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Distribution and conservation status of the dwarf inanga *Galaxias gracilis* (Teleostei: Galaxiidae) an endemic fish of Northland dune lakes

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Surveys of 27 Northland lakes revealed two new locations for *Galaxias gracilis* but confirmed its restricted geographical distribution. It is now present in 11 lakes on the west coast of the North Island within 50 km of Dargaville, and in Lake Ototoa on the South Kaipara Head, where it was introduced in 1986. Densities of *G. gracilis* were determined by nocturnal fyke netting in the littoral zone of the North Kaipara lakes. It was abundant in two of these lakes, common in two, rare in five, and extinct or close to it in at least three others. We conclude that *G. gracilis* has one of the most restricted geographical distributions of any New Zealand native fish, and that its densities have declined in over 80% of the lakes from which it has been recorded. Although trout predation could account for the current low density of *G. gracilis* in three lakes, it is not responsible for low densities in six others. Factors responsible for the decline of this species are therefore unknown, so it is a threatened species in terms of its conservation status.

Keywords: *Galaxias gracilis*, threatened fish, Northland lakes, fish surveys, Galaxiidae, trout predation

INTRODUCTION

Landlocked galaxiids were first discovered in 10 lakes on the west coast of the North Island of New Zealand in 1950 but were not identified to species level (Cunningham et al. 1953). Land-locked populations of *Galaxias maculatus* (Jenyns) and *Galaxias fasciatus* Gray were later found in some of the more southerly lakes surveyed (McDowall 1972; Schipper 1979), but the galaxiids in lakes on the North Kaipara Head and further north remained unidentified.

In 1965 a sample of these unidentified galaxiids was obtained from Lake Rototuna on the North Kaipara Head. On the basis of differences in meristic features (i.e., the number of vertebrae and gillrakers), and the divergence of these from *G. maculatus*, these fish were described as a new species, *Galaxias gracilis* McDowall (McDowall 1967). The common name for this species 'dwarf inanga' refers to its diminutive size relative to the landlocked *G. maculatus*, or 'inanga', from which it is thought to have evolved (McDowall 1990).

By 1968 *G. gracilis* had been identified from only four lakes, but by 1972 it had been reported from five of the 16 dune lakes on the North Kaipara Head (Poutu Lakes), as well as from three of the four Kai Iwi dune lakes (Table 1). In 1977 it was reported from a further Poutu lake, bringing its total locations up to nine.

Unidentified galaxiids were also reported from Lake Rototoa, near the tip of the South Kaipara Head (Cunningham et al. 1953). Subsequently McDowall (1978, 1990) reported that *G. gracilis* was present in lakes of the North Kaipara Head, including Lake Rototoa. However, there is no Lake Rototoa on topographical maps covering the North Kaipara Head. The Lake Rototoa to which McDowall referred, and in which Cunningham et al. (1953) found galaxiids, is on the South Kaipara Head. To add to the confusion, this lake is now

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labelled Lake Ototoa (NZMS 260 Q09). *G. fasciatus* was the only galaxiid present in this lake in 1979 (Schipper 1979; Thompson 1989). Lake Kuwakatai, which is also on the South Kaipara Head, contained landlocked *G. fasciatus* but not *G. gracilis* (C. Schipper, pers. comm., 1984). *G. gracilis* was therefore not present in these two lakes on the South Kaipara Head before 1986. *G. gracilis* was successfully introduced into Lake Ototoa in 1986 (Thompson 1989).

Unidentified galaxiids were also found by Cunningham et al. (1953) in Lakes Ngatu and Waiparera, north of the Kai Iwi lakes. McDowall (1972) later identified the galaxiids in Lake Waiparera as landlocked *G. maculatus* but, although we suspected that the galaxiids in Lake Ngatu would also be landlocked *G. maculatus*, we could not discount the possibility that they might be *G. gracilis*. Unidentified galaxiids were also reputed to be present in other, more northerly lakes by Department of Conservation staff. Hence the restricted geographic distribution of *G. gracilis* could not be confirmed, and other *G. gracilis* populations might occur in unexplored lakes, both within and beyond its known geographic range.

Although *G. gracilis* was described as long ago as 1967 (McDowall 1967), there was no study of its life history, ecology, or conservation status up until the 1990s despite the fact that, by 1970, its survival was apparently threatened in four lakes. Rainbow trout (*Oncorhynchus mykiss* Richardson) were stocked into four Northland lakes containing *G. gracilis* between 1953 and 1968 (Fish 1966; Cudby & Ewing 1968). *G. gracilis* was an important prey species for the stocked trout in these lakes (Fish 1966; Cudby et al. 1969), and the abundance of galaxiids soon declined to the point where they were scarce (Fish 1966; Cudby 1970). Thus, by 1977 *G. gracilis* was believed to have a highly restricted geographical distribution, and was thought to have declined in four of the nine lakes where it occurred. Its future therefore appeared precarious, and this led McDowall (1990) to state that "the dwarf inanga has not had IUCN listing, but probably demands as much attention from conservationists as any other New Zealand species. Its limited number of habitats renders this species highly vulnerable." Studies of its conservation status and ecology were therefore urgently required.

This paper reports the results of surveys to (a) systematically identify lakes in Northland containing *G. gracilis*, and (b) assess its relative abundance in all lakes so that its conservation status could be determined.

Table 1 Cumulative increase in lakes reported to contain *Galaxias gracilis* populations between 1967 and 1977. Sources: [1]McDowall (1967); [2]Cudby & Ewing (1968); [3]McDowall (1972); [4]NIWA New Zealand Freshwater Fish Database.

