Assessment of Environmental Effects of the Introduction of Grass Carp (*Ctenopharyngodon idella*) to Hydrilla Affected Lakes in the Hawke's Bay

NIWA Client Report: HAM2008-085
June 2008

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Prepared for

MAF Biosecurity New Zealand

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Executive Summary

MAF Biosecurity New Zealand has contracted NIWA to prepare an assessment of the environmental effects for the introduction of grass carp (*Ctenopharyngodon idella*) to hydrilla affected lakes in the Hawke's Bay.

Hydrilla (*Hydrilla verticillata* (Lf) Royle) is an alien submerged aquatic weed, which is currently restricted to the Hawke's Bay region in three lakes, Lake Tutira, Waikōpiro (also called Waikapiro) and Opouahi, with historic weed beds known from a fourth lake on the privately owned Eland farm.

Hydrilla is listed as a notifiable organism, an unwanted organism, and was identified as a pest for eradication through a National Interest Pests Response. MAF Biosecurity New Zealand have developed an operational plan to manage hydrilla to achieve the goal of eradication in New Zealand (MAF Biosecurity New Zealand 2008) using two tools, the herbivorous fish grass carp and the aquatic herbicide endothall.

Grass carp were imported into New Zealand to manage aquatic weeds. They have been successfully used to eradicate *Egeria densa* from Lake Parkinson, *Elodea canadensis* from Lake Waingata and hydrilla from Lake Eland (i.e., no hydrilla plants have been found since 2003, but the longevity of tubers indicates that eradication cannot be confirmed until 10 years after the last plant).

The hydrilla lakes have multiple uses including boating, fishing, camping, walking, picnicking, water takes for domestic and stock supply, and provide habitat for native flora and fauna. Lake Tutira and Waikōpiro in particular are of significance to local Māori.

The primary effect of introducing grass carp into these lakes will be to reduce the threat of hydrilla nationally by removing the hydrilla weed beds. This is likely to cause little or no change in water quality in the lakes, but will change the composition of aquatic flora present (leaving only turf plant species). Removal of hydrilla and other tall macrophytes will alter the composition of aquatic and benthic macroinvertebrates, and change the food chain for the fish species within these lakes. It may also affect the cover for certain fish.

Containment measures for grass carp will be put in place to maintain stocking numbers in the lakes, and hence browsing pressure on the hydrilla. Should any grass carp escape they will move downstream and reside in the lower reaches of the outflow. However, they will be too few in number to have any noticeable impact in the river.

In order to identify and mitigate any effects of plant removal, MAF Biosecurity New Zealand has made the commitment to a long term and responsive monitoring programme for these lakes including

water quality, vegetation, macroinvertebrates, fish and birds. Monitoring and comparison with baseline data will also lead future management decisions on grass carp stocking rates, the timely use of exclosure cages for aquatic plant restoration/refugia, and the potential to alter or assist with the stocked trout populations (for Lake Tutira).

1. Introduction

Hydrilla (*Hydrilla verticillata* (L.f..) Royle) is an invasive aquatic macrophyte, which has earned worldwide recognition as one of the worst weeds amongst submersed plant species. It is characterised by its prolific growth over a wide range of ecological conditions, its vegetative reproduction and long-lived propagules (tubers and turions), and its ability to displace native vegetation and form mono-specific stands that can locally degrade fish and wildlife habitat. Weed beds of hydrilla are also a direct nuisance to lake users such as bathers, anglers and boaties, and plant material washed ashore by wind and wave action (later putrefying on the beaches) reduces the aesthetic value of the lakes, and access to the water. Hydrilla poses a significant threat to the amenity, cultural biodiversity and economic values of other waterways (DOC 2001, Hofstra et al. 2000, Walls 1994).

Hydrilla is currently restricted to the Hawke's Bay region in three lakes, Lake Tutira, Waikōpiro (also called Waikapiro) and Opouahi, with historic weed beds known from a fourth lake on the privately owned Eland farm. In Lake Tutira, the largest of the affected lakes, hydrilla was first positively identified in 1963, at which time it formed extensive weed beds (Tutira Technical Committee 1977). Today hydrilla occupies an estimated 25 ha and excludes native vegetation between ca 1.5 to 7 m water depth in Lake Tutira, and the 1 to 6m water depth zone in Lake Waikōpiro. In Lake Opouahi hydrilla was first recorded in 1984, and today forms discrete clumps of vegetation with a discrete band at the jetty (Hofstra et al. 2008). In contrast, Lake Eland had extensive beds of hydrilla that covered an estimated 1ha of this small 4 ha lake (i.e., the 1.5 to 4 m water depth zone).

Because physical and chemical control measures had met with little success for the control of hydrilla, and grass carp (*Ctenopharyngodon idella*) had previously been used to remove similar weed species such as *Egeria densa* in New Zealand (Mitchell 1986, Rowe et al. 1999), and to control hydrilla in the USA (de Kozlowski 1991, Hanlon et al. 2000, Kirk and Henderson 2006) grass carp were stocked in Lake Eland in 1988 (Clayton et al. 1995). Seventeen months after they had been introduced, grass carp had removed ca. 99% of the hydrilla biovolume, and although plants subsequently grew from the germination of tubers buried in the sediment, fish browsing pressure was maintained (Clayton et al. 1995), and no hydrilla has been recorded from Lake Eland in annual surveys since 2003.

However the continued presence of hydrilla in the publicly accessible Lakes Tutira, Waikōpiro and Opouahi, poses a threat to other lakes and waterways in New Zealand through human behaviour. Hydrilla is listed as a notifiable organism and an unwanted organism under the Biosecurity Act 1993, and was identified as a pest for eradication through the National Interest Pests Response Programme completed in December 2006. MAF Biosecurity New Zealand has developed an operational plan to manage hydrilla to achieve the goal of eradication (MAF Biosecurity New Zealand 2008). Eradication is considered achievable over a period of twenty years through the use of grass carp, in tandem with the herbicide endothall (Hofstra and Champion 2008). Grass carp are a key tool to achieve eradication of hydrilla from New Zealand. For the use/introduction of grass carp into the affected lakes (Tutira, Waikōpiro and Opouahi) approval is required from the Hawke's Bay Council of Fish and Game New Zealand (Freshwater Fisheries Regulations, R59) and the Department of Conservation (Conservation Act 1986, Reserves Act 1977). Additional releases of grass carp beyond the first require the approval of the Ministry of Fisheries (Conservation Act 1986).

MAF Biosecurity New Zealand has contracted NIWA to provide an Assessment of Environmental Effects (AEE) to support the applications for approval to release grass carp into the hydrilla affected lakes, Lakes Tutira, Waikōpiro, and Opouahi, for the hydrilla eradication programme.

2. Natural Values of the Lakes

2.1 Lake Tutira

2.1.1 Location and Morphological Features

Lake Tutira is located ca. 36 km north of Napier (along SH2 from Napier to Wairoa (NZMS 260 V20 at grid reference 460 126, longitude 176.89231, latitude 39.22511) in the Arapaoanui River catchment (Hooper 1989). It lies adjacent to Lake Waikōpiro (Figure 1), separated by a narrow causeway and joined by the Tautenga culvert (Figure 2) which flows in periods of high water. During adverse storm events such as Cyclone Bola, water has also been known to cross the causeway (Rowe 2004).

The catchment on the eastern and southern sides of the lakes is steep, hill country, with peaks of 494 m above sea level. The lake lies at 155 m ASL. The lake most likely formed from the partial collapse of a ridge, which dammed the valley at the south end (Grant 1966, Tutira Technical Committee (TTC) 1977). Originally the catchment land area of the lake was ca. 2719 ha, but with the diversion of Sandy Creek (also referred to as Papakiri Stream) to bypass the lake to reduce the nutrient load going into the lake, the catchment area was reduced to 844 ha. Once in native forest (Walls 1994), the catchment and a larger block of land was leased in 1873 for farming and in 1882 by Guthrie-Smith (Tutira Recreation Board (TRB) 1982) who has described in detail the changes that occurred to the catchment and to the lake over from that time and into the early 1900s (Guthrie-Smith 1926). Having an interest in natural science and conservation, Guthrie-Smith fenced off an area of native forest on Tutira Station in the 1890's. The catchment was then, as is today, predominately in pastoral farmland with sheep and cattle grazing the hillsides (Hooper 1989) (Figure 1).

Figure 1: Aerial photograph of Lakes Tutira and Waikōpiro (Survey Series Hawke's Bay 2000) showing the causeway between the two lakes and the immediate farmland catchment.

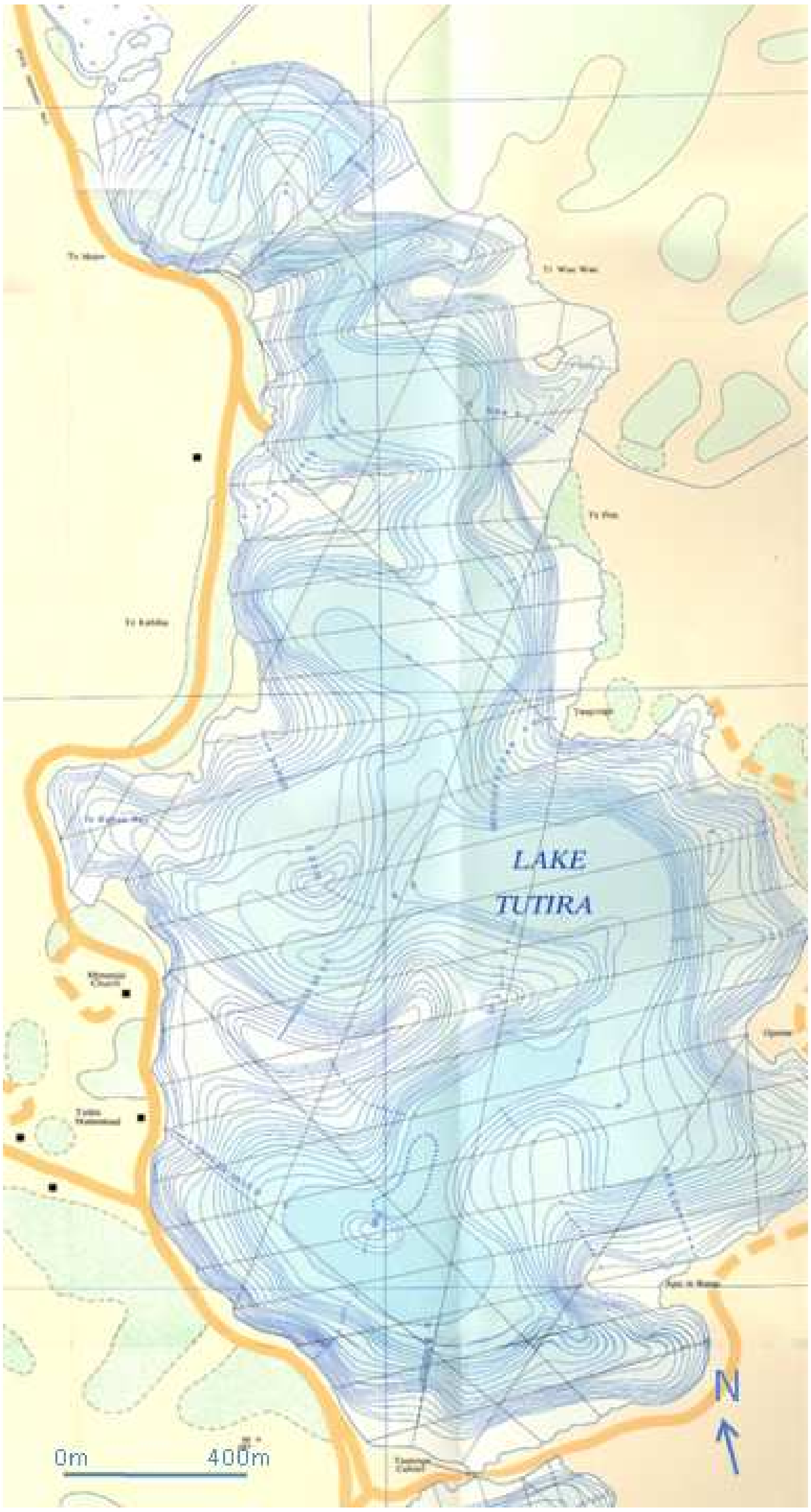

Figure 2: Bathymetric map of Lake Tutira showing the lake contours and the culvert to Lake Waikōpiro under the causeway (south end) (from Irwin 1978).

Lake Tutira is ca. 174 ha with a mean depth of 20 m and a maximum depth of 42 m (Table 1), (TTC 1977). After the diversion of Sandy Creek in the north, the remaining inlet streams include the Kahikanui, Oporae, Hutt, the Tautenga culvert (from Lake Waikōpiro), House, Stockyard, and Church Streams. These streams drain 26% of the total Tutira catchment, the balance being held by Sandy Creek. There is one outlet stream (Tutira Stream) at the north end of the lake where it enters into the Mahiaruhe Stream (TTC 1977) until it joins the Waikoau River.

Table 1: Morphometric features of Lake Tutira.

	Data from Tutira Technical Committee Report (1977)	From S. Wadhwa (NIWA) using LINZ aerial photographs 2003-04
Area (ha)	174	172
Volume (m^3)	36.1×10^6	
Shoreline (km)	7.99	7.86
Mean depth (m)	20.8	
Maximum Depth (m)	42	
Maximum Length (km)	2.4	2.39
Maximum Width (km)	1.2	1.16

2.1.2 Water Quality

Lake Tutira water quality has undergone many changes in the past including increased sediment loads produced by land slides and storm events, and as a consequence of the drain that was dug in the 1890’s through the wetland at the north end of the lake. This connected Sandy Creek directly to the lake, thereby removing the filtering effect of the wetland and increasing the sediment load in the lake as documented by Guthrie Smith (1926). More recent catchment land use change has impacted on the lake water quality, with increased surface run off and the advent of topdressing both increasing nutrient loads in the lake (Teirney 1980). Concern was first expressed over water quality in 1959 with discolouration, algal growth, and the appearance of dead fish in the summer months (TTC 1977). An initial survey of the lake in 1970 confirmed its advanced state of eutrophication (Teirney 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 plantings and diversion of Sandy Creek (Hooper 1989) and the installation of aerohydraulic guns to improve water mixing and oxygenation and hence trout habitat (Teirney 1980, 2008).

The diversion of the main inlet stream was designed to reduce sediment and nutrient loading into the lake by redirecting the water to the Mahiaruhe stream (TTC 1977, McColl 1978). Under normal stream flow conditions this diversion reduced Lake Tutira catchment from 2717 ha to 843 ha. However, under flood conditions the lake still receives most of the run-off from the entire catchment.

Aerohydraulic guns were installed and turned on in October 1975 to disrupt the thermal stratification of the lake in summer, to improve oxygenation for trout habitat and to reduce the release of nutrients from the lake sediments (Teirney 1980, Teirney 2008). However their use was discontinued in March 1979 due to increased running costs. Teirney (2008) considers it is unlikely that the aerohydraulic guns had an effect on trout stocks in Lake Tutira.

Water quality in the early 1970s is summarised by the Tutira Technical Committee (1976) (Table 2). The thermocline in Lake Tutira usually forms in October and persists until April/May (Teirney 2008). In winter when the lake is well mixed water temperature is ca. 10ºC and the DO (dissolved oxygen) in the bottom waters of the lake were usually 7 g/m^3. From December, the temperature of the epilimnetic water ranges from 20-24ºC, and at a ca. 6 m depth it drops to 9-10ºC characterising the hypolimnion (Teirney 2008). By January, the DO levels usually drop to 1-2 g/m^3 in the hypolimnion with the bottom waters (below ca. 8 m) being anoxic in February (Hooper 1989, Teirney 2008).

