to control excessive weed growth in lakes, ponds, drains and storm-water retention systems. Releases of grass carp to lakes and ponds have provided successful weed eradication outcomes (e.g., Elands farm lake (Clayton et al. 1995), Lake Waingata (Rowe et al. 1999)), but others have resulted in escape of juvenile grass carp into the Waikato River, raising the debate on ability of grass carp breeding in New Zealand conditions (Chisnall 1997). 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 that are still valid today, and suggest that a conservative approach is adopted (Clayton and Wells 1999). They recommend that some areas be identified as exclusion zones from the use of grass carp (Clayton et al. 1999) and that where grass carp are released a number of parameters should be monitored depending on site specific attributes, including, aquatic vegetation, water quality, fish and waterfowl populations and containment structures (Clayton and Wells 1999).

DOC have noted that continued "*interest in the use of grass carp for this purpose*" (i.e., aquatic weed control and/or eradication) "*is ongoing, as are applications to transfer this species into new locations. Despite their current and historical use in New Zealand, insufficient information is available regarding the effects of grass carp on the ecosystems that they are transferred into. The collection of quantitative data regarding the effects and effectiveness of grass carp transfers is needed to optimise future decision making*" (DOC 2012).

DOC developed a project (DOC 2012) to gain an understanding of the effects and effectiveness of grass carp when used as a biological control organism in New Zealand. The project had two key components;

1. The preparation of a brief document summarising the current knowledge base in New Zealand regarding (A) the effectiveness of grass carp in terms of achieving desired vegetation control/eradication outcomes; and (B) the effects of grass carp on water quality, habitat quality, flora and fauna at transfer locations, (for which DOC would provide necessary information).

2. Field investigations that will provide robust, quantitative data sufficient for statistical analysis regarding (A) the effectiveness of grass carp in terms of achieving desired vegetation control/eradication outcomes; and (B) the effects of grass carp on water quality, habitat quality, flora and fauna at transfer locations. A list of possible field sites was provided (Appendix A).

Stage one of the project, an information summary, was prepared based primarily on DOC records, NIWA data and reports and published papers (Hofstra 2013a). The information summary detailed the existing data limitations for robust statistical analyses on the effectiveness and effects of grass carp for the majority of waterbodies of interest. In addition to demonstrating that insufficient quantitative data currently existed, it was recognised that a single field season would not be sufficient to provide useful data for most lakes to meet the criteria for a robust statistical analysis of grass carp effectiveness and effects. However it was agreed that there was "*significant value in pulling together the knowledge that did exist on the effects and effectiveness of grass carp … drawing on published, unpublished, anecdotal and other information*" (DOC contract amendment 20 June 2013). To that end DOC requested that stage two of the project proceed with a redefined scope, as outlined below (Scope, section 1.2).

1.2 Scope, Stage Two – knowledge review

DOC contracted NIWA to prepare a report (Stage 2 Knowledge review) that pulled together the existing knowledge on the effectiveness and effects of grass carp, drawing on published, unpublished, anecdotal and other information for the lakes of interest. The information, would be used to review the knowledge on (rather than statistically analyse) the effectiveness of grass carp in terms of the weed control and/or eradication outcomes for which they were stocked and the effects of the grass carp on water quality, habitat quality and flora and fauna at the transfer locations.

The lakes of interest included all the sites listed in Appendix A and B of the stage one report (Hofstra 2013a), noting that for some sites, the amount of information available would be limited. The priority was to focus on waterbodies that have the potential to provide the most useful information. Some lakes would be eliminated from those listed, for example where records indicate grass carp have escaped, or were never released (e.g., Lake Te Koutu and Wainamu Bay Reserve). With respect to drawing on published, unpublished, anecdotal and other information, NIWA would request information from local authorities on lakes within their catchments for inclusion in the review. This would not include an analysis of raw data files (should they be forthcoming), but rather incorporate existing monitoring reports and summary data as supplied.

Field investigations would be carried out if necessary and aligned with other work programmes, such that they would provide additional and more current information on A) the effectiveness of grass carp in terms of achieving desired vegetation control/eradication outcomes; and B) the effects of grass carp on water quality, habitat quality, flora and fauna at transfer locations.

DOC also requested that some focus is assigned to the question *" is it possible to achieve macrophyte control at a nominated level or will future applications to introduce grass carp to a given waterbody need to be evaluated with the assumption that the likely outcome will be near or total macrophyte eradication?*" (Contract section 2.1).

2 Approach

The lakes of interest are listed in Table 1. This includes all of the sites from the DOC list of potential lakes (DOC 2012) and the NIWA shortlist of lakes from the stage one report for which an assessment could be usefully undertaken (Hofstra 2013a). The priority was to focus on waterbodies that have the potential to provide the most useful information.

Information obtained from stage one of the project included DOC files, NIWA reports and publications, and a database and internet search for grass carp, relevant lake names, and regions (Hofstra 2013a). The information gathered for stage one was supplemented for the current stage two report by conducting a search of MPI records, contacting DOC, regional council, Fish and Game staff, and for some locations local residents, to access any further published information, but also to facilitate the collection of unpublished and anecdotal information where it was potentially available.

Field investigations were carried out as aligned with other work programmes and when it was considered that they would provide additional and more current information on the effectiveness of grass carp for weed control, and their effects at transfer locations.

The information gathered from agency records and field visits was collated for each lake, and is presented in section 3. While the collated information does not purport to provide an exhaustive and comprehensive review of the effectiveness and effects of grass carp in New Zealand waters, it does integrate a substantial body of knowledge from a variety of sources for the waterbodies of interest. The review was encompassing, within the constraints of the project such as access to information and time to follow ‘leads’. Throughout the report the terminology for plant and animal names is as indicated in the source documents.

Table 1: Lakes included in the knowledge review of grass carp effectiveness and effects

Upper North Island	Lower North Island	South Island
Lake Heather, Northland	Lake Tutira, Hawkes Bay	Lake Hood, Canterbury
Lake Omapere, Northland	Lake Waikōpiro, Hawkes Bay	
Lake Swan, Northland	Lake Opouahi, Hawkes Bay	
Lake Kereta, Auckland	Elands farm lake, Hawkes Bay	
Lake Wainamu, Auckland	Lake Rotomanu, Taranaki	
Maygrove Lake, Auckland	Lake Henley, Masterton	
Link Drive, Auckland		
Chelsea Sugar pond, Auckland		
Western Springs Lake, Auckland		
Wainamu Bay Reserve, Auckland		
Waiatarua Park Lake, Auckland		
Tahuna Torea, Auckland		
Hayman Park, Auckland		
Wattle Park, Auckland		
Puhinui Reserve, Auckland		
Manuwai Lane Lake, Auckland		
Lake Te Koutu, Waikato		

3 Lakes

This section is organised by region, and then by lake or waterbody. In endeavouring to answer the questions of grass carp effectiveness and effects, information has been collated relative to the before and after dates for grass carp stocking in the selected waterbodies. However, it is important to understand that the most significant changes and threats to the lakes occurred in relation to the invasive weed species, and/or nutrient loads in the preceding years or decades. For example, grass carp introductions occurred to provide a solution to the most recent problem (i.e., weeds) in already compromised systems, that had been recognised as at risk of flipping from a vegetated to an algal dominated state (e.g., Omapere, Swan) or had a history of algal blooms (e.g., Tutira) and high nutrient loads (e.g., stormwater retention ponds). Consequently, it is not always feasible to draw conclusions retrospectively around cause and effect, especially when data or information available is sparse or intermittent at best.

3.1 Northland lakes

3.1.1 Lake Heather

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 (Appendix C).

The lake itself is a Reserve administered by the Department of Conservation, and is part of the Sweetwater Dune Lakes Conservation Area. The lake has no permanent inlet or outlet, and lake level is maintained by groundwater seepage and evaporation. Beyond a marginal strip, the land surrounding the lake is mostly in pasture and owned by Landcorp Farming Ltd (70%) and in private ownership (30%). Access is through 3 km of private land with a locked gate (Champion et al. 2005).

3.1.1.1 Grass carp stocking – When, how many and why

DOC files contained the aquatic transfer (AQTRANS 01/21) and an Operational Plan for the introduction of grass carp into Lake Heather. A copy of the environmental impact assessment (EIA Lake Heather, 2010) was obtained from MPI (Steve Pullan, MPI Auckland).

The approval (AQTRANS 01/21) was signed on 19th April 2010, with an expected release date of 29th of June 2010 for 400 grass carp. The grass carp were to be over 25cm in length, with the stocking density equating to ca 50 fish per vegetated hectare. The stated purpose for stocking grass carp in the approval was for weed control and management (AQTRANS 01/21, 2010).

The operational plan (appended to the EIA) stated an intention to manage stocks to achieve objectives of submerged weed control and eradication of the target species, egeria (*Egeria densa*), and hornwort (*Ceratophyllum demersum*) (EIA Lake Heather, 2010). 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. It was anticipated that grass carp numbers could be reduced once weed was suppressed or eliminated. However grass carp would be left in the lake for a further two years after the last records of egeria and hornwort. It was envisaged that all grass carp be removed from the lake after five years (in consultation with MPI, DOC and iwi) with a longer term goal of lake restoration (Wells and Champion 2011).

The weed eradication programme in Lake Heather is in progress.

3.1.1.2 Ecology and biology of the lake before grass carp release

Flora

The NIWA Aquatic Plant Database holds vegetation survey records from six survey dates (1985, 1988, 2001, 2004, 2008, 2010) prior to the release of grass carp, and in addition a rapid assessment of aquatic vegetation was undertaken in 2009. There are several publications (Tanner et al. 1986, Champion et al. 2002, 2005, Wells and Champion 2010) that describe the vegetation of Lake Heather, as illustrated by Figure 1 (sourced from Champion et al. 2002), which shows a native plant profile (1985) and indicates the extent that invasive species altered the native vegetation within the lake (2001) (Champion et al. 2002). For example, between these two surveys, the alien weed species, hornwort and egeria, established in Lake Heather. Hornwort displaced native flora in the lake, particularly the *Chara australis* which showed a marked reduction in abundance (Figure 1). Egeria was also distributed throughout the lake, although it was growing at a much lower density than hornwort (Champion et al. 2002). In addition to the species shown in Figure 1, *Potamogeton cheesemanii, Utricularia gibba* and the charophyte *Nitella pseudoflabellata* were found in the lake growing as isolated plants at 1 site each (Champion et al. 2002).

Over the next decade 2001 to 2010, the lake vegetation underwent further changes. Submerged plant records show that *Myriophyllum propinquum*, the nationally critically endangered *Utricularia australis* (de Lange et al. 2013) and the exotic *U. gibba* were uncommon and restricted to areas within the reed beds at <2 m depth (Champion et al. 2005), but by 2010 the exotic *U. gibba* was reported as common (Wells and Champion 2010). The pest plants hornwort and egeria had an extensive impact on the native vegetation, with a marked increase in abundance of hornwort since 2005 (Wells and Champion 2010). Only *Potamogeton ochreatus* appeared able to exist with the weed species (Champion et al. 2005), though *P. ochreatus* was mostly restricted to the deepest parts of the northern basin and was expected to be displaced by the hornwort within 2 years (Wells and Champion 2010).

In 2010, hornwort and egeria were described as well-established with surface-reaching beds throughout much of the lake, and it was considered that the long term presence of these species in the lake would alter the lake sediments making them highly organic, flocculent and unsuitable for future submerged vegetation (Wells and Champion 2010). In addition, a heightened risk of lake-wide deoxygenation was documented (Wells and Champion 2010).

Lake Heather is surrounded with emergent vegetation 5 to 20 m wide, extending from the shoreline to a maximum of 2.3 m depth (Champion et al. 2005). The dominant species were *Eleocharis sphacelata*, with *Machaerina articulata, Eleocharis acuta, Typha orientalis* and *Schoenoplectus tabernaemontani* locally important. On the western edge, a low sudd dominated by *Ludwigia palustris, Isolepis prolifera* and mats of the exotic weed *U. gibba* were present between tall emergent vegetation and pasture. *Myriophyllum robustum* a nationally threatened (At Risk –declining (de Lange et al. 2013)) native milfoil, was recorded in 1985 growing in a swamp adjacent to the lake and again in 2004, yet despite searches of swampy areas around the lake and amongst the marginal vegetation this species was not found in other surveys (Champion et al. 2002, Wells and Champion 2010). The alien pest plant alligator weed (*Alternanthera philoxeroides*) has been recorded over an area of 80 m^2 amongst *E. sphacelata* and *T. orientalis* (Champion et al. 2005).

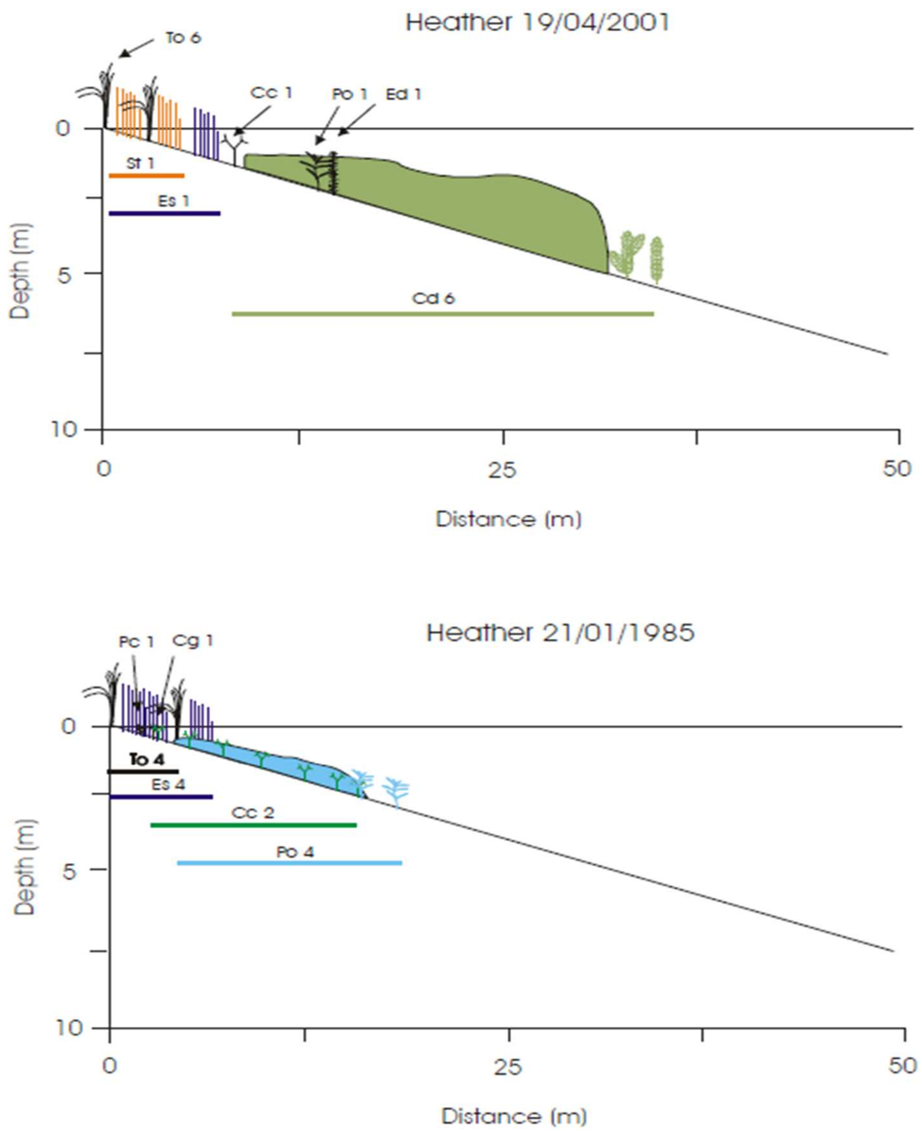

Figure 1: Vegetation profiles of Lake Heather showing the change in vegetation between 1985 and 2001 after invasion of the alien weed *Ceratophyllum demersum* (sourced from Champion et al. 2002, Figure 5). Plant codes correspond to the species name in brackets: To (*Typha orientalis*), Cc (*Chara australis)*, Po (*Potamogeton ochreatus*, Ed (*Egeria densa*), St (*Schoenoplectus tabernaemontani*)*,* Es (*Eleocharis sphacelata*), Cd (*Ceratophyllum demersum*), Pc (*Potamogeton cheesemanii*), Cg (*Chara globularis*). Numbers after plant names refer to the average cover values ranging from 1 to 6.

Fauna

SCUBA based vegetation surveys in the past have provided the opportunity to record observations of fish, macroinvertebrates and waterfowl at Lake Heather. Common bullies (*Gobiomorphus cotidianus*) were observed in high numbers in the lake, as well as two eels (*Anguilla* sp.) (Champion et al. 2002). The NIWA FBIS database recorded shortfin eels (*Anguilla australis*). Eels and common bullies are the only two native species of freshwater fish that have been formally recorded in Lake Heather. The fish diversity is described as low (EIA Lake Heather 2010) due to the lack of fish passage between Lake Heather and other waterbodies, and while the bully populations may be self-recruiting, it is considered that the eel population is likely dependent on stocking. Gambusia were also observed in the lake in 2008 (EIA Lake Heather 2010) and NRC water quality sampling team reported a large fish leaping from the lake (Champion et al. 2005).

An assessment of macroinvertebrates from Lake Heather was described by Ball et al. (2009), (Table 2). There were 27 macroinvertebrate taxa recorded, amongst which Odonata (dragon- and damselflies) and Hemiptera (*Sigara arguta*, also recorded by Champion et al. 2005) were well represented (Ball et al. 2009). Four dragonfly species were common and *Xanthocnemis* (damselflies) were particularly abundant. Chironomidae were moderately abundant, and the only molluscs found were *Pseudosuccinea* and *Physa*. The whirlgig beetle *Gyrinus* was also found (Ball et al. 2009).

Table 2: Abundance of macroinvertebrate taxa found in Lake Heather (from Appendix 2 in Ball et al. 2009).

Macroinvertebrate Taxa		Abundance
Odonata, Aeshnidae	*Aeshna brevistyla*	33
Odonata, Coenagrionidae	*Xanthocnemis zealandica*	229
Odonata, Corduliidae	*Hemicordulia australiae*	72
Odonata, Libellulidae	*Diplacodes bipunctata*	17
Odonata, Libellulidae	*Tramea loewii*	19
Coleoptera, Dytiscidae	*Onychohydrus hookeri*	1
Coleoptera, Gyrinidae	*Cyrinus convexiusculus*	9
Coleoptera, Hydrphilidae	*Enochrus tritus*	1
Coleoptera, Hydrphilidae	Hydrophilid indet.	2
Hemiptera, Corixidae	*Diaprepocoris zealandiae*	169
Hemiptera, Corixidae	*Sigara* spp.	116
Hemiptera, Notonectidae	*Anisops assimilis*	31
Hemiptera, Veliidae	*Microvelia macgregori*	1
Diptera, Chironomidae	Chironomini	22
Diptera, Chironomidae	Orthocladiinae	45
Diptera, Chironomidae	Tanypodinae	8
Diptera, Chironomidae	Tanytarsini	7
Trichoptera, Hydroptilidae	*Paroxyethira hendersoni*	9
Trichoptera, Hydroptilidae	*Paroxyethira* spp.	2
Trichoptera, Leptoceridae	*Triplectides cephalotes*	3
Lepidoptera, Crambidae	*Hygraula nitens*	15
Mollusca, Lymnaeidae	*Pseudosuccinea columella*	13
Mollusca, Physidae	*Physa acuta*	32
Crustacea, Cladocera		1
Acari, Oribatida		1
Turbellaria, Dugesiidae	*Cura pinguis*	1

Lake Heather is recognised as providing excellent habitat for waterfowl (Champion et al. 2005, NRC 2007-2011). Over 50 paradise shelducks (*Tardorna variegata*) and 3 Canada geese (*Branta canadensis*) were seen during a field visit in 2005. Records from the 1990's include the nationally threatened bittern (*Botaurus poiciloptilus*) and the regionally significant dabchick (*Poliocephalus rufopectus*) and Australasian little grebe (*Tachybaptus novaehollandiae*). The lake is an important moulting site for paradise shelduck (Champion et al. 2005).

Water quality

Water quality data are available for Lake Heather from 1989 and are summarised in Table 3. The earlier data have gaps and there is limited scope for making assessments (Matheson and Gibbs 2005). However because, Lake Heather had a 'high' ranking, it was recommended that water quality monitoring was carried out as part of the Lake Monitoring Network along with ongoing Lake Condition Monitoring of vegetation and pest plant surveillance (5 yearly) (NRC 2005). A regular water quality monitoring programme is currently undertaken by Northland Regional Council. In addition, observations of underwater visibility have been noted during vegetation surveys.

Lake Heather is described as mesotrophic to eutrophic (Table 3). Although surrounded by pasture, the lake is entirely fenced and approximately one-third of the area had been planted (e.g., with cabbage trees (*Cordyline australis*) and flax (*Phormium tenax*)), and the remainder was manuka/kanuka scrub (Champion et al. 2002). The riparian buffer at Lake Heather has been implicated in improving water clarity (Champion et al. 2002) and described as providing a nutrient sink, minimising nutrient loads reaching the lake from the surrounding pastoral catchment (NRC 2007-2011). For example, Lake Heather does not show the elevated nutrient loads normally associated with pastoral land use (NRC 2007-2011).

In 2001 water visibility was estimated to be 5 m and a fine filamentous alga was recorded growing over patches of hornwort (Champion et al. 2002). A large increase in the maximum depth of submerged vegetation took place between 1985 (3 m depth limit) and 2001 (at least the maximum lake depth of 6 m) (Champion et al. 2002). Colonisation by tall vegetation (hornwort had expanded to dominate the vegetation), was identified as likely to reduce re-suspension of bottom sediments by wave action, therefore increasing water clarity and penetration of light allowing vegetation to grow deeper. However, it was also recognised that the bottom limit attained by hornwort is not such a useful indicator of improved water clarity, because the plant does not produce roots and plants can drift and slump into deep water giving the appearance of still growing (Champion et al. 2002). Furthermore it can tolerate unfavourable conditions such as very low light levels and low water clarity (Champion et al. 2002).

Champion et al. (2005) report a secchi disk reading of 3.6 m, indicating moderate water clarity that was lower than the previous record. Secchi, nutrient and algal measurements (TN 391 mg N m^{-3}, TP 75 mg P m^{-3}, chlorophyll a 2.9 mg m^{-3}) suggested a mesotrophic to eutrophic status and N limitation (N:P <10) with the TP concentration being relatively high (Champion et al. 2005). At that time it was considered that the lake may be undergoing a decline in water quality as indicated by the decrease in secchi depth, and may be related to the increase in TP concentration. It was recommended that any trend should be confirmed with water quality sampling at least once per season for 2-3 years to determine the extent of enrichment and impact on algal biomass over this time and to establish a good baseline for future targeted sampling during critical months of the year (Champion et al. 2005).

Summer stratification occurs occasionally in Lake Heather with deoxygenation of bottom waters. NRC (2006) reports that the lake stratified over summer with moderate deoxygenation (1.4 mg/L dissolved oxygen (DO)) of bottom water with higher concentrations of nutrients (TN 548 mg/m³; TP 92 mg/m³) in relation to the upper water column (TN 348 mg/m³; TP 11 mg/m³). Secchi disc depth (3.8m), nutrient and algal biomass data indicated moderate water clarity and mesotrophic status, however the bottom water nitrogen and phosphorus concentrations were high (NRC 2006).

From 2007 to 2011 three significant trends were identified in the water quality of Lake Heather (NRC 2007-2011). One increasing trend was observed in DO% which increased at a rate of 2.3 % saturation per year and was attributed to the dense aquatic weed beds. Water clarity was difficult to measure, with dense weed growth preventing accurate secchi measurements. A decreasing trend in conductivity was also observed at a rate of 0.5 ms/m³ per year (NRC 2007-2011).

Table 3: Summary water quality data for Lake Heather

Parameter	**Matheson and Gibbs 2005 (data noted as occasional (7 times 1989-2004) and limited)**	**NRC 2007-2011 Report (data from 5 years)**		
		Min	**Median**	**Max**
Temperature (°C)		12.5	18.1	27.5
Dissolved Oxygen	6-9 mg/l (indicates good oxygenation)	84% Sat	96.2% Sat	122% Sat
Chlorophyll *a*	<10-40 g m^{-3} (indicates very high enrichment but possibly also low)	1.4 mg/l	3.8 mg/l	9.6 mg/l
Water Clarity	3-6m (Secchi range indicates moderate water clarity)	1.69m	3.75m	4.4m
Total Nitrogen (mg/m³)	300-400 (indicate high enrichment)	278	316	856
Total Phosphorus (mg/m³)	<4-25 (indicate low to high enrichment)	5	11	29
Ammoniacal Nitrogen (mg/m³)		0.5	2	13
Nitrate Nitrogen (mg/m³)		0.5	0.75	4
Dissolved Reactive Phosphorus (mg/m³)		0.5	0.5	14
Suspended Solids	<1-3 gm^{-3}	0.6	1.25	3.4
Conductivity		16	18.55	21.8
pH		6.5	7.35	8.3
Trophic Level Index		2.52	3.63	4.17
Trophic state	Probably mesotrophic to eutrophic	Mesotrophic		
NB: Burns et al. (2000) describes TLI of 3-4 as mesotrophic and a TLI of 4-5 as eutrophic. In addition to the above publications, Lake Heather was recorded as having a TLI of 4.3 in Sorrell (2006), it was reported as eutrophic in Hamill (2006), and with a TLI of 3.8 from 2005 to 2009 (% annual change was not significant) in Verburg et al. (2010).				

Habitat quality

Over the decade from 2001, Lake Heather was described as highly ranked in ecological status (Champion et al. 2005) with endangered plants present and excellent water bird habitat, and later as moderate to low (Wells and Champion 2010), recognising that the submerged native vegetation was highly impacted by the exotic weeds hornwort and egeria. The low LakeSPI scores of 22% in 2004 and 17% in 2010 reflect the extent that native vegetation had been impacted by the invasive exotic species (for LakeSPI see www.lakespi.niwa.co.nz) (Wells and Champion 2010).

3.1.1.3 Changes in ecology and biology after grass carp release

Flora

The aquatic vegetation from two profiles, that were representative of the northern and southern basins of the lake, were surveyed in 2010 prior to the release of grass carp (Wells and Champion 2010). Egeria formed a tall (average 2m) band from the edge of the marginal *E. sphacelata* to about 4m deep around the margins of the whole lake. In deeper water (>4m) hornwort formed tall beds (4-5m maximum height) reaching the surface in places (Wells and Champion 2010). Vegetation profiles from these two sites were recorded in subsequent years following the release of the grass carp (Wells and Champion 2011, 2012a, 2013a). In 2011 the egeria had been heavily grazed and reduced to basal stalks, but only about 20% of the hornwort had been removed. Most of the hornwort was still recorded up to 3.4m and had also expanded further in the north basin and displaced the beds of the native *Potamogeton ochreatus* (Wells and Champion 2011). By 2012 the egeria was nearly all gone, and about 50% of the hornwort had been removed. Although there were bare patches, the hornwort was up to 2.2m tall (Wells and Champion 2012a).

By 2013, no egeria was found in the lake but the hornwort was still present with 51-75% cover and an average height of 0.4 m tall. This was a reduction from the previous year and it is anticipated it will be gone by 2014. Although the rate of weed removal by grass carp was slower in Lake Heather than in Lake Swan, steady progress toward the eradication goal is recognised (Wells and Champion 2013a). In 2014 only fragments of hornwort were located during a lake survey with no other submerged vegetation seen (Champion, NIWA, pers comm).

Submerged native plants declined following invasion by hornwort and egeria. For example the abundance of charophytes declined (up to 2010), were at low levels in 2011, and were not recorded at all in subsequent profiles (2012 and 2013) in the presence of grass carp. Similarly there was a reduction in *P. ochreatus* in response to the invasive plant species, and a continued reduction in abundance following the release of grass carp (e.g., not recorded in 2012 and 2013 profiles). In the last two surveys native plant species have only been recorded from water less than 40cm deep. These changes were anticipated and outlined in the EIA (2010) for Lake Heather e.g., " the margins of the lake are bordered by a dense fringe of emergent *Machaerina*, *Typha* and *Eleocharis* species. Grass carp are capable of controlling all of these species." "A band of emergent plants can be expected to remain in shallow (<30cm) water." However by 2014, significant browsing of the *E. sphacelata* was evident (Champion, NIWA, pers comm).

Fauna

In the EIA for Lake Heather (2010), with regard to fauna, it was considered that "the main impact is indirect and a consequence of vegetation removal which exposes some fish to increased predation from predators. Hence small benthic bullies become more exposed to piscivorous fish such as eels". However it has also been noted that there was no significant fishery in this lake and the release of grass carp was unlikely to affect any fishery if they were present, and that the natural values had been degraded by the presence of aggressive weeds (Correspondence 29th March 2010 MPI).

It was recognised that "weed dwelling invertebrate populations would be reduced by weed removal. However native fish are opportunistic carnivores and will shift to benthic foods such as midge larvae that may become available with weed removal" (Mitchell 1988, EIA for Lake Heather 2010).

"Paradise ducks and Canada geese are the most herbivorous bird species found at Lake Heather and so are the species most likely to be affected by weed removal. However this impact is negligible as these species are capable of flying to neighbouring lakes." (EIA for Lake Heather 2010). The introduction of grass carp and removal of hornwort and egeria is generally predicted to have no effect on the" bird species "visiting or using the lake in the long term" (EIA for Lake Heather 2010).

There have not been any documented observations to indicate a change or effect on fauna following the release of grass carp.

Water quality

Changes in water quality that could occur as a consequence of removing aquatic macrophytes from a lake over a short time scale were described in the EIA for Lake Heather (2010). "In small waterbodies this may lead to a short-term increase in phytoplankton. Turbidity can increase particularly if removal of the weed beds exposes sediments and shorelines to wave erosion and silt re-suspension. Ensuring that a band of plants remains around the perimeter of small water bodies can reduce potential adverse effects by lowering external silt and nutrient loading" (EIA for Lake Heather 2010). This was already in place at Lake Heather.

In addition "if nothing is done to control or eradicate hornwort and egeria in Lake Heather then water quality is likely to deteriorated with the collapse of the weed bed. The lake would then become dominated by algae and possibly contain toxic algae species" (EIA for Lake Heather 2010).

No effects as a consequence of the grass carp introduction up to the NRC 2007 – 2011 report have been determined.

Habitat quality

Lake Heather retained a moderate to low ranking in recognition of the significant impact that alien weeds have had in the lake, but the grass carp are removing them, and the lake still provides excellent water bird habitat (Wells and Champion 2013b). However in that same report the threat posed by the marginal aquatic weed *A. philoxeroides* to the emergent plants was also documented Wells and Champion 2013b).

Summary of effectiveness and effects

Grass carp were introduced to Lake Heather as part of a lake restoration programme aimed at eradicating both egeria and hornwort and safeguarding nearby high-value lakes from the spread of these weeds.

Lake Heather is in the early stages of a weed eradication and lake restoration programme, where target weed has been significantly reduced. 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."

There have been some off target effects with grass carp browsing on submerged native plants, in line with predictions in the EIA (EIA for Lake Heather 2010).

Lake Heather is regarded as having high to medium ecological value and medium pressure/threat rating (Champion and de Winton 2012).

Effectiveness	Flora: effective target weed control, with a significant reduction in abundance of the target species (egeria removed, 70% hornwort reduction, Wells and Champion 2013a). All beds of hornwort were removed, but fragments of this were plant found in 2014. Steady progress toward weed eradication goal.
Effects	Flora: Native submerged macrophytes were already impacted by the invasive weed species. Grass carp have reduced the remaining submerged plants and the marginal emergent plants where they extend into the water. Fauna: No changes noted. Water quality: No major or adverse changes reported in association with grass carp (NRC 2007-2011 Water quality state and trends report). Habitat quality: No changes noted.

3.1.2 Lake Omapere

Lake Omapere is the largest lake in Northland, and is situated between Kaikohe to the south and Okaihau to the north (Appendix C). It is a dammed lake, the previous outflow towards the Bay of Islands was obstructed by volcanic activity (Jolly and Brown 1975, NRC 2002). The lake is almost circular in shape, occupying an area of ca 1,206 ha (Leathwick et al. 2010). It has a small catchment of 32.71 km^2 (Livingston et al. 1986) that is predominantly in pasture. The lake is shallow with a maximum depth of 2.6 m and may be as low as 1.5 m in summer (Champion et al. 2005). Several small streams flow into the lake, and the outflow forms the Utakura River, which flows in a westerly direction through the Utakura Valley to the Hokianga Harbour (Champion and Burns 2001). Access is through private property (Champion et al. 2005).

"The waters of the lake, as well as its bed and margins were vested in the Lake Omapere trustees on behalf of Ngapuhi by the Maori Land Court in 1955. The lake is customary land reserved for general purposes of Te Runanga A Iwi O Ngaphuhi" (Report of the Maori Affairs committee, April 2001).

3.1.2.1 Grass carp stocking – When, how many and why

DOC files contained the aquatic transfers (FIS 90503, AQTRANS 01/03, AQTRANS 01/04), an Operational plan and an EIA (Champion and Rowe 1996) for Lake Omapere. No monitoring reports were amongst the DOC files.