Water quality data for the 1980s is summarised by the Hawke's Bay Catchment Board (Hooper 1989). The lake is 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). Total phosphorus above 0.05 g/m^3 is known to cause eutrophication problems in lakes, and although values above this occurred 25% of the time during the monitoring period, there was a distinct downward trend in total phosphorus, which along with the nitrogen data indicated an improvement in lake condition at that time (Hooper 1989). Median total phosphorus concentrations from 1984 to 1987 ranged from 0.04 g/m^3 in 1984 to 0.02 g/m^3 in 1987. Similarly, a decline in inorganic nitrogen and total nitrogen occurred over this period from medians of 0.26 g/m^3 to 0.08 g/m^3 and 0.7 g/m^3 to 0.4 g/m^3 for inorganic nitrogen and total nitrogen, respectively (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 this 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 this lake (Burns and Rutherford 1998b). Tutira increased in temperature (surface water) by 0.39ºC over the monitoring period as did other lakes in the study (Burns and Rutherford 1998b).

Hawke's Bay Regional Council resumed water quality monitoring in Lake Tutira in May 2008 (pers com Ian Gear; P Arnold NIWA Napier). Initial monitoring data available are presented in Table 2.

Table 2: Lake Tutira Water Quality data summary 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 ^oC			10	24	13.3	17.2	13.7
DO%	96	121.2			88.3	95	*
DO mg/l	9.6	10.3			8.9	9.8	*
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
Epilimnion/surface profile							
Temp ^oC		10.3	11.7	24	9.9	11.6	10.7
DO%	80.7	0	6.733	9.125	2.7	29.6	*
DO mg/l	8.8	0			0.3	3.4	*
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
* Instrument error.							

2.1.3 Aquatic Plants

In the past, Lake Tutira supported a wholly native aquatic vegetation. However, at some time prior to 1963 the submerged aquatic weed hydrilla was introduced to its waters. By 1963, hydrilla had formed dense weed beds extending to a depth of 7.6 m and covering 16.9% of the total lake surface area (TTC 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)).

To control the infestation of hydrilla at the public boat ramp in Lake Tutira weed mat was used in 1988/1989, however this was largely unsuccessful (Clayton pers com). Today hydrilla dominates the littoral zone of the lake from water depths of 1.5 m and deeper, excluding native plants and developing dense monospecific stands up to 5.5 m in height (Table 3) (Hofstra et al. 2008). The alien plant *Elodea canadensis* is also present in Lake Tutira from 0.2 to 3.5 m water depths, reaching heights of 2.5 m (Table 3). The most diverse plant community occurs in the shallow water zone and includes the low mound or turf plant community or may include emergent species (e.g., *Typha orientalis*) (Table 3). The diversity of this zone includes 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 3).

The decline in native plant species distribution and increase in hydrilla over the years since its introduction is reflected in the current LakeSPI (Lake Submerged Plant Indicator) scores for Lake Tutira. LakeSPI utilises the data on the diversity and extent of native plants and the degree of impact of invasive weed species, which, together with other components (eg depth of plants) give an indication of overall lake condition, expressed as a percentage of how close a lake is to its best possible condition. For Lake Tutira the invasive condition index is 90% (indicating a highly impacted lake), the native condition index is 17% and the overall lake condition is 18% (LakeSPI values based on 2008 survey data).

Table 3: Lake Tutira vegetation survey 2008 summary data.

Plant 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.
For % Cover data 1=1-5%, 2=6-25%, 3=26-50%, 4=51-75%, 5=76-95%, 6=96-100%.

2.1.4 Fish and Invertebrates

Eastern brook trout (*Salvelinus fontinalis*) were introduced into Lake Tutira in 1890 by Guthrie-Smith but these liberations were unsuccessful (Appendix 1). Subsequent liberations of brown (*Salmo trutta*) and rainbow (*Oncorhynchus mykiss*) trout in the 1900’s were successful, and from 1959 annual liberations of rainbow fingerlings was made by the Acclimatisation Society (Tutira Technical Committee 1977). Trout continue to be stocked by the Hawke’s Bay Fish and Game Council. Although they previously spawned in the Sandy Creek catchment providing recruitment for a self sustaining population of brown and rainbow trout in Lake Tutira (Marine Department Report 1956) degradation of spawning habitat has occurred (Teirney 2008). Consequently, trout are now released into the lake to maintain the fishery.

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 mosquito fish (*Gambusia affinis*) (New Zealand Freshwater Fish Database, DOC 2002, Hofstra et al. 2008). Koaro (*Galaxias* *brevipinnis*) may occur in the upper reaches of the tributary streams provided a bush canopy is present. In a fish survey in May 2008, longfin and shortfin eels, common bullies and trout were caught in the lake, while banded kokopu were only caught in an inlet stream (only one stream had suitable habitat). Gambusia were observed in the shallow-water, lake margins but were not caught (Hofstra et al. 2008). While live goldfish (*Carassius auratus*) were not found in Lake Tutira in the 2008 survey one possible well digested gold fish was retrieved from a trout gut. Since goldfish do occur in the adjoining Lake Waikōpiro they can be expected in Tutira. Amongst the eel catch, 79% were shortfins with the remainder longfin eels, two of which were the largest caught in the lake. Most of the shortfin eels caught were very similar in length indicating a narrow size class and few juveniles. Common bullies were abundant in the survey indicating a healthy population (Hofstra et al. 2008). Unlike eels and banded kokopu, bullies are not good climbers and so have a very limited ability to penetrate inland to high altitudes. They do not occur naturally in lakes such as Tutira and so will have been stocked to create a lacustrine population.

Koura (*Paranephrops planifrons*) 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. Historically, when water quality was high and hypolimnetic de-oxygenation minimal, koura will likely have been abundant in the sub-littoral zone of the lake (Hofstra et al. 2008). Similarly freshwater mussels (kakahi, *Hydriella menziesi*) 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 (Oligochaetes), chironomids, ceratopogonids, waterboatmen, dragonflies and damselflies (Odonata), caddisflies (Trichoptera), snails, leeches and flatworms (Hofstra et al. 2008). The highest diversity is 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). Amongst the benthic sediments where the taxonomic diversity was lower, the abundance of the invertebrates present was greater than the abundance of those same invertebrates in the shallows (Hofstra et al. 2008).

2.1.5 Birdlife

Populations of black teal (pateke, *Aythya novaeseelandiae*), New Zealand dabchick (weweia, *Poliocephalus rufopectus*), Australian coot (*Fulica atra*), mallard (*Anas* *platyrhynchos*), grey duck (parera, *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 (*Prosthemadera novaeseelandiae*), bellbird (korimako, *Anthornis melanura*), kingfisher (kotare, *Halcyon sancta vagans*), pigeon **(**kereru / kukupa, *Hemiphaga novaeseelandiae*) and morepork (ruru, *Ninox novaeseelandiae*) became less abundant returning to the bush (Tutira Technical Committee 1977).

In a more recent survey (2008) of birds on the lake, eight species were recorded from the lake at the dawn (Table 4). 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 (Table 4) were previously observed at the lakes (Heighway and Mackenzie 1963, TRB 1982, Hooper 1987, Walls 1994).

Table 4: Species and number of birds observed on Lake Tutira (2008).

Bird Species	**Number**
Black Shag *(*Kawau*, Phalacrocorax carbo)*	2
Black Swan *(Cygnus atratus)*	81
Australian Coot *(Fulica atra)*	78
New Zealand Dabchick (Weweia, *Poliocephalus rufopectus*)	5
Kingfisher (Kotare, *Halcyon sancta vagans)*	2
Little Black Shag *(*Kawaupaka*, Phalacrocorax sulcirostris*)	4
Mallards (*Anas platyrhynchos)*	55
White faced heron *(Ardea novaehollandiae)*	2

2.1.6 Recreational, Education and Farming

Herbert Guthrie-Smith created a wildlife refuge around the lake edges (Tutira and Waikōpiro) at the turn of the 20th century (Appendix 1). The Government recognised the importance of the lakes when it declared them a Wildlife Refuge in 1957. In 1973 the Lake Orakai, Tutira, and Waikōpiro Wildlife Refuge Order 1973 was issued preventing the use of motorised craft on the lakes. The lakes are used during moulting by Paradise shelduck (putangitangi, *Tadorna variegata*) and black swans. The Wildlife Refuge status and absence of motorised craft makes the lakes ideal places for ornithologists to observe a wide range of waterfowl such as New Zealand dabchick and Australian coot.

Following the First World War, Guthrie-Smith subdivided much of his holding for settlement by returning soldiers. Upon his death in 1940 the remaining 2000 acres was left in trust for the nation. The Guthrie Smith Arboretum, established in 2002, covers 200-acres and is progressively being planted in exotic and indigenous trees. Guthrie-Smith had set aside some 15 acres of land to regenerate naturally in the 1890s. This regrowth forest is incorporated in the arboretum.

The Guthrie-Smith Outdoor Education Centre provides an educational link for New Zealand's youth and New Zealanders generally through school camps and provides activities such as climbing and abseiling, canoeing, sailing, tramping, survival courses and environmental studies.

The Tutira Recreation Reserve was created in 1976. Later the Hawke's Bay Regional Council purchased 463 ha on the eastern side of the lake from the Guthrie-Smith Trust. This land is now managed by the Hawke's Bay Regional Council as it works toward retiring the Tutira catchment from farming. A combined Department of Conservation and Hawke's Bay Regional Council camping ground, shelters, toilets, tracks and observation points provide facilities for both day trippers and those choosing to stay over night.

While rainbow trout (*Oncorhynchus mykiss*) were first liberated in Hawke's Bay rivers in 1867 following the arrival of 42,000 ova from Otago, trout were not introduced to Tutira until later. The first attempt to naturalise trout in Lake Tutira occurred in 1890 when Guthrie-Smith received a consignment of brook trout (*Salvelinus fontinalis)* eggs from North America. Taking delivery of a case of ova at Tangoio, and despite his best efforts frequently bathing the eggs in the waters of the streams he crossed on the way to Tutira, the ova, which were in good condition, failed to establish.

The lakes, particularly Tutira, are popular with anglers fishing for Loch Leven browns and 'R' type rainbow trout. Lake Tutira is stocked annually with both rainbow and a lesser number of brown trout. Both shore and lake fishing techniques are used. Surveys of angler usage carried out by NIWA for the Fish and Game Council New Zealand do not distinguish between Lake Waikōpiro and Tutira. In the 2001/2002 survey, fishing effort on the Tutira Domain lakes was estimated at 2,300 (±380) angler days per year (Unwin and Image, 2003). This is a 25% reduction on the 1994/95 figure of 3,090 (±150) angler days per year. Usage of local rivers is much higher (Mohaka River 7000, Tutaekuri River 6700, Ngaruroro River 6200, Tukituki River 17,000).

Lake Tutira is the second largest lake in the Hawke's Bay Region (Waikaremoana is larger). Consequently its trout fishery is considered to be of regional importance. Historically angler usage nearly doubles during winter months (June-September) suggesting that it is a winter rather than a summer fishery.

Following concern over the degradation of the lakes' water quality, which had been largely due to nutrient run-off from the surrounding farm land, Hooper (1987) indicated where, as part of a series of measures to improve water quality in the lakes, stock access to the lake's shores had been restricted. Cattle and sheep are still able to graze some margins of the lakes. The Hawke's Bay Regional Council has established a management plan for the land surrounding the lakes. A programme of replanting has commenced. No water takes have been consented for Lakes Tutira and Waikōpiro (HBRC).

2.1.7 Cultural Usage

Ka kāti a Tangitū
Ka tūwhera a Maungaharuru
Ka kāti a Maungaharuru
Ka tūwhera a Tangitū.

The whakatauākī (proverb) talks about the boundary of Ngāi Tatara, from the foreshore of Tangitū to the mountain range of Maungaharuru and explains the right times of gathering food resources.

When the kaimoana and fish at sea is at its leanest the season is closed.
We then turn to land like that of Maungaharuru and Tutira and our rivers, to gather food.
When the food resources are scarce inland (Maungaharuru) we then return to the sea (Tangitū).

This gives rise to the whakatauākī:

Kei o rātou rekereke o rātou kāinga.
"their homes were in the heels of their feet"

(They moved to gather food resource when and where ever they became available).

Tutira was an important place for Māori as the coastal people moved from the coast to the inland rivers and mountains and the inland people moved from the mountains to the coast following the cycle of food. The hapū, Ngāti Pahauwera and Ngāti Tū have a long association with Tutira, Waikōpiro, and Opouahi. Both hapū are vitally interested in the well being of the streams, rivers, lakes and the sea and the maintenance and restoration of the mauri of the waters. Flax and raupo grew around the lakes and in the associated wetlands. Tutira and Waikōpiro held plentiful supplies of kakahi (mussels), eels and banded kokopu. Waterfowl were also present.

Another proverb:

> **Te wai-ū o koutou tīpuna.**
> *The milk of your ancestors …*

refers to the food available from the local lakes and rivers. The places about the lakes are named reflecting the importance of the lakes and the areas close to them in sustaining the population. Wāhi tapu (sacred places) and urupā (burial sites) are found close to the lakes.

While foot trails linked the five villages around the lake and the hinter-land, where possible, travel was by water. Guthrie-Smith in his book, Tutira, refers to:

> *"…even in the 'eighties (1880's) there were several old canoes afloat; others still intact rest to this day submerged and safe in Waikōpiro."*

He notes:

> *"Conditions of eel-fishing on Tutira were remarkable, perhaps unique. As has been explained, in ancient times the waters of the considerable Papakiri stream (Sandy Creek) never directly reached the lake; they soaked through a morass of several hundred acres, finally dripping into the creek Tutira, the creek that carries off the surplus water of the lake. The Māoris believe that in this great sponge of peat and root-fibre lived immense numbers of eels which never visited the lake, and which communicated with the creek by means of holes in the banks. They state, in confirmation, that although eel-weirs built on the bank require the whole width of the stream Tutira, catches as heavy are obtained in the lowermost as in the uppermost pā tuna. There were, at any rate, three sorts of eels distinguished: the common lake kind—tātārākau; another, also from the lake, rarely caught, much larger, and bronze in colour—riko; and*

thirdly, the eel of the creek Tutira—pakarara. The bellies of the two kinds of lake eels were, when taken, full of food, chiefly, I gather, a small water-snail; those of the creek eels were invariably empty. The pakarara, when opened up and sun-dried, would keep for four or five days, the tātārākau and the riko for as many weeks."

Local hapū Ngāti Tū and Pahauwera observe that the lakes and the surrounding lands have strong cultural and spiritual significance to them. The eels of the lakes and rivers sustained their ancestors. The stories of the hapū recognize and embrace tātārākau, riko and pakarara.

Ngāti Tū state with pride that their eels are the best in the Hawke's Bay.

2.1.8 Summary of Lake Values

The Tutira recreation reserve was created in 1976. Hawke's Bay Regional Council purchased 463 ha on the eastern side of the lake from the Guthrie-Smith which is now managed by the Hawke's Bay Regional Council as it works toward retiring the Tutira catchment from farming. A combined Department of Conservation and Hawke's Bay Regional Council camping ground, shelters, toilets, tracks and observation points provide facilities for both day-trippers and those choosing to stay over night. Today, Lake Tutira is a recreation reserve that is administered by the Department of Conservation as a public facility (Walls 1994). The northern end of the lake is owned by Ngāti Tū a hapu within Ngāti Kahungunu (Walls 1994) and leased to Fish and Game.

Lake Tutira is a eutrophic lake with low water quality. There were some signs of lake recovery, but the lake still deoxygenates below ca. 8m (Teirney 2008) each year, creating a large dead-water zone in the hypolimnion. This now limits the lake as habitat for fish and deep-water invertebrates such as koura.

Hydrilla, which was first positively identified from the lake in 1963, now occupies an estimated 25 ha in Lake Tutira, where the weed beds extend from 1 to 9 m water depth (at some sites) and is on average 3 m in height, with 100% cover (i.e., dense monospecific stands) (Hofstra et al. 2003). However a relatively high diversity of aquatic macrophytes was present amongst the turf plant community in the shallow water zone (Hofstra et al. 2008).

Lake Tutira is a regionally significant trout fishery and contains stocked rainbow and brown trout. Because of its altitude and distance inland, native fish are restricted to the diadromous climbing species (i.e., eels and banded kokopu). Although the lake provides good habitat for eels, the deoxygenation of the hypolimnon prevents eels from inhabiting deeper waters and now limits them to the shallow (<10 m) lake edge during summer months. Similarly, banded kokopu are confined to a single stream because of both habitat degradation and the predatory impact of trout. Bullies and gambusia (a pest fish species) were stocked into this lake and have established breeding populations. Both koura and freshwater mussels will have once been more abundant in the lake but are now scarce because of poor water quality. Trout and eels dominate with invertebrates and common bullies providing the main food sources for these species. No rare fish species occur in this lake and its fishery values are confined to the trout fishery, to eels and a single population of banded kokopu.

Nineteen invertebrate taxa have been recorded from Lake Tutira, with the highest diversity associated with the turf plant community and the tall macrophytes. Taxa included mites (Acarina), worms (Oligochaetes), chironomids, ceratopogonids, waterboatmen, dragonflies and damselflies (Odonata), caddisflies (Trichoptera), snails, leeches and flatworms. The lake's koura and mussel populations have been reduced by habitat degradation related to poor water quality.

Populations of black teal, New Zealand dabchick, Australian coot, mallard, grey duck, pukeko and black swan have all been reported from Lake Tutira in the 1970s (Tutira Technical Committee 1977). Additionally in 2008 black shags, kingfishers, little black shags and white-faced herons were also recorded on the lake (Hofstra et al 2008).

Lake Tutira and its surrounds have a long history of use by Māori and are highly valued.

2.2 Lake Waikōpiro

2.2.1 Location and Morphological Features

Lake Waikōpiro is a small (ca 11 ha) lake located in Hawke's Bay (NZMS 260 V20 at grid reference 463 115 (latitude 176.89450, longitude-39.23676)). It lies to the south of Lake Tutira and is connected to it via the Tautenga culvert (Figure 3). A small causeway separates these two lakes and was increased in height during the 1940s (Hooper 1987). The lake is trapezoidal in shape and its basin is pan shaped (i.e., flat bottomed with steep shelving sides). 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, which is at 18 m (Table 5). A small sandy beach occurs on the north-eastern side of the lake.

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 (Figure 4). During summer when rainfall is low or absent, this stream is dry. Water drains from Lake Waikōpiro through the Tautenga culvert into Lake Tutira in periods of high water (Figure 3). The Lake Waikōpiro catchment in the 1980s underwent riparian planting on the eastern and southern make 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).

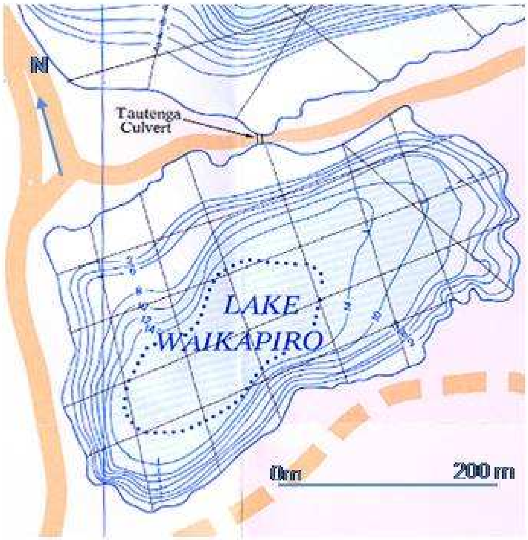

Figure 3: Bathymetric map of Lake Waikōpiro showing depth contours and the Tautenga Culvert joining it to Lake Tutira (from Irwin 1978).

Table 5: Morphometric features of Lake Waikōpiro.

	Data from Hooper (1987)	From S. Wadhwa (NIWA) using LINZ aerial photographs 2003-04.
Area (ha)	11	10.1
Shoreline (km)		1.379
Maximum Depth (m)	18	
Maximum Length (km)		0.495
Maximum Width (km)		0.261

Figure 4: Aerial photograph of Lake Waikōpiro showing the riparian vegetation around the lake's margin (mostly willow trees), the wetland area to the southwest, and the single inlet stream from the wetland (stream entrance to lake is arrowed).

2.2.2 Water Quality

Recent measures of water quality are not available for Lake Waikōpiro, however monitoring by Hawke's Bay Regional Council will resume in June 2008 (I. Gear pers. comm.). Historic data on water quality are available and were summarised by the Hawke's Bay Catchment Board (Hooper 1987). This report provides a good picture of water quality in the lake in the mid 1980s.

In 1984/85, Lake Waikōpiro was described as eutrophic (Hooper 1987). This was because of its high nutrient loading (both nitrogen and phosphorous), the complete deoxygenation of its hypolimnion (waters below about 6 m) during summer months, its poor water clarity (median secchi disc of 0.69 m), the presence of periodic blue-green algal blooms (including potentially toxic *Microcystis* spp.), and the dense beds of the exotic weed *Hydrilla verticillata*. Water temperatures over the sampling period ranged from 14.6 to 23.8 ºC and are typical for such a low altitude (155 m a.s.l.) lake. Other relevant water quality parameters are noted in Table 6 (adapted from Hooper 1987). Acidity (pH) was not recorded at this time.

Table 6: Water quality parameters in Lake Waikōpiro (after Hooper 1987).

Variables	Parameters		
	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/m^3)	3	8	26
Chlorophyll *a* (mg/m^3)	7	17	58
Total P (g/m^3)	<0.01	0.07	0.12
Total soluble P (g/m^3)	0.01	0.02	0.04
Soluble reactive P (g/m^3)	<0.01	0.01	0.03
Nitrate N (g/m^3)	<0.01	0.11	-
Ammonia N (g/m^3)	<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).

Low water clarity in Lake Waikōpiro was often associated with high chlorophyll *a* levels and the lowest secchi disc measurements coincided with a bloom of *Microcystis* (Hooper 1987). Comparison of total nitrogen to phosphorus ratios in this lake indicated that in 1984/85 phosphorus may have been more limiting than nitrogen.

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 using 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.

2.2.3 Aquatic Plants

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 5.9 m with dense cover (100%) and stands averaging 2 m in height (NIWA, FBIS). In 2001 hydrilla in two plots (each c. 1 ha in area) in Lake Waikōpiro was treated with endothall (dipotassium endothall), which significantly reduced the hydrilla biovolume for a year (Hofstra and Champion 2001, Hofstra et al. 2003). Subsequently hydrilla was reported to occupy an estimated 3.2 ha in the lake (Hofstra et al. 2003).

In a more recent survey, hydrilla continues to dominate the littoral zone of the lake, although a small band of native plants form the turf community found in the shallow water zone (Table 7) (Hofstra et al. 2008). For example, twelve aquatic plant species were recorded in the shallow lake water (up to 1.2m water depth), and beyond that only two species occurred (the introduced *Elodea canadensis* and hydrilla) and water from 2.2m down to ca. 6.4m became exclusively dominated by hydrilla (Table 7). Aquatic plant species also known from previous surveys and/or diver observations include *Myriophyllum pedunculatum*, *Potamogeton ochreatus*, and *Glossostigma diandrum* (NIWA unpublished data, 2002).

The impact of hydrilla in Lake Waikōpiro as indicated by its LakeSPI invasive condition index (93%) is high. The native condition index is low (14%) as is the overall lake condition (16%) reflecting the relatively poor ecological condition of the lake compared with its potential (Lake SPI values from 2008 survey data).

Table 7: 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.

2.2.4 Fish and Invertebrates

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*) were also observed.

A 2008 fish survey of lake reported rainbow trout, shortfin eels, good numbers of common bullies (*Gobiomorphos cotidianus*), juvenile goldfish and gambusia (Hofstra et al. 2008). Both longfin and shortfin eels were expected to be present, but low in abundance because of the deoxygenated hypolimnion and poor summer water quality (Rowe 2004). However the eel catch was dominated by shortfin eels, which is the case for most New Zealand lakes subject to eel fishing (Hofstra et al. 2008).

Juvenile goldfish were caught in fyke nets, and gambusia were present in the shallows of the lake. This pest fish species 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) (Rowe et al. 2007). There were no rare or threatened native fish species in this lake.

Live freshwater mussels were noted by NIWA divers at one of nine stations in 2001/2002. Koura (freshwater crayfish) are potentially present, but like mussels are likely to be rare because of the poor water quality in this lake, the summer deoxygenation of its hypolimnion, and smothering by exotic weed beds (Rowe 2004). No koura have been observed by divers since 2001/2002 indicating that if still present, they are scarce (Hofstra et al. 2008).

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 (Oligochaetes), 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).

2.2.5 Birdlife

Black swans (*Cygnus atratus)* are reported as the main birdlife present on the lake. Hooper (1987) also noted Australian coot (*Fulica atra*), grey teal (tete, *Anas gibberifrons gracilis*), and paradise shelduck (*Tadorna variegata*) (when moulting). It is likely that black teal (pateke, *Aythya novaeseelandiae*) and New Zealand dabchick (weweia, *Poliocephalus rufopectus)* will utilise the lake as a feeding area at times because they are known to occur on Lake Tutira. However, they are more likely to prefer Lake Tutira to Waikōpiro as the former provides more habitat. Because it is more sheltered than Tutira, Lake Waikōpiro may be utilised more by these birds when strong north-westerly winds occur and foraging is prevented in Lake Tutira by large waves.

Pukeko and several small black shags were seen around the lake in April 2004. There was also evidence that herons stalk small fish such as common bullies and gambusia in the shallows.

Hooper (1987) noted that lakes in the Tutira Domain supported the largest breeding population of Australian coot in the region. Falla (1982) indicated that they only occur in some lakes and prefer those where the aquatic vegetation is in deeper waters, beyond the diving depth of other ducks. As the depth of aquatic macrophytes in Lake Waikōpiro is limited to 5.7 m, this lake is unlikely to be as attractive to Australian coots as Lake Tutira.

More recently a dawn survey of birds on Lake Waikōpiro reported five species including two black shags (*Phalacrocorax carbo*), eight black swans (*Cygnus atratus*), four New Zealand dabchicks (weweia, *Poliocephalus rufopectus*), fifteen Mallards ducks (*Anas platyrhynchos*) and two Paradise shelducks (putangitangi, *Tadorna variegata*) (Hofstra et al. 2008).

2.2.6 Recreational, Educational and Farming Uses

Hooper (1987) noted that Lake Waikōpiro was utilised for walking, camping, ornithology, picnicking, fishing and boating (no motors are permitted). The marginal fringe of willows and other trees has recently been felled on the southern and western shoreline permitting better access and views.

No water takes have been consented for Lake Waikōpiro (HBRC), however, stock (mainly sheep) have had access to the lake for drinking.

Some anglers fish in Lake Waikōpiro for trout and it has been periodically stocked by the Hawke’s Bay Fish & Game Council. Trout can also enter Lake Waikōpiro from Tutira via the Tautenga culvert. Surveys of angler usage carried out by NIWA for Fish & Game New Zealand do not distinguish between Lake Waikōpiro and Tutira. Smaller lakes such as Waikōpiro and Opouahi are clearly less important but can provide speciality fishing. Lake Waikōpiro is occasionally used by school parties visiting the Guthrie-Smith Outdoor Centre. Because the lake is small and relatively sheltered, it has been used as a venue for learning aquatic skills such as kayaking.

2.2.7 Summary of lake values

Lake Waikōpiro acts as a small and more sheltered adjunct to Lake Tutira. Although Tutira is the main lake for wildlife, angling, and boating purposes, Waikōpiro is likely to prove more popular for walking as it can be circumnavigated within 30 minutes. Because it is more sheltered than Tutira, its value for wildlife as well as for recreation and education is likely to be increased during periods of strong winds, which restrict such activities on Tutira.

There are no rare or threatened species in Lake Waikōpiro and it does not contain any ecological communities of special interest because of their diversity. In general, the natural values of Lake Waikōpiro are restricted mainly to its wildlife (i.e., fish & birds). The natural values of its plant fauna, its macro-benthic invertebrates (i.e., mussels and koura), and its water quality have been largely compromised over the years by the clearing of surrounding forest, the invasion of exotic plants and by high nutrient loadings from the use of agricultural fertilisers.

The main social values of the lake include its use for recreational and educational activities including walking, picnicking, camping, ornithology and kayaking. It also contributes, albeit in a small way compared with Lake Tutira, to angling. Commercial eeling is prohibited. Local iwi can be expected to have used it as an important customary eel fishery in the past (see section 2.1.7).

2.3 Lake Opouahi

2.3.1 Location and Morphological Features

Lake Opouahi is the smallest (ca. 6ha) and highest (480 m a.s.l.) of the hydrilla affected lakes and is located in the hills north of Lake Tutira and inland (NZMS 260 V19 (longitude 176.835831, latitude 39.14872)). It is situated in the Department of Conservation administered Opouahi Scenic Reserve, which more recently under a joint venture arrangement with the Environment, Conservation and Outdoor Education Trust has also become home to the Pan Pac Kiwi Crèche following the construction of predator proof fencing..

Lake Opouahi has high scenic value and is surrounded by native bush and swampland (Figures 5 and 6), with ca. 20 to 30% of the lake's catchment (44 ha) in farm land

(Hooper 1987). The lake is likely to have formed from a landslide which blocked the valley, as evidenced by the drowned trees in the lake (Bennett 1968, Department of Lands and Survey 1981). The lake sides drop steeply to a relatively flat bottom at 24 m (Table 8) (Rowe 1980, 1987, Walls 1994). 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 (Figure 5). The lake outflow on its southern side is the Awatamatea Stream which eventually joins the Waikoau River (Hooper 1987).

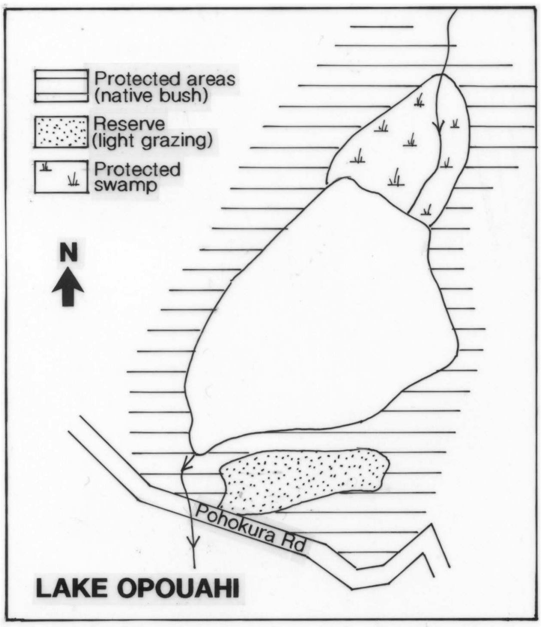

Figure 5: Lake Opouahi.

Figure 6: Lake Opouahi viewed from the northern wetland looking south to the jetty showing the bush lined lake shore (photo by R Wells).

Table 8: Morphometric features of Lake Opouahi

	Data from Hooper (1987)	From S. Wadhwa (NIWA) using LINZ aerial photographs 2005-06.
Area (ha)	5.83	5.67
Shoreline (km)		0.981
Maximum Depth (m)	24	
Maximum Length (km)		0.356
Maximum Width (km)		0.227

2.3.2 Water Quality

Historic data on water quality are available for Lake Opouahi and were summarised by the Hawke's Bay Catchment Board (Hooper 1987). Reported nutrient loadings of 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 9) (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 secchi disc reading of ca. 10 m (Nov 1984), although these are reduced over the summer months to readings of 3.3 m (Feb) due to phytoplankton growths (Table 9) and there is little suspended matter and low dissolved colour (Hooper 1987).

Hawke's Bay Regional Council resumed water quality monitoring of Lake Opouahi in May 2008. These data are presented in Table 8.

Table 9: Water quality parameters in Lake Opouahi.

Variables	**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)				*	*
Dissolved Oxygen (g/m^3)				*	*
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).
* Instrument error. Lake depth was 22.7 m and Lake height was 0.810 m (May 2008).
Additional temperature data in brackets from Rowe (1980).

2.3.3 Aquatic Plants

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).

Hand weeding of hydrilla was attempted in Lake Opouahi, where widespread occurrences of low density weed growth was common, and weed mat was used in 1988/1989 to control the main infestation in the lake at the jetty. Regrowth of hydrilla was noted at all sites where hand weeding was attempted, the rhizomatous nature of the plant and inter-twined growth with surrounding charophytes, reducing the effectiveness of hand weeding (J. Clayton pers. comm.). Hand weeding was considered unsuitable for further use due to the rhizomatous nature of hydrilla and risks of spread associated with fragmentation. The use of weed mat however appeared to slow down the spread of hydrilla within Lake Opouahi (Clayton et al. 1995), although is considered to be of limited use generally (Hofstra et al. 2003).