The initial operational plan (Jamieson Holdings 1996a) and EIA (Champion and Rowe 1996) for the introduction of grass carp into Lake Omapere were based on a stocking density of ca 4.6 fish per hectare (5,400 grass carp for the estimated 50% weed cover). This very low stocking rate aimed to control the macrophytes by gradual reduction, rather than reducing the levels quickly or eliminating macrophytes altogether" (Operational plan (Jamieson Holdings 1996a)). The EIA specified grass carp in the 25-30 cm length range to avoid losses from shag predation and to avoid the risk of understocking as a consequence of predation losses (Champion and Rowe 1996). The use of grass carp was "proposed to prevent the oxygen weed egeria from forming dense surface reaching mats in the lake" (Champion and Rowe 1996). An assessment of weed cover and biomass immediately prior to fish liberation in spring to mid-summer was advocated to refine the desired stocking rate and compensate for increased plant growth from the current 50% weed cover (Champion and Rowe 1996).

The approval (FIS90503) to transfer grass carp to Lake Omapere for aquatic weed control was signed in September 1997. The proposal was for a low level stocking of grass carp in order to maintain a 50% vegetative cover for the improvement of water quality in the lake (DOC Application Report 1997). A total of 18,500 grass carp measuring 25-30 cm in length were to be introduced initially, with further releases planned dependent on the monitoring outcomes (DOC Application Report 1997).

A variation to the approval FIS09503 was sought in March 2000 (AQTRANS 01/03). AQTRANS 01/03 sought to alter some of the requirements and the conditions in the original schedule of FIS 090503. Approval (AQTRANS01/03, commencement date 15 April 2000) was granted for the release of 31,750 grass carp. This was a stocking density of ca 20.5 fish per hectare. This low stocking density was also aimed at a gradual reduction of the dense weed beds of egeria (Operational Plan (Aquaculture NZ 2000)). The goal was to maintain a stocking rate of grass carp that would achieve a macrophyte and biomass coverage of ca 10% in the lake (Operational Plan (Aquaculture NZ 2000)).

AQTRANS01/04 was signed 28 June 2000 and replaced the schedule of AQTRANS 01/03. AQTRANS01/04 approved the release of ca 250 000 grass carp to control the volume of plants present in the lake at that time. Approval was not granted for the introduction of fingerling grass carp (i.e., grass carp were to be over 200 mm in length) (Correspondence, 28th June 2000 DOC).

A total of 8000 grass carp were released in August of 2000 (4th, 16th and 28th) (Correspondence, January 2001, NZWR). At that time there were insufficient grass carp over 200 mm available and an application was made for juvenile grass carp to be introduced. However, with the initial introduction having been made, responsibility for approving introductions transferred to MPI (then Ministry of Fisheries).

While the risks associated with grass carp escape were low, the Ministry of Fisheries decided to stipulate a minimum size of 60 mm, when it approved release of ca 250 000 carp on 15 December 2000 (Report of the Maori Affairs Committee April 2001).

A total of 40,643 fish were liberated into Lake Omapere between August (8000 grass carp) and December 2000 (32643 grass carp on the 16th) (Correspondence, January 2001, NZWR). Of the grass carp released in December 2000, 1,700 were "larger ones", and 30,974 were smaller (ca 140mm in length, ranging from ca 81-215mm) amongst which there was some mortality (Pullan 2001), and after transport there were 24 dead or moribund fish (Pullan 2001).

The remaining number of fish in the lake is unknown, as shags may have preyed on many of the smaller fish from the December 2000 introduction and some fish may have died as a result of benthic de-oxygenation in February 2001 (Champion and Burns 2001). In 2002 a further 20,000 grass carp were released (Ray et al. 2006). In October 2004 NRC obtained a permit to remove some of the grass carp from the lake and by March 2005, 400 grass carp had been removed (Ray et al. 2006). Between October 2004 and June 2006 over 2,000 grass carp were removed from the lake (Gray 2012). A conservative estimate of the number of grass carp remaining in the lake was made at 9,000 (Gray 2012).

3.1.2.2 Ecology and biology of the lake before grass carp release

Lake Omapere was invaded by the introduced submerged plant egeria and since that time has undergone a phase where surface-reaching weed beds of this 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 summarised below. However more detailed descriptions and discussions are presented in a number of published and unpublished reports on Lake Omapere (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 (for the most recent and comprehensive summary) and references therein).

Flora

The aquatic plant database (AQPD, NIWA) holds vegetation survey records from two years, 1984 and 1999, prior to the introduction of grass carp. However, only 1984 survey was a detailed, while 1999 was a casual record of one plant species (*Utricularia gibba*).

FBIS also contains the survey data from the four profiles surveyed in 1984. Ten native plant species were recorded (*E. acuta, E. sphacelata, M. articulata, Glossostigma submersum, Juncus* spp*, Lilaeopsis novae-zealandiae, M. propinquum, Persicaria* spp*, S. tabernaemontani, T. orientalis*), all of which occurred in shallow water (less than 0.8m) and at only one or two of the four sites surveyed. In contrast, the egeria was present at all four profile sites, and dominated the vegetation to the maximum water depth (2.5m+). Indeed, "shallow water plant communities appeared to be excluded from other likely sites in Lake Omapere by dense growths and drift accumulations of egeria" (Tanner et al. 1986).

In the summer following the 1984 survey, Lake Omapere lost its submerged vegetation and remained in an algal-dominated phase for the next seven years (Champion and Burns 2001). A decline in phytoplankton numbers from September 1993 allowed the egeria to recolonize the lake (Champion and Rowe 1996), with first plants observed in October 1994 (Ray et al. 2006). In the mid 1990's, there was a diverse community of low-growing plants on the lake margin (Champion and Rowe 1996).

Isoetes sp. aff. *kirkii*, a native quillwort, was reported from the lake margin near the outlet in 1984 (Tanner et al. 1986). *I.* sp. aff. *kirkii* was not recorded after the algal bloom in the mid 1980's (Champion and Rowe 1996), until a few remnant plants were discovered on 21 March 1997 (DOC Application Report 1997) by DOC. Some 44 plants were found by DOC early in1997. A further visit by NIWA and DOC staff in April 1997 failed to detect any *I.* sp. aff. *kirkii,* however the water clarity was poor at this time and hampered observations (Correspondence July 1997, NIWA). Of the 3 plants sent to NIWA by DOC, 2 were flabellate in appearance and one was not (Correspondence July 1997, NIWA). A subsequent survey in1998 (P. Champion, NIWA pers. comm.) by NIWA located 3 plants which were removed and cultivated. This population of *I.* sp. aff. *kirkii,* is regionally significant being the only known population of this genetically distinct entity and the only naturally established site of *Isoetes* north of Rotorua (DOC Application Report 1997). The plants removed for cultivation and safekeeping, remain in the aquatic plant cultivation tanks at NIWA (Champion et al. 2002). *I.* sp. aff. *kirkii* has not been found in Lake Omapere since (Champion et al. 2002, Champion and de Winton 2012).

In June 1995, egeria was observed growing in small clumps (ca 1m in diameter) and was up to 1m tall (Ray et al. 2006). By March 1996 egeria had again spread to form large patches up to 15m across and covered ca 50% of the lake floor. Plants were mostly between 0.5 and 1m and up to a maximum of 1.3m tall (Champion 1996). Low covers of *P. ochreatus* and *Chara australis* were noted in the open patches between the clumps of egeria (Champion and Rowe 1996). In December of 1996 there was poor water clarity, and tall (ca 0.8 to 1.5m in height) dense egeria (Champion et al. 1997). By February 1997 tall and dense growth of egeria is recorded as well as some patches of charophytes (Champion et al. 1997). Weed bed collapse and an algal bloom were predicted by Champion and Rowe (1996).

An alien bladderwort (*Utricularia gibba*) was sampled on one occasion in 1999 in Lake Omapere but not since that time. Introduction to Lake Omapere may have occurred either from contaminated nets for eels or when fish were liberated into the lake (Champion et al. 2002).

Fauna

Historically Lake Omapere was a 'food basket' that supplied tuna (eel) and torewai (freshwater mussels) to local iwi (White 1998). Eel fishing methods included using spears and torches from canoes (White 1998) suggesting the lake waters were relatively clear (Schallenberg et al. 2013). Lake Omapere is listed as an important lake fishery for Northland (Richardson 2005), and commercial eeling began in the lake in 1982 (Champion and Burns 2001). Between 1991 and 2001 there were reported catches of 72 tonnes (Schallenberg et al. 2013).

In the NZFFD there were Lake Omapere records from 1966 to 2011. Records from 1965, 66, 88 and 97 include multiple entries for short and longfin eels (*A. australis, A. dieffenbachii*), common smelt (*Retropinna retropinna*), goldfish (*Carassius auratus*), and freshwater mussels (*Echyridella menziesi*), as well as one silver carp (*Hypophthalmichthys molitrix*) and koura (*Paranephrops planifrons*) on one occasion in 1997. The common bully (*Gobiomorphus cotidianus)* (Kokich 1987) and gambusia (*Gambusia affinis*) were also listed as present (DOC Application Report 1997). Of the native fish species in the lake, none were considered rare or endangered (Champion and Rowe 1996).

In 1985 following the collapse of the egeria, a large number of dead mussels were found on the lake shore, probably as a consequence of benthic deoxygenation. However healthy juvenile mussels were found in the lake in February 1986. The mussel population was described as very large in June 1995, and small in 2004 (Ray et al. 2006).

Silver carp were evaluated as an option to mitigate further algal blooms in Lake Omapere (Lake Omapere Task Force 1986, Kokich 1987) and 350,000 fish were released between 1987 and 1989. Amongst the silver carp that were released, Ray et al. (2006) report that the 250,000 juvenile (2 to 2.5cm) silver carp released in 1987, had no observed effect on algae, and high fish mortality was considered likely. There may be a remnant population of silver carp in the lake (DOC Application Report 1997).

There has not been any systematic survey of aquatic macroinvertebrates (Champion and Rowe 1996), rather observations of invertebrates are recorded during the macrophyte surveys. These have included *Potamopyrgus antipodarum, Austropeplea tomentosa, Hygraula nitens,* dragonfly larvae (Odonata), planarians, freshwater sponges, bryozoans and chironomids (Champion et al. 2005). At times, dense cover of freshwater mussels have been recorded in lake sediments, especially in the open patches (Champion and Rowe 1996). .

Lake Omapere and its surrounds, has been recognised as supporting a diverse range of waterfowl and other bird species (DOC Application Report 1997). The list of bird species recorded from Lake Omapere includes black shag (*Phalacrocorax carbo*), North Island fernbird (*Bowdleria punctata*), black swan (*Cygnus atratus*), paradise shelduck (*Tadorna variegata*), grey duck (*Anas superciliosa*), mallard (*Anas platyrhynchos*), pied shag (*Phalacrocorax varius*), little black shag (*Phalacrocorax sulcirostris*), little shag

(*Phalacrocorax melanoleucos*), white faced heron (*Ardea novaehollandiae*), Australasian harrier (*Circus approximans*), pukeko (*Porphyrio melanotus*), red-billed gull (*Larus novaehollandiae*), black backed gull (*Larus dominicanus*), spur-winged plover (*Vanellus miles*), Australasian bittern (*Botaurus poiciloptilus*), pied stilt (*Himantopus himantopus*) and kingfisher (*Halcyon sancta*) (DOC Application Report 1997, Champion and Rowe 1996, Ogle 1982).

Black swan numbers appear to fluctuate with submerged plant biomass. Up until 1983 the black swan population was migratory, decreasing over winter and increasing during summer (Kokich 1987). In 1983 a breeding population was established on the Lake (Kokich 1987). Prior to the collapse of weed beds in 1985 an estimated 8000 swans utilised Lake Omapere. This dropped to 1000 the following year, and then increased to 3000 in 1995 (summer assessment by Northland Fish and Game) and 8000 in 2001 (Champion et al. 2005).

Water Quality

Lake Omapere was utilised as a source of potable water for the Kaikohe Borough from the early 1970's until 1985 (NRC 2001). NIWA unpublished data from 1982 indicates good water clarity with a secchi disc depth > 2m (Vant and Davies-Colley unpublished data cited in Champion and Burns 2001). During that time, further development of the surrounding catchment for pastoral farming contributed to additional nutrient loads in the lake (Schallenberg et al. 2013). In 1985, a thick algal bloom was reported on the lake, the main species were *Anabaena circinalis, A. flos-aquae* and *Microcystis aeruginea* (Ray et al. 2006). As a result of this bloom the Northland Area Health Board gave notice that taking of water was prohibited on the grounds that the water was so polluted it was dangerous to health. The NAHB also recommended against bodily contact with the polluted water down the Utakura River, as far away as Hokianga Harbour (DOC Application Report 1997)).

The algal bloom coincided with a change in vegetation within the lake. The egeria that had previously formed a continuous cover over most of the lake bed declined to very low levels in 1985/86 (DOC Application Report 1997). To mitigate further algal blooms the Lake Omapere Task Force (established in 1986) evaluated the use of silver carp (OTF 1986, Kokich 1987), which were subsequently introduced. No systematic monitoring of water quality was undertaken until 1992 by NIWA.

The water quality in the main body of the lake has been sampled by NIWA/NRC from 1992 to 1997 (Champion et al. 1997) and 2001 (Champion and Burns 2001). Water quality monitoring from 1992 captured a step-wise shift in improved water quality with decreased chlorophyll *a*, total phosphorus and total nitrogen in the water (Burns et al. 2000) and higher water clarity (increased secchi depth, ca 0.5 to 1.3 in 1993 to 2m in 1996), and a return of submerged plants in late 1993 (Champion and Burns 2001). The trigger appeared to be the recovery of the mussel populations to densities where they could theoretically filter a volume equivalent to that of the lake in 20 hours (Champion and Burns 2001). The increase in freshwater mussel population is seen as a likely mechanism for a change from turbid to clear water conditions in Lake Omapere, facilitating the further recolonisation of submerged plants (Champion and Burns 2001). However other mechanisms may also be responsible and/or have contributed to improved water clarity (e.g., increased zooplankton, or reduced wind action). Egeria beds increased from 1994 to 2000, and again grew over most of the lake (Schallenberg et al. 2013).

Habitat Quality

Habitat quality for flora and fauna within the lake was dramatically altered by the colonisation and decline of egeria in Lake Omapere, as described by Champion and Burns (2001) and Champion (2002).

Water quality parameters including total nitrogen, total phosphorus, suspended sediments and chlorophyll *a* all declined, with a subsequent increase in water clarity in response to egeria colonising Lake Omapere (Champion and Burns 2001). However, during February 2001, deoxygenation of bottom waters occurred as a result of surface-reaching beds of egeria preventing movement of oxygen through the water column. This event killed many freshwater mussels on the lake bottom and also resulted in a die-back of egeria. This die-back resulted in the release of nutrients into the lake from decomposing weed (Champion and Burns 2001). The deoxygenation event is seen as the most likely mechanism to explain the collapse of egeria in 1985 (Champion 2002) and a similar occurrence was predicted in the near future without management to reduce the egeria biomass (Champion and Burns 2001).

3.1.2.3 Changes in ecology and biology after grass carp release

Flora

In the summer of 2000-2001, egeria was the only submerged aquatic plant in water deeper than half a metre (AQPD), it again formed surface-reaching weed beds (Champion and Burns 2001), and was recognised as a major problem within the lake (NRC 2002). In the April 2001 survey egeria was the only submerged species forming a complete cover over the entire lake which had maximum depth of 2.2m and the average height of the egeria was 0.6m (Champion et al. 2002). The egeria was in poor health (generally leafless) and large areas of the shoreline were smothered by detached decomposing shoots of this plant (Champion and Burns 2001). At the time of the survey there was an algal bloom (*Anabaena circinalis*) over much of the lake (Champion et al. 2002).

The submerged vegetation of Lake Omapere collapsed in 2001 and the lake has remained in a devegetated state dominated by cyanobacterial blooms since that time (Ray et al. 2006, Wells and Champion 2012b). Aquatic plant surveys from 2004 (Champion 2004) to 2011 did not record any egeria (Gray 2012). *Ottelia ovalifolia* was recorded in localised patches in an inflow stream (Gray 2012). In April 2012, a profile from the south side of the lake to the north side, was spot dived, and very small amounts of *Glossostigma cleistanthum* were found at 0.4 m deep at the south end and one tiny plant *Chara australis* at 1.4 m deep was found. High covers of *G. cleistanthum* and *G. elatinoides* were found amongst basalt boulders during a snorkel search around the eastern shore (Wells and Champion 2012b).

As described in earlier vegetation surveys, the western shore of Lake Omapere supported marginal vegetation consisting of dense bands of *M. articulata, Schoenoplectus tabernaemontani* and *Typha orientalis* to a water depth of 1.2m to 1.3m. The remainder of the shoreline was pasture with the rush *Juncus edgariae* common near the edge of the water (Champion et al. 2002). A range of turf species such as *Lilaeopsis novae-zelandiae, Myriophyllum propinquum, Gratiola sexdentata, Glossostigma elatinoides* and *G. cleistanthum* were recorded in the wettest areas (Wells and Champion 2012b). Two nationally critically threatened plants (de Lange et al. 2009) were discovered during the 2012 vegetation survey. These were the annual composite *Centipeda minima* subsp. *minima* (nationally endangered in de Lange et al. 2013) and the fern *Ophioglossum petiolatum* (threatened in de Lange et al. 2013). These discoveries significantly increase the ecological value of Lake Omapere. Alligator weed (*Alternanthera philoxeroides*) was well established and formed large floating mats on the eastern shoreline of the lake. (Wells and Champion 2012b).

Planktonic algal counts in 2004 were dominated by *Microcystis wesenbergii* (Champion 2004). Blue-green algae at the outlet from Lake Omapere were dominated by the species *Microcystis wesenbergii, Microcystis flos-aquae, Anabaena circinalis* and *Microcystis aeruginosa* (Ray et al. 2006). The algal community in Lake Omapere changed substantially over the last two decades and is documented in Gray (2012).

Fauna

Records from 2005, 2007, 2008, 2010 and 2011 include multiple entries for short and longfin eels, goldfish and freshwater mussels. Additional species recorded include multiple entries for gambusia, Northland mudfish (*Neochanna helios*) in the tributary streams, freshwater shrimp and koura, as well as grass carp on one occasion in 2008 (NZFFD), and catfish (*Ameiurus nebulosus*) (Richardson 2005).

Although gambusia have been recorded from this lake, they have not been seen during the NIWA/NRC surveys over the past decade (Champion et al. 2005). Large populations of nationally vulnerable Northland mudfish (*Neochanna helios*) has been recorded from the wetland margins of Lake Omapere (Barrier 2003, Allibone et al. 2010).

Of the silver carp and grass carp that were liberated into Lake Omapere, the remaining number of fish is unknown, as shags may have preyed on many of the smaller fish from the introductions. Reduction in numbers from the original stocking are also likely due to natural mortality and harvesting (Ray et al. 2006). Some fish may have died as a result of benthic deoxygenation in February 2001 (Champion and Burns 2001), as did up to 80% of the mussels (NRC 2001).   During a fish survey carried out in 2005, no mosquito fish, catfish, common bully or smelt were caught or seen (Gray 2012).

Around 60 tonnes of eels have been taken from the lake over 1999 to 2001 (Champion and Burns 2001). Catfish were first recorded from the lake, when they were caught in an eel fishing net (NRC 2001). They are an exotic pest fish that are hardy and able to survive low oxygen conditions. Catfish are known to stir up bottom sediments, may disturb weeds and contribute to turbidity problems, and may have a significant adverse effect on the lake, including the eel fishery (NRC 2001).

A comprehensive fish survey in 2009 by Williams et al. (2009) found gambusia in the lake, but no catfish, smelt or bullies. Williams et al. (2009) report 73 tonnes of eels were removed between 2003 and 2008. A 2008 fishery assessment in Lake Omapere showed a high proportion of commercial-sized eels (i.e., > 220 g), with shortfin eels having amongst the highest growth rates recorded in New Zealand (Williams et al. 2009). However, few shortfin and longfin eels in the catchment were of the large size preferred for customary take and the size required to migrate out of the catchment to breed (Williams et al. 2009). On the basis of this commissioned research the Lake Omapere Trust placed a rāhui (prohibition) in 2010 and commercial harvesting ceased (Schallenberg et al. 2013).

Amongst the aquatic macroinvertebrates, the mussels are known to have undergone a major decline during 2001/02 and were described as rare within the lake by Champion et al. (2005). The consequence of the loss of mussels was considered significant, as mussels are believed to have a role in sustaining the lake in a clear water state by filtering algae from the water. It was considered that the loss of so many mussels (up to 80%) may make it easier for algae to proliferate in the future (NRC 2002). Assessments of the mussel population undertaken from 2004 to 2010 indicate a patchy distribution with some areas of high density (Gray 2012) In 2012 mussels were reported to have recovered and were abundant right across the lake confirming the lake was not experiencing anoxic (minimal oxygen) episodes (Wells and Champion 2012).

The number of black swan on Lake Omapere, again dropped after the weed bed collapsed for a second time in 2001 (Champion et al. 2005). Over the last decade annual swan counts have varied in numbers from 50 to 400 (Northland Fish and Game unpublished data cited in Wells and Champion 2012).

Water Quality

Water quality measurements taken in February and April 2001 showed a large increase in nutrient levels (TN and TP) in Lake Omapere, attributed to dissolved nutrients released by the large amounts of rotting egeria present within the lake (Champion and Burns 2001). It was anticipated that high concentrations of readily available nitrogen and phosphorus within the water column, of Lake Omapere could signal the change from a macrophyte to an algal dominated phase. The situation was described as "an unstable point where macrophytes are showing indications of potential decline, while planktonic algal concentration and other sources of turbidity are not sufficient to prevent light penetration to the bottom of the lake" (Champion and Burns 2001).

Matheson and Gibbs (2005) describe Lake Omapere as eutrophic to hypertrophic (Table 4). Water quality in Lake Omapere from 2003 to 2006 was described as very poor. Chlorophyll α, total nitrogen, total phosphorus and secchi values were indicative of a lake in a hypertrophic state, meaning it was highly enriched with poor water clarity and frequent algal blooms and surface scums (NRC 2005, 2007). The trend analysis reported by NRC (2006) showed that water quality had not improved in Lake Omapere over the preceding 10 years, and in fact with the shift from a weed dominated lake to an algal dominated lake in the end of 2001, water quality deteriorated.

However, since 2007 reduced nitrogen and chlorophyll *a* were noted, and described as a potential "result of flax planting and fencing along the lake margin which keeps stock away from the lake" (Verburg et al. 2012). When developing a nutrient budget for the lake Verburg et al. (2012) also noted that mean nitrogen and phosphorus concentrations in the lake were higher than in the total inflow. This was noted as unusual and not seen in healthy lakes where nutrient concentrations are in equilibrium with the external loading, which indicated strong internal loading. In Lake Omapere internal phosphorus loading exceeded external phosphorus loading by 60% (Verburg et al. 2012).

During the algal-dominated phase the nutrient legacy in the sediments fuels internal high regeneration rates of nitrogen and phosphorus levels. These greatly exceed loads from the catchment, some of which is removed from the lake via the Utakura River and denitrification (microbial transformation of nitrate to atmospheric gas). However during the egeria dominated state, nutrients accumulated in the sediments (Verburg et al. 2012). It is was thought that a new clear water phase was about to start (or had started in 2009) (Verburg et al. 2012) as a consequence of sustained nutrient exports down the Utakura River. In addition, the recent improvement in water quality (hypertrophic to eutrophic) may have been assisted by increased mussel populations (Schallenberg et al. 2013).

The lake still has very high nutrient levels. While catchment loadings are high due to farming, nutrients arising from lake sediments during anoxic (low oxygen) episodes have had a much greater influence on the nutrient budget of Lake Omapere and elevates nutrients in the lake in the order of 380% greater than catchment inputs (Verburg et al. 2012). Although Lake Omapere is in an enriched and turbid state (Gray 2012), the water quality is currently improving (NRC 2007-2011) without excessive weed growth causing anoxia and with suspended sediments flushing from the lake during turbid water events (Verburg et al. 2012).

Table 4: Summary water quality data for Lake Omapere

Parameter	Matheson and Gibbs 2005 (data noted as all 5 sites since 2001, but outlet and bridge from 1989-1992)	NRC Reports 2005, 2006 (monthly at 2 sites)		Gray 2012 (data for 1, 3, 5 year periods to Sep 2011)		
		Ave 2004-2005	Ave 2005-2006	Oct 2010 to 2011	Oct 2008 to 2011	Oct 2006 to 2011
Dissolved Oxygen	6 – 13.1 mg/l (upper), 2.9 – 13.1 mg/l (lower)					
Chlorophyll *a*	<10-370 g m^{-3} (upper), <10-210 g m^{-3} (lower)	79 g/m^3	0.06 g/m^3	0.005 mg/L	0.005 mg/L	0.020 mg/L
Water Clarity, Secchi (m)	0.1-1.8+ (indicates low water clarity)	<0.4	0.33	0.73	0.68	0.53
Total Nitrogen (mg/m³)	400-5900 (upper), 300-500 (lower), (indicates high to very high enrichment)	1967	1.45 g/m^3	0.5 mg/L	0.59 mg/L	1.01 mg/L
Total Phosphorus (mg/m³)	12-296 (upper), 6-826 (lower (indicates low to very high enrichment) (indicate low to high enrichment)	187	0.117 g/m^3	0.09 mg/L	0.13 mg/L	0.15 mg/L
Suspended Solids	1-197 gm^{-3} (upper), <1-527 gm^{-3} (lower)	60 gm^{-3}		22.57 mg/L	24.44 mg/L	45.2 mg/L
Trophic Level Index (TLI)			6.27	4.79	4.98	5.46
Trophic state	Eutrophic to hypertrophic	Hypertrophic				
NB: Sometimes very high suspended solids (Matheson and Gibbs 2005). Champion and Burns (2001) describe the lake as eutrophic from 1994 – 2000 (TLI of 4.56). Verburg et al. (2010), describe Lake Omapere as having significantly improved TLI (by 2% per year) over the last 10 years from 2000. Based on 2005-2009 data the lakes TLI was 6.1 (Verburg et al. (2010).						

Habitat quality

Lake Omapere was given a low ranking by Northland Regional Council (NRC 2005) due to its devegetated state and poor water quality, although it was recognised that the lake margins support an endangered mudfish. "The Lake Omapere Trust and Northland Regional Council are working in partnership on the Lake Omapere Restoration and Management Project" … which aims to "to improve water quality and the overall health of Lake Omapere in the long term" (NRC 2005).

More recently in 2012, the ranking of Lake Omapere was improved to high, recognising that although it is still devegetated with high nutrient issues (hypertrophic), three critically endangered species have been reported from its margins (Wells and Champion 2012). However the population of taxonomically cryptic submerged aquatic fern, *I. kirkii*, has not been seen since 1988.

Champion and Burns (2001) postulated two stable states for Lake Omapere: a clear water state where the lake is dominate by aquatic macrophytes (egeria) and a turbid state dominated by algae. There can be a rapid switch from one state to the other (Ray et al. 2006).

Although stocking of grass carp was too late to avoid the collapse of egeria in late 2001, the effective eradication of this weed has halted its boom-bust cycle of invasion alternating with an algal-dominated state (Schallenberg et al. 2013). Furthermore there have not been algal blooms in the lake since 2007 and many of the ordinary practices of water use in the catchment have resumed (Schallenberg et al. 2013). In 2011 eels were again harvested from the lake as traditional kai, for the first time in more than a decade (Schallenberg et al. 2013).

Water quality is closely linked to the other components of the Lake Omapere ecology, its restoration and management. To that end, enhancement of the freshwater mussel population and re-establishment of native aquatic plants are all vital in improving water quality in Lake Omapere. However, the freshwater mussels and native aquatic plants are also dependent on water quality improving, particularly clarity, before successful restoration can occur (NRC 2006).

Summary of effectiveness and effects

Grass carp were introduced into Lake Omapere as part of a lake management initiative to control the egeria. Although the timing and number of grass carp released was not sufficient to prevent the weed bed collapse and lake wide deoxygenation, their continued presence has prevented the cycle of egeria domination, collapse and algal blooms from repeating.

As a consequence of the algal blooms and poor water quality in the 1980's, Lake Omapere has been relatively well studied in the last two decades, and there is a comparatively large volume of data available for the lake (e.g., Gray 2012, Ray et al. 2006, Champion and Burns 2001 and references therein). However the literature also highlights that the lake was in a compromised condition (Gray 2012) prior to the release of grass carp, with cycles of egeria forming excessive weed beds leading to anoxia, nutrient release, vegetation collapse and toxic algal blooms (Wells and Champion 2012). In such a compromised lake the effectiveness of the grass carp to remove the weed cannot be independently assessed with respect to changes that were already occurring in the lake, nor can the effect of the grass carp on the lake be assessed in terms of native flora, fauna and water quality measures (Hofstra 2013a). In addition over the timeframe of a decade (from 2000 to present 2013), with multiple grass carp release dates, including the release of juvenile fish that are more susceptible to predation, several references to fish being removed or harvested, there is little clarity on the actual stocking density in the lake over the last decade, against which to measure effects or effectiveness.

Recognising those limitations, an effort has been made to elucidate the knowledge on the changes that have occurred in the presence of grass carp, rather than effectiveness or effects that can be directly attributed to grass carp (see summary table below).

Effectiveness	Flora: Prior to the introduction of grass carp, it was predicted that the lake was in an unstable state and the egeria would collapse, the timeframe for the collapse was not certain (Correspondence, 15 June 2000 Champion). However, in terms of 'effectiveness' it can be stated that in the presence of grass carp, egeria has not re-established in the lake.
Effects	Flora: Native submerged macrophytes were already impacted by the invasive weed egeria and the turbid water algal dominated cycle within the lake. The submerged native plant *I.* sp. aff. *kirkii* had not been found since 1998, several years prior to the introduction of grass carp. Individuals of the submerged plants *Chara australis* and *Glossostigma* were recorded in the lake, with higher plant cover recorded amongst the basalt boulders in 2012 (Wells and Champion 2012b). In the mid 1990's, there was a diverse community of low-growing native plants on the lake margin (Champion and Rowe 1996). In 2012 a range of turf plant species occur in the wettest areas (Wells and Champion 2012b). Fauna: There was a dramatic reduction in black swan and mussel numbers associated with the weed bed collapse. No changes attributable to the presence of grass carp were noted for most species. Water quality: Lake Omapere is an example of a lake where water quality, including clarity has improved during the time that grass carp have been present in the lake (NRC 2007 to 2011). The boom-bust cycle of egeria to an algal-dominated turbid state has been halted. Habitat quality: dramatic changes in habitat have occurred while grass carp have been in the lake, from the collapse of the egeria to an algal dominated turbid water phase, and recently to water quality improvements. In summary, no changes in habitat quality have been attributed directly to the grass carp.

3.1.3 Lake Swan / Roto-otuauru

Lake Swan (also known as Lake Roto-otuauru) is a 17.4 hectare dune lake, enclosed in old stabilised sand dunes, located on the North Kaipara Head (Pouto Peninsula) (Appendix C) (Livingstone et al. 1986). The lake has a relatively small catchment (less than 25ha), with no defined inlet, and an intermittent outflow (during periods of extreme rainfall) to the sea on the eastern side of peninsula (Livingstone et al. 1986). Diffuse leakage through the surrounding sand dunes controls the water level (Mitchell 2008) and the lake has a maximum depth of 5.5m (Cunningham et al. 1953, Kokich 1991, Hamill 2008).

The lake is owned by Te Uri o Hau and the Crown (LINZ under Land Act 1948) (NRC 2009a). A marginal strip of the shoreline surrounding the lake is administered by DOC. Beyond the marginal strip, the land is in private ownership and is predominately in pasture, primarily for dry stock farming (Mitchell 2008), with some areas of scrub and pine (NRC 2007-2011). There are also water takes for dairyshed wash-down and horticultural irrigation, although the lake is primarily used for stock drinking water, recreation, duck shooting and aesthetics.

Stock have been excluded from the lake, and the majority of the lake margin is surrounded by a dense fringe of *Eleocharis sphacelata* and raupo (*Typha orientalis*). Water quality data collected from Lake Swan indicates a mesotrophic to eutrophic status (Matheson and Gibbs 2005, NRC 2007-2011).

There is no public access to the lake (Mitchell 2008).

3.1.3.1 Grass carp stocking – When, how many and why

There were no records for Lake Swan amongst the DOC files, other than reference to the aquatic transfer (AQTRANS 01/19) on a spreadsheet (DOC unpublished records 2010).

The aquatic transfer application (NRC 2009a), EIA and a draft Operational Plan (Mitchell 2008) for the introduction of grass carp into Lake Swan were obtained from MPI (Steve Pullan, MPI Auckland).

In the EIA the release of 850 grass carp over 25cm in length was proposed. With an estimated area of aquatic weeds covering 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). DOC records (unpublished 2010) indicate 800 grass carp were released (40 per veg/ha); however an NRC media release reports over 800 were released (NRC (2009b), http://www.nrc.govt.nz/Environment/Weed-and-pest-control/Case-studies/Grass-Carp-in-Lake-Swan/ viewed Dec 2013) by the Mahurangi Technical Institute, in May 2009.

The goal of the grass carp introduction was 100% weed removal (i.e., 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 from Lake Swan, allow restoration of the native vegetation and the lake as a whole.