Subsequent plant surveys in 2002 and 2008 (Hofstra et al. 2003, 2008) have shown that hydrilla continues to form discrete clumps within the lake rather than broad bands of vegetation, with the exception of the jetty region. At the jetty hydrilla covers an estimated area of $300m^2$ with ca 90% cover between ca 1 to 4 m water depth, and a maximum height of 2 m (Hofstra et al. 2003). At other sites in the lake both hydrilla and the introduced weed elodea (*Elodea canadensis*) extend into the deeper water (7.5m), as did charophytes in some profiles (Table 10). A diverse community of native plants occurred in the shallow water zone (ca less then 1m), with a total of twelve aquatic plant species recorded from the lake (Table 10).

Lake Opouahi is unique amongst the hydrilla affected lakes in that the distribution of hydrilla is patchy and native charophytes still exist in some of the deeper water zones. This is corroborated by its higher native condition index (28%), lower invasive weed impacts (65%) and overall better lake condition (31%) than the other hydrilla affected lakes (LakeSPI values from 2008 survey data).

Table 10: Lake Opouahi vegetation survey summary data.

Species	No. of Sites	Depth range (m)	Max. Height (m)	Ave. Height (m)	Max. Cover	Median Cover
Baumea 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

2.3.4 Fish and Invertebrates

Historically, Lake Opouahi has been stocked with both rainbow trout (*Oncorhynchus mykiss*) and brook char (*Salvelinus fontinalis*) (Rowe 1980), however they were not recorded in a recent survey and may be extinct in this lake although further sampling would be required to confirm this (Hofstra et al. 2008). Smelt have been in the lake since they were stocked sometime prior to 1994 and they continue to thrive. Common bully numbers in Lake Opouahi are relatively low compared with the other hydrilla affected lakes and this is likely to be related to the presence of large, piscivorous longfin eels. Lake Opouahi has a good population of medium to large longfin eels (3.25 CPUE) and smaller-sized shortfins were also present (Hofstra et al. 2008).

Koura are present but scarce, with only one being caught by electric fishing in the inlet stream in a recent Lake Opouahi survey (Hofstra et al. 2008). The current scarcity of koura may, as is the case for the common bully, be associated with eel predation, as koura are a major prey species for eels (McDowall 1990). Historically, when water quality was high and hypolimnetic de-oxygenation minimal, koura will likely have been abundant in the sub-littoral zone of Lake Opouahi (Rowe 1980).

Climbing galaxiids, especially banded kokopu generally occur in lakes accessible by eels, however, none were reported in this lake or its inlet stream although this provides good habitat for galaxiids. The absence of galaxiids is likely to be related to the historic stocking of both trout and smelt into this lake. Trout predation reduces juvenile and adult galaxiids whereas adult smelt compete with juvenile galaxiids for planktonic prey and prey on fish larvae. Restoration of galaxiids may now be prevented by the presence of smelt. Additionally, it is possible that this stream may be reduced to a low flow during summer months, and since the construction of the predator proof fence around Lake Opouahi, fish access into the lake maybe restricted, even though a bypass system has been constructed. Monitoring of its effectiveness should be undertaken by the Department of Conservation and the Environment Conservation and Outdoor Education Trust to ensure native fish access is maintained (Hofstra et al. 2008).

Macroinvertebrate sampling in Lake Opouahi has shown a relatively high diversity and abundance of snails on native charophytes compared with hydrilla and elodea, and compared with other hydrilla affected lakes. The diversity and abundance of invertebrate taxa is generally related to habitat, with the shallow water zone and areas with macrophytes having a higher diversity of taxa (15 and 13 respectively), with 11 taxa reported from the benthic sediments (Hofstra et al. 2008). The taxa recorded in Lake Opouahi include chironomids, caddisflies (Trichoptera), damselfly (*Xanthocnemis*), dragonflies (*Hemicordulia*), snails (*Gyraulus, Physa, Potamopyrgus*), pea mussels (Sphaeriidae), ostracods, mites (Acarina), oligochaetes, and waterboatmen (Hofstra et al. 2008).

2.3.5 Birdlife

Lake Opouahi is described as a lake of moderate to high value (Hooper 1987). Hooper (1987) notes that although the swampland in the catchment provides excellent wildlife habitat, waterfowl are not abundant on the lake, as a consequence of the small littoral zone, due to the steep sloping lake margins. The spotless crake (puweto, *Porzana tabuensis*), a small rail, has been seen in the wetland at the head of the lake (Hooper 1987) along with more recent sightings of New Zealand 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 reported (Hofstra et al. 2008).

2.3.6 Recreational, Educational and Farming Uses

Lakes Opouahi is surrounded by remnant forest and set aside primarily for conservation as the Lake Opouahi Scenic Reserve. The forest is now the core of the "Pan Pac Kiwi Creche" which is an open pest proof sanctuary that the public can access freely. The crèche is a joint venture between the Department of Conservation and the Environment, Conservation and Outdoor Education Trust raising kiwi chicks to be released back into the Kaweka Range and other sites in Hawke's Bay. Work commenced in 2002 to raise money to build the 5km predator proof fence encompassing the Lake Opouahi catchment. The first six kiwi chicks were released into the creche in March 2008 ranging from 10 to 30 days old.

The Lake Opouahi Scenic Reserve has a number of tracks that allow access around the lake and into the adjoining forest.

Adjoining farms draw water for drinking and farm water from Lake Opouahi. Three rights to take from the lake are recorded by the Department of Conservation. A fourth party draws water from one of the supply lines to one of the right holders. Opouahi Station uses water flowing in the stream from Lake Opouahi for stock water. From about September onward and through the summer stock drink water directly from the stream.

2.3.7 Summary of Lake Values

Lake Opouahi is situated in the Department of Conservation administered Opouahi Scenic Reserve. The Department of Conservation and the Environment Conservation Outdoor Education Trust in a joint venture operate the Pan Pac Kiwi Crèche. Lake Opouahi is a small (6 ha) lake of high scenic value, surrounded by native bush and swamp land.

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), having 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). Despite the presence of hydrilla, Lake Opouahi still has a relatively diverse community of aquatic plants, particularly in shallow water (ca less than 1 m).

Historically, Lake Opouahi was stocked with both rainbow trout and brook char, which no longer appear to be present in the lake. The lake is no longer stocked with trout and does not provide a fishery. Smelt were introduced and continue to thrive. Now that trout are no longer present in this lake, smelt can be regarded as a pest species. Common bully numbers are relatively low compared with the other hydrilla affected lakes and this is likely to be related to the presence of large, piscivorous longfin eels. Lake Opouahi has a good population of medium to large longfin eels and smaller shortfins were also present (Hofstra et al. 2008). Koura are scarce and only reported from the inlet stream in 2008 (Hofstra et al. 2008).

Macroinvertebrate sampling in Lake Opouahi has shown a relatively high diversity and abundance of snails on native charophytes compared with hydrilla and elodea, and compared with other hydrilla affected lakes. The taxa recorded in Lake Opouahi include chironomids, caddisflies, damsel- and dragonflies, snails, pea mussels, ostracods, mites, oligochaetes, and waterboatmen (Hofstra et al. 2008).

Lake Opouahi is described as a lake of moderate to high value to birds, with the only at risk species (rated sparse by Hitchmough 2002) being the spotless crake (Hooper 1987). Other birds recorded on the lake include mallard ducks, black swans, black shag and kingfisher (Hofstra et al. 2008).

The lake and scenic reserve are enjoyed by people for walking and picnicking, and the lake water is used (through water takes) for drinking and farm supply.

3. Grass Carp – Effectiveness for Hydrilla Reduction

3.1 Grass carp effectiveness

Grass carp were imported into New Zealand with the intent that they would be used to manage aquatic weeds including hydrilla (Rowe and Schipper 1985). They have been used successfully overseas for the control of hydrilla, and in New Zealand for the eradication of other submerged aquatic macrophtyes (see review by Rowe and Hill 1989). In New Zealand grass carp have successfully eliminated *Egeria densa* from Lake Parkinson, *Elodea canadensis* from Lake Waingata and hydrilla from Lake Eland (i.e., no plants have been found since 2003, known tuber viability indicates that eradication cannot be declared until 10 years after the last plant). They have also eliminated submersed weed species from a large number of ponds and private dams.

Grass carp are a warm water, herbivorous fish (Rower & Schipper 1985) and feeding on macrophytes begins at a length of ca. 150 mm and at water temperatures over ca. 15ºC, increasing with both fish size and water temperature up to at least 30ºC. Grass carp feeding in New Zealand waters is therefore maximal during summer months and minimal during winter with the feeding season being largely determined by water temperatures. This means that stocking densities need to be higher in New Zealand waters than in locations where water temperatures remain high (>20ºC) all year round. It is clear from the use of this fish both overseas and in New Zealand to date, that grass carp will eat hydrilla and, at the right stocking density, have the capacity to eliminate it in lakes Tutira, Waikōpiro and Opouahi.

3.2 Lake Eland – a New Zealand grass carp and hydrilla case study

Lake Eland was a grass carp trial site to determine their effectiveness to control and potential to eradicate hydrilla, which commenced in 1988 (Neale 1988a). Lake Eland is a 4 ha spring fed dam on a privately owned farm. In the 1980s hydrilla 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, Lake Eland was utilised for the grass carp trial. The trial design included an assessment of water quality, invertebrates, vegetation, fish and birds (Neale 1988a).

Water quality and invertebrates were monitored by the Hawke's Bay Catchment Board. Triploid grass carp were supplied by the, then Ministry of Agriculture and Fisheries, birds counts were undertaken by the Department of Conservation, and vegetation was monitored by the Aquatic Plants Section MAF Tech (now Aquatic Plants Group, NIWA) (Neale 1988a).

Lake Eland water quality in 1984/93 is summarised (Table 11). The lake was considered more suitable for wildfowl than recreational or fishery purposes, receiving high nutrient loads from its ca. 26 ha pastoral catchment (Sander 1994). Lake Eland is eutrophic, as indicated by summer mean chlorophyll values (chl-*a*) and phosphorus concentration and is subject to algae blooms. A thermocline forms occasionally at ca 2m depth, with bottom waters becoming anoxic in the late summer and the temperature of the hypolimnion was recorded at 13ºC. Water quality results indicate little change as a result of the introduction of grass carp to Lake Eland. Secchi depth appears to have declined. 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).

As a landlocked lake, Eland had no fish of an intrinsic value in the absence of migration pathways to the sea eg., no self sustaining eels population. However, common bullies that had been deliberately introduced and were present in low numbers at that time of the grass carp introduction (Neale unpublished report 1988b) are now abundant in the absence of hydrilla weed beds (and any major predators) (Hofstra et al. 2008).

Aquatic invertebrates sampled in 1987 included snails (*Potamopyrgus*, *Physa* and *Ferissia*), waterboatment (*Sigara*), chironomids, trichoptera (*Oxyethira* and *Paroxyethira*), moths (*Hygraula nitens*), damselflies (*Xanthocenemis*) and tubifex worms (Neale unpublished report 1988b). 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 be a shift in diversity i.e., snails were not found in the 2008 survey, but mites were.

Bird species reported from Lake Eland since 1984 by the Hawke’s Bay Acclimatisation Society include mallard (*Anas platyrhynchos*), paradise (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). More recently, on a day survey black swan, mallards, little black shag (*P. sulcirostris)* and kingfisher (kotare, *Halcyon sancta vagans*) were reported (Hofstra et al. 2008). This is comparable with single day bird surveys from Lake Eland from 1988 to 1989 where from two to ten species of bird were recorded on the survey days (Champion, unpublished survey sheet dated April 1989).

An aquatic plant survey in 1987 included five emergent species (*Typha orientalis, Schoenoplectus tabernaemontani, Juncus edgariae, Bolboschoenus fluviatilis, Eleocharis acuta)*, four marginal species (*Persicaria decipiens, Ludwigia palustris, Lobelia perpusilla, Callitriche stagnalis*) and twelve submerged species (*Glossostigma elatinoides, Glossostigma submersum, Lilaeopsis ruthiana, Elatine gratioloides, Potamogeton crispus, Potamogeton cheesemanii, Potamogeton ochreatus, Chara corallina, Nitella cristata, Myriophyllum propinquum, Elodea canadensis* 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 and the hydrilla had 100% cover to 4 m and occurred to depths of 4.5 m (Neale unpublished report 1988b). Hence the native plants that are present in the lake had a limited distribution and abundance with hydrilla dominating the littoral zone of the lake bed (Neale unpublished report 1988b).

Triploid grass carp were stocked by MAF Fish in December 1988. Initially 100 fish/ha of ca 270 mm in length were stocked in November 1988 (Clayton et al. 1995). An assessment of vegetation in April 1990 revealed a major reduction in hydrilla, 17 months after 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 Lake Eland 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).

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

Table 11: Lake Eland 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

4. Potential Impacts of Grass Carp in Lakes Tutira, Waikōpiro and Opouahi

The potential impacts of grass carp in New Zealand waters were addressed by Rowe & Schipper (1985). Predation on other fish is not an issue as grass carp have no teeth and once over about 150 mm in length are herbivorous. Furthermore, as they only breed in rivers that meet stringent conditions on flow, river length, juvenile rearing habitat, and water temperature, they will not breed in New Zealand waters. Stocked populations will eventually die out unless restocking is undertaken to replenish populations. Their life span in the wild is likely to range from 10-20 years.

Research in both New Zealand and overseas during the past twenty years has shown that the main impacts arising from the use of the grass carp in lakes is related to their removal of all aquatic and marginal vegetation and the consequences of this on the lake ecosystem (Rowe 1984; Mitchell et al. 1984; Mitchell 1986; Rowe & Schipper 1986; Rowe & Hill 1989; Rowe et al. 1999). As the amount of aquatic vegetation varies greatly between lakes, any impacts need to be considered on a case-by-case basis. Clearly, small, shallow lakes where vegetation is a major component of the ecosystem will be more affected than large, deep lakes where it is a relatively minor component. Biological control by grass carp will have much the same ecological effect on a lake as intensive use of herbicides, however, biological control takes much longer to achieve (e.g., years rather than weeks) and is more lasting. Because of this, it does not cause an abrupt shock to the ecosystem. However, this form of biological control cannot be targeted to specific plant species or areas and is generally much more widespread and lasting than chemical control.

Removal of all aquatic and marginal vegetation in lakes (whether caused by herbicide application, water level draw-down, or by grass carp) can affect ecosystem functioning and can have some ramifications for water quality, fish, wildlife, and recreational uses. Potential changes that can be expected in Lakes Tutira, Waikōpiro and Opouahi as a consequence of the proposed control of hydrilla by grass carp (and to some extent initially by herbicide) are outlined below.

4.1 Water quality

International studies on the effects of grass carp on lake water quality have been equivocal. Some have recorded a decline in some parameters (e.g., turbidity and chlorophyll *a* levels) whereas others have recorded no change (Lembi et al. 1978, Clayton et al. 1995). Such differences are likely to reflect the fact that aquatic plants play different roles in different lakes. In New Zealand, the effects of weed removal by grass carp were studied in Lake Parkinson, which is approximately 2 ha in size and 7 m deep. Mitchell et al. (1984) found that weed removal here had no effect on water temperature or oxygen levels, but resulted in a short-term rise in particulate phosphorus. There were no algal blooms and chlorophyll *a* levels, reflecting phytoplankton biomass, remained much the same. Water transparency (secchi disc) also stayed much the same during spring and summer, but declined during autumn in the two years immediately after weed removal. Overall, there was no significant decline in the water quality of this already eutrophic lake and the changes observed were consistent with a pulse of nutrients from the macrophytes entering the water column and then being assimilated into zooplankton before being incorporated into the lake's sediments.

As Lakes Tutira, Waikōpiro and Opouahi are deeper than Lake Parkinson, they contain a proportionately smaller area of habitat for exotic weed growth. The effects of weed removal by grass carp in these lakes would therefore be expected to be proportionally less than in Lake Parkinson. This supposition is reinforced by the results from Lake Eland, where there were no significant changes in water quality detected following the introduction of grass carp (Sander 1994, Clayton et al. 1995) (see section 3.2).

4.2 Aquatic plants

Grass carp have been shown to have preferences for certain species of macrophytes. However, preferences can change because water temperatures have a large bearing on grass carp behaviour. For example, their feeding activity is optimal when water temperatures exceed 21ºC, but this declines once water temperatures fall below about 15ºC and is negligible at temperatures lower than 10ºC (Rowe & Schipper 1985). Thus, in lakes that stratify during summer, they frequent the warmer surface waters and do not feed on macrophytes present in colder, deeper waters, unless food is lacking in the warm, surface-water zone. As a consequence, the more palatable, shallow-water macrophyte species are browsed first. In Lakes Tutira and Waikōpiro these will include hydrilla and elodea (*Elodea canadensis*) and native plants such as *Potamogeton ochreatus, P. cheesemanii* and *Myriophyllum triphyllum* that still persist on the margins of the hydrilla beds. In Lake Opouahi, this will include native charophytes as well the hydrilla and elodea. In general, grass carp will not browse on turf-forming species such as *Glossostigma* and *Ranunculus limosella*, or on plants floating on the water surface such as duckweed (*Lemna minor*) (Rowe & Schipper 1985). As a consequence such species will persist under grass carp grazing.

However, browsing will eventually remove all other vascular vegetation (submerged and emergent) below about 20 cm unless these fish are excluded from specific areas by exclosures. Fenced exclosures were successfully used in Lake Waingata (Northland) to protect patches of raupo (*Typha orientalis*) on the shoreline from browsing by both grass carp and cattle (Rowe et al. 1999).

Grass carp do not browse in very shallow waters, and experience in New Zealand lakes stocked with grass carp has indicated that, when water levels are stable, a range of low-growing plant species can develop in waters less than about 20 cm deep. Turf-forming species thrive in such conditions and they form a mat down to depths of 1-2 m as grass carp cannot effectively browse their low (ca 1cm tall) growth form. This mat stabilises the lake edge, and provided it is not pugged and broken up by cattle or people accessing the lake edge, it prevents wave action from re-suspending silt. Such a low-growing turf plant community can be expected to remain as has occurred in Lake Eland (Hofstra et al. 2008) and Lake Waingata (authors pers. obs.).

4.3 Fish and wildlife

One of the major concerns over the use of grass carp for weed control in Lakes Tutira and Waikōpiro is the potential impact it may have on the trout fishery. There are two main issues to consider. Firstly, weed beds can provide cover for some fish and may protect them from predation. Secondly, weed beds provide a habitat for some invertebrates which are a food for fish.

The effects of grass carp on a stocked population of rainbow trout was studied in Lake Parkinson (Rowe 1984). The main effect here was a reduction in trout numbers related to increased predation of recently stocked trout by shags. The weed beds in this lake were therefore important in providing protection from predation by shags. This effect will be important in shallow lakes lacking other cover (i.e., Lake Parkinson was 7 m deep and had very little limnetic cover provided by wood debris), but will be less significant in deeper lakes as trout can seek cover in deeper waters. Lake Tutira is 42 m deep and Waikōpiro is 18 m deep, but in summer, deoxygenation of the hypolimnion will mean that trout are restricted to waters above 8 m. Newly stocked trout will therefore be vulnerable to shag predation in this lake during summer months after weed control. This could result in a reduction in the number of young trout that survive. However, the reduction in macrophyte cover will increase cover dependence on the large amount of wood debris that remains on the lake bed (particularly along the western shore of Lake Tutira and scattered throughout the littoral zone in Lake Waikōpiro (divers observations, NIWA). This provides refuge habitat in shallow water. The effects of weed removal on trout density are therefore difficult to predict *a* *priori*. If trout numbers decline because of shag predation on newly stocked fish, then this impact can be offset by an increase in the size of trout stocked into this lake, however, this could increase stocking costs. Stocking in late autumn (i.e., after mixing occurs) would minimise the risk of predation by shags and allow maximum time for some trout to grow (during winter months) to a size where they are less vulnerable to shag predation.

There are no smelt in Lakes Tutira and Waikōpiro so the main prey species for trout can be expected to be common bullies, supplemented by water boatmen and other aquatic invertebrates associated with weed beds (mainly snails), and terrestrial arthropods (e.g., cicada , green beetle) (Teirney 2008). In a recent study ca. 80% of the stomach contents of trout from Lake Tutira (in autumn) were primarily bullies and waterboatmen (J. Smith, NIWA pers. comm.). Data presented by Teirney (2008) indicated that in the 1970s, trout fed mainly on bullies throughout the year, with snails supplementing this in winter and water boatmen and terrestrial insect species in summer. The removal of almost all vegetation in Lakes Tutira and Waikōpiro will reduce the number of aquatic invertebrates normally associated with macrophytes in the lake. Snails will be most affected and will not be as abundant to trout as a winter food supplement. However, the removal of all weed can be expected to greatly increase the number of chironomid larvae in the benthos as occurred in Lake Parkinson and Lake Eland after weed removal (Mitchell 1986, Hofstra et al. 2008). With an increased area of benthos and more chironomid larvae, common bullies increase in density. Both of these species are eaten by trout and common bullies can be expected to become more important in trout diet after weed removal. Other important prey species such as water boatmen and terrestrial arthropods will not be affected by weed removal.

The growth rate and condition of trout in Lake Parkinson increased following weed removal by grass carp. This increase was attributed in part to the decline in trout density, but it also indicated that the main foods of trout were not limiting. Common bullies were the main summer prey of trout both before and after weed removal (Rowe 1984), and the population of bullies expanded in this lake following weed control (Mitchell 1986). In essence, the food web leading to trout was simplified and changed by weed removal. Aquatic insects such as caddis larvae and odonata were reduced, but this change was compensated for by an increase in benthic foraging space, an increase in the availability of common bullies on the lake bed, and an increase in mid-water prey such as smelt, which were formerly protected by the weed beds.

Similar changes in the food web leading to trout would be expected following weed removal in Lakes Tutira and Waikōpiro (Figure 8). Snails can be expected to decline, although they will still occur on the lake bottom where they feed on periphyton films. Common bullies and chironomid larvae can be expected to increase in abundance and water boatmen may increase in importance as a trout food because they will be more exposed to predation after weed removal. Overall, aquatic food production will not be reduced in this lake by weed removal, and only the prey species involved in transferring it to trout will change. As a consequence, no noticeable change in the growth rate of stocked trout is expected in the lakes.

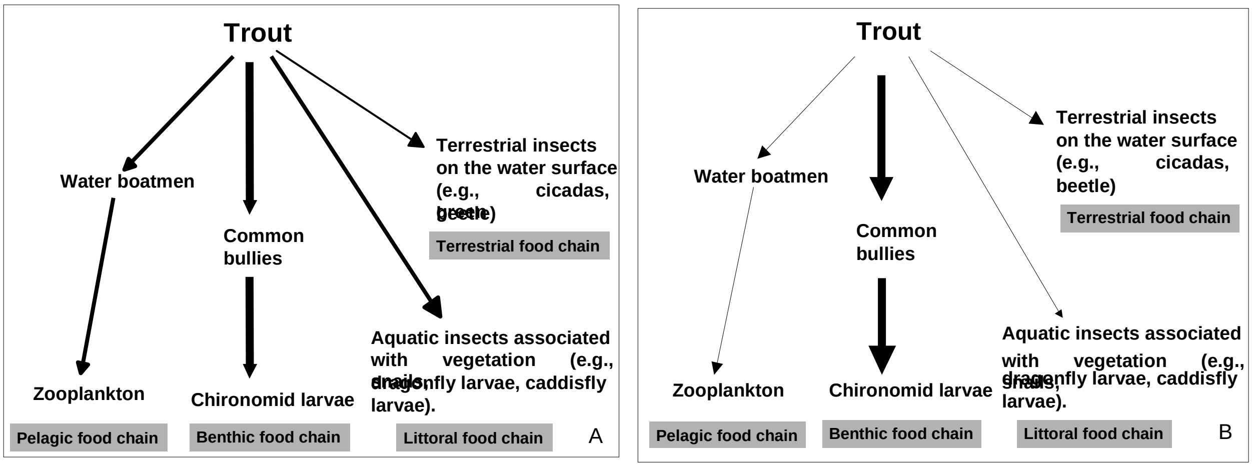

Figure 7: Generalised food web for trout: (A) before, and (B) predicted after control of hydrilla in Lakes Tutira and Waikōpiro. Line thickness indicates the strength of the relationship.

Potential impacts on other fish also need to be considered. Increased predation by shags on bullies and eels can be expected after weed removal, but neither species are major prey for shags even in lakes where there is no cover. Benthic foraging habitat for fish will increase and, as populations of common bullies and eels thrive in shallow, productive, silt bottomed and weed-free lakes (Rowe 1999b) they can be expected to also thrive in Lakes Tutira, Waikōpiro and Opouahi after weed removal. After hydrilla removal from Lake Eland the self sustaining population of bullies is abundant (Hofstra et al. 2008).

Longfin eels are present in Lakes Tutira and Opouahi (Hofstra et al. 2008) and are regarded by DOC as threatened and in gradual decline because of a reduction in elver recruitment rates over the past decade. This reduction is thought to be related to the high harvest rate of eels (including longfins) and a consequent shortage of migrant females reaching marine spawning grounds to breed. However, longfin eel densities may also have been reduced nationally by the creation of dams that block access to mainly longfin eel habitat and land use changes from forest to pasture streams because shortfins dominate in pasture streams. Furthermore, elver recruitment could be temporarily reduced by changes in marine currents and oceanic conditions. Nevertheless, it is prudent to maximise the number of large female longfins that can go to sea to spawn. The main prey for large eels in lakes are koura and small benthic fish such as bullies and gambusia. Koura are already scarce in these Hawke's Bay lakes, and weed removal can be expected to increase bullies which are a major prey for large eels. Food supply for large eels will therefore not be affected by weed removal. Such eels are generally too large to be affected by shags and other predators so survival is not an issue. Juvenile eels thrive in shallow, turbid lakes with silt bottoms where the principal food is likely to be chironomid larvae. Hence juvenile eels are also expected to be unaffected by weed removal.

The presence of grass carp will potentially lead to a lowered carrying capacity for waterfowl (Williams 1984). Birds primarily feeding on hydrilla (especially swan and Australian coots) can be expected to decline as their prime food source (hydrilla) is removed from Lakes Tutira, Waikōpiro and Opouahi. Other species of waterfowl may be similarly affected and seek alternative feed and/or waterbodies. However, some black swans still used Lake Waingata (Northland) for breeding and rearing after grass carp removed all the aquatic and marginal vegetation there (authors pers. obs.), and black swan have been recorded on Lake Eland in the absence of hydrilla (Hofstra et al. 2008). Intensive browsing by black swans has been linked to nutrient cycling and eutrophication in small shallow lakes and to regular changes between vegetated and non-vegetated states (Mitchell et al. 1988).

Lake Tutira has freshwater mussels and koura (scarce). Mussels have been sampled from Lake Waikōpiro in the past (not at recent survey 2008 sites). Koura are expected to be present in Lake Opouahi as they are in the inlet stream (Hofstra et al. 2008). At present, these macro- invertebrates are rare and are probably in danger of extinction in Lake Waikōpiro firstly because of the low water quality in the lake (i.e., summer hypolimnetic deoxygenation and blue-green algal blooms) and, secondly, the smothering and reduced DO effects of hydrilla beds. With the removal of hydrilla from large expanses of beach and lake-bed, the mussel populations may well expand in Lakes Tutira and Waikōpiro, particularly if their distribution has been limited by dense macrophytes. Koura are scarce in these lakes, and the effect of grass carp introduction on them is unknown. Although they are reputed to feed on macrophyte detritus, they can also feed on small benthic invertebrates and dead animal matter. Removal of macrophytes will not remove a key food base. Although deoxygenation of the hypolimnion greatly affects koura distribution and hence abundance in lakes, other factors limiting the abundance of koura are unknown. Without cover provided by macrophytes they may be more vulnerable to predation by trout, shags and eels. However, their distribution already appears restricted to solid cover (e.g., koura in Lake Tutira was found under a rock) and may therefore remain restricted to rocks and logjams on the lake-bed. Given their current scarcity in these lakes, the introduction of grass carp is unlikely to result in a significant change in abundance.

4.4 Effects of weed removal on lake use

The control of hydrilla in Lakes Tutira, Waikōpiro and Opouahi can be expected to increase some uses of the lake. In Lakes Tutira and Waikōpiro swimming will become more attractive and safer. At present, it is inhibited by the mats of detached plant stems that wash ashore as a consequence of swan grazing, and by the presence of entangling weed beds in deeper waters. Boating will also be easier close to shore. The water quality of these lakes will not change, so its use for stock watering or water takes (for Lake Opouahi) will not be affected. Angling from the shore would be improved in the sense that surface reaching weed beds would no longer snag hooks and create a nuisance to anglers. Most angling from the shore of Lake Tutira would be expected to occur from the beach area around the north-eastern edge. This is because the dense margin of willow trees prevents casting in most other locations. This beach area is where hydrilla growth is most prevalent and where it can be expected to inhibit shore angling at present. The removal of the weed bed will provide a greater foraging area for trout.

The aesthetics features of these lakes are likely to improve for Lakes Tutira and Waikōpiro as there will no longer be periods of weed putrifying on shore after storm events.

4.5 Summary of effects

The effects of stocking grass carp into Lakes Tutira, Waikōpiro and Opouahi will arise primarily because hydrilla and other littoral macrophytes will be extensively reduced, to the point of eliminating the hydrilla and the vegetative phases of other macrophytes. Removal of aquatic vegetation by a combination of initial herbicide application at high risk sites (to achieve an 80% reduction) and then grass carp stocking to both reduce the remaining weed and eradicate hydrilla is not expected to produce any significant changes in the water quality, fish populations, invertebrate abundance, wildlife, or uses of Lakes Tutira, Waikōpiro and Opouahi. No rare or threatened species are present in these lakes and the overall environmental effects will be less than minor. Some changes could well result in improved use of the lake.

The elimination (eradication will be declared following a period of ten years surveillance, with no hydrilla being found) of hydrilla followed by the removal of grass carp from these lakes provides an opportunity for re-colonisation by native plant species, (to water depths currently occupied by hydrilla), and their associated invertebrates. Native aquatic plants that grow in the deeper water (ca. to 6m) such as charophytes, *Myriophyllum triphyllum* and *Potamogeton cheesemanii* have a more open growth habit (than hydrilla) that will provide habitat for a wide range of macroinvertebrates and the current fish fauna, without impeding recreational activities on these lakes.

5. Mitigation Measures for Grass Carp Impacts

Appropriate mitigation measures for grass carp impacts are best determined and/or refined through a responsive monitoring programme that assesses the state of the lakes and their flora and fauna against baseline information, in conjunction with stakeholder input/feedback, and addressing potential effects (as outlined below).

5.1 Water Quality

No discernable decline in water quality is expected following the stocking of grass carp in the hydrilla affected lakes (section 4.1). Nevertheless, regular monitoring of water quality within the lakes is recommended. In May 2008 a monthly water quality monitoring programme was initiated for Lakes Tutira and Opouahi by Hawke's Bay Regional Council (contracted to NIWA Napier). Lake Waikōpiro water quality monitoring will commence in June 2008 (I Gear pers. comm.). Parameters measured included temperature, dissolved oxygen (DO) and light profile, secchi disc, suspended solids, chlorophyll-a, nitrogen and phosphorus. Initial data is presented in sections 2.1.2 and 2.3.2 for Lakes Tutira and Opouahi respectively. Additionally a buoy will be installed on Lake Tutira (timeframe end of June 2008) that will continuously measure a range of meterological and water quality parameters including, wind direction, wind speed, humidity, rainfall, water temperature, DO and algal fluorescence.

This data will provide a current baseline of water quality from these lakes (to further assess the state of the lakes) and with which to compare any future changes.

Should a significant decline in water quality become apparent during the monitoring as a result of the eradication project, and concerns arise that are identified as public health issues, then MAFBNZ have the capacity to seek/negotiate alternative water sources for affected parties.