3.1.3.2 Ecology and biology of the lake before grass carp release

Flora

The earliest detailed records of the aquatic flora of Lake Swan were made by Cunningham et al. (1953) and Tanner et al. (1986). The more comprehensive vegetation survey from

Tanner et al. (1986) shows that the most common submerged species were charophytes and *P. ochreatus*, which occurred to a depth of 4.5m. *E. densa* was first recorded in the lake in 1992 (Champion et al. 1993), and by 2001 it had formed dense beds up to 2.5m tall and occupied most of the lake from a depth of 0.6m to 4.2m (Champion et al. 2002). One small basin in the lake was deeper than this (4.7m maximum depth) and had a low cover of egeria and the native *P. ochreatus*. Much of the egeria was covered in a dense cyanobacterial epiphyton. Where emergent plant beds were open or absent the lake had a distinct shallow water community consisting of 10 species; *Glossostigma elatinoides, Myriophyllum votschii, Myriophyllum triphyllum, P. ochreatus, L. novae-zelandiae*, *Chara fibrosa, C. australis, C. globularis, Nitella* sp. aff. *cristata* and the alien plant *Elodea canadensis. Ottelia ovalifolia* was noted outside of the profile sites (Champion et al. 2002). The emergent plant species that almost surrounded the lake, included *Eleocharis sphacelata* growing to 2.5m tall and to a depth of 1.5m, occupying 80% of the lakes margin, and *Typha orientalis* growing to 3m tall and to a depth of 0.5m, occupying 50% of the margin (Champion et al. 2002).

Since its invasion, egeria has 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. 1988) but has not been found by subsequent surveys (Champion et al. 2002).

Hornwort was first discovered in Lake Swan 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).

In 2005, marginal emergent plant species surrounded about 75% of the lake forming a dense fringe 5 to 10 m wide of *E. sphacelata*, with *E. acuta, S. tabernaemontani, M. articulata* and *T. orientalis* (Champion et al. 2005).

Exposed areas of turf plants contained the regionally rare *Gratiola sexdentata* and *M. votschii*. The invasive alligator weed was present at low cover (at the access point) and was described as posing a significant threat to the marginal vegetation of the lake (Champion et al. 2005). Amongst the submerged flora, a wide range of turf species were present at a few locations with *G. elatinoides* the dominant species. A few charophytes persisted in the shallow water but have been displaced from deeper water by the invasive weeds hornwort and egeria and there were no longer any charophyte meadows. The submerged vegetation was dominated by the tall-growing invasive species hornwort and egeria (Champion et al. 2005).

Fauna

NZFDD report cards (from 1970 to 1991) include the following four species; dwarf inanga (*Galaxias gracilis*), shortfin eels, common bully and freshwater mussels. Several large schools (50 to 100 fish) of the dwarf inanga have been reported (Champion et al. 2002). Dwarf inanga are small fish thought to have evolved from populations of the whitebait *Galaxias maculatus* that became landlocked (Rowe and Chisnall 1997). With a limited distribution and subsequent reduction of habitat, dwarf inanga are listed under the New Zealand Threat Classification System as At Risk, Declining (Goodman et al. 2014).

Because it is currently lacking any permanently flowing outlet to other waterbodies, the lake is inaccessible for unassisted colonisation by native freshwater fishes (Mitchel 2008).

However, Lake Swan has supported commercial eel fishing in the past (Mitchell 2008). Longfin eels are reported from the lake (Cunningham et al. 1953, Mitchell 2008), as well as large (up to 1m long) shortfin eels (Champion et al. 2002). Other authors have noted common bullies (Rowe and Chisnall 1997), freshwater mussels, snails (*Potamopyrgus antipodarum*), chironomids, freshwater sponges and backswimmers (*Anisops wakefieldi*) (Cunningham et al. 1953, Champion et al. 2002, Champion et al. 2005) and jellyfish (Kokich 1991).

In August 2007, only one common bully was observed (Mitchell 2008), and no dwarf inanga were observed in an April 2008 survey (NIWA), however they were observed in the 2001 and 2005 NIWA surveys and a previous survey in 1970. "Dwarf inanga were also observed during a survey of the lake by Te Uri o Tau in January 2008" (Mitchell 2008).

Fencing the lake to exclude cattle, and the large stands of marginal emergent plants surrounding much of the lake has created a desirable habitat for many water birds (Champion et al. 2005). Black swans have at times been abundant on the lake, with over 60 counted on one field visit (Champion et al. 2002). Mallard ducks, dabchick, welcome swallow and little shags have also been reported (Mitchell 2008). Threatened species recorded from the lake include the nationally endangered bittern (*Botaurus poiciloptilus*) (Robertson et al 2013) and the regionally significant dabchick (*Poliocephalus rufopectus*) and fernbird (*Bowdleria punctata vealeae*) (Champion et al. 2005).

Water Quality

Lake Swan was described as eutrophic by Kokich (1991). Water clarity prior to the establishment of introduced weed beds in 1992 was poor (Wells and Champion 2011), with signs of eutrophication relating to farming practises (Champion et al. 1993). When the lake stratifies in summer there is an associated anoxia of bottom waters (DO down to 0.4mg /L) with elevated concentrations of nutrients. During a lake survey Champion et al. (2005) recorded the thermocline at 4m, with thick black water below.

In general there is little water quality data available, as summarised by Matheson and Gibbs (2005), with monitoring only having been carried out on four occasions (Table 5). No changes were reported in water clarity, pH and chlorophyll *α* since 1990 (NRC 2007). However a slight decrease in nutrient levels was described, with increased macrophyte growth (NRC 2007). Lower nutrient records are expected with a macrophyte filled lake but levels could rapidly increase with plant collapse. Overnight depletion of dissolved oxygen may occur with very dense weed beds present throughout the water column. Water quality in Lake Swan was expected to deteriorate at some time in the future from impacts of the invasive weeds (Champion et al. 2005).

Habitat Quality

Previously Lake Swan was a native lake of high value, with charophyte meadows and the tall growing submerged plant *P. ochreatus* dominating. By 2005, the native species were nearly all displaced by pest plant species (Champion et al. 2005) and Lake Swan was given a ranking of 'moderate' (NRC 2005), which recognised the lakes highly degraded state (Champion et al. 2005). With the worst submerged invasive weeds already in the lake the potential consequences for the lake were, that without management intervention, the "Lake could flip'' into an algal dominated lake (Champion et al. 2005, NRC 2007). Further, while the large emergent plant beds in the shallower water were seen as providing good habitat for some species, the presence of dense weed beds could result in dissolved oxygen depletion in the water column, and reduce available habitat for fish species (Champion et al. 2005).

The status of Lake Swan as a consequence of the invasive weed beds was also reflected in the very low LakeSPI score of 21%, with egeria and hornwort having greatly reduced native values in the lake (Champion et al. 2005, NRC 2007) (Table 6).

The eradication of hornwort and egeria was considered necessary to prevent the spread of New Zealand's worst submerged weeds and to prevent water quality degradation in Lake Swan (NRC 2007).

Table 5: Summary water quality data for Lake Swan

Parameter	Matheson and Gibbs 2005 (2 monitoring sites, four times since 1990)	NRC 2007-2011 (monitoring results from the last 5 years)		
		Min	Median	Max
Dissolved Oxygen	8.1-9.9mg/L (indicates good oxygenation)	75.4%Sat	90.5% Sat	105% Sat
Chlorophyll *a*	3-<10 mg m^{-3} (moderate, and low to high enrichment)	1.9 mg/L	3.7 mg/L	25.3 mg/L
Water Clarity, Secchi	>1.5-3.7m (low to moderate clarity)	1.01 m	3.1 m	3.8 m
Total Nitrogen	350-600 mg/m^3 (indicates high enrichment)	121	597.5	1130
Total Phosphorus (mg/m^3)	9-29 mg/m^3 (moderate to high enrichment)	8	15	609
Suspended Solids		0.25	0.95	5.7
Trophic Level Index (TLI)		2.98	3.86	6.09
Trophic state	Mesotrophic to eutrophic	Mesotrophic		
NB: Cunningham et al. (1953) report 2m Secchi. Hamill (2006) report a TLI of 4.33 and eutrophic condition. NRC (2007) reports a TLI of 3.9 mesotrophic condition.				

Table 6: LakeSPI report card summary for Lake Swan

LakeSPI Index · Native Index · Invasive Index

Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2011	Non-vegetated	0%	0%	0%
April 2009	Moderate	21%	33%	96%
March 2005	Poor	18%	30%	94%

Source http://lakespi.niwa.co.nz/lake/50403, January 2014.

3.1.3.3 Ecology and biology of the lake after grass carp release

The EIA concluded that, "using these fish to eradicate aquatic weeds has major potential benefits for the future conservation of valuable lakes and associated aquatic plant communities within the Pouto lakes region". "There is little risk of significant adverse effects on unique conservation values at the release site or within the highly modified wider catchment" (Mitchell 2008).

Flora

In 2010, about half of the hornwort and most of the egeria had been consumed by grass carp. The remaining egeria was covered in *U. gibba*. "Charophytes persisted at one small site in shallow water (to 1.8m) on the northern shore", but were being consumed by grass carp" (Wells and Champion 2010).

By 2011, no further *U. gibba* was found. Of the target species, all of the hornwort and the egeria had gone, except for a few shoots of hornwort floating amongst the marginal vegetation. The marginal emergent plants were also reduced considerably in extent with only remnants of the *T. orientalis* left. The area least grazed was in the arm at the north end of the lake, where the lake extends into a wetland. Low growing turf species were not affected by grass carp grazing (Wells and Champion 2011).

By 2012, there were no signs of hornwort, egeria or other submerged plants in the lake (other than turf species) and it was considered that there was no longer any risk of egeria or hornwort spreading to adjacent high value lakes (Wells and Champion 2012a). When the same five survey sites were visited in 2013, no target weeds were recorded, although patches of alligator weed were present with no evidence of grass carp consumption (Wells and Champion 2013a). In May 2014, no submerged macrophytes were recorded from the lake (Champion, NIWA, pers comm).

Fauna

The same native species are reported from the lake (NRC 2007-2011), as those found there prior to the introduction of grass carp. However, there has been a decline in the number of black swans since the weed beds were reduced in the lake (Wells and Champion 2012a).

Conversely, Mitchell (2008) commented that if still "present in the lake dwarf inanga are considered likely to benefit from the presence of grass carp" as they did in Lake Waingata. Although no recent fish survey data was obtained, NRC (2007-2011) report dwarf inanga as present.

Water Quality

Lack of historical water quality data for Lake Swan prior to the introduction of invasive weeds, makes it difficult to assess effects. A recent report by NRC (2007-2011) which spans the year of grass carp introduction (2009), states that "key variables indicate water quality has deteriorated in Lake Swan over the past 5 years with TLI increasing 0.22 units or 5.43 % per year". "The removal of aquatic plants by the grass carp is the likely cause of the deterioration in water quality" (NRC 2007-2011).

In June of 2011, following weed removal by grass carp, Lake Swan experienced a short (month long) cyanobacterial bloom. Following an investigation as to the potential cause of the bloom, Rowe (2011) describes the most likely cause as "a sudden increase in phosphorus concentration in the lake water column in early March 2011. This would have increased the phytoplankton biomass in the lake during subsequent months as evidenced by the rapid increase in chlorophyll *a* in March and May 2011" (Rowe 2011). Local weather conditions, a prolonged period of calm and hot weather in mid-February, followed by wind inducing mixing of the lake water, are likely causes of the phosphorus peak (Rowe 2011). Further 'calm weather' in June 2011 then resulted in a change in algal species composition (Rowe 2011).

A vegetation survey carried out since the stocking of grass carp describes water clarity as "low, having been reduced from about 4m in 2009 to 0.5m in 2011" (Wells and Champion 2011). The deterioration in water clarity was considered likely to have resulted from the removal of submerged weeds (Wells and Champion 2011). The tall beds of hornwort and egeria would have enhanced water clarity through the uptake of nutrients from the water column and also by stabilising bottom sediments preventing suspension by wind. A greater deterioration in water quality would have been expected if the weed beds were unmanaged and underwent a collapse similar to that which occurred in Lake Omapere and most Waikato shallow lakes (Wells and Champion 2011). An algal bloom was noted during a lake survey in May 2014 (Champion, NIWA, pers comm).

Habitat Quality

The ecological ranking of this lake is "moderate" as it has been highly degraded by aquatic weeds, and is now in a largely de-vegetated state (NRC 2007-2011). Once invasive plant species have been controlled and grass carp removed it is expected that habitat will improve rapidly with native submerged plant regeneration (Wells and Champion 2011). However it was recommended that stock be completely excluded from the marginal emergent plants around the lake, to preserve habitat (Wells and Champion 2011).

Despite the poor state of the vegetation, dwarf inanga, a number of rare birds and a population of the freshwater mussels are all present (NRC 2007-2011).

Summary of effectiveness and effects

Effectiveness	Flora: effective target weed control, with a significant reduction in abundance of the target species by 2010, and no fragments found by 2013 (Wells and Champion 2013a) and 2014 (Champion, NIWA pers comm). Significant progress toward weed eradication goal.
Effects	Flora: Native submerged macrophytes were already impacted by the invasive weed species. Grass carp have reduced the remaining submerged plants and started grazing the marginal emergent plants where they extend into the water. Native turf plants persist. The invasive alien plant, alligator weed, is not impacted (Wells and Champion 2013a). Fauna: Limited information. Swan numbers have reduced, no other changes noted. Water quality: It was recognised that the lake may flip to an algal dominated state if the weed beds were not managed. NRC (2007-2011) attributes grass carp feeding on aquatic plants to "degraded" water quality. There is little historic data (pre-grass carp) for such a comparison. Annual visits since 2009, do indicate reduced water clarity. That statement is made in the context of the improved clarity achieved when weeds initially colonised the lake, and the likely consequences of degradation that could take place following weed collapse (Wells and Champion 2011). Habitat quality: Loss of habitat for swans, and some reduction in marginal emergent plant species, otherwise no changes noted that can be directly attributed to the grass carp.

3.2 Auckland Region – rural lakes

3.2.1 Lake Kereta

Lake Kereta, also spelt Kareta, is a eutrophic, shallow (historic maximum depth of 5m) sand dune lake (Livingstone et al. 1986, Mitchell 2007) of ca 26 ha on the South Kaipara Head (Wilcock and Kemp 2000, Leathwick et al. 2010) (Appendix C). The lake has no specific inlet or outlet and is filled from rainfall and ground water seepage (Mitchell 2007). The lake bed is crown and private ownership (Mitchell 2007), and the rural catchment is in pasture and plantation pine (Gibbs et al. 1999). The pine forest on the western shore has a narrow riparian marginal strip of manuka-dominated scrub (Mitchell 2007).

3.2.1.1 Grass carp stocking – When, how many and why

DOC files included an application for the release of grass carp into Lake Kereta (Correspondence, 8th June 2007 Jamieson), and a copy of the April 2009 Survey by NZWR (2009a).

A copy of the aquatic transfer (AQTRANS 02/58) was sourced from MPI (October 2013). The aquatic transfer was for 36,500 grass carp larger than 65mm to be released into Lake Kereta and was dated the 1st of February 2008. An operational plan, and an EIA for the introduction of grass carp into Lake Kereta (Mitchell 2007), were also obtained from MPI.

There were four grass carp releases between March 2008 and April 2009 totalling 14799 fish, although nearly a third of these were under 10cm in length (i.e., 1600, 2208 and 5991 grass carp from >15cm to ≤ 20cm in March 2008, March 2009 and April 2009 respectively, and 5000 fish from > 6cm to ≤ 10cm in May 2008) (from G Jamieson, see de Winton 2012). Assuming no mortality the stocking rate would be over 500 grass carp per hectare, which is well above the recommended high rate of 100/vegetated hectare. Because of likely losses, due to shag predation shortly after stocking, the actual stocking density in the lake, in number per vegetated hectare cannot be determined.

The objectives as outlined in Mitchell (2007) were to introduce grass carp and manage stocking density to remove ca 70% of the nuisance aquatic plants in the long term and to maintain the plants at or below that level, and to maintain a varying stocking density of fish suitable to achieve the objectives. “The intention is to ultimately eradicate hornwort from the lake” (Mitchell 2007).

3.2.1.2 Ecology and biology of the lake before grass carp release

Flora

AQPD records from 1988 include *G. elatinoides, M. triphyllum, Nymphaea* sp., *Azolla pinnata, E. acuta, L. novae-zelandiae, P. cheesemanii, Potamogeton crispus, S. tabernaemontani, T. orientalis, E. sphacelata, Juncus* sp. and *Zizania latifolia*. Earlier records (Cunningham et al. 1953) describe some of the same species, for example, a dense stand of *E. sphacelata* was growing in stagnant water. *E. sphacelata*, milfoil and pondweeds rooted in the soft peaty substrate in a bay, and *Z. latifolia* was found around the southern shore of the lake (Cunningham et al. 1953). The western shoreline vegetation was absent in the more exposed situations (Cunningham et al. 1953).

A decade later the predominantly native vegetation had been displaced by hornwort (Gibbs et al. 1999). A survey in November 1999 found the entire lake bottom was dominated by hornwort apart from areas of planted waterlilies and southern marginal areas where the introduced Manchurian wild rice and the indigenous sedge *S. tabernaemontani* formed emergent marginal communities. Scattered plants of *M. triphyllum* were found in the areas dominated by waterlilies (Gibbs et al. 1999).

Fauna

NZFFD records all precede the release of grass carp into Lake Kereta and list the following species; common bully, rudd, tench, gambusia, goldfish and koi carp. The role of the exotic fish species, in particular rudd and koi carp, in the decline in water clarity has been documented (Rowe et al. 2003), with Lake Kereta descried as having low water clarity and high levels of suspended solids (Rowe et al. 2003).

Mitchell (2007) identified the dominant fish species as perch, tench and gambusia, reflecting that "because it is lacking a defined outlet to other waterbodies, the lake is unavailable to unassisted colonisation by native freshwater fishes. But for decades this lake has been a target for experiments with illicit releases of exotic fish: as a result there are at least six species of exotic fish present in the lake. In addition there are a few common bullies still present, probably relics of original introduction of native fishes by Maori".

Extensive beds of freshwater mussels were noted in the lake in 1953 (Cunningham et al. 1953) and a range of common macroinvertebrate taxa were evident amongst the weed beds in 1999 i.e., damselfly larvae (*Xanthocnemis zealandica*), hemipterans (*Sigara*), copepods and midge larvae (*Naonella forsythi*) were evident in both samples, as well as large numbers of aquatic mites (Acarina) (Gibbs et al. 1999).

Planktonic rotifers were sampled from Lake Kereta as part of a larger (33 lake) study, although species data were not described for individual lakes by Duggan et al. (2001). A list of the taxa can be found in Gibbs et al. (1999, which refers to the PhD thesis of Duggan 1999). Subsequently rotifer assemblages were also used to assess changes in lake state (Fowler and Duggan 2008).

Grey ducks (*Anas superciliosa*), black swans, pied stilts, and dabchicks were recorded from Lake Kereta by Cunningham et al. (1953). Gibbs et al. (1999) noted a large population of black swans, and Mitchell (2007) also lists mallard ducks, paradise shelduck, pukeko, welcome swallows, kingfishers, Caspian tern, white faced heron, black shag, little shag and spur-wing plover.

Water Quality

Between 1992 to 2002, Lake Kereta was highly turbid and the water quality was poor, with very high faecal coliform counts (well above the recommended guideline of 200 MPN for bathing waters) that have been attributed to the unrestricted access of stock to the lake and the large population of waterfowl (Table 7). In 1999, the faecal coliform counts and turbidity (excluding storm events) were described as declining, which indicated an apparent overall improvement in water quality (Gibbs et al. 1999). The lake was also described as highly enriched and capable of producing large algal blooms given the right conditions (Gibbs et al. 1999). In 2000, water quality variables were regarded as similar in magnitude to previous years and most notable for elevated faecal bacteria concentrations and occasionally very high pH values (Wilcock and Kemp 2000).

Table 7: Summary water quality data for Lake Kereta

Water quality and bacteriological data from surface water samples	Gibbs et al. 1999 Annual mean data from 1992 to 1998			Wilcock & Kemp 2000 Values from Feb, Aug and Dec 2000		Wilcock & Martin 2003 Values from Jan - Dec 2002	
	Min	Mean	Max	Median	Mean	Median	Mean
pH	7.5	8.5	9.8	9.2	9.3	9.3	9.3
Conductivity (mS/m)	21.4	26.3	34.5				
Chloride (mg/l)	23.5	42.3	61.1	44.4	43.9	42.6	42
BOD (mgO/l)	1.6	2.7	3.3	1	1	1	1
Turbidity (NTU)	1.7	6	16	3.49	3.46	1.4	1.5
SS (mg/l)	2.9	10.1	31	4.5	4.9	1.2	1.9
Chlorophyll *a* (µg/l)	5	17.7	60.2	5.9	7.4	2.8	3.2
Faecal coliform (MPN)/100ml	4	479	5400	33	182	130	140
Presumptive coli (MPN)/100ml	39	676	5400	500	450	200	208
P (m/f) (µg/l)	6	11.4	26				
P (total, (µg/l)	20	48.3	83	20	17	20	20
NH_4/NH_3 (µg/l)	4	19.6	137	10	15	5	9
NO_2 (µg/l)	1	2.6	4	1	1		
NO_3/NO_2 (µg/l)	3	7.6	15	6	5	9	9
TKN (mg/l)	0.2	0.9	2	0.5	1.8	0.3	0.8
NB: Cunningham et al. (1953) report at 3m secchi. Livingstone et al. (1986) secchi was a max of 3m in Feb 1950 and a min of 1.5m in Feb 1973 with only two readings between the studies.							

Habitat Quality

Lake Kereta is described as a "degraded lake" that should be managed to improve its overall water quality i.e., less turbidity, less bacteria, lower nutrients, and less risk of developing algal blooms (Gibbs et al. 1999). Its severely degraded water quality (as indicated by high turbidity, high faecal coliforms, and high nutrients) is attributed directly or indirectly to two main factors, "the direct access of stock to the water — defecating directly into the water (bacteria, nutrients), bank erosion and bed destabilisation (turbidity, suspended solids), grazing marginal fringe plants (removal of buffer zone for groundwater nutrients)" and the "presence of coarse fish — grazing aquatic macrophytes and preventing their regeneration in spring (switch to phytoplankton dominance, increasing nutrients through lack of plant uptake), disturbing the lake bed while foraging (suspended solids, high turbidity)" (Gibbs et al. 1999).

In using rotifer assemblages to infer trophic state, Fowler and Duggan (2008) consider that Lake Kereta "began the study as mesotrophic/eutrophic but ended as eutrophic/supertrophic".

The change in habitat quality within the lake may be best represented by the shift in lake condition following the introduction of hornwort (Table 8). For example the LakeSPI index shows a significant decline in native plant habitat with the invasion of hornwort (see http://lakespi.niwa.co.nz/lake/49884).

Table 8: LakeSPI Report Card summary for Lake Kereta

LakeSPI Index Native Index Invasive Index

Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
February 2012	Non-vegetated	0%	0%	0%
October 2008	Poor	8%	4%	96%
November 1999	Poor	15%	21%	93%
February 1988	Excellent	82%	67%	6%
January 1950	Excellent	100%	100%	0%

Sourced http://lakespi.niwa.co.nz/lake/49884, January 2014.

3.2.1.3 Ecology and biology of the lake after grass carp release

Flora

Observations made by NIWA in 2008 (after grass carp release earlier in 2008) showed hornwort extended at >75% cover over most of the open water areas of the lake, with heights of between 0.5 and 2m (de Winton et al. 2009a). Other species recorded in the lake included *T. orientalis, M. articulata, Z. latifolia, E. acuta, I. prolifer, L. peploides* subsp. *montevidensis* and *S. tabernaemontani.* In 2009 the NZWR report describes hornwort as still abundant (NZWR 2009a).

By 2012 only remnant hornwort plants were located, it was “apparent that most of the weed biomass (>99.9% of previous levels) has been removed from the lake” (de Winton 2012). Other aquatic plant species (e.g.,*T. orientalis, L. peploides, M. triphyllum, G. elatinoides*, *Nitella*) were restricted to the margins of the water. Beds of at least two *Nymphaea* cultivars were still present, although the extent of them had been reduced and rhizomes widely dispersed around the lake.

Amongst the wetland, heavy grazing and uprooting (e.g., *E. sphacelata, I. prolifer*) was noted at the lake margin. In more open areas of water within the wetland *U. gibba*, *Landoltia punctata* and *A. pinnata* were also recorded (de Winton 2012).

Although there was a significant reduction in hornwort by 2012, hornwort was yet to be eradicated and it was considered that there was a high likelihood of hornwort persisting under the current lake conditions for some time. Of particular concern was the refuge habitat provided by beds of *Z. latifoila* and the presence of hornwort in an adjacent (currently disconnected) basin of the lake to the north (de Winton 2012).

Fauna

Although there are few data available, with only fish observations from 2009 (NZWR 2009a), no changes have been noted compared with before grass carp release.

However, a recent study (Duggan et al. 2014) has indicated a change in the relative abundance of copepods in Lake Kereta following the release of grass carp. Rather than direct or indirect effects of grass carp, the reduction in a native New Zealand copepod (*Calamoecia lucasi*) is attributed to competition with a Northern American copepod (*Skistodiaptomus pallidus*) (Duggan et al. 2014).

Water Quality

Trends in water quality described by Hammill (2014) over the previous decade include; no statistically significant trends in the TLI score or its constituent variable (TN, TP, and Chl *a*) over the long term or short term, although there was considerable inter-annual variation in water quality. Periods of relatively good water quality occurred between about 2001 and 2006, and between 2009 and 2010, with periods of particularly poor water quality (chl *a* concentrations were regularly over 60 mg/m^3), in 2006 to 2008 and in the summer of 2011/12. This corresponded to high concentrations of TN and TP and occasional low concentrations of dissolve oxygen (DO). However since 2010 the percent saturation of DO in the lake has become more stable, "which probably reflects the loss of hornwort from the lake with the introduction of grass carp" (Hammill 2014).

Habitat Quality

Lake Kereta was regarded as in poor condition prior to the release of the grass carp (LakeSPI), and as recently as 2012 there was no indication that this had improved.

Summary of effectiveness and effects

The information review from Lake Kereta provides challenges for assessment, firstly because there is limited information before and after stocking, but also because the actual or effective stocking density of grass carp is unknown. Fingerling grass carp were approved for release (against DOC policy) due to the low likelihood of any fish escaping. However the losses of fish in this size class from predation (piscivorous fish and shags) are unknown but suspected to be high (de Winton 2012). So although there was a significant reduction in hornwort by February 2012 (de Winton 2012), the actual stocking density of grass carp that achieved this is uncertain. However given that there was >99% weed biomass removed by 2012, it is likely that grass carp browsing between 2008 and 2012 was responsible. Hence, the 'unknown' stocking density was high enough to achieve effective control. In this case, as compared with Lake Omapere where small grass carp were also stocked, the high number of small grass carp was large enough to offset losses from predation.

Effectiveness	Flora: Effective control of hornwort was achieved, with a significant reduction in abundance of the target species, four years after stocking with grass carp. Only a few fragments of hornwort were noted in 2012.
Effects	Flora: Native submerged macrophytes were already impacted by the invasive weed hornwort. Native plants are currently restricted to the margins. Fauna: Limited information. No changes noted, other than for copepods. Water quality: In the decade preceding grass carp stocking Lake Kereta was described as a degraded lake. No significant trends in the TLI score or its constituent variables (TN, TP and Chl *a*) have been detected over the long or short term. There has been considerable inter-annual variation in water quality, although the DO has been more stable since 2010. Habitat quality: Poor condition since the invasion by hornwort (LakeSPI). Other than stabilised DO, there have been no indication of improved habitat quality since the removal of the weed beds.

3.2.2 Lake Wainamu

Lake Wainamu is a 15ha lake situated near Bethells Beach on Auckland's West Coast (Appendix C). The lake was formed by the damming of three streams by a sand dune at its western end (Champion 1995). The catchment is steep and covered with forest (ca 85%), the remainder in pastureland and scrub (Wilcock and Kemp 2000). However a photo from 1979 shows that pasture on both the western and eastern sides of the lake was more extensive at that time (Rowe and Smith 2001). The majority of the land surrounding the lake is part of the Lake Wainamu Scenic Reserve (Surrey 2008).

The lake itself is ca 15m deep (Gibbs et al. 1999), however the lake depth varies over time. For example the deepest depth record in a 2001 survey was 12.8m (Rowe and Smith 2001).

3.2.2.1 Grass carp stocking – When, how many and why

The DOC files contained a copy of an EIA (Champion 1995), and a post release monitoring report by ARC (Surrey 2010). A copy of the aquatic transfer (AQTRANS02/60, 2008), and the approved operational plan and EIA (Surrey 2008) were provided by MPI.

The invasive weed, egeria had formed surface reaching weeds beds around the perimeter of the lake, and had "the potential to precipitate a vegetation collapse in the lake if the biomass of egeria continues to increase, which would reverse recent observed improvements in lake water clarity." The ARC sought to introduce grass carp to the lake in order to eradicate egeria and allow the natural re-establishment of the native charophyte communities that existed prior to the weed infestation (Surrey 2008).

The operational plan, required as part of the approval process, stipulated that 6 monthly monitoring would be undertaken to " assess the impact that the grass carp are having on the biomass and composition of aquatic vegetation in the lake, as well as keeping track of the number of grass carp that survive" (Surrey 2010). The plan was to remove the fish once eradication of the egeria had been determined (Operational plan Lake Wainamu, Surrey 2008).

In March 2009 ARC released 270 grass carp in order to eradicate the egeria that had virtually eliminated the lake's formerly abundant native aquatic vegetation and was also affecting recreational values for users (Surrey 2010). The grass carp were inserted with PIT tags, and were of approximately 350 mm in length, but no less than 250 mm (AQTRANS02/60, 2008). The target stocking rate was 100 fish per vegetated hectare.

3.2.2.2 Ecology and biology of the lake before grass carp release

Flora

The AQPD has records of the following species in Lake Wainamu from surveys from 1990 to 2005 and 2007; *U. gibba, M. articulata, C. australis, E. sphacelata, N. pseudoflabellata, Nitella* sp. aff. *cristata, Typha orientalis, Carex* sp., *E. acuta, S. tabernaemontani, C. fibrosa, C. globularis, G. palustre, Isachne globosa, L. punctata, O. ovalifolia, E. densa, Myriophyllum aquaticum, Ludwigia peploides* subsp*. montevidensis* and *A. pinnata.* Phytoplankton species from 2004 and 2005 sampling events are listed in Rowe et al. (2005).

In the early 1990's the submerged vegetation in Lake Wainamu was primarily native with a narrow band of pondweed *(P. ochreatus*) between 2 and 3m water depth and the charophyte

C. australis growing to 4.5m. The introduced *U. gibba* occurred as a sprawling mat over submerged plants (Figure 2) (Champion 1995).

Egeria was first noted at the outflow from the lake in 1990. Weedmat was laid over the majority of the egeria in an attempt to prevent its spread into the main body of the lake. However during an inspection egeria was noted growing between the weed mat and a plug of floating raupo and spike sedge which completely blocked the outlet of the lake at that time. Egeria colonisation of the lake occurred over the next two years (Champion 1995).

By 1995 egeria had established in Lake Wainamu, and occupied the entire perimeter within the lake, from the outside edge of the emergent vegetation to 4m water depth, with some plants found down to 5.5m (Figure 2) (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, with only emergent marginal plants growing around the entire lake (with the exception of the mobile dune face), extending to a depth of 2.5 m (Gibbs et al. 1999).

Vegetation recovery occurred several years later. In less than one year (since Nov 2004), there was a substantial increase in the abundance of the submerged vegetation and an extension of the depth range occupied by plants (de Winton et al. 2005). Whilst egeria was the most abundant submerged macrophyte, areas of native charophytes had also developed from seed banks in the sediment. This vegetation recovery was considered due to improved water clarity over the previous year (de Winton et al. 2005). It may also be related to decreased disturbance by coarse fish following control measures, as these fish may directly impact plant establishment in addition to the indirect influences mediated via water clarity. Further the increase in the presence of submerged macrophytes may both influence and reflect the ecological conditions of the lake. "For example, continued improvement in water quality may in turn be influenced by the rate and extent of vegetation development, while the expansion of egeria and potential for pest fish numbers to increase raises concerns over vegetation stability and the risk of a future vegetation 'crash' "(de Winton et al. 2005). Although an increase in macrophyte cover was seen as important for the maintenance (and further improvement) of clear water within the lake, it was also recognised that the initial cause of the submerged plant decline after 1995 was unknown and that the cycle of plant decline and increased turbidity could therefore occur again (Rowe et al. 2005).

By November 2007, egeria had increased substantially in Lake Wainamu, with an estimated 2.2ha of the lake now occupied by the weed. The vegetation in the lake was considered unstable, and at moderate to high risk of collapse and further reduction in lake conditions likely (de Winton et al. 2008).

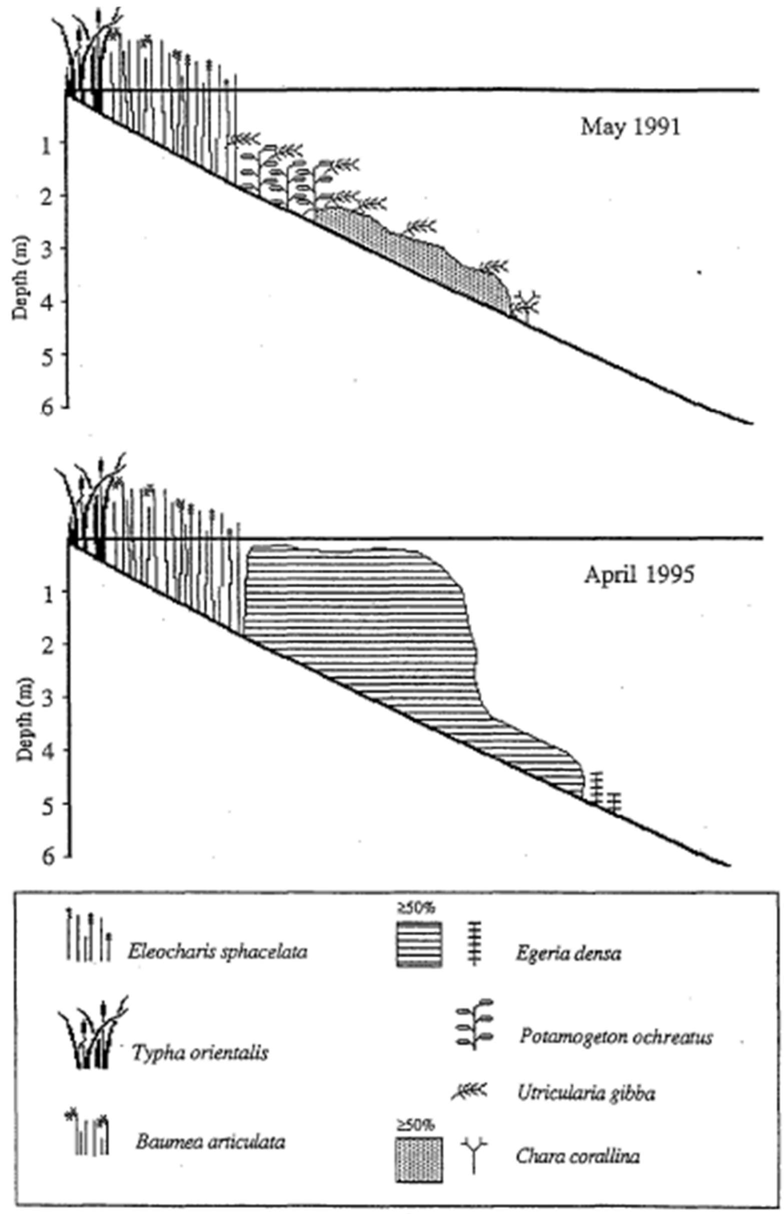

Figure 2: Profile of submerged vegetation in Lake Wainamu before and after invasion of the lake by egeria (sourced from Champion 1995).

Fauna

NZFFD records include, rainbow trout, catfish, goldfish, perch, rudd, tench, common smelt, short and longfin eels, banded kokopu, inanga, common bullies and grey mullet.

A very large population of small (up to 20cm long) perch was noted during the scuba inspection in 1995 (Champion 1995). A decline in the local mullet population, and the presence of pest fish koi carp was also reported (Champion 1995), although no koi have been found since and it has been suggested that this fish was a mis-identified goldfish by locals (Surrey 2008). Gambusia were reported by Gibbs et al. (1999). No mussels found in the November 1999 survey (Gibbs et al. 1999).

A comprehensive survey of the fish fauna was undertaken by Rowe and Smith (2001) to determine whether koi carp and/or other pest fish could be responsible for the turbid condition of Lake Wainamu. No koi were found in the lake. Exotic fish included perch, goldfish and gambusia and tench. Native species included eels, bullies, mullet and shrimps, but no crayfish. Although eels were abundant, and mullet were present it was apparent that populations of other native fish (bullies, smelt, and banded kokopu) had declined, subsequent to the introduction of exotic fish (Rowe and Smith 2001).

"A programme of netting carried out by ARC since 2004 has resulted in close to 10,000 exotic fish being removed from the lake, with 85% of these being perch. This has virtually eliminated large perch from the lake, although there are still juvenile fish present." "Netting continues to be carried out annually in order to manage the exotic fish populations" (Surrey 2008).

A range of macroinvertebrate taxa have been recorded from the littoral zone of Lake Wainamu, all of which are common. For example, hemiptera (*Sigara* sp.), mites (Acarina), snails (*Physa* sp., *P. antipodarum*, *Lymnaea columella),* Hydrophilidae beetle larvae, damselflies (*Xanthocnemis zealandica)*, caddisflies (*Paroxyethira hendersoni*), chironomids larvae, copepods and amphipods (*P. fluviatilis*), and oligochaete worms (Gibbs et al. 1999, Surrey 2008).

Planktonic rotifers were sampled from Lake Wainamu as part of a larger (33 lake) study, although species data were not described for individual lakes by Duggan et al. (2001). A list of the taxa can be found in Gibbs et al. (1999, which refers to the PhD thesis of Duggan 1999). Subsequently rotifer assemblages were also used to assess changes in lake state (Fowler and Duggan 2008). Zooplankton species from 2004 and 2005 sampling are listed in Rowe et al. 2005).

The nearby Te Henga wetland and Lake Wainamu both contain several rare birds; banded rail (*Rallus philippensis*) and Australasian bittern, and the North Island fernbird and spotless crake (Champion 1995). Weed beds had little effect on bird life. Waterfowl recorded as present at the lake include, black swan, mallards, grey duck, little black shag, pied shag, paradise shelduck, and pukeko (Surrey 2008).

Water Quality

Lake Wainamu is classified as a eutrophic lake (Surrey 2008) that, based on water quality data from 1992 onwards (Table 9), had a notable decline after 1995 (Gibbs et al. 1999). Lake Wainamu was further described as a transitional lake, meaning that it "needs to be managed to stop the switch from aquatic plant dominance to algal dominance" (Gibbs et al. 1999).

A review of water quality monitoring data undertaken in 1999, indicated that a sudden change in water quality had occurred over the preceding 5 years, with the lake having switched from aquatic macrophyte domination to phytoplankton domination. In addition it appeared that light limitation was preventing the full use of the available nutrients by the phytoplankton present (Gibbs et al. 1999). It was hypothesised that the presence of coarse fish in the lake may have contributed to switching the lake (Gibbs et al. 1999, Rowe and Smith 2001). However, inspection of the lake also showed that livestock had unrestricted access, although steep banks may prevent extensive activity except perhaps where the steam inflows enter at the south-eastern end of the lake (Gibbs et al. 1999).

During the 1990s the degraded water quality was illustrated by the high turbidity associated with high suspended solids, reduced water clarity (Figure 3) and occasionally elevated faecal coliform counts (Gibbs et al. 1999). Thermal stratification occurs in summer and the hypolimnion becomes anoxic with substantial nutrient releases from the sediments. The water quality continued to deteriorate as indicated by the loss of submerged plants, the increase in nitrate concentrations, the increase in phytoplankton biomass, and the further reduction in water clarity (Gibbs et al. 1999).

The cause of the change in water quality was probably related to the high nitrate levels that occurred in the water column in late 1995. The timing of water quality change (Gibbs et al. 1999) indicated that nitrate levels increased markedly in the winter of 1995 and that this preceded the summer increase in both phytoplankton (chl a) and turbidity. Macrophytes were growing to a depth of 5.5m in April 1995 so the collapse is unlikely to have preceded the increase in nitrate in 1995. This sequence of events indicates that the increased turbidity in the lake after 1995 was mainly biological in origin and was caused by a high annual production of planktonic algae with the later collapse of macrophytes then exacerbating this (Rowe and Smith 2001). From 2000 to 2004 similar water quality data was observed to previous years (Wilcock and Kemp 2000, Macaskill and Martin 2004). The optical model developed for the lake indicated that its turbidity is caused mainly by suspended organic particles (Rowe et al. 2005).

Habitat Quality

The condition of Lake Wainamu has been reported for six occasions since 1991 using LakeSPI. Data from 1991 to 2005 (Table 10) show changes in the condition of the lake and its habitat quality as a consequence of the impact of invasive species and the associated low native condition. In 2005 the LakeSPI condition score was 24%, indicating the relatively impacted waterbody with restricted vegetation development due to poor long-term water clarity, and widespread invasion by submerged weeds. It was anticipated that the condition would decline further in the future with continued development and dominance by egeria (de Winton et al. 2005).

By 2007 the invasive condition index (LakeSPI) of the lake was close to the maximum of 93% recorded in 1995, prior to the vegetation collapse (de Winton et al. 2008). The possibility of a future vegetation decline and a return to a highly turbid lake, was of a moderate to high risk. The lake factors that would contribute to a plant collapse were described as the development of surface-reaching egeria beds, a poor and variable light climate persisting, and increased disturbance from coarse fish populations (de Winton et al. 2005).

Table 9: Summary of water quality and bacteriological data from surface and bottom water samples.

Parameter	Gibbs et al. 1999 Annual mean data from 1992 to 1998	Wilcock & Kemp 2000 Median, Mean values from Feb, Aug and Dec 2000	Wilcock & Martin 2003 Median, Mean values from Jan – Dec 2002
pH	7.6 (7.3)	7.6 (7.4), 7.7 (7.3)	8 (7.8), 8 (7.7)
Conductivity (mS/m)	22.0 (21.4)		
Chloride (mg/l)	42.2 (41.3)	35.6 (35.8), 36 (36.4)	40.5 (40.5), 40.3 (40.5)
BOD (mgO/l)	2.1 (0.4)	1 (1), 1 (1)	1 (1), 1.4 (1)
Turbidity (NTU)	8.4 (10.8)	11 (12), 12.07 (13.07)	11.5 (11.7), 11.7 (12)
SS (mg/l)	3.9 (4.4)	3.7 (2.8), 3.7 (2.9)	3.7 (3.2), 4.2 (3.1)
Chlorophyll *a* (µg/l)	11.6 (12.6)	9 (6), 9 (37)	15 (7), 13 (7)
Faecal coliform (MPN)/100ml	26 (15)	4 (8), 5 (8)	29 (15), 141 (16)
Presumptive coli (MPN)/100ml	97 (33)	30 (23), 30 (32)	50 (15),203 (21)
P (m/f) (µg/l)	11 (13.8)		
P (total, (µg/l)	37.1 (68.4)	30 (40), 13 (17)	15 (15), 18 (15)
NH_4/NH_3 (µg/l)	16.6 (19.7)	5 (30), 13 (30)	5 (20), 6 (19)
NO_2 (µg/l)	3.2 (5.0)	4 (4), 4 (4)	
NO_3/NO_2 (µg/l)	22.5 (27.3)	7 (8), 25 (26)	19 (23), 30 (31)
TKN (mg/l)	0.4 (0.4)	0.3 (0.5), 0.4 (0.5)	0.5 (0.8), 0.8 (0.9)
NB: Bottom water sample data are recorded in brackets. Rowe and Smith (2001) secchi disc reading (mean of 3) was 1.25m. Rowe et al. (2005) secchi disc exceeded 2.5m			

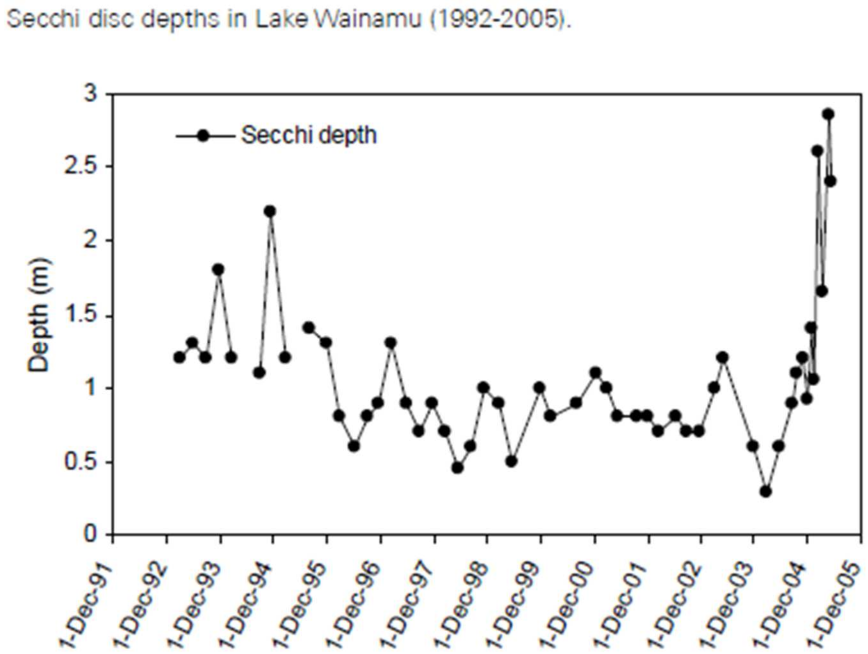

Figure 3. Water clarity sourced from Rowe et al. (2005).

Table 10: LakeSPI Report Card summary for Lake Wainamu

LakeSPI Index Native Index Invasive Index

Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2011	Non-vegetated	0%	0%	0%
November 2007	Poor	16%	16%	85%
October 2005	Moderate	24%	22%	73%

Sourced http://lakespi.niwa.co.nz/lake/45819, January 2014.

LakeSPI scores for the current Lake Condition together with estimated scores on three other occasions. Earlier results are indicative only.

Date	LakeSPI (%)	Native condition (%)	Invasive condition (%)
2005	24	22	73
2004	15	0	81
1995	8.5	0	93
1991	60	41	15

Sourced from de Winton et al. (2004).

3.2.2.3 Ecology and biology of the lake after grass carp release

Flora

In the EIA (Surrey 2008) it was "anticipated that the successful stocking of grass carp into Lake Wainamu will result in the ecological state of the lake changing from a macrophyte-dominated system to a devegetated system for a period of time, before the grass carp are removed and recolonisation by native aquatic plants can occur".

The release of grass carp in March 2009 was followed by a marked decrease in the amount of egeria by April 2010 (Surrey 2010). The "grass carp had reduced the overall heights of the egeria beds in the lake between October and April, although their depth range was still similar" (Surrey 2010). By 2013, it was considered "very likely that all of the egeria has been removed from the lake" (Correspondence December 2013 NIWA), although plants were present in the outlet stream.

Fauna

Surrey (2008) in the EIA stated that "eradication of egeria from the lake will reduce the amount of cover and food available for the fish species already present. This may lead to increased predation by piscivorous birds, such as shags, although the main species likely to be affected will be exotic coarse species, such as goldfish, perch and rudd." The "efficiency and effectiveness of ARC's annual exotic fish removal programme is likely to be increased when the weed beds are eliminated, as the exotic fish will have fewer refuges to hide in and less time will be spent by staff clearing weed entangled nets". Waterfowl were considered unlikely to be impacted as they would be capable of moving to new locations (Surrey 2008).

No reports have been located that detail the response of fauna to the removal of most of the weed or the related presence of grass carp.

Water Quality

Surrey (2008) in the EIA stated that "De-vegetation of the lake bed by grass carp will therefore increase the likelihood that the lake may change to a more turbid state in the short term, at least until the carp are removed and native vegetation can re-establish to assist in binding lakebed sediment. However, long-term turbidity impacts following vegetation collapse, as occurred between 1995 and 1999, are likely to occur if the egeria is left to grow unchecked (de Winton et al. 2008)".

Hammill (2014) reports an apparent improvement in the TLI score in Lake Wainamu over the 20 year period (1993 to 2012), caused by better water clarity (secchi depth) during the period 2005-2010, and a decline in TP concentration since about 2009. However it was also noted that there have been changes in monitoring and laboratory methods (Hammill 2014). Changes in water clarity, TSS and turbidity were attributed to changes in macrophyte cover in the lake, with poorer clarity during periods when the lake had little macrophyte cover (Hammill 2014).

Habitat Quality

As predicted the lake has been devegetated by the grass carp (Surrey 2008), with no submerged plants present. No reports have been located that detail the response in habitat quality to the presence of grass carp.

Summary of effectiveness and effects

Effectiveness	Flora: Target weed species removed within four years.
Effects	Flora: Native vegetation was compromised by the invasive weed, and a prior vegetation collapse. Without intervention, grass carp presence will prevent the re-establishment of native submerged aquatic plants. Fauna: Data deficient. Water quality: An apparent improvement in the TLI score in Lake Wainamu over the 20 year period (1993 to 2012), caused by better water clarity during the period 2005-2010, and a decline in TP concentration since about 2009. Poorer water clarity was noted when there was little plant cover. Habitat quality: The submerged plants have been removed by the grass carp, but there is little or no additional information on habitat quality.

3.3 Auckland Region – urban or man-made ponds

The majority of the ponds in this section function primarily as stormwater retention ponds. In general they have limited natural values and compromised water quality, characterised by low clarity, high suspended sediment and/or nutrients. Given the primary function is not as natural systems, few biodiversity data or monitoring information were available for these ponds (compared with the lakes in this report) and the structure of this section reflects the limited available information.

3.3.1 Maygrove Lake

Maygrove Lake is an artificial lake and a stormwater retention pond located adjacent to Lakeside Drive and Chalmers Close in the Maygrove residential estate, Orewa, Auckland (Operational Plan for Maygrove Lake 2007) (Appendix C). The pond is ca 1.01 hectares and has a maximum depth of 2m, it receives water directly from rainfall and immediate runoff around the pond and from storm water inlets serving the surrounding residential catchment. There is a purpose built concrete outlet (Operational Plan for Maygrove Lake 2007). Although constructed primarily to manage storm water within its catchment, the pond was also designed as an ornamental feature for the area (Decker 2007a).

The DOC files contained three surveys of Maygrove Lake (NZWR 2007, Aquaculture NZ 2009a and 2009b). Copies of the aquatic transfer (AQTRANS 02/39, signed in February 2007), the operational plan (2007) and the EIA (Decker 2007a) were obtained from MPI.

The purpose of introducing grass carp was to control aquatic weeds i.e., “prevent nuisance aquatic plants becoming a problem in the pond” (Operational Plan for Maygrove Lake 2007). The objective was to maintain a stocking density that would achieve the desired level of weed control (Operational Plan for Maygrove Lake 2007). The EIA states the weed is *Lagarosiphon* (Correspondence November 2006, MFish).

The introduction of 100 grass carp of ca 250 mm in length was proposed (Operational Plan for Maygrove Lake 2007), and also described as 100 fish per vegetated hectare (Decker 2007a).

3.3.1.2 Ecology and biology of the lake before grass carp release

The pond is described as having no particular seasonal use for plants, fish, birds or other animals, with no rare or endangered species present (Decker 2007a). The EIA lists eels, gambusia and goldfish in the pond, and five species of bird at the site (mallard/grey ducks, kingfisher, plover, pukeko and shags) (Decker 2007a).

Water level in the pond is controlled by a weir, and the discharge passes over the weir into the estuarine area of the Orewa River (Correspondence November 2006, MFish). The pond has a maximum depth of 2m, and basic water quality data is presented in the EIA (e.g., temperature 12.7 °C, DO 7.35 mg/L, pH 8.22, Secchi 15cm, (Decker 2007a)).

Plants identified within the pond were as follows; *Lagarosiphon major*, filamentous algae, *Nymphaea* spp., water cress and paspalum. Of these the lagarosiphon and the algae were described as abundant in the EIA (Decker 2007a).

The aquatic plant growth in the pond was considered to reduce the aesthetic value of the pond and compromise its ability to manage storm water (Decker 2007a). The weed cover was estimated as 90% in a 2006 survey (Decker 2007a).

3.3.1.3 Ecology and biology of the lake after grass carp release

The NZWR monitoring report (2007) describes a "noticeable decrease in lagarosiphon" and 70% floating aquatic weed (NZWR 2007). In that report, the aquatic weed egeria is described as sparse, and *P. crispus* as present. So it would seem that since the EIA was completed, additional aquatic species have become established in the lake (i.e., they were not mentioned in the plant list in the EIA).

Subsequent monitoring reports in 2009 (Aquaculture 2009 a, b) record 70% and 60% weed cover for September and November respectively. In September no lagarosiphon was recorded, and egeria was the only submerged macrophyte recorded. However, in November both species were listed.

The Aquaculture NZ 2009a report states that the lake has "recently undergone a major spraying programme of nuisance aquatic plants". "Our survey showed it has been successful for causing a reduction in the volume of above surface aquatics such as raupo, various sedges, and large leaf water lily. However it appears to have had little effect on submerged species, that include large quantities of egeria and filamentous algae in the lake." In the subsequent report it is suggested that erecting an outlet screen should be revisited, given the increase in nuisance aquatic plants since the September survey (Aquaculture NZ 2009b).

Based on this sparse monitoring data, there appears to have been limited weed control. Although the absence of a security/containment screen as indicated in a monitoring report (2009a) leaves a degree of uncertainty as to how many (and for how long) fish remained in the pond. There were no records to indicate that grass carp are still in the lake.

Rudd were noted in the pond and described as common along with goldfish, and gambusia were abundant and eels sparse. The same bird species were reported as those seen in the survey for the EIA, in addition black backed gulls and white faced heron were also recorded at the pond (NZWR 2007). No discernable impacts on other fish and waterfowl by grass carp, were noted.

The limited water quality information available describes the pond water quality as "good" or "satisfactory" with the bottom sediment of the pond visible in 2007 (NZWR 2007) and secchi readings of 0.3 and 0.5m in September and November 2009 respectively (Aquaculture NZ 2009a, b). No discernable impacts by grass carp were noted.

Summary of effectiveness and effects

Maygrove Lake is an artificial lake and storm water retention pond, with little natural values. No negative impacts on the values and function of the pond have been noted as a consequence of the grass carp. However it seems plausible that grass carp may have escaped, and compromised effectiveness of the weed control.

Effectiveness	Flora: Limited information on which to base an assessment of effectiveness when grass carp are likely to have escaped and the stocking density was uncertain.
Effects	Flora, fauna, water and habitat quality: No effects of grass carp have been recorded in this man-made stormwater retention pond.

3.3.2 Link Drive

The Link Drive pond is a shallow (average depth ca 1.5 m) 1.2 ha man-made stormwater retention pond on the North Shore of Auckland (Appendix C).

The catchment containing the pond is in the Auckland suburb of Glenfield, and is immediately surrounded by retail outlets and roads. Access to the pond is off Link Drive from Target Road. Both the inlet and the outlet are boxed culverts to control stormwater, and a float regulated weir controls the flow through the outlet, and hence the water level within the pond (Jamieson Holdings 1996). The pond and catchment hold no endangered or particularly environmentally sensitive species. The outlet flows into the tidal portion of Wairau Creek (Decker 1996a).

3.3.2.1 Grass carp stocking – When, how many and why

DOC files included seven monitoring reports from July 2005 to November 2009 (NZWR 2005 – 2009). A copy of the risk assessment report (Decker 1996a), the MFish approval for further transfer of grass carp into the Link Drive pond (MFish 2010) and some correspondence was provided by MPI.

The purpose of introducing grass carp into the Link Drive pond was to control the macrophytes and along with silver carp the algal blooms (Decker 1996a). The aim was to improve the aesthetic value of the pond and the water quality, and it was anticipated that the introductions would have little if any adverse environmental impacts (Decker 1996a). The proposed initial stocking rates in the risk assessment report (RAR) were 150 grass carp and 50 silver carp for a pond with ca 95% weed cover (Decker 1996a). An approval was granted in 1996 (AQTRANS0039).

Subsequently, there was a MFish approval to release further grass carp, dated 31st August 2010 (CA150). The approval was to release 25 grass carp (of a minimum size 25cm), into the Link Drive pond (Site 98/CA150), to control aquatic weed (50% egeria, filamentous algae and willow weed) (Correspondence 31st August 2010, MFish). In the recommendation report it was noted that there were concerns over the screens on the Link Drive site, as the electrified barrier had proven to be ineffective, and indicates that further stocking of grass carp would be sought, once a suitable screen was in place (Correspondence 31st August 2010, MFish).

Further comments on the Link Drive pond indicate that grass carp escaped from the pond on more than one occasion, and were removed from the pond prior to a large silt removal operation although the intentions were to replace them post operation (DOC unpublished records, 2010). No records were found to indicate that grass carp have since been reintroduced.

3.3.2.2 Ecology and biology of the lake before grass carp release

Decker (1996) describes extensive beds of macrophytes covering ca 95% of the pond and restricting the flow-through of water. The plants are highly visible and trap litter that enters the pond. Waterfowl are also affected as the bed of macrophytes promote avian botulism (Decker 1996a).

An electric fishing survey carried out in 1996 found the following species, bullies, eels (short and longfin), mosquito fish, tench, goldfish and koi carp. Few macroinvertebrate taxa (e.g., dragonfly nymphs, caddisfly larvae and waterboatmen) and waterfowl (e.g., ducks and shags) have also been observed in the pond (Decker 1996a).

Water quality in the pond was considered "poor due primarily to the "choking" effect of extensive beds of macrophytes" (Decker 1996a). The pond receives nutrients from the surrounding area (Decker 1996a). "however with the level of macrophytes reduced, continued inputs of nutrients will promote increases in the level of phytoplankton and thus may result in algal blooms". Hence the introduction of silver carp was also described in the RAR (Decker 1996a).

3.3.2.3 Ecology and biology of the lake after grass carp release

The information that was available amongst monitoring reports in the DOC files is shown in Table 11. Although there appear to be changes in plant cover and species assemblage over time, without corresponding data on water level fluctuations, and with known escapes of grass carp, any attempt to interpret the effectiveness of grass carp grazing may be misleading.

Table 11: Plant monitoring information

Date	% water surface covered with plants	Species list
Sep 2005	0%	Alligatorweed, willow weed, *Eleocharis* sp.
Mar 2006	60%	*P. crispus*, egeria, *Nymphaea* sp., alligatorweed, willow weed, *Eleocharis* sp. Algae
Dec 2007	35%	*P. crispus*, egeria, *Nymphaea* sp., willow weed, *Eleocharis* sp. Algae.
Apr 2008	20%	*P. crispus*, egeria, *Nymphaea* sp., willow weed, *Eleocharis* sp. Algae.
Mar 2009	45%	Egeria, algae, willow weed. Reduction in egeria near the outlet.
Sep 2009	1%	Algae. The water level was higher than usual.
Nov 2009	50%	Algae, egeria, *P. crispus*
Information was sourced from NZWR monitoring reports (NZWR 2005-2009).		

The majority of the species reported in the RAR were also noted as present in the monitoring reports (NZWR 2005-2009).

Water quality was varyingly described as good or satisfactory in the monitoring reports from 2005 to 2009, with few secchi disc records ranging from 0.3 to 0.5m (NZWR 2005-2009).

Summary of effectiveness and effects

The Link Drive pond is a man-made storm water retention pond, with few natural values. No negative impacts on the values and function of the pond have been noted as a consequence of the introduction of grass carp.

Effectiveness	Flora: Limited information on which to base an assessment of effectiveness, particularly when grass carp are likely to have escaped and the stocking density was uncertain.
Effects	Flora, fauna, water and habitat quality: None detected.

3.3.3 Chelsea Sugar Ponds

Chelsea Sugar Refinery is located in Birkenhead, Auckland, (Appendix C) and has a series of four ponds that retain water from Duck Creek and the surrounding catchment, and drain into the Waitemata Harbour. The artificial ponds were excavated (from 1884 to 1917) and have a uniform maximum depth, with gently sloping sides to ca 3m (Decker 1995a). The ponds were developed to provide a cooling water reservoir for the sugar refinery and subsequently became a multi-use facility, e.g., ornamental and aesthetic values as well as increased stormwater function with the urban development of the surrounding catchment (Kanz et al. 2012). However the urban development occurred almost entirely without consideration of the effects of stormwater discharges on the receiving environment (Kanz et al. 2010). Prior to urban development in the upper catchment, water of the Chelsea ponds was reported to have been clear. Subsequent high volumes of erosion and sedimentation in Chelsea ponds can be largely attributed to urbanisation (Kanz et al. 2012). In more recent decades there has been increased public concern over the incidence of avian botulism in summer (Kanz et al. 2012).

3.3.3.1 Grass carp stocking – When, how many and why

Grass carp were first approved for use in pond 3 for the biological control of nuisance aquatic plants (AQTRANS0017, 1992). The number of grass carp was not specified on the approval. 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 in 1995 as a result of a large scale anoxic event in the pond (Kanz et al. 2012).

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 a further approval was granted to release grass carp and silver carp into the Chelsea ponds (CA126). The numbers of fish approved for the ponds were as follows; 395 grass carp (>25cm), 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).

3.3.3.2 Ecology and biology of the lake before grass carp release

The floating aquatic weed *Salvinia molesta* was first recorded at Chelsea in 1970 (Tanner 1981). The particular pond where it occurred is not stipulated in the report, only that the pond was 3 ha in size (Tanner 1981). Ponds 2 and 4 are the largest ponds at 2.5 and 3 ha respectively (Kanz et al. 2012), so presumably it was one of those ponds. The plants were sprayed in 1975, the pond was drained in 1977 and refilled in 1978. An inspection was carried out in 1980, and no *S. molesta* was found (Tanner 1981).

In the early 1990s there was a second infestation of *S. molesta*, which occurred in ponds 2 and 3 (Figure 4). The herbicide diquat and manual removal of plants resulted in eradication of *S. molesta* from this site by MAFQual and NSCC (North Shore City Council) (P Champion, NIWA (previously with MAFQual) pers comm).

Figure 4. Paul Champion and Rod Smart amongst the floating weed *Salvinia molesta* in pond 2 at the Chelsea Sugar Refinery, Birkenhead.

No endangered or rare plants have been reported from the Chelsea ponds and the following species list was reported by Decker (1995); egeria, *L. major, Juncus articulatus, L. palustris, I. prolifera, Bolboschoenus fluviatilis, Carex virgata, Carex fascicularis, Cotula coronopifolia, E. sphacelata, Glossostigma elatinoides, M. propinquum, P. cheesemanii, P. ochreatus* and *T. orientalis.*

In 1995 ponds were described as suffering from the presence of beds of egeria (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).

The presence of the dams (that create the ponds) in the catchment have resulted in potential barriers to fish migration into and out of the catchment. Although the pond environments comprise poor habitat for native fish, a total of six different native fish species have been recorded from Duck Creek, upstream of the ponds (Kanz et al. 2012). Fish species that had been identified from the ponds included longfin eels, common bully, goldfish, koi carp, gambusia, and rudd. There were anecdotal reports of shortfin eel, perch, and tench (Decker 1995a).

3.3.3.3 Ecology and biology of the lake after grass carp release

The ponds suffer from high nutrient levels, low DO, high temperatures and sedimentation with associated ecological implications of reduced public amenity values and health concerns (Kanz et al. 2012). The ponds are described as eutrophic to supertrophic which is primarily attributed to accumulated nutrient-rich sediments in the ponds. Nutrient levels in all ponds exceed ANZECC trigger values for slightly to moderately disturbed ecosystems. In addition a rich organic layer, possibly of buried macrophytes is found within the sediment in ponds 3 and 4 and potentially historic effluent discharges may also be a factor (Kanz et al. 2012).

Pest fish (illegally introduced) have been recorded in the ponds, and can have a significant effect on water quality. Koi carp in particular are thought to mobilise sediments through their feeding activity, and potentially increase nutrient re-suspension, thereby reducing water clarity (Kanz et al. 2012). Waterfowl in large numbers, as can occur on the Chelsea ponds, and may also contribute to low water quality in ponds, particularly in respect of nitrogen and phosphorous inputs (Kanz et al. 2012).

Barley straw bales have been placed in ponds 3 and 4 in late September annually since 2008. The use of barley straw bales is considered to mitigate algal blooms and indirectly avian botulism (Kanz et al. 2012).

Aerators were installed in pond 3 in the summer of 2003, and were reported to have stabilised and improved DO levels (Kanz et al. 2012). However the indirect negative effects of re-suspension of sediment and associated nutrient cycling due to the physical action of the aerators have not been determined (Kanz et al. 2012).

In 1995, although some impact was seen, the existing grass carp stocks (estimated at 64 in pond 3 in October 1992) were considered insufficient to control the weed in the pond (Decker 1995a). In the same report the description of leafless stems of the submerged macrophytes and decomposing vegetation (Decker 1995a), were likely indicators of an aquatic system under stress. Subsequently Kanz et al. (2012) make reference to a large scale anoxic event that killed many grass carp (and other fish) in 1995. After the 1996 fish releases, when NSCC took over pond management, there was concern about the weed growth in ponds 2, 3, 4 along with blue-green algae in pond 4 (Correspondence 27th August 2010 MFish).

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”.

The macrophyte community in the Chelsea ponds was considered unstable (Kanz et al. 2012). Reportedly dense mats of aquatic plants (in particular lagarosiphon*)* dominate and experience seasonal dieback (Kanz et al. 2012). In addition to the use of grass carp, aquatic vegetation has 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). Although the possibility that plant growth rates vary in different years is also considered, and long term monitoring is considered necessary to verify the effectiveness of the grass carp in Chelsea ponds (Kanz et al. 2012).

In February 2014 no submerged macrophytes were recorded from any of the ponds visited (2, 3 and 4). Small patches of marginal aquatic plants on the water edge included *Myosotis laxa, Lycopus europaeus* and *L. palustris*. The second pond had emergent *T. orientalis* and *L. palustris*. Mallard ducks, black swans and black backed gulls where all present on the water and there was a black shag rookery in an adjacent tree. Three grass carp (up to 60 cm long) were observed swimming in the shallow water of the littoral zone of pond 4. Visibility in the water of pond 4 (closest to the sea) was ca 0.4 m and the water appeared turbid from a declining algal bloom (despite the strawbales). 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 was comparatively clear.