5.2 Aquatic Plants

The desired outcome is eradication of hydrilla from these lakes and New Zealand. Although hydrilla is a preferred food for grass carp so are other soft and palatable aquatic plants, such as charophytes. Additionally when the grass carp have eaten their preferred species they will switch to less desirable plants. There will be a loss of all aquatic plants, i.e., complete devegetation of all aquatic plants that are accessible to the grass carp. This means that only low growing turf plants in the shallow water zone that the grass carp are unable to reach or feed on will remain. Hungry grass carp will consume raupo after all other macrophytes are eliminated.

Initially annual vegetation monitoring is recommended at sites outlined in the baseline survey (Hofstra et al. 2008), however dependent on findings (e.g., duplication of results between sites) the number of sites or the frequency of monitoring may need to be adjusted (see section 6).

Following the eradication of hydrilla, determined by regular vegetation monitoring, restoration of native aquatic flora may be required. This process may be initiated prior to grass carp removal, should that be needed, through the use of exclosure cages in the lakes littoral zone once hydrilla is believed to have been eradicated. Exclosure cages can be used to exclude the grass carp from an area where native flora has the opportunity to regenerate, and the presence/absence of hydrilla determined in a controlled study. This would also facilitate an assessment of the viable native seed bank of the lakes. Regeneration from native seed bank is anticipated (as has happened in Lake Eland), however if regeneration is not abundant, the potential for eco-sourcing of plants/seed bank could be investigated, as well as the possibility of maintaining plants in cultivation.

Lake Opouahi is unique amongst the hydrilla affected lakes in that the distribution of hydrilla is patchy and native charophytes still exist in some of the deeper water zones. The potential exists in this lake only, to use an exclosure cage/barrier at the outset of the eradication programme to prevent grass carp from eating plants within the designated exclusion area, whilst maintaining the hydrilla eradication objective. The feasibility would need to be assessed with a site visit to select an area/s where sufficient native vegetation exists that is free of hydrilla, and that an exclusion barrier could be erected and maintained in. This needs to be considered by the Technical Advisory Group and MAF Biosecurity New Zealand. However, this must be contingent on the understanding that regular monitoring for hydrilla in the exclusion zone is carried out, if any is found inside that cannot be hand pulled then the exclusion barrier will need to be removed to enable grass carp access. Also for consideration, is the opportunity to restore Lake Opouahi entirely its indigenous fish and vegetation. It is likely that an added advantage of the use of grass carp will be that they also eliminate the introduced weed elodea (*Elodea canadensis).* Grass carp will feed on the elodea as well as the hydrilla. If the Department of Conservation considers the removal of the elodea a priority then any exclosure area/s will also need to be free of elodea. MAF Biosecurity New Zealand and the Department of Conservation will need to consider this possibility. The risk associated with the use of a grass carp exclosure area is that any hydrilla present and not found within the exclosure could potentially lengthen the term of the eradication programme in this lake and therefore nationally. Additionally if MAF Biosecurity New Zealand removes the grass carp from the lake once the hydrilla is eliminated the Department of Conservation may wish to consider removing the smelt at that time.

5.3 Fish and Wildlife

Monitoring of fish in the hydrilla affected lakes is recommended to identify the need for mitigation measures as appropriate. Following the removal (at least 80% of the weed beds) of the hydrilla a fish survey to assess impacts on fish populations and to compare with the baseline data (Hofstra et al. 2008) will be undertaken. Subsequent monitoring (methods, species targeted and frequency) will be dependent on the results of that survey, and advice received from the Technical Advisory Group.

In the absence of hydrilla weed beds, newly stocked trout may be more vulnerable to shag predation in Lake Tutira, resulting in an initial fall in the number of young trout that survive. This potential decline in trout numbers may be offset by an increase in the size of trout stocked into this lake and/or by more regular stocking, however, this could increase stocking costs. Detection of any impacts on the trout fishery will require the establishment of baseline data on angler catch rates as well as trout size and condition, supplemented with the collection, as needed of such data via creel survey to identify any decline resulting from weed removal.

Macroinvertebrate monitoring is also recommended for the year following the removal (at least 80% of the weed beds) of the hydrilla, to assess changes in macroinvertebrate presence and relative abundance with the change in substrate habitat.

Bird counts will be made while carrying out vegetation monitoring, to develop a longer term assessment of bird presence and relative abundance on the lakes.

5.4 Effects of weed removal on uses of the Lakes

No mitigation is envisaged as only benefits in terms of water activities e.g., better access for swimming, boating and angling, are anticipated. There are not likely to be any effects on use for people visiting the lakes for non-water activities.

5.5 Potential effects of grass carp escape on the Aropaoanui river

Some grass carp may escape from Lake Tutira during a major storm event that floods the lake and overtops the barriers. Such fish can be expected to move downstream to the lower reaches of the Aropaoanui River. Those that are not flushed out to sea by the high flows and die because of exposure to saline water, will remain in the few large pools that occur in the lower reaches of this river and will feed on fringing macrophytes and terrestrial grasses growing along the river banks. There have been no reported impacts of grass carp in riverine environments because densities remain too low to affect macrophytes even after intensive stocking over many years to increase their numbers (Rowe and Schipper 1985).

5.6 Summary of mitigation measures

Appropriate mitigation measures for grass carp impacts are best determined and/or refined through a monitoring programme that assesses the state of the lakes and their flora and fauna against baseline information, in conjunction with stakeholder input and addressing known potential effects.

Monitoring for water quality is being undertaken by Hawke's Bay Regional Council in Lakes Tutira and Opouahi, and will commence in Lake Waikōpiro in June 2008. Assessment of water quality over time will be undertaken, and particularly for Lake Opouahi with regard to the water takes from that lake.

Annual vegetation monitoring is recommended initially at sites outlined in the baseline survey (Hofstra et al. 2008), however dependent on findings (e.g., duplication of results between sites) the number of sites or the frequency of monitoring may need to be adjusted (see section 8). The potential exists within Lake Opouahi to use exclosure cages to retain native refugia in the lake.

Bird counts will be made while carrying out vegetation monitoring, to develop a longer term assessment of bird presence and relative abundance on the lakes.

A longitudinal study on the impact of the eradication of *Hydrilla verticillata* on the flora/fauna, trout and indigenous fish populations will be undertaken by MAF Biosecurity New Zealand. Following the baseline survey in 2008 flora and fauna surveys and monitoring activity will occur at strategic points throughout the project in the following years:

- Annually 2009, 2010, 2011
- Biennially 2013-2019

- Triennially 2022-2028
- Final 2032

Future monitoring (methods, species targeted and frequency) will be determined by the results from the baseline survey and those of subsequent surveys.

Fish monitoring can be separated into trout and native species. Trout monitoring will involve the establishment of a baseline data set on angler catch rates and trout growth rate and condition for the age cohorts in the lake. Recent data collected over the past few years may be available to complement the historic data collected by Teirney (2008). However, it will be important to obtain data over the next year to help establish this baseline. The planned survey schedule, supplemented with creel surveys as needed, will provide data to guide the project and inform decision making. If there is no major change in these fishery statistics over this period, then it can be concluded that weed removal is not affecting trout. However, if mean catch rates decline then this will imply a higher mortality rate of the stocked trout and a need to revise the stocking policy (i.e., size of trout and timing of stocking). If trout growth rate and condition declines over this period and is not related to changes in lake water quality (e.g., from a warmer summer), or the length of the growing season (e.g., colder winter conditions), then there will be a need to examine feeding frequency and diet as well as data on prey abundance to confirm a food shortage. Reduced growth of trout caused by a reduced abundance of prey can be compensated for by a reduced stocking density of trout, but this will reduce catch rates, requiring some other form of mitigation.

No mitigation is envisaged for changes in water activities as only benefits are expected (e.g., better access for swimming, boating and angling are anticipated). There are not likely to be any effects on lake use for people visiting the lakes for non-water activities.

6. Grass Carp Operation

The goal is to eradicate hydrilla. Grass carp will be used in tandem with endothall treatment of high risk weed beds (Hofstra and Champion 2008) to eliminate hydrilla from Lakes Tutira, Waikōpiro and Opouahi, and hence to eradicate hydrilla from New Zealand (MAF Biosecurity New Zealand 2008). The use of grass carp for hydrilla control/eradication has been demonstrated in Lake Eland (section 3), and their operational use for Lakes Tutira, Waikōpiro and Opouahi is outlined below.

6.1 Stocking of grass carp

Grass carp would be stocked into Lakes Tutira, Waikōpiro and Opouahi at the smallest size compatible with avoidance of mortality from shag predation. Thus, fish over 30 cm fork length but less than 35 cm would be required and will need to be obtained from the contracted supplier. Use of this size range of fish would maximise access to hydrilla while not compromising survival.

Stocking rates for Lake Tutira, Waikōpiro and Opouahi are 2354, 214 and 200 fish respectively. These stocking rates are based on 100 grass carp per vegetated hectare in the lakes.

6.2 Protection of native aquatic vegetation

Lake Opouahi is unique amongst the hydrilla affected lakes in that the distribution of hydrilla is patchy and native charophytes still exist in some of the deeper water zones. The potential exists in this lake only, to use an exclosure cage/barrier at the outset of the eradication programme to prevent grass carp from eating plants within the designated exclusion area, whilst maintaining the hydrilla eradication objective (see section 5.2 Mitigation – aquatic plants).

An assessment of potential areas must be conducted before this initiative can proceed.

6.3 Containment

Deliberate or accidental removal of grass carp from these lakes needs to be prevented. Grass carp are generally very wary and intelligent fish and are particularly difficult to catch. They generally shun areas frequented by people such as jetties, beaches etc. particularly when people are around. As a result, any deliberate removal is highly unlikely to be successful and would not remove sufficient fish to reduce browsing pressure on hydrilla, especially after the first summer. By which time the fish will have grown in weight such that the overall increase in total biomass will compensate for any small loss in fish numbers.

Commercial eel fishing is not permitted in these lakes, so accidental capture by commercial eel fishers in fyke nets is unlikely. In general, grass carp are rarely caught in fyke nets, so even accidental capture by non-commercial eel fishers is very unlikely. Trout anglers may inadvertently hook the occasional grass carp if they use a floating lure or a nymph that resembles a piece of plant material (i.e., coloured green). However, such lures are rarely used in lakes such as Tutira and Waikōpiro and grass carp are likely to avoid areas where anglers are fishing. Nevertheless, some angler education (e.g., notices) will be desirable to warn of this possibility and to inform anglers that any grass carp must be released back into the lake alive. As the grass carp are removing the hydrilla and thereby increasing angler's accessibility to trout, it is in their interests to leave the grass carp in the lake.

Waikōpiro Containment

To maintain browsing pressure in Lake Waikōpiro, and prevent emigration of grass carp into Lake Tutira via the Tautenga culvert, a screen will be constructed and fixed to the Waikōpiro end of the two culvert pipes. It is recommended that the screen be fixed to the culvert in such a way as to minimise the risk of unauthorised removal. A circular frame design would enable the screens to be bolted to the inside of the culverts, or if a sleeve design is used, it could be bolted over the end of the culverts. Vertical bars welded to the circular frame would need to be constructed of 1 cm diameter steel rod and spaced at 50 mm centres so that gaps between them are no greater than 40 mm. This provides a 10% safety margin should the bars become bent during installation. The 40 mm gaps in this screen will allow passage of bullies, most eels and juvenile trout between the two lakes, but will prevent the movement of large (> approx. 50 cm long) eels and large (> approx. 35 cm long) trout through the culvert. Large eels can travel overland between Lakes Waikōpiro and Tutira during wet nights, so the screen is not a major barrier for large eels. However, any large trout present in Lake Waikōpiro will be confined to this lake along with grass carp.

If a large storm event raises water levels to the point where the causeway is inundated and grass carp escape into Lake Tutira, restocking in Waikōpiro will need to be carried out. However, any subsequent increase in grass carp numbers to Tutira from Waikōpiro will be minor relative to fish numbers to be stocked there.

Tutira containment

Hawke's Bay Regional Council will make and install the grass carp containment barriers at the outlet of Lake Tutira (within the lake itself) and in the outlet stream to prevent grass carp from moving downstream out of Lake Tutira. Design specifications will be determined at a site meeting (July 3rd, 2008) by NIWA, Hawke's Bay Regional Council and MAF Biosecurity New Zealand. The barrier will be likely to include a metal screen (as for the culvert) across the outlet, and a fine-meshed net to collect floating trash, set in the lake (surface to bottom) in front of the outlet.

Opouahi containment

At the Lake Opouahi outlet there is already an exclusion barrier in place to ensure that the Kiwi sanctuary (which includes the lake and its surrounds) remains predator free. The adequacy of this barrier for grass carp containment will be reviewed by NIWA, Hawke's Bay Regional Council and MAF Biosecurity New Zealand at a site meeting on July 3rd, 2008.

6.4 Monitoring of environmental effects

Monitoring of water quality, aquatic vegetation, macroinvertebrates, fish fauna and birds are described earlier (Section 5 - Mitigation).

6.5 Monitoring of grass carp density

The number of grass carp present in the lake can be expected to steadily reduce through natural mortality. Knowledge of actual grass carp numbers present is important for the management of aquatic vegetation. Where browsing pressure by the grass carp is too great, or is not keeping pace with plant growth, removal or addition of fish could be respectively required. However, the number of fish present needs to be assessed in order to determine the number to be removed or added. Obtaining measures of changes in grass carp density over the entire 10-15 year period envisaged for this trial has not been attempted before and therefore presents a technical challenge that can be addressed in several ways.

Firstly, visual assessments of grass carp numbers have been used in some lakes to date but, while providing an indication of the minimum number of fish present, are of limited accuracy. These counts are based on regular, late-summer, observations of fish present at the water surface and could be undertaken from a highpoint such as the hill on the eastern side of Lake Waikōpiro which provides a good view of most of the lake. Counts are less feasible for larger lakes like Lake Tutira, or where there is not a good vantage point as in Lake Opouahi. Observations would need to be made from the same place on each occasion and would require the use of binoculars and a camera with a zoom lens (a polaroid filter is also desirable). On calm, autumn mornings, grass carp are often seen congregating in loose schools close to the water surface in certain areas of lakes. Once such a preferred area is located and the best vantage point to see the fish is established, the observer makes a series of visual counts of the number of fish present at any one time over a period of 15 minutes. The maximum figure is recorded. This figure may be increased later after examination of photographs as this often shows up fish that can be missed by observers. Such a count would be made on 3-5 mornings over a period of a week each year. Optimal conditions for observations include no wind, clear skies, and a warm night (e.g., calm, fine weather) and generally occur in the morning between 8-10 a.m. The maximum number of fish observed is plotted against time and a trend line is fitted to the data between years. Reductions in grass carp density between years will be reflected by a drop in the slope of this trend line, with the extent of the drop (%) reflecting the extent of mortality. This observer-based method could be calibrated against actual density (determined from 3 monthly monitoring of tagged fish) during the first year by comparing known fish numbers with observed fish numbers.

More accurate and potentially cheaper alternatives include radio-tagging and PIT (passive integrated transponder) tagging, but these methods have not been trialled on grass carp yet. If radio tags were inserted into the abdomen of each fish before it is released, then individual fish could be readily identified, counted and tracked within the lake for 1-2 years depending on tag battery life. Tests of radio tagging with other large fish indicate that this method would work well for grass carp but would be of limited duration. Radio tagging provides a means of both counting and locating individual fish within the lake so that distribution patterns can be determined and over-wintering habitats identified. However, tag life is limited to several years. Alternatively, fish could be tagged with PIT tags and individually identified each year over the 10-15 year period when attracted to an antenna in the lake. This method is potentially better than radio-tagging for assessing fish numbers over long time periods but requires a field test to demonstrate its viability.

Addition/removal of grass carp

If one of the annual assessments of hydrilla, following initial vegetation decline, indicates little control is occurring (i.e., plant cover is not decreasing or is increasing), and assessments of grass carp numbers have indicated a reduction in density, then further stocking would be needed. The number of fish required would depend on the extent of fish reduction and the growth of weed density.