Summary of effectiveness and effects

The 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 the stocking density. During the more recent stocking events (from 2010) other control measures have been implemented that cloud the interpretation over grass carp effectiveness for weed control such that, further monitoring was considered necessary by the managers (now AC) (Kanz et al. 2012)..

Effectiveness	<u>Flora</u>: Effective weed control was achieved intermittently, and in conjunction with weed cutting.
Effects	<u>Flora, fauna, water and habitat quality</u>: None detected. The system was, and is still highly compromised.

3.3.4 Wainamu Bay Reserve Pond

Located in Te Atatu North, the Wainamu Bay Reserve pond is a stormwater retention pond described as having nuisance aquatic plants. An approval to introduce 20 grass carp (greater than 25cm in length) was granted (AQTRANS 02/62) in December 2009. However there were no records to indicate that grass carp where released at this location, rather that the release was on hold (DOC unpublished records 2010). The lake was not investigated further.

3.3.5 Western Springs Lake

Western Springs is located in central Auckland (Appendix C). It is a small (ca 4ha) shallow (max depth 2.9m) artificial reservoir constructed by the Auckland Council in 1875 to contain water discharged from a spring before it passed through swampy land and into Motions Creek. In the 1960's, landscaping of the lake shore began, and the lake is now in an urban park with ornamental, passive recreation and wildlife values. The nutrient inflow into the lake is sufficient to support extensive plant or algal growth (Tanner 1981, Decker 1995b).

3.3.5.1 Grass carp stocking – When, how many and why

A stocking density of 1000 grass carp and 250 silver carp was proposed for Western Springs Lake, based on a density of 250 grass carp per hectare (Decker 1995b, Jamieson Holdings 1996c).

In 1996, an unspecified number of grass carp were approved for release into Western Springs Lake to control the submerged aquatic weeds (AQTRANS0036, 1996). This same approval was also for an unspecified number of silver carp (AQTRANS0036, 1996). The target weed reduction was 70% (Decker 1995b), and the dominant species was *Egeria densa* (DOC unpublished records, 2010). In August 1996, 3 triploid were released (Correspondence 13th September 1996 DOC, Correspondence 28th August Jamieson Holdings) and an application was made to release up to 1000 juvenile diploid grass carp (Correspondence 30th August 1996 MFish). The application was approved (AK032/98, 1996).

Subsequently there appears to have been one or more escapes. Seven large grass carp were found in Motions Creek several years later, which were believed to have escaped from Western Springs lake during a 1996 flood, and were returned to the lake (Correspondence September 2001 Jamieson).

In 1997 there was an intention to remove some of the grass carp from the lake while it was being drained to remove the large populations of koi, catfish and tench (Correspondence 4th July 1997 MFish). The removal of 21 grass carp between the third and fourth surveys (March 1997 and August 1998) was reported by NZWM (2000).

In addition, an inspection of the lake in 1998 found the security screens were missing from the outlet weirs. The screens were reinstated (DOC unpublished records 2010), however fish were likely to have escaped during the period that the screens were absent, leaving the stocking density within the lake largely uncertain.

In April 1999, 132 grass carp were reportedly removed by trapping and electric fishing in one area, leaving a maximum of 851 grass carp in the lake. However the actual number was most likely to be much less than that (NZWM 2000) given the anticipated heavy predation of juvenile grass carp, and an unknown number of escaped fish.

Large grass carp (22) were removed in 2007 and a further 21 fish were removed in 2009 (NZWM 2009).

3.3.5.2 Ecology and biology of the lake before grass carp release

The diversity of native plants and animals was generally low, with introduced species dominating. Records from 1981 (Tanner 1981) describe the presence of the native plant *P.*

ochreatus, the introduced submerged species egeria*,* elodea, and *P. crispus,* the marginal weed *M. aquaticum*, and the floating weed *S. molesta*. The eradication of the salvinia was recommended using a combination of harvesting and herbicide (paraquat), which including cutting the submerged plants. Due to the close proximity of Western Springs Lake to Auckland Zoo, the salvinia eradication programme was undertaken exclusively using manual/mechanical removal. However it was also noted that grass carp could provide a solution for the control of submerged plants in this lake (Tanner 1981).

In 1995, aquatic plant growth was described as a major problem in the lake (Decker 1995b). Species identified as being present in the lake were egeria*, P. crispus*, a milfoil species and *Lemna disperma* (Decker 1995b).

The presence of native and introduced pest fish species has been recorded in the lake, including; short and longfin eels, common bullies, goldfish, koi carp and mosquito fish, and possibly tench and perch (Decker 1995b).

A wide range of bird species (34) have been reported from the park, with black swans, mallard and grey ducks and pukekos the most common. The large number of waterfowl and dense weed beds were linked with outbreaks of avian botulism in late summer (Correspondence 6th June 1997 Auckland City Council). The water quality in the lake was described as poor prior to the introduction of grass carp (Decker 1995b).

3.3.5.3 Ecology and biology of the lake after grass carp release

Grass carp had greatly reduced the level of macrophytes by January 1997, while nearly complete plant removal had occurred by August 1998 and no *E. densa* was recorded in October 1999 (NZWM 1997, 2000). In subsequent years there have been few plants, with the lake largely de-vegetated (NZWM 2003, NZWR 2004, 2009).

There appears to have been some difficulty in managing grass carp numbers, and pest fish species are still present in the lake (Correspondence 4th July 1997 MFish, NZWR 2009b).

Swan deaths in the past had been linked to avian botulism, and linked to rotting weed masses floating on the lake. There was no report of avian botulism in the summer of 1996/1997 (Correspondence 6th June 1997 Auckland Council).

Species of waterfowl remain common on and around the lake, with dabchick reportedly breeding in the area and grey teal observed on the lake. A large number of black swans were also present (NZWM 2000). As in the past the lake still suffers from periodic algal blooms (NZWR 2009b), and there was a localised bloom in the main body of the lake in February 2014. Also in February 2014, no submerged plants were present, and the marginal species *Iris pseudacorus, Cyperus papyrus* and *Carex secta* were noted. Coots, mallard ducks, black swans, Canadian geese, and little black shags were all observed.

Summary of effectiveness and effects

The diversity of native plants and animals is generally low, with introduced species dominating. The lake provides habitat for a range of waterfowl. The lake and its surrounding park have important public amenity values.

There is uncertainty around the effective stocking density, however the target weed species has been removed (although the intent was a 70% reduction).

Effectiveness	Flora: The target weed species has been removed from the lake.
Effects	Flora, fauna, water and habitat quality: No changes associated with weed removal by grass carp have been detected.

3.3.6 Waiatarua Reserve Lake

The Waiatarua Wetland Reserve is located in Meadowbank, Auckland (Appendix C). The reserve has a wetland with boardwalks and paths, excavated ponds and channels fed by stormwater. In September 2004 the reserve was further developed with opening of the restoration project.

Grass carp were approved for release into the Waiatarua wetland reserve in 1994, to control *Egeria densa*, with a 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 (ACC) 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 have significant ponding, water level fluctuations, and little water circulation with dense growths of submerged macrophytes. The dominant submerged species was egeria 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). However, there have not been any fish present at the site for 10 years, since the council decided to turn the site into a wetland (G Jamieson, NZWR, pers comm).

The February 2014 site visit revealed drains clogged with aquatic plants including *O. ovalifolia,* egeria*, Persicaria decipiens, Glyceria declinata, Alisma plantago-aquatica, J. articulatus* and *Paspalum distichum.* The pond in the wetland had a variety and large number of water fowl, but no submerged aquatic plants were observed.

The target weed species, egeria, 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

Summary of effectiveness and effects

Effectiveness	Flora: Not reported. Insufficient information on which to make an assessment.
Effects	Flora, fauna, water and habitat quality: None detected.

3.3.7 Tahuna Torea

The Tahuna Torea Reserve is located in Glen Innes, Auckland (Appendix C). The lake in the reserve had problems with macrophytes and grass carp were introduced to control the plants (AQTRANS0022, 1993), primarily egeria (DOC unpublished records, 2010). The goal was to reduce the volume of weed by 60% (DOC unpublished records, 2010).

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

In February 2010 the pond was surveyed for hornwort. Herbarium records from 1982 listed Tahuna Torea as one of the first records of hornwort in Auckland hornwort as being present (de Winton 2010). No hornwort was found. The ephemeral habitats were choked with marginal plants (e.g., *L. peploides* subsp *montevidensis*) and water lilies, and the main lagoon had compromised water quality with extensive filamentous algal cover (de Winton 2010).

The lake water was turbid 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, P. distichum, T. orientalis* and *B. fluviatilis*. There was a large population of mallard ducks and pukekos, and gambusia were also present.

The target weed species, egeria, was no longer present. However there is a lack of available 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).

Summary of effectiveness and effects

Effectiveness	Flora: Limited information on which to make an assessment, although anecdotal knowledge indicates that the grass carp effectively removed the target weed (exceeding 60% reduction), and potentially assisted by weed harvesting.
Effects	Flora, fauna, water and habitat quality: None detected.

3.3.8 Hayman Park

Hayman Park is located in urban Manukau, Auckland (Appendix C). 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 25cm) were approved for release to control nuisance aquatic weeds (AQTRANS02/21, 2005) primarily egeria, filamentous algae and *P. decipiens* with a target weed removal goal of 70% (NZWR 2006a). 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). Following the manual weed clearance, removal of grass carp (30 to 40) was suggested to reduce the stocking density (NZWR 2006a) and by November 2006 the addition of a further 10 grass carp to the lower pond was recommended (NZWR 2006b). In 2007 no egeria 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 2009c, Aquaculture NZ 2009a). However between September 2009 and November 2009 monitoring records show a change from ca 2% weeds to 90% weeds, although the water level was very low in 2009 (Aquaculture NZ 2009d). 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 egeria was reported from the ponds (NZWR 2011).

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

Summary of effectiveness and effects

Effectiveness	Flora: The target weed species has been removed (exceeding the 70% goal) using grass carp in conjunction with manual weed removal.
Effects	Flora, fauna, water and habitat quality: None detected.

3.3.9 Wattle Farm Reserve

Wattle Farm reserve is located in South Auckland (Appendix C). 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 presently in the pond (Decker 2002). Fish were released on the 4th of April 2005 (Aquaculture NZ 2008). Plant species listed as present include, egeria, lagarosiphon, *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 2006ab). In February 2007 an increase in *P. crispus, M. aquaticum* and filamentous algae was reported (2007a), and 100 grass carp were release on 25th February

2007 (2007b). By March 2009 marginal plants of raupo and willow weed were reported as common, and submerged plants were not present (NZWR 2009c, Aquaculture NZ 2009a). In November 2009 there was extensive modification of 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*. 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* (which was reported to MPI and AC). The *A. philoxeroides* plants were in poor condition with a large number of flea beetles (a biocontrol agent) evident on the plants. 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.

Summary of effectiveness and effects

Effectiveness	Flora: Reduction of the target species has been achieved.
Effects	Flora, fauna, water and habitat quality: None detected.

3.3.10 Puhinui Reserve

The Puhinui Reserve pond is situated in the Puhinui Reserve in South Auckland (Appendix C), 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 2006a, 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,* egeria*, Callitriche stagnalis, Azolla* spp., *L. disperma* and *P. distichum* (Decker 2006a). In March 2008, 24 grass carp (>25cm long) 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 a significant reduction in the egeria from March 2008 with 80% egeria and 20% open water, to March 2009 when there was 75% open water (NZWR 2009c, Aquaculture NZ 2009c). By 2011 the egeria was reported with 80% cover (NZWR 2011; Correspondence 18th March 2011 MFish).

In February 2014 no egeria was observed, and 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, E. acuta,* and *J. articulatus*. The pond water was dark (peaty) and there were no submerged macrophytes.

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

Summary of effectiveness and effects

Effectiveness	Flora: Target plants have been reduced.
Effects	Flora, fauna, water and habitat quality: None detected.

3.3.11 Manuwai Lane Lake

The Manuwai Lane Lake is located in Drury (Appendix C). It is a small (ca 1 ha and 7m deep) man-made pond that originally supplied water for orchards and irrigation (Decker 1996b). The pond was formed in 1965 by damming a small stream and water was used for irrigating a commercial peach orchard and pasture. In the past the pond was regularly pumped dry every summer until about 1987 (Correspondence October 1996, Hoffman) thus preventing macrophytes becoming established. In the 1990s the adjacent landowners wished to keep the pond full of water for its aesthetic values (Decker 1996b). 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, and holds no endangered or particularly environmentally sensitive species (Decker 1996b).

3.3.11.1 Grass carp stocking – When, how many and why

The aquatic transfer (AQTRANS0051, FIS0041) for grass carp and silver carp into the lake at Manuwai Lane for aquatic weed and algal control was dated May 1997. A risk assessment report (RAR) (Decker 1996b), operational plan (Aquaculture NZ 1996) and monitoring reports (NZWR 2006cd, NZWR 2009d) were obtained from MPI.

The purpose of introducing the grass carp into the lake was to control the macrophytes. The intention was to reduce macrophytes to a level of about 60% of the current level (Decker 1996b). Stocking rates of up to 200 grass carp and 100 silver carp are recommended (Decker 1996b). 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 1996b).

3.3.11.2 Ecology and biology of the lake before grass carp release

In the RAR (Decker 1996b) large beds of hornwort in all of the shallow reaches, with azolla covering a large part of the surface of the pond were reported. Other aquatic and marginal species included duckweed, *Nymphaea* spp, *T. orientalis, P. decipiens* and filamentous algae (Decker 1996b).

After a site visit in November 1996 the following plants were noted: duckweed, azolla, milfoil and filamentous algae. Both the azolla and milfoil were present in large quantities and were considered likely to cover the pond in a few months (Correspondence November 1996, MFish).

There is little reference to the quality of the habitat in the lake prior to the release of grass carp, other than the historic de-watering process that had limited colonisation opportunities by both native fish and plant species. The only species recorded as present in the pond in 1996 were short and longfin eels and gambusia (Decker 1996b). Waterboatmen and snails were also recorded (Decker 1996b). No water quality data is available for the pond (Decker 1996b). Although it was recognised that the pond received nutrient from surrounding farmland, that may promote algal blooms (Decker 1996b).

The continued development of large beds of hornwort, (as reported in Decker 1996b) would likely have led to a deterioration in water quality and provided only poor habitat quality for a limited range of aquatic species.

However it is interesting to note that in the same year (1996) a MFish staff visit does not record hornwort but records milfoil. Although it cannot be verified, it seems possible that the hornwort identification by Decker (1996b) and the milfoil identification by Mr Pullan (1996) may in fact have been the same plant. The native milfoil (*Myriophyllum triphyllum*) can be mistaken for hornwort. 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. Parrot's feather was recorded from the lake some 10 years later (NZWR 2006c).

While it is possible that both species (hornwort and milfoil) may have been present, 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 1996b), and "azolla and milfoil are present in large quantities" (Correspondence 6th November 1996, MFish)). The implications for the lake are, that the continued development of large beds of hornwort, (as reported by Decker (1996b)) would likely have led to a deterioration in water quality and provided 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.

3.3.11.3 Ecology and biology of the lake after grass carp release

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 2006cd), and that hornwort was not seen for over two years (2006c), although *Azolla* spp was abundant (NZWR 2009d). Large fish have been observed, along with eels and gambusia (NZWR 2006cd). Bird species included Canadian geese, kingfisher, mallard and paradise ducks, plover, pukeko and shags (NZWR 2006cd, 2009d).

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

Summary of effectiveness and effects

The target level of weed removal was partial control and even though 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 it is worth noting, that correct plant identification is key to predicting the likely outcomes of a perceived weed invasion, and the need to intervene with weed control.

Effectiveness	Flora: Target level of weed removal was partial control. Two decades later, no submerged macrophytes were recorded from the lake.
Effects	Flora: Marginal species still present. Fauna, water and habitat quality: None detected, information is limited.

3.4 Waikato

3.4.1 Lake Te Koutu

Lake Te Koutu is situated in the Te Koutu Reserve in the township of Cambridge. The only aquatic transfer for carp amongst the DOC files (DOC unpublished records 2010) was AQTRANS W0004 from Waipa District Council for silver carp in 1999. Likewise MPI records have a copy of the same approval for silver carp (not grass carp).

Given that no grass carp were transferred to this lake, the lake was not investigated further.

3.5 Hawke's Bay

3.5.1 Eland Farm Lake

Eland's lake is a small (4ha and ca 7 to 8m deep) man-made dam on private land in the Hawkes Bay region (Appendix C). The lake drains an almost exclusively pastoral catchment with no defined input stream or channel (Hooper 1987, HBRC 1994). In the 1980s hydrilla (*Hydrilla verticillata*) covered ca 1 ha of the lake down to ca 4.5 m of this shallow (max depth 7 m) lake (Champion unpublished data 1988). As it has no inlet or outlet streams and is isolated from public access, the lake was utilised for a grass carp trial (Clayton et al. 1995). The trial design included an assessment of water quality, invertebrates, vegetation, fish and birds (Neale 1988a).

3.5.1.1 Grass carp stocking – When, how many and why

Eland's lake was a grass carp trial site to determine the effectiveness of grass carp to control and potential to eradicate hydrilla, which commenced in 1988 (Neale 1988a). Triploid grass carp were supplied by the, then Ministry of Agriculture and Fisheries (MAF). Initially 100 fish/ha of ca 270 mm in length were stocked in November 1988 (Clayton et al. 1995). A second release of grass carp (200) took place in 1991 (NIWA unpublished data).

3.5.1.2 Ecology and biology of the lake before grass carp release

Flora

An aquatic plant survey in 1987 included five emergent species (*T. orientalis, S. tabernaemontani, J. edgariae, B. fluviatilis, E. acuta*), four marginal species (*P. decipiens, L. palustris, Lobelia perpusilla, C. stagnalis*) and twelve submerged species (*G. elatinoides, G. submersum, L ruthiana, Elatine gratioloides, P. crispus, P. cheesemanii, P. ochreatus, C. australis, N.* sp. aff. *cristata, M. propinquum,* elodea and hydrilla) (Clayton et al. 1995). Amongst the submerged species all but hydrilla occurred in less than ca 1 m of water, 5 species had less than 5% cover, the *Glossostigma* species and elodea had 76-95% cover (Neale unpublished report 1988b). 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 1988b).

In 1988, the hydrilla occupied an estimated 1ha of the lake and completely covered the 1.5-4m water depth zone (Clayton et al. 1995).

Fauna

As a landlocked lake, Eland's lake had no fish of an intrinsic value in the absence of migration pathways to the sea e.g., no self-sustaining eel population (Neale unpublished report 1988b). Having had a trout fishery established ca 1920-1960 but not maintained, the lake had no fish of particular recreational value. Bullies that were introduced as a food source for trout persisted in the lake (Neale unpublished report 1988b).

Aquatic invertebrates sampled in 1987 included snails (*Potamopyrgus, Physa* and *Ferissia*), waterboatmen (*Sigara*), chironomids, Trichoptera (*Oxyethira* and *Paroxyethira*), moths (*Hygraula nitens*), damselflies (*Xanthocnemis*) and tubifex worms (Neale unpublished report 1988b).

Bird species reported from Eland's lake since 1984 by the Hawke's Bay Acclimatisation Society include mallard (*Anas platyrhynchos*), paradise shelduck (putangitangi, *Tadorna variegata*) and grey ducks (parera, *A. superciliosa*), black swan (*Cygnus atratus*), scaup (papango, *Aythya novaeseelandiae*), black shag (Kawau-tua-whenua, *Phalacrocorax carbo*) and little shag (kawaupaka, *P. melanoleucos*), New Zealand dabchick (weweia, *Poliocephalus rufopectus*) and pukeko (*Porphyrio porphyrio*) (Neale unpublished report 1988b).

Water Quality

Eland's lake water quality in 1984/93 is summarised (Table 12). The lake was recognised as receiving high nutrient loads from its ca. 26 ha pastoral catchment (Sander 1994). Lake Eland was eutrophic, as indicated by summer mean chlorophyll values (chl-*a*) and phosphorus concentration and is subject to algae blooms. A thermocline formed occasionally at ca 2 m depth, with bottom waters becoming anoxic in the late summer and the temperature of the hypolimnion was recorded at 13ºC.

Table 12: Eland's lake water quality monitoring – summary data from 1984 to 1993.

Data from Sander 1994	1984-1988 Oct			Nov 1988-1993		
	Min	Median	Max	Min	Median	Max
Temperature Surface (ºC)	11	17.5	23.7	9	19	24
Conductivity (µmho/cm)	55	70	100	50	65	130
Secchi disc (m)	0.51	1.14	1.77	0.6	1	1.42
Suspended solids (g/m^3)	3.0	10	13	16*	31*	84*
Chlorophyll *a* (mg/m^3)	7.5	30	76	1	17.1	55.8
Total P (g/m^3)	<0.01	0.047	0.098	0.01	0.06	0.12
Total soluble P (g/m^3)	0.021	0.027	0.03	<0.01	0.03	0.09
Soluble reactive P (g/m^3)	<0.01	0.01	0.02	<0.01	0.01	0.03
Nitrate N (g/m^3)	0.011	0.02	0.68	<0.01	0.03	0.34
Ammonia N (g/m^3)	<0.02	0.03	0.05	<0.01	0.03	0.54
* denotes limited sampling						

Habitat Quality

A trout fishery was established in the lake and abandoned several decades before the release of grass carp (Neale unpublished report 1988b). The lake was generally considered more suitable for wildfowl than recreational or fishery purposes (Sander 1994).

3.5.1.3 Ecology and biology of the lake after grass carp release

Flora

An assessment of vegetation in April 1990 revealed a major reduction in hydrilla, 17 months after the grass carp were released. At this time the native plants *Glossostigma* and *Typha* were not visibly reduced, however in April 1991 evidence of grass carp browsing on *Typha* was first noted, whilst the dense beds of *Glossostigma* and *Lilaeopsis* remained to a depth of ca 2 m and were abundant to 1 m (Clayton et al. 1995). 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). An annual (April) vegetation survey of Eland's lake has continued since then, with a single 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). *P. ochreatus* was also recorded from grass carp exclosure cages located in the shallow water in 2013 and remained there in 2014. In addition *M. propinquum, E. gratioloides and G. elatinoides* were all noted in shallow water (P Champion, NIWA, pers comm).

Fauna

Grass carp have been observed in the lake as recently as April 2014. Bullies that were introduced as a food source for trout were abundant (Hofstra et al. 2008). Eighteen years after 95% of the hydrilla weed beds have been removed (Clayton et al. 1995) the macroinvertebrate fauna were dominated by chironomids, mites and oligochaetes, with other taxa (Ceratopogonidae, Trichoptera (*Triplectides*), *Xanthocenemis*, *Hemicordulia, Oecetis* and *Sigara*) also reported (Hofstra et al. 2008). Although the number of taxa has remained similar over this period there appears to have been a shift in diversity i.e., snails were not found in the 2008 survey, but mites were (Hofstra et al. 2008).

During a single-day survey black swans, mallards, little black shag (*P. sulcirostris)* and kingfisher (kotare, *Halcyon sancta vagans*) were reported from Eland's lake (Hofstra et al. 2008). This was comparable with single-day bird surveys from Eland's lake from 1988 to 1989 where from two to ten species of bird were recorded on any given day (Champion, unpublished survey sheets). In 2014, dabchick, mallard and black swan were noted (P Champion, NIWA, pers. comm.)

Water Quality

Water quality results indicated little change as a result of the introduction of grass carp to Eland's lake (Table 12). Suspended solids may have increased, but limited sampling after 1999 limits comparison. Nutrient and chlorophyll-a concentrations appear to have decreased since 1988 indicating a possible improvement in the trophic status of the lake. However determination of water quality changes over time is difficult based on the data available as sampling was irregular (Sander 1994). In addition it had been mentioned in the 1990's that a top dressing load was dumped in and around the lake, further compromising ability to determine cause and effect relationships with lake water quality (K Mitchell, Eland farm owner, pers comm). In some years (e.g., 2005 and 2006) during annual autumn surveys, algal blooms have been evident (Hofstra et al. 2008).

Habitat Quality

As recently as 2014 this farm lake remained accessible to stock as a source of water. The surrounding farmland has now been sold for plantation forestry. As noted previously the lake had been stocked with bullies for trout, and did not contain a native fishery. The lake is suitable for waterfowl.

Summary of effectiveness and effects

The Eland's lake grass carp trial has demonstrated the effectiveness of grass carp at removing hydrilla, while a turf plant community is retained in shallow water and so too was the habitat for a range of macroinvertebrate taxa, common bullies and waterfowl.

Effectiveness	Flora: Effective weed eradication was achieved.
Effects	Flora: Restricted to shallow water and exclosure cages where plants are inaccessible to the remaining grass carp. Fauna: No discernable change for fish or waterfowl. There has been a shift in the abundance of some macroinvertebrate taxa. Water and habitat quality: No significant changes reported.

3.5.2 Lake Tutira

Lake Tutira in the Hawkes Bay (Appendix C) is a recreational reserve administered by the Department of Conservation as a public facility and is part owned (northern end of the lake) by hapu within Ngati Kahungunu (Walls 1994). The lake is a 174 ha lake with a mean depth of 20 m and a maximum depth of 42m (Hooper 1989). It was most likely formed from the partial collapse of a ridge, damming a valley at the now south end of the lake (Tutira Technical Committee 1977). Historically the lake produced a bountiful supply of freshwater foods for iwi such as eels, mussels and kokopu. The margins and swamps at the head of the lake provided flax, all of which favoured Maori occupation of the lake-shore where five pa sites existed in the early 1800s (Tutira Technical Committee 1977). Since then the lake and its catchment have undergone massive changes. With the exception of native forest fenced off by Guthrie-Smith on Tutira Station in the 1890s, the majority of the native vegetation surrounding the lake has been converted to farmland (Walls 1994). Sheep and cattle grazing on the hillsides led to consolidated soil and increased the sediment run–off (Tutira Technical Committee 1977). Inlet water to the north of the lake was no longer filtered after a channel was cut through the swamp (1890s). Populations of black swan became established alongside the black teal, dabchick, coot, mallard, grey duck and pukeko while many species of native bird including tui, bellbird, kingfisher, pigeon and morepork retreated to the bush (Tutira Technical Committee 1977). The lake is currently stocked with rainbow trout by Fish and Game.

3.5.2.1 Grass carp stocking – When, how many and why

Hydrilla is an alien submerged aquatic weed that is found in the Hawke's Bay, and was identified as a pest for eradication through the National Interest Pests Response (NIPR) programme (MAFBNZ 2008).

MPI developed an operational plan to manage and eliminate hydrilla in Lakes Tutira, Waikōpiro, Opouahi and Eland and to achieve the goal of eradication from New Zealand (MAFBNZ 2008). Eradication was considered achievable in the long term through the use of grass carp, and sustained grazing pressure (MAFBNZ 2008).

The stocking density for Lake Tutira was based on 100 grass carp per vegetated hectare, which equated to 2354 grass carp (30 cm in length) (Hofstra and Rowe 2008). Approval was obtained to introduce grass carp into Lake Tutira for the eradication response in December 2008 (AQTRANS0501). The grass carp were released on the 11th December 2008.

Some losses of grass carp were reported from Lake Tutira following a major flood event in April 2012 (I Gear, In Gear Global pers comm).

3.5.2.2 Ecology and biology of the lake before grass carp release

Flora

Lake Tutira, in the past, supported an entirely native aquatic vegetation. At some time prior to 1963 the submerged aquatic weed hydrilla was introduced and by 1963 it formed dense weed beds extending to a depth of 7.6 m and covering 16.9% of the total lake surface area (Tutira Technical Committee 1977). Aquatic plant surveys conducted on Lake Tutira since then have documented the increase in distribution of hydrilla around the lake, from 73% of the profiles in 1981 to 90% of the profiles in 2002 (NIWA, FBIS (Freshwater Biodiversity Information System)).

In 2008 hydrilla occupied an estimated 25 ha in the lake, with weed beds extending from 1 to 9 m water depth (at some sites), to a maximum height of 5.5m, and up to 100% cover. The dense monospecific stand of hydrilla excluded native plant species. The alien plant elodea was also present in Lake Tutira from 0.2 to 3.5 m water depths, reaching heights of 2.5 m (Table 13). The most diverse plant community occurred in the shallow water zone and included the low mound or turf plant community or may include emergent species (e.g., *T. orientalis*) (Table 13). The diversity of this zone included 18 species of submerged, marginal, and emergent aquatic plants (Hofstra et al. 2008) from a total of 20 species in the lake that occurred in this shallow water zone (Table 13).

Fauna

Lake Tutira was stocked with brown (*Salmo trutta*) and rainbow (*Oncorhynchus mykiss*) trout in the 1900's, and from 1959 annual liberations of rainbow fingerlings were made by the Acclimatisation Society (Tutira Technical Committee 1977). Trout continue to be stocked by the Hawkes Bay Fish and Game Council.

The native fish fauna includes longfin (*Anguilla dieffenbachii*), and shortfin (*Anguilla australis*) eels, banded kokopu (*Galaxias fasciatus*), common bully (*Gobiomporphus cotidianus*) as well as the introduced gambusia (*Gambusia affinis*) (New Zealand Freshwater Fish Database, DOC 2002, Hofstra et al. 2008). In a fish survey in 2008, longfin and shortfin eels, common bullies and trout were caught in the lake, while banded kokopu were only caught in an inlet stream. Gambusia were observed in the shallow-water, lake margins but were not caught (Hofstra et al. 2008). Goldfish (*Carassius auratus*) were not found in Lake Tutira in the 2008 survey but do occur in the adjoining Lake Waikōpiro so can be expected in Tutira as well. The eel catch was dominated by large shortfins, most of which were very similar in length indicating a narrow size class and few juveniles. In other words, there is now a barrier to upstream migration, so stocking is required to sustain the eel populations. Common bullies were abundant in the survey indicating a healthy population (Hofstra et al. 2008).

Koura have been reported from the lake (DOC 2002), but are scarce, with only two found in the lake in a recent survey and a third from an inlet stream (Hofstra et al. 2008). The current scarcity of koura is thought to be associated with a lack of suitable habitat. Mussels were only found in the shallow water zone ca 1.5 m, but historic mussel beds at the bottom limits of the hydrilla weed beds (ca 9 m) were reported (Hofstra et al. 2008).

Nineteen invertebrate taxa were recorded from Lake Tutira in 2008, including, mites (Acarina), worms (Oligochaeta), chironomids, ceratopogonids, waterboatmen, dragonflies and damselflies (Odonata), caddisflies (Trichoptera), snails, leeches and flatworms (Hofstra et al. 2008). The highest diversity associated with the shallow water zone and the macrophyte weed beds, both with 16 taxa, compared with 6 taxa that were present in the benthic sediments, below the maximum depth of the weed beds (Hofstra et al. 2008).

Populations of black teal (*Aythya novaeseelandiae*), dabchick (*Poliocephalus rufopectus*), coot (*Fulica atra*), mallard (*Anas platyrhynchos*), grey duck (*Anas superciliosa*), pukeko (*Porphyrio porphyrio*) and black swan (*Cygnus atratus*) have all been reported from Lake Tutira in the 1970s, while many native species of bird including tui, bellbird, kingfisher, pigeon and morepork became less abundant returning to the bush (Tutira Technical Committee 1977). In a 2008 survey of birds on the lake, eight species were recorded. In addition to swan numbers noted on Lake Tutira many other swans were observed on the shoreline (in marginal vegetation) and not counted, along with frequent pukeko. All of the bird species recorded in 2008 were previously observed at the lakes (Heighway and Mackenzie 1963, TRB 1982, Hooper 1987, Walls 1994).

Water Quality

Lake Tutira water quality has undergone many changes in the past including forest removal, fertiliser addition, and increased sediment loads produced by landslides and storm events, and as a consequence of a drain that was dug in the 1890's through the wetland at the north end of the lake. The drain removed the filtering effect of the wetland and increased the sediment load in the lake as documented by Guthrie Smith (1926). Many decades later when the Tutira Technical Committee was set up and a lake monitoring programme initiated, recommendations to improve lake water quality, included reducing nutrient inputs through riparian plantings and the diversion of Sandy Creek (Hooper 1989). The diversion of Sandy Creek (also referred to as Papakiri Stream), bypassed the lake to reduce the nutrient loads going into the lake, and the catchment area was reduced to 844 ha.

More recent catchment land use change has impacted on the lake water quality with increased surface run off and the advent of topdressing both increased nutrient loads in the lake (Tierney 1980). Concern was expressed over water quality from 1959 with discolouration, algal growth, and the appearance of dead fish in the summer months (Tutira Technical Committee 1977). This culminated in a survey of the lake in 1970 that confirmed its advanced state of eutrophication (Tierney 1980). Subsequently, the Tutira Technical Committee was set up and a lake monitoring programme initiated, as well as recommendations to improve lake water quality. These included reducing nutrient inputs through riparian planting and diversion of Sandy Creek (Hooper 1989) and the installation of benthic aerohydraulic guns to improve water mixing and oxygenation of bottom waters and hence trout habitat (Tierney 1980, 2008a).