Removal of grass carp may be desired after hydrilla has been eradicated. Otherwise, the grass carp will die out naturally over a period of 10-20 years through a combination of reduced food (starvation), disease and old age. Where a reduction in grass carp density is required, the best option currently available for achieving this is the use of Prentox bait pellets (Rowe 1999a). The lakes are too deep for trammel or gill netting to be successful. The Prentox bait system involves training grass carp to feed on floating, food pellets (trainer pellets), which are broadcast onto the lake surface every morning for up to 15 days by an automatic feeder anchored in the lake. After 15 days, treatment pellets (containing a substance toxic to fish such as rotenone or antimycin) are then substituted for the trainer pellets and fish that eat these die. Uneaten pellets float and are later collected from the shoreline. This system has worked well in the USA and has been trialled with mixed success in New Zealand and Australia. The success of initial applications, but failure of secondary applications in New Zealand is thought to relate mainly to quality control over the composition of treatment pellets, and to a loss of their toxicity in the secondary applications. However, it is also apparent that grass carp can quickly learn to avoid treatment pellets, so that repeated applications are much less successful than the initial one. Because of this limitation, research is currently focussed on improving the toxicity of the treatment pellets while reducing the ability of grass carp to distinguish them from the trainer pellets on the basis of either taste or texture. Effects of treatment pellets on other fish species have not been fully evaluated yet. There is no evidence that they affect common bullies, but eels and trout have not been tested. As the treatment pellets float and as most uneaten pellets are collected before they sink, opportunities for other species to feed on them are limited.

A further, as yet untried option to capture grass carp would be to use the trainer pellet system to attract and concentrate them within a small area. The trainer system is highly effective at this. A purse-seine net would then be raised from the lake bed around the pod using compressed air to rapidly inflate a flexible hose fitted to the rim of the net. As with the Prentox pellet system, this method requires ‘management’ research to demonstrate its feasibility before it can be guaranteed. Management research can only be carried out effectively in realistic situations such as a lake containing a population of grass carp.

Contingency plans for escapement

Should grass carp escape from Lake Waikōpiro and Tutira some fish can be expected to migrate down the Arapaoanui River, where they will reside in the lower reaches above the estuary. These fish are too few to have any noticeable impact in the river and they will not breed in this river (Rowe & Schipper 1986).

The main contingency plans following an escape of grass carp will revolve around re-stocking as soon as is possible (as required) to maintain browsing pressure on the hydrilla. This will require prior identification of the cause(s) of any breach and the subsequent repair of fences/screens before restocking. It may also involve management of other factors responsible for or contributing to the escapement. Once security is re-established and unlikely to be breached again, restocking can be undertaken.

6.6 Proposed schedule for management actions

A tentative schedule identifying the sequence and seasonal timing of key actions related to the stocking of grass carp in the lakes is outlined Table 12.

In order to both stock grass carp during the summer growing season and allow sufficient time for them to browse down the hydrilla, a decision to stock would need to be obtained by September. This will allow preliminary management actions to be undertaken before stocking can be organised. The latest time for stocking would be January; otherwise it would need to be delayed until the next October.

Table 12: Proposed schedule of actions relating to the introduction of grass carp into Lakes Tutira, Waikōpiro and Opouahi.

Management action	**Time/periodicity**
Preliminaries:	
1. Preparation of AEE and operational plan to stock grass carp >30 cm	June 2008
2. Inform key stakeholders and make AEE available	July 2008
3. Seek approvals from the Minister and Director General of Conservation	Aug – Sep 2008
Assuming the application is approved:	
1. Hawke's Bay Regional Council constructs and installs screens	Oct 2008
2. Confirm delivery dates for grass carp	Oct 2008
3. Investigate feasibility of Lake Opouahi exclosures	Sept - Oct 2008
4. Treatment with endothall to achieve 80% control on risk sites	Nov - Dec 2008
5. Macrophyte survey (1 month after endothall treatment)	Dec 2008 – Jan 2009
6. Exclosures installed in Lake Opouahi if appropriate.	Nov 2008
7. Stock grass carp	Nov - Dec 2008
On-going management:	
1. Screen maintenance (weed removal phase -1st two summers)	Weekly (Oct-Apr)
2. Screen maintenance (control phase)	Monthly + floods
3. Monitoring surveys	
Annually	2009, 2010, 2011
Biennially	2013-2019
Triennially	2022-2028
Final	2032
Potential ad hoc management:	
1. Grass carp addition / removal	

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9. Appendix 1: Hydrilla eradication project – Tutira Lakes Historic Timeline (I Gear)

Year (M/D)	Event	Reference
Pre-European times	Māori had established both permanent and temporary dwellings, gardens of kumara and taro, and managed wild crops such as aruhe (bracken fern) close to Tutira and Waikopiro. The lake and the area surrounding it was well known for its eels, kakahi (fresh water muscles), birds along with its rongoa (medicine). Mokihi (rafts) were made from raupo, flax growing in the water on the lake shores for transport on the lake. Flax growing on land was used for ropes, nets and weaving.	
1787	Hand written note on HB F&G copy of the Tutira Catchment Control Scheme 1980 records "L.W. Clarry [of] Moeangiangi [Station]. Tutira overflow at southern end of the lake was blocked off in 1787." NB: Guthrie-Smith (1965) reported that Te Whatu-I-Apiti, a chief of the Heretaunga tribe diverted Papakiri Stream so that the lake would decompose killing off the eels on which the local tribes depended. The story goes that a frightful stench followed but later the embankments were destroyed "the fresh healing waters of the stream stayed the process of decomposition".	Tutira Technical Committee, 1976. Lake Tutira: Technical Committee Report. Hawke's Bay Catchment Board and Regional Water Board
1861 (13 Mar)	William Herbert Guthrie-Smith was born at Helensburgh on the Clyde in Scotland	http://www.teara.govt.nz/1966/G/Guthrie-smithWilliamHerbert/Guthrie-smithWilliamHerbert/en
1867	A. M. Johnson, Otago receives the first consignment of brown trout *Salmo trutta* for introduction into New Zealand	McDowell R M 1989 New Zealand Freshwater Fishes. Heinemann Reed
1868	The genesis of the Hawke's Bay Acclimatisation Society occurred as interested Hawke's Bay people imported birds and animals from 'the homeland'.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1873	Some palisades of deserted pa still standing at sites around Tutira.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1873	Tutira Station 61,140 acres first leased from Māori owners.	
1880s	First black swans reported at Tutira.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1880	William Herbert Guthrie-Smith emigrates from Scotland to New Zealand settling at Tutira. NB: In 1880, accompanied by Arthur Cunningham, a Rugby friend, Guthrie-Smith sailed for New Zealand, and on arrival went to work as cadet on the estate of his uncle, George Dennistoun, of Peel Forest Station, South Canterbury. Two years later he and Cunningham jointly bought Tutira estate in Hawke's Bay for £9,750, the amount for which it was mortgaged.	http://www.teara.govt.nz/1966/G/Guthrie-smithWilliamHerbert/Guthrie-smithWilliamHerbert/en; Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.

1881 (17 Nov)	Hawke's Bay Acclimatisation Society was gazetted.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1882	W.H. Guthrie-Smith and A.M. Cunningham take over the lease of Tutira station. NB: Guthrie-Smith reports that there were some 800 - 900 teal on Lake Tutira when he first arrived.	http://www.teara.govt.nz/1966/G/Guthrie-smithWilliamHerbert/Guthrie-smithWilliamHerbert/en; Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1883	Californian Rainbow trout introduced into New Zealand	
1884	Trout ova (48,000) were imported from Otago and liberated in Hawke's Bay rivers.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1884	Guthrie-Smith first 'leased' Tutira. NB: Guthrie-Smith, never had all the 36 owners (or successors) sign his lease. He only ever held, therefore, an incomplete 'holding title', and farmed with the possibility that at any time, those non-signatories could have a portion of his lease partitioned out for themselves.	http://www.waitangi-tribunal.govt.nz/reports/viewchapter.asp?reportID=d6d0c6a3-efe6-4507-b4b3-6dd4bf5c5552&chapter=14#H201.9.8. also: http://www.waitangi-tribunal.govt.nz/doclibrary/public/researchwhanui/district/11B/Chapt06.pdf
1890's	First attempt by Guthrie-Smith to introduce trout - brook trout (*Salvelinus fontinalis*) using imported ova - this was unsuccessful.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1890	During this decade a drain was cut through the swamp at the head of the lake. This swamp had previously seeped into Tutira - the outlet of the lake. The filtering effect of the swamp was destroyed leading to the building up of a delta where Papakiri (Sandy Creek) now flowed into the lake.	Tutira Technical Committee, 1976. Lake Tutira: Technical Committee Report. Hawke's Bay Catchment Board and Regional Water Board
1893	6 ha (15 acres) directly behind the Tutira Station homestead was set aside by Guthrie-Smith to regenerate.	
1895	Guthrie-Smith writes that black swans are rarely, if ever, seen on Lake Tutira.	H. Guthrie-Smith. 1895 Bird-life on a Run. Art. XXXIV. Transaction s of the New Zealand Institute: Read before the Hawke's Bay Philosophical Institute, 12th August, 1895; http://www.teara.govt.nz/1966/G/Guthrie-smithWilliamHerbert/Guthrie-smithWilliamHerbert/en
1899-1900	Willows grown from a weeping willow that grew next to Napoleon's Tomb on St Helena, pines and eucalyptus were planted around the lakes. Guthrie-Smith established the area immediately around the lake as a wild life sanctuary.	Tutira Technical Committee, 1976. Lake Tutira: Technical Committee Report. Hawke's Bay Catchment Board and Regional Water Board
1901	First sods of the Napier - Wairoa road were cut.	Guthrie-Smith H 1926 Tutira: The Story of a New Zealand Sheep Station. Whitcombe and Tombs, Wellington.

1904	George Douglas Hamilton '*Trout-fishing and sport in Māoriland'* published by the Government Printing Office. NB: A keen sportsman, Hamilton may have been the first to establish a trout hatchery in the North Island. When not engaged in his legal battles he occupied himself in later years with stocking the rivers of southern Hawke's Bay with trout. He presided over the Hawke's Bay Bush Districts Acclimatisation Society in the 1890s, the Bush Districts Farmers' Club, both the Woodville District and Dannevirke Jockey Clubs and the Hawke's Bay Angling and Shooting Club from its inception in 1901 until his death.	
1911	Guthrie-Smith publishes 'Birds of Water, Wood and Waste'. Illustrated with many black and white images of birds on and around Lake Tutira.	
1917	650mm of rain fell over three days, drowning the principle habitat of fernbirds - raupo and cutty grass around the lake edge - and leaving 150mm of silt over it. Fernbirds were not seen at Lake Tutira after this event.	Guthrie-Smith 1927 Birds of Water, Wood and Waste. Whitcombe and Tombs, Wellington.
1919	Weka no longer found at Tutira.	
1920	Earlier liberations of Rainbow and Brown Trout into Lake Tutira were possible.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1921	*Tutira*, W Herbert Guthrie-Smith was published by William Blackwood and Sons, of Edinburgh.	
1925 (July)	Guthrie-Smith completed a bathymetric survey of the lake taking 356 soundings	Tutira Technical Committee, 1976. Lake Tutira: Technical Committee Report. Hawke's Bay Catchment Board and Regional Water Board
1928	396 mm of rain fell in 11 hours.	Kidson, E. 1930 NZ Journal of Science and Technology 12: 53-60
1929	Guthrie-Smith had Lake Tutira and the surrounding land designated a sanctuary for imported and native game.	
1931 (3 Feb)	Napier earthquake: Raised the bed of the lake, and surrounding land, several feet and raised a large area of swampy ground along the lower reaches of Papakiri (Sandy Creek).	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1931 (3 Feb)	Napier earthquake. Hawke's Bay Acclimatisation records destroyed. Only records from 1922-23 onward are held by Internal Affairs (the amended Animals and Game Protection Act 1921 required annual returns from Acclimatisation Societies).	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1936	Lease of Tutira Station expired and Guthrie-Smith was allowed to purchase 809 ha.	
1938 (Apr)	ANZAC Day storm. 675mm (27 inches) of rain fell in the area over a period of four days. Made the course of the Papakiri Stream more direct - previously meandering. (39 inches of rain was recorded elsewhere in Hawke's Bay.)	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1938	686 mm of rain fell over four days	Tutira Technical Committee, 1976. Lake Tutira: Technical Committee Report. Hawke's Bay Catchment Board and Regional Water Board

1940s	Height of the causeway between Tutira and Waikopiro was increased by earth works.	Hooper, G. (1987). Hawke's Bay small lakes water quality survey. Unpublished report. Hawke's bay Catchment Board.
1940 (4 Jul)	Guthrie-Smith passed away aged 79. Leaving 2000 acres.	http://www.teara.govt.nz/1966/G/Guthrie-smithWilliamHerbert/Guthrie-smithWilliamHerbert/en
1942	Barbara Absolum (Guthrie-Smith's daughter establishes the Guthrie-Smith Trust for the benefit of New Zealand's youth.	http://www.workforce.ac.nz/training_programmes/outdoor_recreation/Guthrie.htm
1947	Trout liberated following the hatching of 310,000 rainbow trout ova at the Greenmeadows Hatchery operated by the Hawke's bay Acclimatisation Society. Fry were released into Lake Tutira and Hawke's Bay rivers during 1946 -47.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1950s	Presence of Hydrilla in Lake Tutira was known.	Walls, G., 1993. The New Zealand Hydrilla Problem: A Review of the Issues and Management Options. Department of Conservation.
1951	Hawke's Bay Acclimatisation Society Annual Meeting records "Lake Tutira produced some good bags and showed the possibility of the lakes being developed into a major fishing area."	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1952	Trout trap installed on Papakiri Stream and the first ova stripped. This large scalestripping was disappointing. NB: Only 1000,000 of the 310,000 ova stripped were reared for liberation.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1956	Marine Department, Freshwater Advisory Service, - Stream and Spawning Survey of Sandy Creek recommends that no further trout releases be made for a period of three years as the trout stock was thought to probably be self-supporting.	Marine Department, Freshwater Advisory Service. Report 23-30:7:56
1957	Waikopiro, Tutira and Orakai declared a Wildlife Refuge under the Wildlife Act 1953.	
1958	The Hawke's Bay Acclimatisation reported "The establishment of smelt in the lakes was an innovation under consideration".	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1958	Experimental fishing season continues.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1959 (30 Apr)	Lake Tutira research ends (Marine Department)	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1959	The Hawke's Bay Acclimatisation Society made recommendations to the Secretary for Marine that: 1. Lake Tutira be open for fishing year round; 2. There be no size or bag limits; 3. Fin clipped fingerlings be released in 1960 and 1961; 4. A further study of stock be made in 1961.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1959	Annual liberations of rainbow trout commenced by the HB Acclimatisation Society.	Tutira Technical Committee, 1976. Lake Tutira: Technical Committee Report. Hawke's Bay Catchment Board and Regional Water Board

1959	First reports of the proliferation of macrophytes by the Acclimatisation Society honorary ranger - Mr W.A. Gunn	Tutira Technical Committee, 1976. Lake Tutira: Technical Committee Report. Hawke's Bay Catchment Board and Regional Water Board
1960s	Smelt were released in Lake Opouahi some time since the 1960s.	
1960	Swan census 254 birds - W A Gunn Tutira identity and former honorary ranger. Gunn believed there was insufficient food to support a much larger population.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1960	Early 1960s - trout were reported as dying in Lake Tutira through lack of oxygen due to prolific oxygen weed growth.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1960	Papariki (Sandy Creek) surveyed. It was concluded that the Lake Tutira fish population was predominantly brown trout not rainbow trout as was the local opinion. The survey concluded that there was adequate food available to support a larger trout population.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1960	"The weed problem continued to be unresolvable" and "remain so as long as aerial top-dressing as practiced."	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1960	Stocking of Lake Elands with rainbow trout ceases.	
1961 (May)	A 5" fingerling trout released into Lake Tutira in August 1960 is caught weighing 3.5lbs.	
1962-63	Estimated that 717 angling days were spent at the lake by some 289 anglers from a survey of angler diaries	Tutira Technical Committee, 1976. Lake Tutira: Technical Committee Report. Hawke's Bay Catchment Board and Regional Water Board
1963	*Hydrilla verticillata* validated as being present in Lake Tutira and Waikopiro	Walls, G., 1993. The New Zealand Hydrilla Problem: A Review of the Issues and Management Options. Conservation Advisory Science Notes #71. Department of Conservation. 42pp.
1963	P.J. Grant completed a bathymetric survey determining that the lake had a mean depth 1.1m shallower than the 1925 survey. This had occurred following sedimentation events. The volume of the lake had decreased 5.17%. 1.9×10^6 cubic meters of sediment had been contributed from the catchment. Grant recorded dense weed beds extending to a depth of 7.6 m and covering 16.9% of the total lake surface which had not been present in 1925	Tutira Technical Committee, 1976. Lake Tutira: Technical Committee Report. Hawke's Bay Catchment Board and Regional Water Board
1964	10,000 rainbow trout fingerlings were released in Lake Tutira. A further 10,000 unfed fry were released into Papakiri (Sandy Creek).	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1964	Crown owned areas of the lake and lake edge declared a domain.	
1965	Lease of the Randall House huts on the shore of Lake Tutira was obtained by the Scinde Angler's Club.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1965	10,000 unfed fry were released into Lake Tutira along with 400 tagged fingerlings.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.