Water quality in the early 1970s was summarised by the Tutira Technical Committee (1976) and in the 1980s by the Hawke's Bay Catchment Board (Hooper 1989) (Table 14). The lake was described as eutrophic but showed signs of improving water quality in the late 1980s, with increasing secchi depths (a minimum of 1.5m) from 1986, and declining chlorophyll-*a* (medians from 13 to 6 mg/m^3 in the summers of 1984/85 to 1986/87) (Hooper 1989). From 1992 to 1996, Lake Tutira was part of a national lakes monitoring programme aimed at evaluating cost effective water quality indicators of trophic state and trophic level change (Burns and Rutherford 1998a). Two sampling stations were set up on the lake to sample the epilimnion and hypolimnion when stratified or from two depths when isothermal (Burns and Rutherford 1998c). Tutira did not change in trophic status over the monitoring period, however there was a general decrease in the numbers of dinoflagellates and an increase in cyanobacterial species (*Anabeana, Oscillatoria* and *Microcystis* sp), which indicate a small decline in water quality for the lake (Burns and Rutherford 1998b). Tutira increased in temperature (surface water) by 0.39ºC during the monitoring period as did other lakes in the study (Burns and Rutherford 1998b).

Hawkes Bay Regional Council resumed water quality monitoring in Lake Tutira in May of 2008 with initial data presented in Table 14.

Habitat Quality

Lake Tutira is the largest freshwater lake in the Hawkes Bay Region and provides habitat for a range of native and introduced aquatic flora and fauna. Declining water quality, and fish habitat and increased aquatic weeds were documented in the 1970's (Tutira Technical Committee 1977, Tierney 2008ab).

Table 13: Lake Tutira vegetation summary data from 2008 (Hofstra et al. 2008).

Species	No. of Sites	Depth range (m)	Max. Height (m)	Ave. Height (m)	Max Cover	Median Cover
Callitriche sp.	1	0.2 - 0.3			1	
Chara australis	12	0.2 - 2.2	0.2	0.1	6	1
Chara globularis	12	0.1 - 2	0.3	0.1	6	1, 2
Elodea canadensis	13	0.2 - 3.5	2.5	0.4	6	1
Glossostigma cleistanthum	1	0.3 - 0.3				
Glossostigma elatinoides	4	0.1 - 0.2			3	1, 2
Hydrilla verticillata	15	0.1 - 7.5	5.5	2.3	6	5
Juncus sp.	2	0 - 0.2	0.7	0.5	4	2, 4
Lilaeopsis ruthiana	10	0.2 - 1.3			5	2, 3
Ludwigia palustris	3	0 - 0.3	0.2	0.2	6	1
Myriophyllum triphyllum	8	0.3 - 1.8	1	0.2	5	1
Nitella hyalina	8	0.2 - 1.2	0.1	0.1	3	1
Paspalum distichum	3	0 - 0.3	0.3	0.2	6	3
Persicaria decipiens	2	0 - 0.2	0.3	0.3	3	1, 2
Potamogeton ochreatus	5	0.5 - 1.3	0.2	0.1	3	1
Ranunculus limosella	10	0.2 - 1.3			5	2
Ranunculus trichophyllus	1	0.9 - 1	0.1	0.1	1	
Ruppia polycarpa	5	0.4 - 1.2	0.1	0.1	3	1
Schoenoplectus tabernaemontani	6	0 - 1.7	2.4	1.2	4	2
Typha orientalis	5	0 - 1.5	4	2.3	6	5
Unidentified mosses & liverworts	1	0.3 - 0.3				
NB: Data are averaged values from the fifteen survey sites. Cover values correspond to percent cover as follows; 1=1-5%, 2=6-25%, 3=26-50%, 4=51-75%, 5=76-95%, 6=96-100%.						

Table 14. Lake Tutira summary water quality data from the 1970's to 2008.

	Tutira Technical Committee (1976)		Hooper (1989) data from 1982 to1986		Burns and Rutherford (1998) data from 1992-1996		HBRC
	Winter	Summer	Range in annual median values		Range in annual median values		May'08
			Min	Max	Min	Max	
Epilimnion/surface profile							
Temp °C			10	24	13.3	17.2	13.7
DO%	96	121.2			88.3	95	41
DO mg/l	9.6	10.3			8.9	9.8	4.1
Chl-*a* (mg/m^3)		16.5	6	13	3.5	7.1	
Secchi (m)	2.7 – 5.0	0.9 – 3.2	1.17	2.47	3.3	4.1	5.3
TP (g/m3)	0.0492	0.0363	0.022	0.063	0.0139	.0206	0.014
total soluble P (g/m^3)			0.015	0.027			
Soluble Rx P (g/m^3)	0.0326	0.0084	0	0.021	0.003	0.0026	<0.004
P diff g/m^3)					0.011	0.018	
Total N (g/m^3)					0.209	0.324	0.37
total O Nitrogen (g/m3)					0.1993	0.2952	-
Kjeldahl N (g/m^3)			0.5	1			0.34
NH_4 (g/m^3)	0.0058	0.0109	0	0.056	0.0067	0.0131	0.011
NO_3 g/m^3			0	0.093	0.0016	0.0231	0.031
Reactive Nitrate N (mg/m^3)	372.5	6					
pH					8.2	8.4	7.6
EC (uS/cm)			129	167	154	169	150
Hypolimnion							
Temp °C		10.3	11.7	24	9.9	11.6	10.7
DO%	80.7	0	6.733	9.125	2.7	29.6	1
DO mg/l	8.8	0			0.3	3.4	0.11
TP (g/m^3)	0.0482	0.1075	0.015	0.048	0.0187	0.0269	0.069
total soluble P			0.013	0.033	0.0041	0.013	0.064
Soluble Rx P (g/m^3)	0.0337	0.0542	0.005	0.026			
P diff(g/m^3)							
Total N (g/m^3)					0.328	0.369	0.328
Total O Nitrogen (g/m^3)					0.2326	0.2437	0.237
NH_4 (g/m^3)	0.0081	0.3023	0.005	0.089	0.0442	0.0538	0.046
NO_3 g/m^3			.037	0.297	0.022	0.0596	0.045
Reactive Nitrate N (g/m^3)	0.3764	0.0175					
pH					7.1	7.5	7.3
EC (uS/cm)			151	169	172	175	172

3.5.2.3 Ecology and biology of the lake after grass carp release

Flora

The first survey after the release of grass carp into the lake was in April 2009. In 2009 the hydrilla was in a state of seasonal decline, with slumped (shorter) weed beds compared to autumn 2008, but it remained the dominant macrophyte by site and in water deeper than ca. 1.5 m, and there was little evidence of grass carp grazing (divers observations). The plant profiles data was generally similar to that in autumn 2008, with a range of marginal emergent species (e.g., *T. orientalis* and *S. tabernaemontani*), turf forming species (*L. ruthiana* and *Ranunculus limosella*) and charophytes (*Nitella hyalina, C. australis* and *C. globularis*) occurring around the lake at different sites (Hofstra 2009).

By 2010 the impact of grass carp grazing was evident, with no hydrilla weed beds recorded from any of the profile sites, although hydrilla plants were still present at six survey sites (out of 15), with reduced cover and limited depth range. The shallow water turf community was similar in composition and cover to 2008 and 2009, and was dominated by native species. The native milfoil, *Myriophyllum triphyllum,* appeared to be a less preferred species by the grass carp and had expanded in distribution and cover (Hofstra 2010). Grass carp browsing was evident on two marginal emergent species, with stands of both *E. sphacelata* and *S. tabernaemontani* having chewed stems below the waterline, and there was a corresponding reduction in presence and cover of *S. tabernaemontani* (Hofstra 2010).

In subsequent surveys (2011 to 2013) the total number of species recorded from the lake remained similar to that prior to the introduction of grass carp, with highest species diversity occurring amongst the shallow water zone (Hofstra 2011, 2012, 2013b). The only hydrilla plants found were small in stature (e.g., 15 cm) with browsed shoot tips, and restricted in distribution such as amongst patches of *M. triphyllum*. The marginal emergent species continued to show evidence of having been browsed by the grass carp. Further reduction of the marginal emergent species was considered likely, depending on water level fluctuations that determine the access that grass carp have to the marginal plants (Hofstra and Clayton 2014).

Fauna

The fish fauna of Lake Tutira has been modified by introduced species (e.g., trout, Gambusia) in the past. Gambusia are a pest species that can reduce populations of galaxiids and displace common bullies from shallow littoral zones during mid-summer and autumn months. It also has the capacity to reduce the aquatic insect larvae of some invertebrates including Odonata (dragonfly). However, trout predation may maintain summer densities of gambusia at low levels (Hofstra and Rowe 2008).

Lake Tutira had a large population of small to medium sized common bullies which provide trout with an abundant food supply (Hofstra and Rowe 2008). There was a large increase in the number of common bullies following weed removal (Smith and Rowe 2011). This increase is likely due to an increase in either the recruitment of juvenile bullies following weed removal and/or to an increase in benthic habitat and food (chironomid larvae). Survival is not expected to increase because weed removal would expose juvenile bullies to greater predation, but weed removal will have exposed logs and other hard objects on the littoral lake bed. These provide spawning habitat for bullies and hence weed removal can be expected to have increased spawning habitat. It therefore appears that weed removal has increased juvenile recruitment through an increase in spawning habitat and that the survival of these fish is then enhanced by an increase in adult habitat and food supply (Smith and Rowe 2011). As common bullies are a significant prey species for large eels and trout, their proliferation is expected to benefit these higher level predators (Smith and Rowe 2011). The eel catch was dominated by shortfin eels which, along with other native fish species (longfin eels, banded kokopu) were unaffected by weed removal to date (Smith and Rowe 2011).

All the macroinvertebrate taxa identified in 2008 were present in Lake Tutira during successive surveys. However, there were differences in the number of sites that taxa occurred at over the sampling period. For example, Acarina, Chironomidae, Gastropoda, Odonata, and Oligochaeta, in all survey years, occurred at more than half of the survey sites, compared with, for example, the Trichoptera, which occurred at fewer survey sites in 2012 than in 2008, and the Bivalvia (primarily mussels), which increased in the number of sites at which they occurred. There were also differences between sites and water depths in the lake, in the number of taxa (diversity) that were present, corresponding to sites and depths that also differed in their plant species presence (Hofstra and Clayton 2014).

Although the diversity has remained, there has been a shift in the relative abundance of the dominant taxa over time with Gastropoda becoming the most abundant taxa in the shallow water (Hofstra and Clayton 2014). Despite shifts in the relative abundance of taxa, the absolute number of macroinvertebrates (with few exceptions of the larger numbers of Gastropoda and Acarina) was similar over the monitoring period (Hofstra and Clayton 2014).

Bird species and numbers have fluctuated over the last five years during the April count (Table 15). There has been a reduction in the numbers of coot in particular since the removal of the hydrilla weed beds (April 2010), while in 2013 the number of black swan on Lake Tutira exceeded previous counts. In contrast, Hawkes Bays Fish and Game have noted a decline in swan numbers on Lake Tutira following weed removal by grass carp (J Cheyne (Fish and Game) to D Rowe (NIWA), pers. comm.). That statement is supported by aerial counts of waterfowl on lakes within the region (Figure 5). Such regional surveys enable a picture of swan movements to be tracked within a region as habitats in more than one waterbody may be suitable or compromised (for different reasons) within a similar timeframe (e.g., macrophyte collapse in Whakaki lagoon, and Lake Runanga from ca 2007 and 2010 respectively (M McDougall Fish and Game pers comm)). In the example of black swans, the regional perspective adds value to interpreting the potential for cumulative impacts on habitat loss for a species.

Table 15: Number of birds recorded during annual autumn single day surveys on Lake Tutira.

Birds Year	2008	2009	2010	2011	2012	2013	2014
Black shag, *Phalacrocorax carbo*	2	5	35	6	6	9	9
Black Swan, *Cygnus atratus*	81	24	76	28	34	112	32
Coot, *Fulica atra*	78		4	6		1	
Dabchick/Weweia, *Poliocephalus rufopectus*	5	18	1		2	8	6
Geese, *Anser domesticus*		3	1		1		
Canadian geese, *Branta canadensis*						28	
Grey teal, *Anas gracilis*							13
Harrier hawk, *Circus approximans*		1			4		
Kingfisher/Kotare, *Halcyon sancta vagans*	2	2	1		1	2	
Little black shag, *Phalacrocorax sulcirostris*	4	4	12	6	4	2	
Little shag, *P. melanoleucos brevirostris*		15	8	4	9	2	
Mallards, *Anas platyrhynchos*	55	35	67	15	23	32	109
Paradise duck/Putangitangi, *Tadorna variegata*		15				2	60
Pukeko, *Porphyrio melanotus*		9	8	1			
Scaup/Papango, *Aythya novaeseelandiae*		4	7	11	4	13	30
White faced heron, *Ardea novaehollandiae*		1	3	2	2	7	7
Pied stilt/Poaka, *Himantopus*						6	

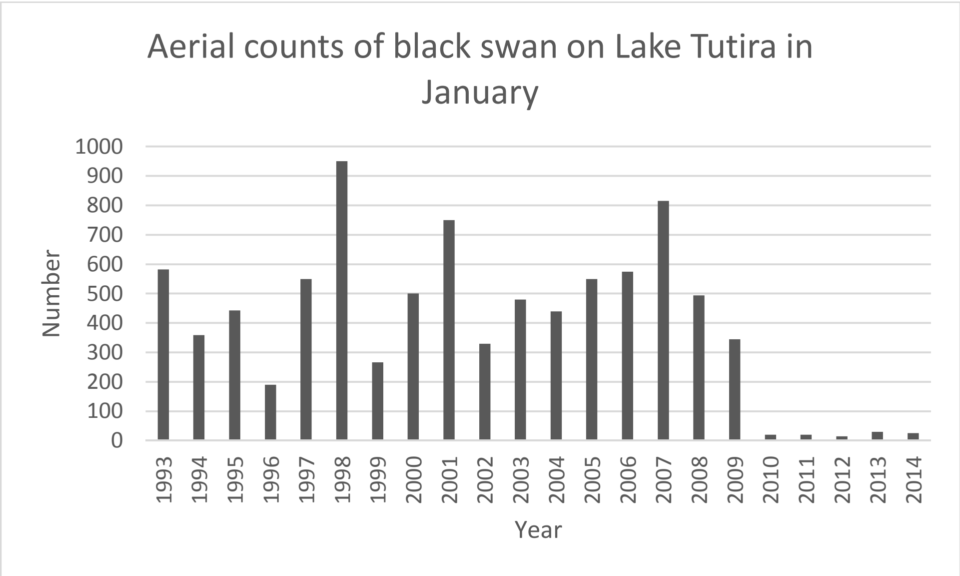

Figure 5. Aerial counts of black swans on Lake Tutira (data supplied by M McDougal, Fish and Game from regional surveys).

Water Quality

Water quality monitoring of Lake Tutira was undertaken by HBRC from May 2008. Monitoring consisted of monthly or quarterly manual sampling of standard parameters and the use of an automated sampling buoy in Lake Tutira (von Westernhagen 2011). To identify and quantify any changes in water quality parameters during the Hydrilla Eradication Response, HBRC examined trends through time, primarily by determining Percent Annual Change (PAC) and calculating annual Trophic Level Index (TLI) values. Monitoring has shown that Lake Tutira exhibits a stable thermal stratification during the summer period (von Westernhagen). The HBRC report describes an increase in water temperature (epilimnion and/or hypolimnion), although there was no concurrent change in dissolved oxygen concentrations over the same period (von Westernhagen 2011). Data from Lake Tutira also indicated an increase in chlorophyll *a* concentration, and soluble reactive phosphorus (SRP), and a decreasing trend in NO_3 concentration (von Westernhagen 2011). In late 2012 there was a larger than usual algal bloom in Lake Tutira. 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). The larger than usual cyanobacteria bloom in the lake in late 2012 was 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.

Although the monitoring programme has detected some changes in water quality parameters in Lake Tutira, these were not attributed to the weed removal (von Westernhagen 2012).

Habitat Quality

Removal of the weed beds by grass carp has led to an increased abundance of common bullies in the littoral zone by an order of magnitude. Other native fish species (longfin eels, banded kokopu) were unaffected to date. As common bullies are a significant prey species for large eels and trout, their proliferation is expected to benefit these higher level predators.

Changes in the macroinvertebrate fauna have reflected changes in the littoral vegetation with the presence of low growing plant species providing a level of complexity for macroinvertebrate fauna. However, Lake Tutira is in a state of transition with further changes in the littoral vegetation likely to occur in response to continued grass carp grazing.

Summary of effectiveness and effects

Grass carp were introduced into Lake Tutira to eradicate the submerged aquatic weed hydrilla. As outlined by MPI, this is a long term eradication response (MAFBNZ 2008), with only five and a half years having passed since the grass carp were stocked. To date target weed control has been achieved, with progress toward the eradication goal.

Effectiveness	Flora: Hydrilla weed beds have been removed, significant progress towards eradication. Regenerating hydrilla plants from propagules were found in 2014.
Effects	Flora: Native flora was already compromised by the hydrilla. Low growing turf forming plant species are present. The native milfoil (*M. triphyllum*) has had an increase in abundance (likely temporary). Marginal emergent plants have been reduced. Fauna: The relative abundance of macroinvertebrate taxa has shifted. Some fish species have increased in abundance, no change was recorded for others. Numbers of waterfowl were variable across the monitoring period, both before and since weed bed removal, some changes have been recorded. Water quality: Changes recorded were not attributed to weed removal. Habitat quality: Habitat for some waterfowl has changed with weed removal. Improved habitat for common bullies.

3.5.3 Lake Waikōpiro

Lake Waikōpiro (also referred to as Waikapiro) is a small (ca 11 ha) lake that is connected to Lake Tutira via a culvert under a narrow causeway (Hooper 1987) (Appendix C). The northern shoreline is characterised by a relatively flat, shallow (<2 m deep) shelf that extends some 10-40 m out from the shoreline. However, on the western, eastern and southern sides of the lake, the bed shelves steeply down to the lake bottom at ca 18 m. The catchment is only 116 ha and is mostly in pasture, apart from a small area of wetland to the southeast of the lake (Figure 4). A small inlet stream drains into the lake from the wetland. During summer when rainfall is low or absent, this stream is dry. Water drains from Lake Waikōpiro through the culvert into Lake Tutira in periods of high water. In the 1980s riparian planting was carried out on the eastern and southern margins and the lower reaches of the inlet stream, and a lake shore reserve was established on the northern and western margins, preventing stock access to the lake (Hooper 1987). Lake Waikōpiro is included in the Tutira recreation reserve.

3.5.3.1 Grass carp stocking – When, how many and why

Hydrilla is an alien submerged aquatic weed that is found in the Hawke's Bay, and was identified as a pest for eradication through the National Interest Pests Response (NIPR) programme (MAFBNZ 2008).

MPI developed an operational plan to manage and eliminate hydrilla in Lakes Tutira, Waikōpiro, Opouahi and Eland and to achieve the goal of eradication from New Zealand (MAFBNZ 2008). Eradication was considered achievable in the long term through the use of grass carp, and sustained grazing pressure (MAFBNZ 2008).

The stocking density for Lake Tutira was based on 100 grass carp per vegetated hectare, which equated to 214 grass carp (30 cm in length) (Hofstra and Rowe 2008). Approval was obtained to introduce grass carp into Lake Tutira for the eradication response in December 2008 (AQTRANS0501). The grass carp were released on the 11th December 2008.

Some fish may have moved into Lake Tutira when the causeway was flooded in 2012 (Hofstra 2012).

3.5.3.2 Ecology and biology of the lake before grass carp release

Flora

Hydrilla is thought to have entered Lake Waikōpiro at some time after it had established in Lake Tutira, where it was positively identified in 1963 (Tutira Technical Committee 1977). A survey conducted on Lake Waikōpiro in 1992 showed that hydrilla had an extensive distribution within the lake to depths of 6 m with dense cover (100%) and stands averaging 2m in height (NIWA, FBIS). In 2001 the hydrilla in Lake Waikōpiro was treated in this lake with endothall (dipotassium endothall), which significantly reduced the hydrilla biomass in the two treatment plots (each ca 1 ha in area) for a year (Hofstra and Champion 2001, Hofstra et al. 2003).

In a more recent survey (2008) hydrilla continued to dominate the littoral zone of the lake, although a small band of native plants described as the turf community was found in the shallow water zone (Table 16). Twelve aquatic plant species were recorded in the shallow lake water (up to 1.2 m water depth), and beyond that only two species occurred (the introduced elodea and hydrilla) in water from 2.2 m down to ca. 6.4 m with hydrilla dominating (Table 16). Aquatic plant species recorded from previous surveys and/or diver observations include *Myriophyllum pedunculatum, P. ochreatus,* and *Glossostigma diandrum* (NIWA unpublished data, 2002).

Table 16: Lake Waikōpiro vegetation summary data from 2008 (Hofstra et al. 2008).

Species	No. of Sites	Depth Range (m)	Max. Height (m)	Ave. Height (m)	Max. Cover	Median Cover
Chara australis	1	0.5 - 0.5			1	
Elodea canadensis	3	0.3 - 2.2	1.5	0.4	6	6
Glossostigma elatinoides	3	0.1 - 0.8			5	1
Hydrilla verticillata	5	0.3 - 6.4	4.6	2	6	6
Lilaeopsis ruthiana	4	0.1 - 0.7			2	1
Ludwigia palustris	3	0 - 0.2	0.1	0.1	2	1
Myriophyllum propinquum	4	0.1 - 0.5	0.1	0.1	2	1
Paspalum distichum	1	0 - 0.4	0.3		3	
Potamogeton cheesemanii	4	0.4 - 0.6			1	1
Lobelia perpusilla	1	0 - 0.1			1	
Ranunculus limosella	1	0.2 - 0.2			1	
Schoenoplectus tabernaemontani	2	0.5 - 1.2	2.5	2.1	3	1, 3

NB: Data are averaged values from the five survey sites. Cover values correspond to percent cover as follows; 1=1-5%, 2=6-25%, 3=26-50%, 4=51-75%, 5=76-95%, 6=96-100%.

Fauna

Hooper (1987) noted that common bullies were present in Lake Waikōpiro, that eels were likely to be present, and that the lake was periodically stocked with rainbow trout. Observations by NIWA divers during botanical surveys in 2001 and 2002 confirmed the presence of eels (mainly shortfin), and goldfish (*Carassius auratus*). A 2008 fish survey in the lake reported rainbow trout, shortfin eels, common bullies, juvenile goldfish and gambusia (Hofstra et al. 2008). The eel catch was dominated by shortfin eels (Hofstra et al. 2008).

Live freshwater mussels were noted by NIWA divers in 2001/2002. Freshwater crayfish were considered potentially to be present, but like mussels, rare, due to the poor water quality in this lake, the summer deoxygenation of its hypolimnion, and smothering by exotic weed beds (Rowe 2004).

A survey to determine the diversity and abundance of smaller littoral and benthic invertebrates in Lake Waikōpiro has shown that 16 taxa are represented including mites (Acarina), worms (Oligochaeta), chironomids (Diptera), ceratopogonids (Diptera), waterboatmen, dragon- and damselflies (Odonata), caddisflies (Trichoptera), snails and flatworms (Hofstra et al. 2008). The shallow water zone and areas with macrophytes had a higher diversity of taxa (13 and 12 respectively) than the benthic sediments below the weed beds (4 taxa). However the benthic sediments had a higher abundance of those taxa (e.g., ceratopogonids and chironomids) that were present (Hofstra et al. 2008).

Black swans (*Cygnus atratus)*, coot (*Fulica atra*), grey teal, and paradise shelduck (*Tadorna variegata*) have been recorded from the lake (Hooper 1987). Pukeko and several small black shags were seen around the lake in April 2004. More recently a single day survey of birds on Lake Waikōpiro reported five species including two black shags (*Phalacrocorax carbo*), eight black swans, four dabchicks, fifteen Mallards ducks (*Anas platyrhynchos*) and two paradise shelducks (Hofstra et al. 2008).

Water Quality

Historic data on water quality were available and summarised by the Hawke's Bay Catchment Board (Hooper 1987), providing a good picture of water quality in the lake in the mid 1980's (Table 17).

In 1984/85, Lake Waikōpiro was described as eutrophic (Hooper 1987). It had high nutrient loading (both nitrogen and phosphorous), complete deoxygenation of its hypolimnion (waters below about 6 m) during summer months, poor water clarity (median secchi disc of 0.69 m), and the presence of periodic blue-green algal blooms (including potentially toxic *Microcystis* spp.). Water temperatures over the sampling period ranged from 14.6 to 23.8 ºC, which were typical of a low altitude (155 m ASL) lake (Hooper 1987).

Table 17: Summary water quality data for Lake Waikōpiro (after Hooper 1987).

	Min	Median	Max
Temperature (ºC)	14.6	22.0	23.8
Conductivity (µmho/cm)	120	148	168
Secchi disc (m)	0.34	0.69	1.53
Suspended solids (g/m³)	3	8	26
Chlorophyll *a* (mg/m³)	7	17	58
Total P (g/m³)	<0.01	0.07	0.12
Total soluble P (g/m³)	0.01	0.02	0.04
Soluble reactive P (g/m³)	<0.01	0.01	0.03
Nitrate N (g/m³)	<0.01	0.11	-
Ammonia N (g/m³)	<0.02	0.02	-
Thermocline when present is at 4 to 6m. Monitoring period was Feb-Mar 1984 (sampled twice); October – April 1985 (sampled 6 times).			

In November 2000 and March 2001, NIWA obtained a continuous 23-day record of oxygen, pH and temperature in the lake related to a trial on endothall (Hofstra et al. 2001). These data show that the water temperatures in November ranged from 16-20ºC with little daily variation, and in March were mostly above 20ºC. DO levels varied diurnally, ranging from 4-14 mg/l in November, and 6-15 mg/l in March. The pH was close to 8 in November, and 7.5 in March.

Habitat Quality

Lake Waikōpiro provides habitat for a smaller range of aquatic flora and fauna than Lake Tutira, and has the confirmed presence of a pest fish species. However Lake Waikōpiro may provide alternative (more sheltered) habitat for waterfowl when Lake Tutira is exposed to high winds (Hofstra et al. 2008).

3.5.3.3 Ecology and biology of the lake after grass carp release

Flora

In Lake Waikōpiro there were no submerged macrophytes present from 2009. There were however, low growing turf forming aquatic plants (e.g., *Myriophyllum propinquum, Lilaeopsis ruthiana* and *Glossostigma elatinoides*) either above the waterline (in 2009 and 2013) or in shallow water (2010, 2011, 2012, 2013) depending on rainfall events and maintenance of the outflow. The shallow water turf community is similar in composition to pre-grass carp condition and is dominated by native species (Hofstra 2010).

To date, the last record of hydrilla from Lake Waikōpiro was a turion (a vegetative propagule) in 2012 (Hofstra 2012).

Fauna

SCUBA divers have continued to observe gambusia, bullies, eels and mussels in Lake Waikōpiro during annual autumn surveys since the lake was stocked with grass carp (Hofstra 2013b).

Since removal of the hydrilla weed beds there have been changes in the composition of the invertebrate community, such as fewer taxa associated with plants (e.g., waterboatmen that were generally captured around the weed beds elsewhere) to an increase in invertebrates associated with the sediments (e.g., chironomids). Other changes include the presence of juvenile mussels record of mussels (Hofstra 2009). Total macroinvertebrate taxa numbers were similar to those obtained before the hydrilla weed beds were removed by the grass carp. Higher diversity was generally found in the shallow water (1.5m,13 taxa) compared with deeper water (6m, 8 taxa) (Hofstra 2013b).

On Lake Waikōpiro generally few bird species and numbers have been recorded (Table 18) compared with the adjacent Lake Tutira. When counts are low, trends (if present) are difficult to detect and must be in context with the type of data collected. For example, although there appears to an absence of mallard ducks in recent years, reporting in 2012 included observation of mallard ducks swimming along the causeway (Hofstra 2012).

Table 18: Birds observed at Lake Waikōpiro during autumn single day surveys.

Bird / Year	2008	2009	2010	2011	2012	2013	2014
Black shag, *Phalacrocorax carbo*	2						
Black Swan, *Cygnus atratus*	8	3	3	1	8	2	
Dabchick/Weweia, *Poliocephalus rufopectus*	4	6	2				
Geese, *Anser domesticus*			5	5	1	6	
Little black shag, *Phalacrocorax sulcirostris*		6					1
Little shag, *P. melanoleucos brevirostris*		1	1		1		
Mallards, *Anas platyrhynchos*	15	16	19				1
Paradise duck/Putangitangi, *Tadorna variegata*	2						
Pukeko, *Porphyrio melanotus*		4					
Scaup/Papango, *Aythya novaeseelandiae*		1	1				
White faced heron, *Ardea novaehollandiae*		1		1	3		2
Pied stilt/Poaka, *Himantopus*						2	

Water Quality

Water quality monitoring of Lake Waikōpiro was undertaken from May 2008 by HBRC (Von Westernhagen 2011). Monitoring has shown that Lake Waikōpiro exhibited stable thermal stratification during the summer. An increase in water temperature (epilimnion and/or hypolimnion) was detected over the sampling period, but there was no concurrent change in oxygen concentrations. There was no change in chlorophyll *a* concentration, total nutrient concentrations (TN and TP) or soluble reactive phosphorus (SRP) concentrations, but a decreasing trend in NO_3 concentration was detected in Lake Waikōpiro (61% per year) (von

Westernhagen 2011). The monitoring results to date have detected some changes in water quality parameters, however they have not been attributed to the hydrilla eradication response (von Westernhagen 2011).

In general the water clarity in Lake Waikōpiro is poor, with elevated levels of chlorophyll *a* (von Westernhagen 2012). The lake is described as eutrophic to supertrophic (von Westernhagen 2012).

Habitat Quality

Lake Waikōpiro provides habitat for a smaller range of aquatic flora and fauna than Lake Tutira. A severe algal bloom in 2012 resulted in diminished amenity values for that period (von Westernhagen 2012).

Summary of effectiveness and effects

Grass carp were introduced into Lake Waikōpiro to eradicate the submerged aquatic weed hydrilla. As outlined by MPI, this is a long term eradication response (MAFBNZ 2008), with only five and a half years having passed since the grass carp were stocked. To date target weed control has been achieved, with progress toward the eradication goal.

Effectiveness	Flora: Hydrilla weed beds have been removed, significant progress towards eradication.
Effects	Flora: Native flora was already compromised by the hydrilla, and submerged plants have been further reduced to a few turf species with reduced cover and abundance. Fauna: The relative abundance of macroinvertebrate taxa has shifted, juvenile mussels have been recorded. No changes have been documented for other taxa. Water quality: Changes detected, but not attributed to grass carp. Habitat quality: None detected.

3.5.4 Lake Opouahi

Lake Opouahi is a 6 ha lake, and is located in the hills (480 m above sea level) to the north and inland of Lake Tutira (Appendix C). It is situated in the Department of Conservation administered Opouahi Scenic Reserve. The reserve has also become home to the Opouahi Kiwi Crèche following the construction of predator proof fencing by ECOED (Environment, Conservation and Outdoor Education Trust) and the first release of kiwi chicks in 2008.

The lake is likely to have formed from a landslide which blocked the valley (Department of Lands and Survey 1981). It has high scenic value and is surrounded by native bush and swampland, with a further ca. 20 to 30% of the lake's catchment (44 ha) in farm land (Hooper 1987). There are several small inlet streams that pass through the northern wetland and the main inflow to the lake from the swamp is the Waipapa Stream. The lake outflow on its southern side is the Awatamatea Stream which eventually joins the Waikoau River (Hooper 1987).

3.5.4.1 Grass carp stocking – When, how many and why

Hydrilla is an alien submerged aquatic weed that is found in the Hawke's Bay, and was identified as a pest for eradication through the National Interest Pests Response (NIPR) programme (MAFBNZ 2008).

MPI developed an operational plan to manage and eliminate hydrilla in Lakes Tutira, Waikōpiro, Opouahi and Eland and to achieve the goal of eradication from New Zealand (MAFBNZ 2008). Eradication was considered achievable in the long term through the use of grass carp, and sustained grazing pressure (MAFBNZ 2008).

The stocking density for Lake Opouahi was based on 100 grass carp per vegetated hectare, which equated to 200 grass carp (30 cm in length) (Hofstra and Rowe 2008). Approval was obtained to introduce grass carp into Lake Opouahi for the eradication response in December 2008 (AQTRANS0501). The grass carp were released on the 11th December 2008. Because there was a large hydrilla weed bed at the jetty in Lake Opouahi, that lake users could encounter, this weed bed was targeted for removal in the first instance. A purpose built cage was constructed to contain 80 of the largest grass carp (to minimise shag predation) in this area (est 500m^2) until the weed bed was significantly reduced (ca 80% reduction). The fish from the enclosure were released into the lake and the fencing removed in February 2009 (Hofstra and Smith 2009).

3.5.4.2 Ecology and biology of the lake before grass carp release

Flora

The hydrilla infestation in Lake Opouahi probably originated from fragments moved from Lake Tutira (Clayton et al. 1995). The Lake Opouahi infestation was first noted in 1984 (Walls 1994), and is likely to have established at some time between 1970 and its first record, because it was not reported in a lake vegetation survey in 1970 (Department of Lands and Survey 1981).

The hydrilla formed discrete clumps within the lake rather than a broad band of vegetation, with the exception of the area in front of the jetty (Hofstra et al. 2003, 2008). At the jetty hydrilla covered an estimated area of 500m^2 with ca 90% cover between ca 1 to 4 m water depth, and a maximum height of 2 m (Hofstra et al. 2008). At other sites in the lake both hydrilla and the introduced weed elodea extended into the deeper water (7.5 m), as did charophytes in some profiles (Table 19). A diverse community of native plants occurred in the shallow water zone (ca less than 1m), with a total of twelve aquatic plant species recorded from the lake (Table 19).

Fauna

Historically, Lake Opouahi has been stocked with both rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*) (Rowe 1980). However trout were not recorded in a 2008 survey and were thought to be extinct from the lake (Hofstra et al. 2008), until they were subsequently released by Fish and Game later in the same year (Ian Gear, InGearGlobal pers comm). Smelt have been in the lake since they were stocked (as prey for trout), sometime prior to 1994 and they continue to thrive. Common bully numbers in Lake Opouahi were relatively low compared with the other hydrilla affected lakes in the Hawkes Bay and this is likely to be related to the presence of large, piscivorous longfin eels (Rowe 1999). Lake Opouahi had a good population of medium to large longfin eels and smaller-sized shortfins (Hofstra et al. 2008).

Koura were present but scarce, with only one being caught in the inlet stream (Hofstra et al. 2008). The scarcity of koura may, as is the case for the common bully may be associated with eel predation, as koura are a major prey species for eels (McDowall 1990).

Although Lake Opouahi appears to be good habitat for climbing galaxiids, they have not been found in the lake. Koaro (*Galaxias brevipinnis*) could readily colonise the lake and its inlet stream, but was not present. The absence of koaro is likely to be related to the historic stocking of smelt into the lake, as this was responsible for the extinction of koaro in another North Island lake (Rowe 1993). Additionally, it is possible that low stream flow in the summer months, and/or the predator proof fence around Lake Opouahi, maybe restricting fish access (Hofstra et al. 2008).

Macroinvertebrate sampling has shown a relatively high diversity and abundance of snails on native charophytes compared with hydrilla and elodea. The diversity and abundance of invertebrate taxa was generally related to habitat, with the shallow water littoral zone and areas with macrophytes having a higher diversity of taxa compared with benthic sediments (Hofstra et al. 2008). The taxa recorded in Lake Opouahi include chironomids, caddisflies (Trichoptera), damselfly (*Xanthocnemis*), dragonflies (*Hemicordulia*), snails (*Gyraulus, Physa, Potamopyrgus,* Sphaeriidae ostracods, mites (Acarina), oligochaetes, and waterboatmen (Hofstra et al. 2008).

Hooper (1987) notes that although the swampland in the catchment provides excellent wildlife habitat, waterfowl were not abundant on the lake. The spotless crake (puweto, *Porzana tabuensis*), a small rail, has been seen in the wetland at the head of the lake (Hughes 1987) along with more recent sightings of dabchick (weweia, *Poliocephalus rufopectus)*. In a 2008 dawn survey at Lake Opouahi mallard ducks (*Anas platyrhynchos*), black swans (*Cygnus atratus*), a black shag (*Phalacrocorax carbo)* and kingfisher (Kotare, *Halcyon sancta vagans)* were recorded (Hofstra et al. 2008).

Table 19: Lake Opouahi vegetation survey summary data from 2008 (Hofstra et al. 2008).

Species	No. of Sites	Depth range (m)	Max. Height (m)	Ave. Height (m)	Max. Cover	Median Cover
Machaerina arthrophylla	1	0 – 1	1	1	4	
Carex secta	1	0 - 0.8	0.4	0.4	3	
Chara australis	3	1.5 - 7	0.3	0.2	5	4
Chara globularis	5	0.2 - 5.7	1.2	0.6	6	5
Elodea canadensis	5	0.2 - 7.5	5.8	1.7	6	3
Hydrilla verticillata	2	1 - 7.5	3.7	2	6	5, 6
Nitella hyalina	1	0.2 - 0.5			1	
Nitella pseudoflabellata	1	0.2 - 0.5			1	
Paspalum distichum	1	0 - 0.5			2	
Potamogeton crispus	1	1 - 1.5	0.5	0.4	2	
Ranunculus trichophyllus	2	0.2 - 2	1.1	0.55	3	1, 2
Typha orientalis	2	0 - 0.8	2	1.65	5	3,4
NB: Data are averaged values from the five survey sites. Cover values correspond to percent cover as follows; 1=1-5%, 2=6-25%, 3=26-50%, 4=51-75%, 5=76-95%, 6=96-100%.						

Water Quality

Historic data on water quality for Lake Opouahi were summarised by the Hawke's Bay Catchment Board (Hooper 1987). Reported nutrient loadings in Lake Opouahi in the 1980s were 0.37 g/m^2/y of phosphorus and 3.8 g/m^2/y of nitrogen, with an N:P ration of 10.3:1 (Hooper 1987). These estimated loadings indicate that at the time of these data Lake Opouahi was borderline eutrophic (Table 20) (Hooper 1987). However with regards to overall lake classification (transparency, dissolved oxygen, algae, plants) Lake Opouahi has been described as oligotrophic to mesotrophic (Hooper 1987). For example the lake can be relatively clear with a secchi disc reading of ca. 10 m (Nov 1984), although that was reduced over the summer months to a reading of 3.3 m (Feb) due to phytoplankton growth (Table 20) and there was little suspended matter and low dissolved colour (Hooper 1987).

Hawkes Bay Regional Council resumed water quality monitoring of Lake Opouahi in May 2008 (Table 20).

Habitat Quality

Lake Opouahi is described as a lake of moderate to high value (Hooper 1987), which in recent years has been enclosed in a predator-proof fence with its forest catchment to provide safe habitat for kiwi chicks to mature. The lake supports waterfowl (in small numbers), and has several native fish species (short and longfin eels and common bullies), while trout were introduced along with smelt (as prey) and they continue to thrive. Climbing galaxiids were notably absent even though the habitat appeared to be suitable (Hofstra et al. 2008). Although the lake had large areas of the aquatic weeds hydrilla and elodea, native charophytes were abundant. There was a relatively high diversity and abundance of snails on native charophytes.

Table 20: Summary water quality data for Lake Opouahi

	October 1984 – April 1985 (Hooper 1987)			May 2008 (HBRC Monitoring Programme)	
	Min	Median	Max	Epilimnion	Hypolimnion
Temperature (ºC)	10.5(9)	15.5	22(24.5)	11.4	9.8
Secchi disc (m)	3.29	8.82	10.47	4.4	
Chlorophyll *a* (mg/m^3)	1.3	3.4	9.6		
Dissolved Oxygen (% Sat)				37.6	2.3
Dissolved Oxygen (g/m^3)				3.89*	0.25
Total P (g/m^3)	<0.01	<0.01	0.03	0.025	0.1
Total soluble P (g/m^3)	<0.01	<0.01	0.03		
Soluble reactive P (g/m^3)	<0.01	<0.01	0.02	0.0057	0.098
Nitrate N (g/m^3)	<0.01	<0.01	0.12	0.0039	<0.002
Ammonia N (g/m^3)	<0.02	<0.02	0.04	0.031	0.2
Conductivity (µmho/cm)	165	180	190	190	210
Suspended solids (g/m^3)	<1	1	2	<3.0	<3.0

Thermocline when present is at 12 to 13m (Hooper 1987), and 15m (May 2008).
* DO low for this time of year as lake appears to still be stratified (possible instrument error).
Lake depth was 22.7m and Lake Height was 0.810m (May 2008).
Additional temperature data in brackets from Rowe (1980).

3.5.4.3 Ecology and biology of the lake after grass carp release

Flora

Vegetation surveys have been carried out annually in autumn since the introduction of grass carp. Hydrilla was only present as a few plants for a single monitoring site (1 of 5) in 2010 (Hofstra 2010), and not recorded from the lake in 2011 (Hofstra 2011), or during annual inspections since then (authors obs).

Amongst the submerged species and aside from the hydrilla, elodea and native charophytes have also shown a decline in presence and abundance. However localised dense patches of charophytes were still present in Lake Opouahi in 2011, although they were a preferred food for the grass carp at that time (Hofstra 2011). By 2012, and since then the submerged plants recorded in annual surveys were generally less palatable species to the grass carp (e.g., *Ranunculus trichophyllus*) or they were relatively inaccessible (e.g., charophytes in grass carp exclosure cages) (Hofstra 2013b).

Fauna

A fish survey was carried out in Lake Opouahi in 2011, since the removal of the hydrilla by the grass carp to report on any potential effects there may have been on the fish population. Removal of the weed beds increased the abundance of common bullies in the littoral zone, and may have increased the use of this zone by shortfin eels in Lake Opouahi. Other native fish species (longfin eels, smelt) were unaffected (Smith and Rowe 2011).

More specifically, the longfin eels in Lake Opouahi were more numerous and fatter than the shortfins. The size structure for longfin eels was very similar to 2008, with no obvious emigration of large longfins. An increase in the number of shortfin eels caught in 2011 was attributed to a change in the distribution or behaviour of the adult shortfin eels following weed removal as there was no evidence of increased recruitment (i.e., an influx of juveniles). The increased catch in 2011 indicates that the weed beds may have previously discouraged shortfins from feeding in the shallow (0-3 m deep) littoral zone. Scarcity of elvers and juvenile eels was noted, and it was considered that recruitment may not be annual, and/or that accumulation of debris may restrict elver passage through the mesh of this fence, and that new recruits may now become more exposed to predation by large eels (and trout) in the lake (Smith and Rowe 2011).

The common bully population increased rapidly in Lake Opouahi as weed removal occurred. Weed removal expands benthic habitat for bullies, and their food supply (chironomid larvae) increases. In addition, logs and rocks formerly covered by weed are exposed and increase the spawning substrate for bullies. As weed removal also increases exposure to predation, the predators (e.g., eels) can be expected to benefit from the increase in bullies caused by weed removal.

Since 2008, there has been a shift in the relative abundance of macroinvertebrate taxa, with samples from the shallow water (less than 1.5m) having a greater variety of organisms which is likely a reflection of the variety of habitat present within this zone (Hofstra 2012).

Single day counts of birds from Lake Opouahi show species both before and since the weed beds were removed (Table 21). Few species and numbers have been recorded both before and since the release of grass carp.

Table 21: Birds observed at Lake Opouahi during autumn single day surveys

Birds Year	2008	2009	2010	2011	2012	2013	2014
Black shag, *Phalacrocorax carbo*	1	2	2	1	1		
Black Swan, *Cygnus atratus*	2						
Dabchick/Weweia, *Poliocephalus rufopectus*		4	4	8	3	5	2
Kingfisher/Kotare, *Halcyon sancta vagans*	2			1	1		
Little black shag, *Phalacrocorax sulcirostris*				1	1		
Little shag, *P. melanoleucos brevirostris*	2						
Mallards, *Anas platyrhynchos*	8	1					1
Scaup/Papango, *Aythya novaeseelandiae*					4		

Water Quality

Lake Opouahi is described as a mesotrophic lake (von Westerhagen 2012) and its water quality is monitored by Hawkes Bay Regional Council. In the 2011 report, significant increases in chlorophyll *a* concentration through time (from May 2008 to April 2011) were found in Opouahi, with maximum values recorded in May 2009 and May 2011 (von Westernhagen 2011). Total nutrient concentrations (TN, TP, SRP (soluble reactive phosphorus) and NO_3) did not show any significant changes (von Westernhagen 2011).

Habitat Quality

The submerged aquatic macrophytes are now restricted to species that are less preferred by the grass carp (e.g., *R. trichophyllus*) or less accessible to them (e.g., marginal emergent plants, or germlings charophytes in the grass carp exclosure cages). The removal of large areas of submerged aquatic plants has resulted in a shift in the relative abundance of macroinvertebrate taxa. Weed removal has resulted in an increase in the population of common bullies. The increase in bullies indicates a restructuring of the littoral food web from macrophyte based macroinvertebrates, to substrate based taxa. For example, when the littoral weed beds were present, snails and a diverse range of invertebrates that inhabit such weed beds, would have provided the main food supply for common bullies. After weed removal, chironomid larvae increase in the newly exposed sediment (Mitchell 1986; Kelly & Jellyman 2007) and provide a better and more accessible food source for the common bully. Predator species (eels, shags) are likely to benefit from an increased population of bullies.

Summary of effectiveness and effects

Grass carp were introduced into Lake Opouahi to eradicate the submerged aquatic weed hydrilla. As outlined by MPI, this is a long term eradication response (MAFBNZ 2008), with only five and a half years having passed since the grass carp were stocked. To date target weed control has been achieved, with progress toward the eradication goal.

Effectiveness	Flora: Hydrilla weed beds have been removed, significant progress towards eradication.
Effects	Flora: Native flora was already compromised by the hydrilla, and submerged plants have been further reduced. Fauna: The relative abundance of macroinvertebrate taxa has shifted. Some fish species have increased in abundance, no change was recorded for others. No change for waterfowl. Water quality: None detected. Habitat quality: Improved habitat for common bullies.

3.6 Taranaki

3.6.1 Lake Rotomanu

Lake Rotomanu is a 9.8 ha lake, with a maximum depth of 10 m (Aquaculture NZ 1998a) 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).

3.6.1.1 Grass carp stocking – When, how many and why

Approval to release 147 grass carp was obtained in September 1999 for the purpose of aquatic macrophyte control (AQTRANS07/03, 1999). An estimated 30 grass carp per vegetated hectare (Aquaculture NZ 2001), this equated to approximately 50% of the 9.8 ha lake (Correspondence 26th January 2005 MFish). The objective was to manage weed levels and remove ca 30% of the weed (Decker 2000), and the target species were lagarosiphon and egeria (Aquaculture NZ 2001).

A second approval was granted on 15th of October 2001 for 343 grass carp, but with the ability to increase this incrementally up to 980 fish and raise the stocking density to 100 fish per vegetated hectare (AK073, 2001), assuming the entire lake was covered in vegetation. However the weed beds collapsed and the incremental stocking did not occur, and the approval expired in August 2003 (Correspondence 26th January 2005 MFish).

Eight grass carp were removed from the lake in June 2003 (Aquaculture NZ 2003), and by September 2004 the introduction of further fish (ca 50) was recommended (Aquaculture NZ 2004).

An approval to introduce a further 50 grass carp was obtained in February 2005 (CA050, 2005). On 8th of October 2005, 50 grass carp (ca 45 cm long) were released into the lake (Aquaculture NZ 2007). In September 2005 a further 50 grass carp were approved (CA063, 2005), followed by 500 in September 2007 (CA090, 2007), and 500 in May 2009 (CA112, 2009). Details of subsequent releases include 500 grass carp on the 4th of September 2007, with a further 250 in both the May 2009 and in October 2009 (Aquaculture NZ 2009e).

The current stocking density appears uncertain, with a question 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 escape, and whether or not all screens remained in place (Correspondence 5th May 2009 Fish and Game). No grass carp have been reported from the adjacent river or the wetland (A. Stancliff, Fish and Game pers comm). However some grass carp have been captured from Lake Rotomanu (A. Stancliff, Fish and Game pers comm).

3.6.1.2 Ecology and biology of the lake before grass carp release

Flora

Dense growths of the submerged weeds lagarosiphon and egeria were reported in the risk assessment report (RAR) (Aquaculture NZ 1998a). A DOC survey in March 1999 recorded a narrow band of lagarosiphon and egeria fringed the shore to a depth of about 1m. Within 5 to 10m of the shore most of the aquatic plants had been removed by a recent herbicide application. However, beyond about 10m the bed of the lake was covered by *Nitella hookeri*, which grew to within about 1m of the water's surface (Duffy 1999). There were small patches of lagarosiphon amongst the *Nitella* (Duffy 1999).

Fauna

Fish fauna recorded in Lake Rotomanu in the RAR included long and shortfin eels, brown trout and rudd, but there were few records of invertebrates from the lake (Aquaculture NZ 1998a). DOC recorded large numbers of the snail *Potamopyrgus*, and a single perch in 1999, and in 1998 rainbow trout, common bullies and inanga were observed in a small pool around the inlet to the lake (Duffy 1999). Mallard ducks and geese have been observed on the lake, although it was noted that other species of birds also frequented the surrounding park (Aquaculture NZ 1998a).

Water Quality

The lake was filled by water from the Waiwhakaiho River and still receives water from the river (during peak flows (S McGill, New Plymouth District Council (NPDC), pers comm)) as well as smaller amounts of water from rainfall and the catchment runoff (Aquaculture NZ 1998a).

Habitat Quality

Lake Rotomanu was recognised as an artificial lake and habitat, with few indigenous species values (DOC 1999), and no rare or endangered species (Correspondence 26th January 2005 MFish). However, waterfowl, native fish and plants species have all been recorded from the lake, and the lake has high recreation values and multiple public uses (Correspondence 26th January 2005 MFish).

3.6.1.3 Ecology and biology of the lake after grass carp release

Flora

In 2001, one transect within the lake had primarily egeria (ca 91%) with lesser amounts of lagarosiphon and *Myriophyllum* species, while similar amounts of lagarosiphon and egeria were reported from a second transect, along with small patches of *Nitella* (Aquaculture NZ 2001). Grass carp feeding activity was noted as "tunnels" in the vegetation (Aquaculture NZ 2001). However, weed control was considered insufficient and the stocking of further grass carp was recommended (Aquaculture NZ 2001).

The lake was sprayed with herbicide between the first (May 2001) and second (December 2001) vegetation surveys to reduce the weed beds (Aquaculture NZ 2002). A collapse in the macrophyte beds was recorded in December 2001, (attributed to a combination of the herbicide application and the grass carp (Aquaculture NZ 2002)) and this was followed by an algal bloom (A Stancliff, Fish and Game, pers comm).

No weed was recorded in June 2002, (only the marginal aquatic plant raupo) and consequently a reduction in grass carp numbers was recommended (Aquaculture NZ 2002). No weed was recorded in April 2003 (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). 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).

Elodea, lagarosiphon*, M. triphyllum* and charophytes were recorded as the most abundant plants in January 2009 (NZWR 2009e), and later in the same year *M. triphyllum* and lagarosiphon were the most abundant species (Aquaculture NZ 2009e). At that time weed harvesting was recommended to reduce the plant biomass (Aquaculture NZ 2009e).

By 2012 a request had been made by NPDC to remove the grass carp from Lake Rotomanu (Jamieson pers comm, with Clayton NIWA, 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 (Jamieson pers comm, with Clayton NIWA, Oct 2012)".

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, NPDC pers comm).

Fauna

Since the release of grass carp, goldfish have been observed in the lake and shags were noted to be feeding on them (Aquaculture NZ 2002). Perch, rainbow trout, and eels were all caught in a 2003 survey and rudd were noted as present (Aquaculture NZ 2003), and common bullies were present in 2004 and 2005 (Aquaculture NZ 2004, 2005). Eels, goldfish, perch and bullies were recorded in 2009 (NZWR 2009e).

Large populations of ducks and geese were recorded on the lake and a dense population of daphnia was observed in the lake in 2003 (Aquaculture NZ 2003). In subsequent years ducks, geese, seagulls, black shags, pied shags black swans and pukekos have all been recorded from the lake (Aquaculture NZ 2005, 2007, NZWR 2009e).

Water Quality

The lake water has most frequently been described as clear (Aquaculture NZ 2001, 2004, 2005, NZWR 2009e), with water temperatures taken during monitoring events ranging from 12.2 to 13°C in May (Aquaculture NZ 2001) ca 8°C in June (Aquaculture NZ 2007), and ca 14 to 22.6°C in December (Aquaculture NZ 2001, NZWR 2009e). The lake temperatures in summer are 22 to 25°C (Correspondence 28th January 2005 Fish and Game, NZWR 2009e).

After the collapse of the weed bed, there was a significant algal bloom in 2001 (Correspondence 5th May 2009 Fish and Game). The algal bloom was attributed to the large pulse of nutrients that were released during decomposition of plants following an application of herbicide (Correspondence 28th January 2005 Fish and Game). The sustained flushing of water in the lake was considered to have remedied the high nutrient concentrations (Correspondence 28th January 2005 Fish and Game).

Algal blooms have occurred since 2001, and the lake has also been closed for recreation with the water level lowered due to poor water quality and the presence of blue-green algae (NZWR 2009e).

Habitat Quality

Lake Rotomanu is a man-made lake with few indigenous species values (DOC 1999), although arguably the conservation values improved through the removal of exotic weeds and increased dominance of native plants (Correspondence 26th January 2005 DOC), albeit temporarily.

Summary of effectiveness and effects

Failure to achieve effective weed control was likely due to a number of contributing factors. It has in particular been attributed to a change in plant composition, the influence of water temperature, and in addition the potential for fish to have escaped has been raised.

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 now achieved with targeted herbicide application (S McGill, NPDC pers comm).

Effectiveness	Flora: Target weed removal was not achieved.
Effects	Flora, fauna, water and habitat quality: Native charophytes were consumed and a shift has been recorded in plant community composition. No other changes were detected that were attributed directly to the grass carp introduction.

3.7 Wellington Region

3.7.1 Henley Lake

Lake Henley is part of the larger Ruamahanga catchment (MDC 1993). The catchment is highly modified by pastoral and urban development with significant impacts on river hydrology and water quality (MDC 1993). The establishment of Lake Henley in 1988 provided the region with a high valued recreational amenity (Buchanan 1991). This artificial lake is 11 ha in area, shallow (ca 1.5 m for much of its area, with a maximum depth of 3m), and includes a number of small islands.

The lake is used for a variety of recreational activities including, angling, canoeing, rowing, sailing, board sailing, and swimming, picnicking and walking (Buchannan 1991).

3.7.1.1 Grass carp stocking – When, how many and why

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 EIA states that long term control of aquatic weeds in Lake Henley could be achieved at a stocking rate of 20 per ha (ca 200 fish of 25 cm), once these fish have reached adult size (40 cm). At that density a reduction in total biomass, but not complete elimination of macrophytes was anticipated, with grass carp opening holes in the weed beds that would benefit recreational use (Buchannan 1991). However, it was acknowledged that spot weed control by chemicals or other means might also be necessary (Buchanan 1991).

In 1993 triploid grass carp (an unspecified number) were approved for release into Lake Henley (AQTRANS0019, 1993) at a stocking density of ca 20 fish/ha (Miller 1994), to decrease the submerged vegetation in the lake by 50% within 6 years (Miller 1994). MFish correspondence, records that the approval was for 200 grass carp on 13th April 1993 (Correspondence 22nd May 2009 MFish) and Aquaculture NZ (1998) reports that “about 200 triploid grass carp were released” in April 1993.

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). Subsequent approval for 1000 grass carp was obtained in 1997 (MFish approval 1997) and 500 triploid grass carp were released in January 1998 (Aquaculture NZ 1998b). As described for the earlier introduction, the 1998 release of grass carp 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). However, the weed control objectives were not achieved with grass carp, and herbicide (diquat) and mechanical cutting were used to clear the dragon boat course (Dugdale and Wells 2001).

In addition, the possible escape of fish from Lake Henley, following the capture of a grass carp (52 cm long) in Lake Wairarapa, highlighted security issues with the site (Dix 1998). For example the grill size at Lake Henley was measured, found to be larger than the size quoted (30mm gap rather 25mm gap), which was theoretically possible for a stocked fish to have escaped (Dix 1998). Furthermore, not all screens were in place (Dix 1998). It was also noted that a grass carp (which subsequently died) had been seen in the wetland adjacent to Henley Lake.

In May 2009 the Masterton District Council obtained approval for a further release of grass carp (up to 500) into Lake Henley (CA104, 2009).

3.7.1.2 Ecology and biology of the lake before grass carp release

Flora

The establishment of Lake Henley in 1988 was followed in 1990 by dense aquatic plant growth and floating algal blooms that threatened the continued recreational use of the lake (Buchanan 1991). The dominant weed species were *P. crispus* and elodea, with dense stands covering much of the lake bed. Filamentous green algae blooms occurred in the warmer summer months, forming dense surface and subsurface growths (Buchannan 1991).

A survey to establish baseline data was conducted in 1993, and concluded that there was 100% cover of vegetation in the lake (Miller 1994).

Fauna

Henley Lake provides habitat for both short and longfin eels, bullies, koura and a wide variety of aquatic invertebrates. No rare or uncommon species are present (Buchannan 1991). The locally important trout fishery is managed by Wellington Fish and Game. Perch were also known to be present (Buchannan 1991).

Waterfowl noted at the lake or the adjacent wetland include, shoveller, grey ducks, grey teal, black swans, Canadian geese, paradise shelducks, mallard ducks, whitefaced herons, banded dotterel, pukekos, black shags and little shags (Buchannan 1991).

Water Quality

Water is supplied to the lake, primarily via a diversion from the Ruamahanga River (Buchannan 1991). During periods when the river water is discoloured the intake water can be re-routed back to the river before it enters the lake. Additional flow is provided by smaller inlet streams (Buchannan 1991, Miller and Death 1997).

The principal outlet takes water to the adjacent wetland, after an estimated 5 day residence time in the lake (Miller and Death 1997). Automatic diversions were advocated, to reduce the silt that flows into the lake (before the manual diversion can be operated) because these inputs were described as “encouraging high plant growth rates and algal blooms during the summer” (Buchannan 1991).

Habitat Quality

While the weeds were considered to form nuisance growths that restricted and were hazardous to recreational use (Buchannan 1991), it was also recognised that the plants provide substrate for invertebrates, contributed directly to the diet of some waterfowl, and provide refuge for fish (Miller 1994). It was envisaged that the low stocking density of grass carp, would reduce the plants and have a limited effect on other components of the ecosystem (Buchannan 1991).

3.7.1.3 Ecology and biology of the lake after grass carp release

Flora

The target reduction of vegetation (ca 50%) was not achieved, with no indication of grass carp activity after the first two years (Miller, 1995). An inspection report from 1996 also notes that insufficient weed control had been achieved (MDC 1996). The latter report also states that there have been no known fish escapes, the screens were secure and more grass carp were advocated (MDC 1996).

The objective of the 1997 release of grass carp, 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). In 1998 the vegetation in the lake was almost entirely comprised of elodea around the edges, with *P. crispus* mainly in the centre of the lake (Aquaculture NZ 1998b).

In November 2000 the submerged vegetation of Lake Henley was surveyed and found to be of low abundance (Figure 6). The native nitella (*Nitella* sp. aff. *cristata*) was the most common species present with an average cover of 15-20%. The weed species elodea and *P. crispus* were sparse with covers of less than 5%. Their low abundance in the lake compared with previous summers was attributed to the lake having been sprayed (December 1999) and the recently lowered water level for bank repairs (Dugdale and Wells 2001).

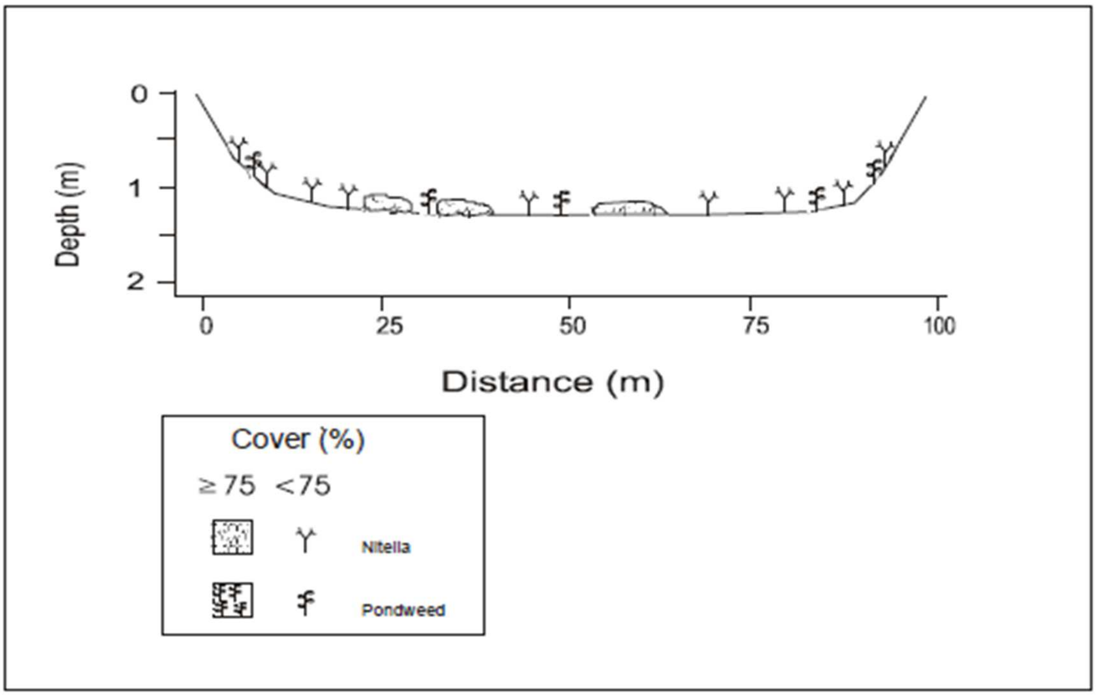

Figure 6: A stylised representation of the aquatic vegetation in Lake Henley (Sourced from Dugdale and Wells (2001) figure 2).

Nitella species are considered desirable components of the submerged vegetation. They are primarily low growing plants that do not impede surface based recreation activities, stabilise the sediments, provide wildlife habitat and food, and compete with suspended algae for available nutrients (Dugdale and Wells (2001). 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). Although weed spraying was undertaken in the intervening years, surface reaching weed beds were recorded in the summer of 2007 (Correspondence 2nd November 2007, and 9th September 2008 Bayley), and in May 2009 the Masterton District Council obtained approval for a further release of grass carp (up to 500) into Lake Henley.

Fauna

The macroinvertebrate communities associated with dense exotic macrophytes were sampled between June 1993 and June 1994 from Lake Henley and an inflow stream (Miller and Death 1997). Communities were dominated by snails (*Potamopyrgus antipodarum*) or oligochaetes (Miller and Death 1997). In general the phytomacrofaunal community was not unlike communities associated with macrophytes in other New Zealand lakes, with low species diversity, likely due to the lack of plant diversity (i.e., habitat) in the lake, and seasonal patterns in the macrofauna were evident (Miller and Death 1997).

No documented changes in fish or waterfowl fauna following grass carp stocking were obtained.

Water Quality

Water quality measurements from June 1993 to 1994 are presented in Miller and Death (1997). Temperature data indicated that grass carp would be most active in the lake between December and March when water temperature were compatible with feeding (Miller 1995), i.e., when the water was above 17.5°C and ca 20°C (based on the graphed data in Miller 1995).

The flow through of water in Lake Henley is relatively rapid, with high nutrient loads in the main flow. Nutrient levels were of the magnitude recorded for enriched lakes in highly developed catchments (Miller 1995).

Habitat Quality

A key component of the management of the lake was to maintain weed beds at a level where their nuisance values were reduced yet their beneficial functions remain (Miller 1994). Although the desired level of plant control was not achieved, or sustained when there was low plant abundance, nor were the beneficial functions of the plants reduced.

Summary of effectiveness and effects

Although containment issues may have compromised the effective stocking density of grass carp in Lake Henley (Dix 1998), subsequent management advice considered it unlikely, that partial weed control by grass carp could be achieved in the lake for an extended period of time (Dugdale and Wells 2001). Further, 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 as such, grass carp were not recommended (Dugdale and Wells 2001).

Effectiveness	Flora: Target weed reduction was not achieved.
Effects	Flora, fauna, water and habitat quality: None detected.

3.8 Canterbury

3.8.1 Lake Hood

Lake Hood is an artificial/man-made lake, which was filled in 2002, and is managed for recreation. The lake is ca 72 ha and varies in depth from 2.3 to 5.5 m. Although separated from the main river, it is in the Ashburton river catchment. The lake supports recreational activities such as boating, canoeing, water skiing and rowing. Residential homes are located around the canals (DOC 2004). The lake receives water from the Ashburton River, Bayliss Creek, Carters Creek and from groundwater (DOC 2004).

3.8.1.1 Grass carp stocking – When, how many and why

The Ashburton Aquatic Park Charitable Trust applied to release 2160 grass carp into Lake Hood in 2004 in order to reduce the quantity of various aquatic plants in the lake and to control the future plant growth (DOC 2004). The release was approved by DOC in 2005 (stocking density of 34 fish/ha, AQTRANS11/01, 2005), and the operational plan stated a goal of 70% weed removal from the body of the lake, with vegetation then maintained at that level (Operational Plan Lake Hood 2005). The grass carp (2000) were released in May 2005 (Decker 2005).

Subsequent approvals for grass carp release by MPI were completed in February 2004 (CA036), October 2008 (CA98), January 2012 (CA117), and in October 2012 (500 fish, CA201) (Pullan 2013).

In addition, in 2009 approval was granted for 5000 small grass carp to be held in ponds adjacent to Lake Hood (CA121, November 2009) prior to their release in the lake. These small (ca 15 cm) fish over-wintered in the holding ponds, but when it came time to release the fish only ca 150 remained (Clayton 2012).

In 2013 the estimated number of grass carp in the lake was 3,800 to 4,000 fish around 7kg in size (Correspondence 11th November 2013 NIWA).

3.8.1.2 Ecology and biology of the lake before grass carp release

Species present in Lake Hood include *P. crispus, N. officinale, P. cheesemanii, C. stagnalis, Glyceria fluitans, Erythranthe guttatus* and various species of filamentous algae. *P. crispus* and filamentous algae were abundant (DOC 2004).