1965 (1 Aug)	The Hawke's Bay Catchment Board reports that between 1925 and 1963: 1. Lake Tutira is 490ft asl and covers 443 acres. 2. The water level has risen by approximately 1 foot; 3. There has been a reduction in the mean depth of about 3.5 ft. The represents sediment from a catchment of about 11 square miles; 4. Two exotic aquatic plants had become established; *Elodea canadensis* and a close relative of *Hydrilla verticillata*. Weed growth extends out to the 25ft contour; Average water temperature is 51 degrees F at 120 ft rising to 63 degrees F at the surface.	
1966	38 of the 400 tagged fish released in the previous year were subsequently caught between May and Sept 1966. These fish had an average weight of 2lbs and were 15 inches in length.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1966	Ngāti Tu agrees to lease 40 hectares at the northern end of Lake Tutira to the Hawke's Bay Acclimatisation. A fifty year lease is signed.	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1967-68	3264 angling events estimated in a survey of angler diaries.	Tutira Technical Committee, 1976. Lake Tutira: Technical Committee Report. Hawke's Bay Catchment Board and Regional Water Board
1968	Quentin Bennett, Marv Carroll and Barry Short dive Lake Opouahi and confirm the drowned forest beneath the surface.	Pers. comm. And article ex Quentin Bennett.
1968	Tauranga Koau was a nesting site for "dozens of black teal". "Unfortunately with the large increase in the number of Black Swan, now permanent residents of the lake, the teal have suffered a severe set-back, …"	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1968	Population of teal on Lake Tutira recognised to be "little more than a score."	Wellwood J M 'Hawke's Bay Acclimatisation Society Centenary 1868 - 1968.
1970s	Formation of the Lake Tutira Technical Committee to investigate the eutrophication of Lake Tutira and to make recommendations to improve the lake's trophic status.	Hooper, G. (1989). Lake Tutira water quality study. Unpublished report. Hawke's Bay Catchment Board.
1970	Full vegetation survey of Lake Opouahi - hydrilla not recorded.	
1971	Grass carp (White Amur) imported into New Zealand by MAF for the purposes of aquatic weed control	http://www.mfe.govt.nz/publications/water/lm-fish-in-nz-lakes-jun02.pdf
1972	Blue-green algal blooms reported in Lake Tutira	Tutira Technical Committee, 1976. Lake Tutira: Technical Committee Report. Hawke's Bay Catchment Board and Regional Water Board
1973	The Orakai, Tutira and Waikopiro Refuge Order prohibits motorised boats and commercial eeling in the lakes.	
1973	The Ministry of Agriculture and Fisheries commence physical and biological parameter surveys in Lake Tutira.	Teirney, L. 1980. Tutira - A Lake worth saving. Soil and Water Feb 1980
1973	Fisheries Division of MAF and DSIR set up monthly sampling programme to investigate the problems in the lake.	Tutira Technical Committee, 1976. Lake Tutira: Technical Committee Report. Hawke's Bay Catchment Board and Regional Water Board

1974	Lake Tutira Technical Committee formed.	Tutira Technical Committee, 1976. Lake Tutira: Technical Committee Report. Hawke's Bay Catchment Board and Regional Water Board
1975 (Oct)	Aerohydraulic guns turned on to mix water through the summer months from October - March. Resulted in well defined thermocline that had previously occurred not developing. A gradual decrease in water temperature occurred throughout the water column - the 10 degree C characteristic of the hypolimnion was not reached until 27m depth in comparison to 12 m prior to 1976.	Teirney, L. 1980. Tutira - A Lake worth saving. Soil and Water Feb 1980
1976	Hawke's Bay Electric Power Board undertakes a preliminary study to determine the technical feasibility of building a power station drawing on Lake Tutira.	Letter from the Chief Engineer, Hawke's Bay Electric Power Board to the Chief Soil Conservator, Hawke's Bay Catchment Board 5 March 1980.
1977 (Apr)	Over 200mm of rainfall over 2 consecutive days.	Hooper, G. (1989). Lake Tutira water quality study. Unpublished report. Hawke's Bay Catchment Board.
1977	Reserves Act is enacted.	
1977	Tutira Recreation Reserve created.	
1979 (Mar)	Aerohydraulic guns turned off due to high running costs	Teirney, L. 1980. Tutira - A Lake worth saving. Soil and Water Feb 1980
1980 (Dec)	Over 200mm of rainfall over 2 consecutive days.	Hooper, G. (1989). Lake Tutira water quality study. Unpublished report. Hawke's Bay Catchment Board.
1981 (Aug)	Normal and low flow waters of Sandy Creek were diverted from Lake Tutira directly into the out-fall stream by passing the lake.	Hooper, G. (1989). Lake Tutira water quality study. Unpublished report. Hawke's Bay Catchment Board.
1982 (Feb)	Hydrilla gazetted a Class B Noxious Plant under the Noxious Plants Act 1978	
1984 (Apr)	Over 200mm of rainfall over 2 consecutive days.	Hooper, G. (1989). Lake Tutira water quality study. Unpublished report. Hawke's Bay Catchment Board.
1984-85	Lake Waikopiro described as eutrophic by the Catchment Board because of high Nitrogen and Phosphorus loading and the complete deoxygenation of the hypolimnion (waters below 6m), poor water clarity and periodic blooms of blue-green algae and the presence of dense beds of *Hydrilla verticillata*.	Hooper, G. (1987). Hawke's Bay small lakes water quality survey. Unpublished report. Hawke's bay Catchment Board.
1984	Grass carp used in Lake Parkinson to remove exotic aquatic weeds	Mitchell et al. (1984) Limnological changes in a small lake stocked with grass carp. New Zealand Journal of marine and Freshwater Research 18: 103-114.
1984	Hydrilla found to be in Lake Opouahi	

1984	1500 - 2500 Diploid grass carp escape from the Akaaka Drain in Waikato	http://www.doc.govt.nz/upload/documents/science-and-technical/casn257.pdf
1985 (13/14 Mar)	244 mm of rainfall was recorded.	
1985 (25/26 Jul)	Following a storm Sandy Creek over flows into Lake Tutira. 309mm of rainfall was recorded on 25/26 July.	Hooper, G. (1989). Lake Tutira water quality study. Unpublished report. Hawke's Bay Catchment Board.
1985	Effects that grass carp might have on trout is considered	Rowe, D. K., Schipper, C. M., 1985 An Assessment of the Impact of Grass Carp (*Ctenopharyngodon idella*) In New Zealand Waters. Fisheries Environmental Report 358. Fisheries Division of the Ministry of Agriculture and Fisheries
1987	Conservation Act is enacted.	
1987	Hawke's Bay Catchment Board report on small lake water quality in Hawke's Bay	Hooper, G. (1987). Hawke's Bay small lakes water quality survey. Unpublished report. Hawke's bay Catchment Board.
1987	Both *Hydrilla verticillata* and *Elodea canadensis* recorded as being present in Lake Waikopiro by the Catchment Board	Hooper, G. (1987). Hawke's Bay small lakes water quality survey. Unpublished report. Hawke's bay Catchment Board.
1988	Rowe and Hill prove that grass carp are an efficient agent for eliminating exotic macrophytes in lakes	
1988	Hydrilla occupies 25 % of Lake Elands	
1988 (7 Mar)	Cyclone Bola - Sandy Creek over flows into Lake Tutira.	Hooper, G. (1989). Lake Tutira water quality study. Unpublished report. Hawke's Bay Catchment Board.
1988	Grass carp introduced to the Elands lake. 400 triploid fish.	
1988 (27 Sep)	Lake Elands vegetation survey, diquat applied [2ppm]	
1988 (2 Nov)	Lake Elands vegetation survey	
1988 (3 Nov)	Lake Elands grass carp (392) released	
1988-89	Weed mat used to control main infestation near jetty in Lake Opouahi and near the boat ramp in Lake Tutira. Hand weeding of low density infestations.	
1990 (Apr)	Hydrilla biomass in Elands lake reduced by 99% following the introduction of grass carp.	
1991 (Apr)	No trace of hydrilla in Elands lake other than regrowth from turions and tubers and occasional stem fragment.	
1991	Additional grass carp (200) released into Elands lake.	
1992	Clayton reports that grass carp have significantly reduced the biomass of grass carp in Lake Elands, Hawke's Bay.	

1993 (Aug)	DoC advocates the use of grass carp in combination with herbicide and weed matting to eradicate hydrilla in the lakes	Walls, G., 1993. The New Zealand Hydrilla Problem: A Review of the Issues and Management Options. Conservation Advisory Science Notes #71. Department of Conservation. 42pp.
1993 (Aug)	Unfavourable perception regarding the use of grass carp the lakes where hydrilla is found is noted by DoC	Walls, G., 1993. The New Zealand Hydrilla Problem: A Review of the Issues and Management Options. Conservation Advisory Science Notes #71. Department of Conservation. 42pp.
1993 (Aug)	Concerns of Māori documented in a DoC report - uncomfortable with the continued presence of Hydrilla in the lakes; because it constitutes a threat to other waterways in New Zealand, it prevents eeling, and prevents restoration of rongoa in the lake shallows	Walls, G., 1993. The New Zealand Hydrilla Problem: A Review of the Issues and Management Options. Conservation Advisory Science Notes #71. Department of Conservation. 42pp.
1993 (Sep)	DoC receive report from C.P. Mitchell - Control Options for Hydrilla verticillata in the Tutira Lakes.	Mitchell, C.P., 1993. Control Options for Hydrilla verticillata in the Tutira Lakes - A report prepared for the Department of Conservation, Hawke's Bay Conservancy.
1994-1995	Fishing effort estimated at 3090 (plus or minus 150) angler days / annum	
1995	An Ecological Assessment of the Impact of Chinese Grass carp in Relation to Oxygen Weed (*Egeria densa*) Control at Lake Wainamu, Waitakere Ranges, Auckland is prepared by NIWA.	Champion, P. D., Rowe D. K., 1995 Ecological Assessment of the impact of Chinese Grass carp in Relation to Oxygen Weed (*Egeria densa*) Control at Lake Wainamu, Waitakere Ranges, Auckland. NIWA Report
1997 (Jun)	Hawke's Bay Regional Council prepares a management plan for land under its control.	Titchener, A. et al. 1997. Management Plan for part of Tutira Station located on the Eastern side of Lake Tutira. Prepared for Hawke's Bay Regional Council.
1997 (Jun)	Mr Fred Reti emphasised the need not to over look the health of the eels in Lake Tutira and their importance as a traditional food source.	Titchener, A. et al. 1997. Management Plan for part of Tutira Station located on the Eastern side of Lake Tutira. Prepared for Hawke's Bay Regional Council.
1999	Integrated control using grass carp and an initial treatment of herbicide reported to have been successful in eliminating *Egeria densa* in Lake Waingata, Northland.	Rowe et al. 1999
2000	HBRC suspend monitoring of the water quality in Tutira / Waikopiro	

2000	Fluridone trialled under lab conditions at Ruakura to control hydrilla. The hydrilla found in New Zealand did not succumb.	Hofstra D. E.; Clayton J. S. (2000). Evaluation of Fluridone for Hydrilla Control in New Zealand. Journal of Aquatic Plant Management.
2000 (Apr)	The impact of hydrilla is considered.	Hofstra D. E., Champion P. D., Clayton J. S., 2000. Hydrilla in the Hawke's Bay - A Discussion Document. NIWA Report
2000 (Nov)	NIWA obtains 23 day continuous record of oxygen, pH and temperature when trialling Endothall in Lake Waikopiro.	Hofstra et al. 2001
2001 (Mar)	NIWA obtains 23 day continuous record of oxygen, pH and temperature when trialling Endothall	Hofstra et al. 2001
2001	NIWA trials Endothall in Lake Waikopiro	
2001 (Nov)	DoC out line their recommendations for a strategy to manage hydrilla - immediate objective is containment. Eradication long term goal.	DoC (2001). Hydrilla in New Zealand: A review of the Problem and Recommendations for Future Action.
2001 (Aug)	Hydrilla declared an Unwanted Organism under the Biosecurity Act 1993	
2001-2002	NIWA undertakes a vegetation survey found on 9 transects spread around the lake's edge. 13 macrophyte species recorded in Lake Waikopiro, included *Hydrilla verticillata; Elodea canadensis; Myriophyllum propinquum; M. pedunculatum; Potamogeton ochreatus; P. cheesemanii; Lilaeopsis novae-zealandiae; L. ruthiana; Chara australis; Persicaria decipens; Ludwegia palustris; Glossostigma elatinoides; G. diandrum*.	
2001-2002	Survey of fishermen shows they do not distinguish between Tutira and Waikopiro. Fishing effort estimated at 2300 (plus or minus 380) angler days / annum. Lake Opouahi estimated at 10 (plus or minus 10) angler days / annum Compared with: Mohaka 7000; Tutaekuri River 6700; Ngaruroro River 6200; Tukituki River 17000.	
2002 (29 Oct)	NIWA and DoC staff met to identify potential sites for hydrilla transfer that will be subject to surveillance.	
2003	No trace of hydrilla in Elands lake.	
2003	DoC contracts NIWA to prepare an operational plan for the containment of hydrilla and for research aimed at developing methods to eradicate hydrilla.	
2003 (Feb)	Operational Plan for the containment of hydrilla prepared by NIWA for DoC. Included research into eradication.	NIWA, 2003. Hydrilla - an Operational Plan for Containment and Eradication Research NIWA Client Report: HAM2002-052. NIWA Project: DOC03249
2004 (Apr)	Environmental Impact Assessment and Operational Plan for the Introduction of Grass Carp (*Ctenopharyngodon idella*) into Lake Waikopiro, Hawke's Bay prepared by NIWA for DoC	NIWA, 2004. Environmental Impact Assessment and Operational Plan for the Introduction of Grass Carp (*Ctenopharyngodon idella*) into Lake Waikopiro, Hawke's Bay. NIWA Client Report: HAM2004-025. NIWA Project: DOC0425
2006	MAF Biosecurity New Zealand, as the lead agency, accepts responsibility for Hydrilla	

2006 (May)	Organism consequence assessment of hydrilla prepared by NIWA for MAF BNZ	NIWA, 2006.Organism consequence *Hydrilla verticillata*. NIWA Client Report: HAM2006-058f. NIWA Project: MAF06205
2006 (Nov)	Management Options Assessment for hydrilla prepared by NIWA for MAF BNZ	NIWA, 2006.Management Options Assessment Report for *Hydrilla verticillata*. NIWA Client Report: HAM2006-159. NIWA Project: MAF07204
2006 (Oct)	Hydrilla designated a Notifiable Organism under the Biosecurity Act 1993.	
2006	Accountability for Hydrilla transferred from DoC to MAF BNZ	
2007 (Dec)	Victoria Lamb, Ian Gear meet with Charlie and Wynne King, Ngāti Pahauwera at Mohaka	
2008 (1 Feb)	Ian Gear met with Bevan Taylor, Ngāti Tu in Napier	
2008 (29 Feb)	MAFBNZ and Key stakeholders meet at Lake Tutira to discuss the eradication of *Hydrilla verticillata*	
2008 (3 Apr)	Hydrilla Technical Advisory Group meets in Napier. The Technical Advisory Group endorses the draft Operational Plan.	
2008 (12-16 May)	Base line flora and fauna surveys of the lakes is undertaken	