Fish, aquatic invertebrates and birds from the catchment, rather than specifically for Lake Hood were listed in the EIA (DOC 2004). Additional information records the following waterfowl; mallard ducks, black shags, paradise shelduck, Canadian geese, grey ducks, black backed gull, black fronted dotterel and white faced herons (DOC 2004).

In receiving water from the Ashburton River, it was reported that Lake Hood is receiving nutrients with the water, and acts as a '"nutrient sink", with the water flowing back to the river being of a significantly higher quality (Correspondence 24th April 2007 AAPCT). The operational plan states that water quality monitoring was undertaken monthly by Environment Canterbury since 2002 (Operational plan 2005).

3.8.1.3 Ecology and biology of the lake after grass carp release

Monitoring reports have been received by DOC since the grass carp were released into the lake. By November 2006 an estimated maximum of 1980 fish remained in the lake (Decker 2007b). Vegetation surveys (May 2005, November 2005, November 2006 and February 2010) on two transects were interpreted as showing ca 30% biomass decline in the first 6 months following the release of grass carp (May 2005 to Nov 2005 (Decker 2005)). However, by February 2010 increased weed cover and biomass was described (Aquaculture NZ 2010). Following an additional survey in 2012, it was suggested that the observed decline in 2005 and 2006 was most likely seasonal rather than from grass carp grazing (Clayton 2012). Both the target weed species *P. crispus* and elodea typically reach peak seasonal biomass earlier than most other aquatic weed species and at temperatures lower than when grass carp grazing would be optimal. Clayton (2012) also records the use of herbicide (diquat) to treat surface reaching patches of pondweeds and elodea.

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).

In January 2014 submerged vegetation in Lake Hood was impacted by spring storm events, although plants persisted in areas of the lake that were sheltered from the NW storm and associated wave-induced damage (Sutherland et al 2014).

Fauna

Monitoring reports consistently record observations of waterfowl (primarily mallard ducks), perch and bullies (Decker 2005, 2006b, 2007b), with salmon, trout, longfin and shortfin eels caught during fish monitoring in 2006 (Decker 2007b). Grass carp released in May 2005 had the right pelvic fin clipped. The fin was largely regenerated in fish caught in 2007 (Jamieson 2007).

Water and Habitat Quality

No changes have been recorded as a consequence of the release of grass carp. However, significant water clarity changes were documented in association with spring storm events (Sutherland et al. 2014).

Summary of effectiveness and effects

A lack of effective weed control has been documented in Lake Hood to date. In addition, Clayton (2012) suggests the seasonal non-synchrony of peak plant growth for target species and fish consumption rates could make it difficult for grass carp to get control over established weed beds. Sutherland et al. (2013) recommended cage trials with grass carp in the lake to ascertain if grass carp are able to actively feed in Lake Hood and what stocking densities are required in order to achieve sufficient weed control in the lake.

Effectiveness	Flora: Effective weed removal has not been demonstrated.
Effects	Flora, fauna, water and habitat quality: None detected.

4 Discussion

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. For introduction of a species to a new location (where grass carp do not already exist) DOC have a statutory role in the approval. To obtain approval, an application must be made to DOC for the new location and an environmental impacts assessment (EIA) may be required. DOC (2012) have noted continued interest in the use of grass carp for weed control, but consider that despite *"their current and historical use in New Zealand, insufficient information is available regarding the effects of grass carp on the ecosystems that they are transferred into".* NIWA were contracted by DOC to undertake a limited but targeted review of the existing knowledge on the effectiveness and effects of grass carp. The purpose of the review was to improve future decision making.

A total of 24 lakes and ponds were selected by DOC for which records were investigated. Of these, grass carp had been released into 22, and NIWA visited 15 during the summer to early autumn field season (2013/2014) to update vegetation records. Amongst the 22 locations, nine were natural lakes and fifteen were man-made lakes, the majority of which are used for stormwater retention.

4.1 Effectiveness

Weed species targeted for control were primarily submerged aquatic plants characterised by their tall dense growth (e.g., *E. densa, C. demersum, H. verticillata*), and the goals ranged from partial removal of plants (e.g., Lakes Hood and Rotomanu) to eradication of the weeds from the waterbody (e.g., Lakes Heather and Swan) and the country (e.g., Eland, Tutira, Waikōpiro and Opouahi) (see Summary Box below).

With the exception of Eland Farm Lake (section 3.5.1), the eradication programmes reviewed in this report are still in progress, meaning that significant reduction in the target weed species has been achieved for all lakes, but eradication has not yet been confirmed (see Summary Box below). Significant reductions in target weed beds (egeria and hornwort) occurred at stocking densities of 40 to 50 grass carp per vegetated hectare, two and three years after stocking with grass carp in Lakes Swan and Heather respectively. Target weeds have not been found in Lake Swan for the past two years (section 3.1.3) and only fragments of hornwort were recorded in Lake Heather (section 3.1.1). In the example of the hydrilla infested lakes, significant weed reduction occurred after two summers, using a high stocking density of 100 grass carp per vegetated hectare (e.g., section 3.5.2). In line with the EIAs for the introduction of grass carp into these lakes, eradication is anticipated in the short term for weeds like egeria and hornwort that do not set seed in New Zealand, and longer term for hydrilla which has long lived vegetative propagules, that require sustained grazing pressure (section 3.5).

Amongst those waterbodies where the goal was partial removal (weed control), usually described as partial control or removal of a specified portion of the weeds (ca 70%) or removal of the majority of a targeted 'nuisance' weed species, this was rarely achieved (see Summary Box below). Complete removal of submerged aquatic plants was documented in the majority of the waterbodies investigated (section 3). Where partial removal has occurred (i.e., there were still some submerged plants recorded, as in the Wattle Farm park pond (section 3.3.9)) this is most likely temporary. In contrast there were examples where adequate weed control was not achieved (e.g., Lakes Henley (section 3.7.1), Rotomanu (section 3.6.1) and Hood (section 3.8.1)) and alternative weed control options have been sought (e.g., Lakes Henley and Rotomanu).

Several factors may contribute to inadequate partial control, or a lack of effectiveness of grass carp in managing the target weeds in a given lake. Of primary importance is recognising whether or not grass carp were/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 was to keep water ski or rowing lanes weed free, that goal is not likely to be consistent with partial 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 other main reason for failure is inadequate containment resulting in escape and hence and inadequate stocking density.

Other factors to consider that influence the effectiveness of the weed control outcome include; accurately identifying plant species, the area of vegetation, determining an appropriate stocking density (including fish size) given the desired timeframe for weed removal, water temperatures (which reflect the plant growing, and fish grazing season), and whether or not other plants species are present that the grass carp may prefer compared with the target plants (Rowe and Schipper 1985, Clayton and Wells 1999).

Summary of the purpose and related outcome of grass carp introduction for each lake

Weed eradication
Lake Heather Purpose: Submerged weed control and eradication of the target species, egeria (*Egeria densa*) and hornwort (*Ceratophyllum demersum*) (EIA Lake Heather, 2010). Outcome: Significant reduction in target weeds achieved, and significant progress towards eradication.
Lake Swan Purpose: Eradication of hornwort and egeria from the lake (Mitchell 2008). Outcome: Significant reduction in target weeds achieved, and significant progress towards eradication.
Lake Kereta Purpose: “The intention is to ultimately eradicate hornwort from the lake” (Mitchell 2007). Outcome: Significant reduction in target weeds achieved, and significant progress towards eradication.
Lake Wainamu Purpose: Eradication of egeria (Surrey 2008). Outcome: Significant reduction in target weeds achieved, and significant progress towards eradication.
Lake Tutira Purpose: Eradication of hydrilla (*Hydrilla verticillata*) (MAFBNZ 2008). Outcome: Significant reduction in target weeds achieved, and significant progress towards eradication.
Lake Waikōpiro Purpose: Eradication (MAFBNZ 2008). Outcome: Significant reduction in target weeds achieved, and significant progress towards eradication.
Lake Opouahi Purpose: Eradication (MAFBNZ 2008). Outcome: Significant reduction in target weeds achieved, and significant progress towards eradication.
Elands farm lake Purpose: Trial for the eradication of hydrilla (Neale 1988a, Clayton et al. 1995). Outcome: Eradication achieved.

Weed control (reduction in target species, or plant volume, or removal of a percentage of the plants)
Lake Omapere Purpose: Gradual reduction of egeria, and maintenance of ca 10% plant cover (Aquaculture NZ 2000). Outcome: The timing and number of grass carp released was not sufficient to prevent a predicted weed bed collapse. Egeria has not re-established in the lake in the presence of grass carp.
Maygrove Lake Purpose: "Prevent nuisance plants becoming a problem" and "maintain a stocking density that would achieve the desired level of weed control" (Operational plan for Maygrove Lake 2007). Outcome: Limited information for assessment of effectiveness, and uncertain stocking density.
Link Drive Purpose: Control macrophytes (Decker 1996a). Outcome: Limited information for assessment of effectiveness, and uncertain stocking density.
Chelsea Sugar ponds Purpose: To control nuisance aquatic plants (AQTRANS0017, 1992). Outcome: Effective weed control was achieved intermittently, and in combination with weed cutting.
Western Springs Lake Purpose: Control of aquatic weeds (AQTRANS0036, 1996), primarily egeria, with target reduction of 70% (Decker 1995b). Outcome: Although the stocking density was uncertain, the target weed species has been removed from the lake (exceeding the 70% reduction).
Waiatarua Park Lake Purpose: Control of egeria, target reduction 60% (AQTRANS0026, 1994). Outcome: Insufficient information on which to make an assessment.
Tahuna Torea Purpose: Aquatic weed control (AQTRANS0022, 1993). Reduce volume by 60%, target was egeria (DOC, 2010). Outcome: Limited information on which to make an assessment, although anecdotal knowledge indicates that the grass carp effectively removed the target weed (exceeding 60% reduction), potentially assisted by weed harvesting.
Hayman Park Purpose: To control nuisance aquatic weeds (AQTRANS02/21, 2005) primarily egeria, filamentous algae and *Persicaria decipiens*, target removal goal of 70% (NZWR 2006a). Outcome: The target weed species has been removed (exceeding the 70% goal) using grass carp and manual removal.
Wattle Park Purpose: To control 60% of the nuisance plants (Decker 2002). Species included: egeria, lagarosiphon, *Potamogeton crispus* and *Ruppia* spp. Outcome: Reduction of the target species has been achieved, patches of *P. crispus* were present in 2014.
Puhinui Reserve Purpose: Grass carp were approved for release to control 70% of the nuisance aquatic plants (AQTRANS02/42, 2007). Species included were *P. decipiens,* egeria*, Callitriche stagnalis, Azolla* spp., *Lemna disperma* and *Paspalum distichum* (Decker 2006a). Outcome: Target plants have been reduced.
Manuwai Lane Lake Purpose: Grass carp were introduced to control macrophytes, reducing to ca 60% (Decker 1996b). Outcome: Two decades after stocking, no submerged macrophytes were recorded from the lake.
Lake Rotomanu Purpose: The objective was to manage weed levels and remove ca 30% of the weed (Decker 2000), and the target species were lagarosiphon and egeria (Aquaculture NZ 2001). Outcome: Target weed removal was not achieved.
Lake Henley Purpose: To decrease the submerged vegetation in the lake by 50% within 6 years (Miller 1994). Outcome: Target weed reduction was not achieved.
Lake Hood Purpose: 70% weed removal from the lake, with vegetation maintained at that level (Operational Plan Lake Hood 2005). Outcome: Effective weed removal has not been demonstrated.

4.2 Effects

Off target impacts or effects can occur with the use of grass carp (Rowe and Schipper 1985, Clayton and Wells 1999). However, it should be noted that monitoring information (availability of data) were generally insufficient to determine effects on water quality and fauna on the majority of waters. Broad trends that were noted include; no observable changes in water and habitat quality and an increase in common bully populations for some locations.

Effects on non-target plants have been described for all of the sites that had comprehensive monitoring programmes (e.g., primarily the natural lakes) over multiple years or at least over the timeframe of the grass carp stocking. These off-target plant impacts were largely consistent with those predicted in the available EIAs, and were determined by the species present in the lake that were accessible to the grass carp. For example, water level fluctuations and the slope of the littoral zone will determine how available marginal aquatic plants (e.g., *T. orientalis* in Lake Tutira, section 3.5.2) (Hofstra 2013b) and the low growing turf forming species are to the grass carp (e.g., Elands, section 3.5.1) (Clayton et al. 1995, Clayton and Wells 1999, Hofstra et al. 2008).

However the presence of invasive weed species invariably have a detrimental effect on native plant biodiversity, abundance and depth range (Howard-Williams et al. 1987, Clayton and Edwards 2006) in the short term, and on native seed bank in the longer term (Rowe and Champion 1994, de Winton and Clayton 1996). Removal of invasive weed beds, followed by removal of the grass carp, may enable the recovery of native plants. For example in Parkinson's lake stocking of grass carp enabled removal of egeria, and removal of the grass carp was followed by the re-establishment of native macrophyte species reproducing from seeds, spores and buried rhizomes (Tanner et al. 1990, Rowe and Champion 1994). Restoration of beneficial aquatic plants in the longer term to enhance ecosystem values and functions is considered desirable for most aquatic systems.

Submerged aquatic plants have important roles in the stabilising of sediments and improved water clarity, nutrient uptake and in providing food and habitat for fauna (Clayton and Wells 1999). While large weed beds of invasive aquatic plants may also stabilise sediments, these weed beds have large DO fluctuations, that can alter the biological diversity within them (Closs et al. 2004), and in shallow lakes this can lead to vegetation collapse and result in a lake 'flipping' to an algal dominated turbid state (e.g., Lake Omapere, section 3.1.2) (Champion and Burns 2001, Schallenberg et al. 2013). Grass carp were introduced into Lake Omapere as part of a lake management initiative to control the egeria. Although the timing and number of grass carp released was not sufficient to prevent the weed bed collapse and lake wide deoxygenation, their continued presence has prevented the cycle of egeria domination, collapse and algal blooms from repeating (Schallenberg et al. 2013). Lake Omapere is an example of a lake where water quality has improved during the time that grass carp have been present in the lake (NRC 2007 to 2011). There are further examples where some water quality parameters have improved following grass carp stocking (e.g., DO in Lake Kereta, Section 3.2.1), or there has been no change (e.g., Wahi Beach Reservoir (Mitchell 1980)), or short term changes (e.g., Parkinson's Lake (Mitchell et al. 1984, Rowe and Champion 1994)). In Parkinson's Lake, limnetic nitrogen and phosphorus increased during the summer after total weed control was achieved by the grass carp. Phytoplankton biomass (chlorophyll *a*) increased and was accompanied by an increase in zooplankton and a spike in ammonia (thought to be from zooplankton excretion). As a consequence, secchi disc depth 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 & Schipper (1985) concluded that in 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.

Lake Swan is an example where weed bed removal by grass carp has been linked to changes in water quality, algal blooms and declining water clarity (section 3.1.3). A report by NRC (2007-2011) which spans the year of grass carp introduction (2009), states that "key variables indicate water quality has deteriorated in Lake Swan over the past 5 years with TLI increasing 0.22 units or 5.43 % per year". "The removal of aquatic plants by the grass carp is the likely cause of the deterioration in water quality" (NRC 2007-2011). However these statements need to be placed in the context of a lake that was recognised as highly degraded, and with the worst submerged aquatic weeds present in the lake it was considered as at risk of 'flipping' into an algal dominated turbid state (before the introduction of grass carp) (section 3.1.3). The potential cause of a cyanobacterial bloom in the lake in 2011 was investigated and attributed to increased phosphorus in the water column, and was not a direct consequence of weed removal (Rowe 2011). Likely causes of the increased phosphorus included local weather conditions, a prolonged period of calm and hot weather in mid-February, followed by wind inducing mixing of the lake water (Rowe 2011). In this example, the cause of change in Lake Swan could only be determined where sufficient lake monitoring data existed with wider catchment and weather conditions. However for the majority of waterbodies investigated in the present report, there was little available information from which to make assessments about changes in water quality as a consequence of the introduction of grass carp. In particular the man-made sites or those operating as stormwater retention ponds were characterised by compromised water quality, and visibility (or water clarity) of 0.5 m was considered 'good' (section 3.3).

Other than limited data or information, an additional factor that confounds interpretation of grass carp effects on water quality and clarity is the presence of pest fish species. Pest fish are often present in waterbodies that pest plants are recorded from (de Winton et al. 2009b). The presence of benthic pest fish (e.g., tench, perch, catfish, goldfish) has been shown to reduce water clarity by reducing sediment stability through browsing activities, and encouraging the re-suspension of silt by wave action (Rowe et al. 2005). This effect is likely to increase after weed removal when more of the shallow littoral zone is exposed to foraging. Improved water clarity can be achieved following removal of pest fish species (Rowe and Champion 1994).

Many information gaps were apparent for aquatic fauna, with little data on macroinvertebrate monitoring for most locations, and particularly for the man-made and stormwater retention systems. Information on fish and waterfowl was also limited for most sites to causal observations. Large scale changes in submerged aquatic plants are likely to result in some change in the associated fauna (Clayton and Wells 1999). In particular plant structural complexity that is consistent with an assemblage of plants, rather than a dense monospecific weed bed, is important for macroinvertebrate diversity, and the food web and habitat for fish and water fowl that may depend either directly or indirectly on the plants. The MPI eradication response in the hydrilla lakes provides the most recent and comprehensive data set on macroinvertebrate diversity and change associated with weed bed removal by grass carp in New Zealand. A shift in the relative abundance of macroinvertebrate taxa has been determined, while the diversity of taxa and total number of macroinvertebrates has remained largely unchanged (section 3.5.2, (Hofstra and Clayton 2014)). Habitat for mussels and bullies has increased. Mussels have increased in the number of sites at which they occur and juvenile mussels have been recorded. The number of common bullies has increased, with likely positive benefits for those fish and bird species that prey on them (sections 3.5.2, and 3.5.4, (Smith and Rowe 2011)). Where bird species are reliant on the aquatic vegetation (e.g., swans), changes in population numbers may be expected and were reported by Fish and Game, but not evident in trends associated with annual (single day) bird counts that were made at these lakes (Hofstra 2013b). In the example of black swans, a regional perspective adds value to interpreting the potential for cumulative impacts on habitat loss for a species.

5 Summary and Recommendations

The values, functions and management goals for a waterbody require consideration when determining the appropriateness of grass carp as a weed control tool. Grass carp can be an effective weed control agent for submerged aquatic plants, although partial weed control in a sustainable form is rarely (if ever) achieved. Grass carp are preferential browsers of plants, and species will be consumed in order of preference, and the access that grass carp have to them. Information on environmental effects, such as impacts on fauna, water and habitat quality was generally limited, or not available. However, most effects or impacts are largely dependent on waterbody characteristics.

The purpose of this targeted knowledge review was to improve future decision making on the use of grass carp. To achieve this the effectiveness of grass carp in terms of weed control and/or eradication outcomes, and the effects of grass carp on flora, fauna, water and habitat quality at the selected transfer locations was assessed. This report acknowledges previous works that assessed the impacts of grass carp in New Zealand (Rowe and Schipper 1985), the cumulative impacts of multiple grass carp releases (Clayton et al. 1999) and the issues of risk assessment for grass carp (Clayton and Wells 1999), and builds on the recommendations from those reports by incorporating findings from the waterbodies that were investigated in the present report. In that regard it is noted that if the monitoring outlined in Clayton and Wells (1999) had been undertaken, there would be better information, in particular on the effects of grass carp to review. However, access to monitoring information was also an issue. The majority of the information was obtained from MPI.

It is recognised that in assessing an application for grass carp, DOC have a limited legislative framework within which to operate. DOC are only responsible for approving grass carp to a new location, with subsequent release decisions the role of MPI. Consequently, it is possible additional grass carp releases may have adverse impacts that were not envisaged in the initial approval by DOC. The recommendations made (below), recognise that some aspects of these issues are already reflected in DOC procedures (i.e., SOP for aquatic transfers and the grass carp EIA policy framework).

To improve future decision making it is recommended that;

1. Applications for releasing grass carp into a waterbody takes in to account and/or includes assessment of:

    a. the ecological functions of the waterbody (e.g., the distinction between a natural lake with higher native and conservation values, than for example a man-made stormwater retention pond),

    b. the weed issues, including the need for weed control, and

    c. the appropriateness of grass carp as a weed management tool for the outcomes sought, including the ability to contain the fish, the stocking density and fish size (minimum 25cm).

2. Applications are assessed on the basis that there will be complete removal of all submerged aquatic plants, (unless the applicant can clearly demonstrate how and why that will not occur).

3. The approval includes (i) the grass carp stocking density and containment measures where required (ii) monitoring requirements for the aquatic plants, (iii) environmental monitoring that aligns with the risks and consequences of adverse effects to that waterbody (e.g., incorporating water quality, flora and fauna for natural lakes where there are concerns for these values, with lesser monitoring criteria for artificial systems), and (iv) submission of monitoring reports to DOC and MPI (ideally in a centralised repository, see point 4).
4. EIAs, applications for stocking grass carp, actual stocking records (release numbers, fish size, location, capture and mortality events) and monitoring reports are supplied and maintained, ideally through a centralised system with DOC and MPI so that information can be readily tracked for waterbodies and catchments, and can be utilised for future risk assessment and for potential cumulative impacts in catchments.

6 Acknowledgements

The contributions of NIWA staff, Dr John Clayton, Dr Dave Rowe, Mr Paul Champion in discussions on this project and review of this report, and Donna Sutherland for information on Lake Hood are very much appreciated and acknowledged.

The assistance of Natasha Grainger (DOC) and Steve Pullan (MPI) with the supply of, and access to records (of their respective organisations) on grass carp releases was very much appreciated. Regional and District Council and Fish and Game staff are acknowledged for discussion, information on lakes and waterways in their regions and additional contacts. Local residents of Manuwai Lane Lake, and Tahuna Torea are thanked for their insightful discussion and lake access (Manuwai Lane). Gray Jamieson is also thanked for providing updated information on several of the sites.

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Appendix A List of potential field sites from DOC

List of potential lakes (DOC 2012).

Northland
Lake Omapere
Lake Swan
Lake Heather

Auckland
Chelsea sugar ponds
Tahuna Torea
Waiaitarua Park Lake
Western Springs Lake
Manuwai Lane
Link Drive
Wattle Park
Hayman Park
Maygrove Lake
Puhunui Reserve
Lake Kereta
Lake Wainamu
Waimanu Bay Reserve Pond

Waikato
Lake Te Koutu

Lower North Island
Lake Rotomanu
Lake Henley

South Island
Lake Hood

Appendix B Short-list of lakes

The short-list of lakes (Hofstra 2013a) contains notes from DOC (unpublished records 2010) with additional notes from NIWA (as described in section 2).

Data Category	Grass carp (Gc)	Aquatic plants	Fish	Macro-invertebrate	Water quality
Lake Heather, small 8ha, shallow 5.5m, dune lake near Kaitaia	400 Gc in 2010 (50 per veg ha) Target plants Cd and Ed.	AQPD records 7 survey dates from 1985 to 2013; Champion et al. 2002, 2005; Wells and Champion 2012.;Champion and de Winton 2012		Ball et al. 2009	Matheson and Gibbs 2005.; NRC 2005, NRC 2007
Lake Swan (Rotootuauru) small dune lake (17.4 ha) on the north Kaipara head	800 Gc (40 p ha). Target plants Cd and Ed	AQPD records 8 survey dates from 1985 to 2013.; Cunningham et al. 1953.; Tanner et al. 1986.; Champion et al. 2002, 2005; Wells and Champion 2012; Champion and de Winton 2012	NZFFD records from 1970, 1985 and 1991.		Kokich 1991; Matheson and Gibbs 2005; Rowe 2011.; NRC 2005, NRC 2007
Lake Wainamu (Bethels beach, West Auckland)	270 Gc (100 per veg ha) in March 2009. Target Ed.	AQPD records from 2005 and 2007.;Champion 1995; Gibbs et al. 1999; de Winton et al. 2005, 2008; Surrey 2010; ARC data; Wells pers. Comm. no Ed in the main body of the lake in 2012.	Gibbs et al. 1999; Rowe and Smith 2001; Rowe et al. 2003; ARC data.	Gibbs et al. 1999;Fowler and Duggan 2008	Gibbs et al. 1999; Wilcock and Kemp 2000.; Macaskill and Martin 2004; Rowe et al. 2005; Sorrell 2006; Verburg et al. 2010; ARC data
Lake Tutira (Hawkes Bay)	2354 Gc in December of 2008, to eradicate Hv	AQPD records; Walls 1994	Tierney 1980, 2008;		TCC 1977; Hooper 1989; HBRC and UoW
		Reports from 2008 to 2011 are on the MPI website (http://www.biosecurity.govt.nz/pests/hydrilla).			
Lake Waikōpiro (Hawkes Bay)	214 Gc in December of 2008, to eradicate Hv.	AQPD records			Hooper 1989; HBRC
		Reports from 2008 to 2011 are on the MPI website (http://www.biosecurity.govt.nz/pests/hydrilla).			
Lake Opouahi (Hawkes Bay)	200 Gc in December of 2008, to eradicate Hv	AQPD records			Dept of Lands and Survey 1981; Hooper 1989; HBRC
		Reports from 2008 to 2011 are on the MPI website (http://www.biosecurity.govt.nz/pests/hydrilla).			
Eland farm lake (Hawkes Bay)	400 Gc in 1998, further release 2 years later, to eradicate Hv.	AQPD records; Clayton et al. 1995	NIWA (prev. MAF data); NZFFD records	NIWA (prev. MAF data); Hofstra et al. 2008	Hooper 1987; HBRC 1994; Clayton et al. 1995

Abbreviations: HBRC (Hawkes Bay Regional Council), UoW (University of Waikato), NRC (Northland Regional Council), AC (Auckland Regional Council), Cd (*Ceratophyllum demersum*), Ed (*Egeria densa*), Hv (*Hydrilla verticillata*).

Appendix C Location of lakes and ponds

Figure C1. North and South Island showing the locations of lakes and ponds reviewed in this report. Individual sites in the Northland, Auckland and Hawkes Bay regions are best located in maps C2 to C4. (Source: Google map adapted from Pullan 2013).

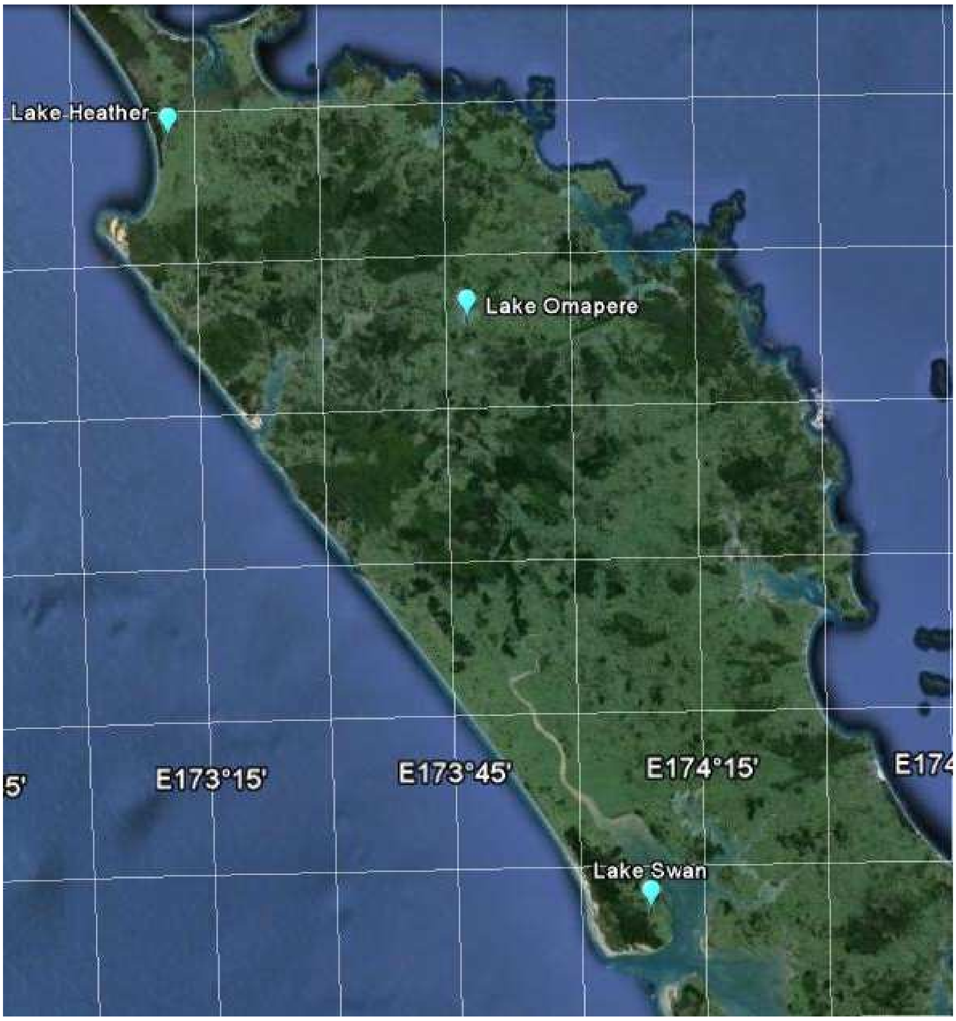

Figure C2. Location of reviewed lakes in the Northland region. (Source: Google map adapted from Pullan 2013).

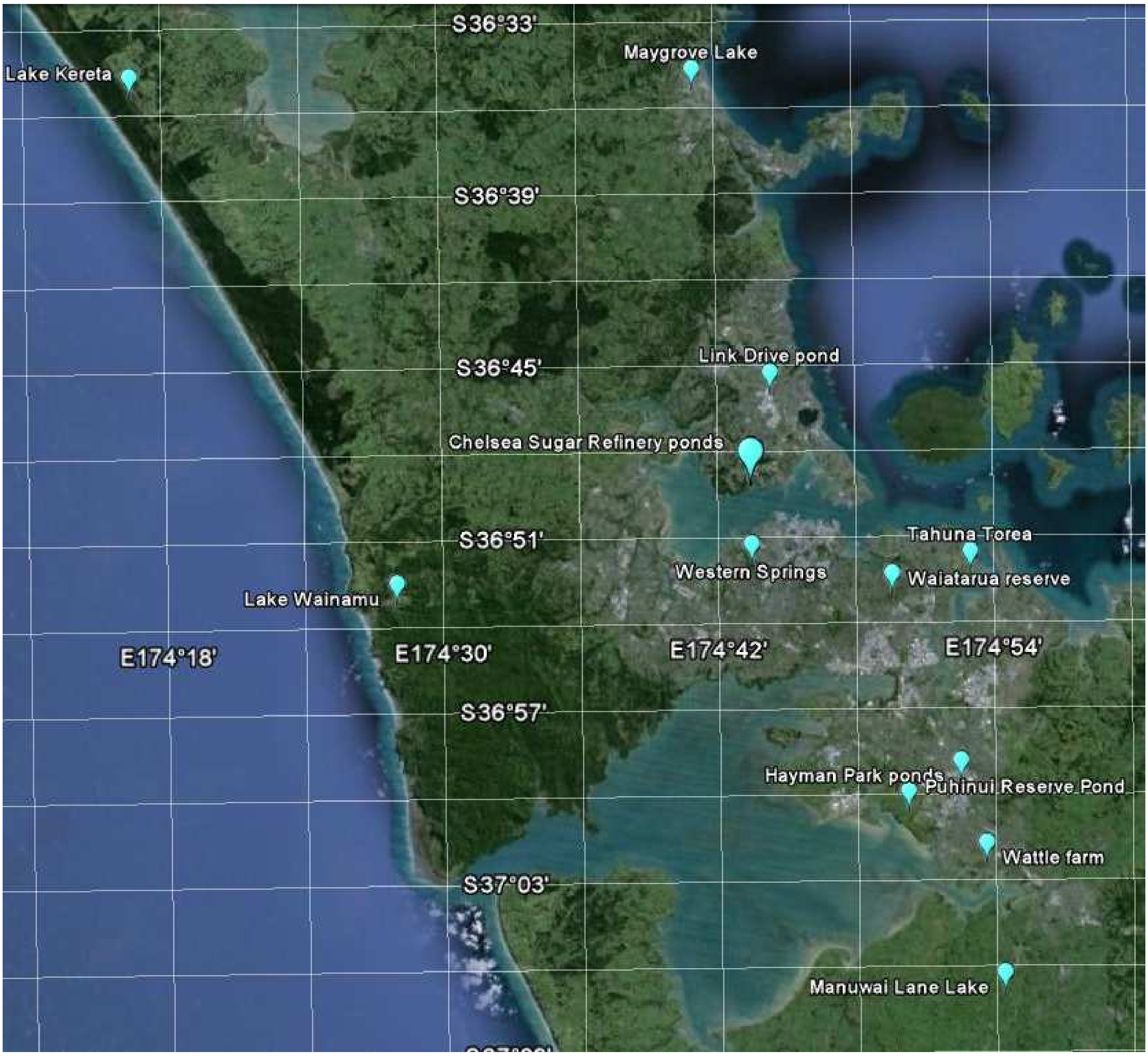

Figure C3. Location of reviewed lakes in the Auckland region. (Source: Google map adapted from Pullan 2013).

Figure C4. Location of reviewed lakes in the Hawkes Bay region. (Source: Google map adapted from Pullan 2013).