	1967	1968	1972	1977
Poutu Lakes				
Rototuna[1]	✔			
Waingata[3]			✔	
Kanono[3]			✔	
Roto-otuauru[3]			✔	
Rotokawau[3]			✔	
Humuhumu[4]				✔
Kai Iwi Lakes				
Taharoa[2]		✔		
Waikere[2]		✔		
Kai Iwi[2]		✔		
Cumulative no. lakes	1	4	8	9

STUDY SITES

The location and main physical characteristics of the lakes surveyed are listed in Table 2. They are mostly shallow dune lakes and, as a result of their proximity to the coast, contain higher levels of chloride than lakes further inland (Cunningham et al. 1953). They have no permanent inlet or outlet streams, and water supply comes mainly from catchment runoff, supplemented in some lakes with subsurface seepage (McLellan 1985). The catchments have been extensively modified, first by logging and second by clearance of the residual native bush and conversion to pasture for grazing. However, the biotas in most of these lakes are relatively unmodified in that native species still dominate the aquatic plant communities (Tanner et al. 1986), and most lakes contain no exotic fish species.

METHODS

We conducted fish surveys in 18 lakes – 10 of which were previously unexplored – in the Poutu and Kai Iwi regions of Northland, within the known geographical range of *G. gracilis* (Table 2). To confirm the restricted geographical distribution of this species we also surveyed two unexplored lakes of volcanic origin (Tauanui and Owhareiti) within the latitudinal range for *G. gracilis* but further inland, and four more northerly lakes including the coastal Lake Te Riu 30 km north of the Kai Iwi lakes. Three dune lakes north of Kaitaia (Ngatu, Rotokawau, and Rotoroa) were reported to contain galaxiids by staff of the Department of Conservation, so these were also surveyed to identify the fish species present.

Initially we tested a range of sampling gear for catching *G. gracilis*, including beach seining, midwater and surface trawling, fyke netting, purse seining, and high-frequency (200 kHz) echosounding. Beach seining was limited to shallow shores devoid of obstacles, which were rare in many of the lakes surveyed. Trawling proved ineffective. Purse seining was effective when post-larval, planktonic *G. gracilis* were reasonably abundant but not when they were rare. High-frequency echosounding can detect small schooling fish in lakes (Rowe 1993), and revealed the presence of schools of galaxiids in the hypolimnion of some of the deeper lakes, but not in shallow ones. In contrast fyke nets set perpendicular to the shoreline in the shallows overnight invariably caught some *G. gracilis*, even in lakes where this species was relatively scarce. Nocturnal fyke netting therefore proved to be the best method both for determining the presence of *G. gracilis* and for estimating their relative abundance. Purse seining and echosounding were used to provide ancillary data on *G. gracilis* distribution, whereas gillnetting (25 mm and 50 mm stretched mesh sizes) and baited fyke nets were used to determine the other fish species present in each lake. If *G. gracilis* were not detected by fyke netting (presence of juveniles or adults), echosounding (presence of fish schools), or purse seining (presence of larvae) in a particular lake they were assumed to be absent.

Sampling to determine the relative abundance of *G. gracilis* was carried out during summer months (February – March) in 1985 and in 1991–93. We set four to six small fyke nets (length 2.0 m, 4–6 mm stretched mesh) around the shoreline before dusk in each lake. Nets were set perpendicular to the shoreline in 1–2 m of water. In general, three nets were set on open shorelines and three close to rush beds. Nets were retrieved the following morning and the number,

Table 2 Location and physical features of Northland lakes surveyed to determine the presence/absence and population status of *G. gracilis*. Areas and altitudes from McLellan (1985) and Irwin (1975).

	NZMS reference	Area (km^2)	Max depth (m)	Altitude (m)
Kaitaia Lakes				
Rotokawau	N7 810 986	0.74	2.5	4
Ngatu	N9 703 788	0.61	5.5	36
Rotoroa	N9 702 759	0.53	8.0	–
Kaikohe Lakes				
Te Riu	N18 018 010	0.09	4.5	–
Owhareiti	N15 453 370	0.76	14.0	77
Tauanui	N15 373 235	0.08	4.0	>240
Kai Iwi Lakes				
Shag	N22 128 874	0.16	15.0	75
Waikere	N22 150 865	0.35	28.5	79
Taharoa	N22 170 855	2.37	35.0	70
Kai Iwi	N22 175 847	0.33	14.0	70
Poutu Lakes				
Unnamed lake	N23 283 697	0.09	–	75
Kapoai	N27 357 570	0.05	9.0	–
Parawanui	N27 375 550	0.07	19.0	50
Wainui	N27 406 503	–	10.0	
Rototuna	N27 565 320	0.09	5.0	100
Phoebes	N32 606 261	–	4.0	–
Rotopouua	N32 633 241	<0.05	9.0	–
Humuhumu	N32 645 234	1.34	15.0	50
Roto-otuauru	N33 665 227	0.18	5.0	35
Rotokawau	N33 672 210	0.29	11.0	40
Waingata	N33 675 204	0.12	7.0	40
Kanono	N33 668 190	0.81	14.0	41
Kahuparere	N33 682 182	0.08	7.5	37
Mokeno	N32 587 205	1.65	5.5	–
Karaka	N32 565 248	–	5.0	–

species, and size of fish (length of all fish, and weight for subsamples) were recorded. If galaxiids were present, a few were kept for identification or, when large catches were obtained, a small sample was preserved in formalin for later analysis of diet, sex, and reproductive status. Most fish were returned alive to the lake.

Galaxiid species present in the lakes surveyed were identified by comparing counts of gillrakers and vertebrae. The gillrakers of *G. gracilis* are longer and more slender than those of landlocked *G. maculatus* (McDowall 1967) and, as *G. gracilis* usually have more gillrakers than *G. maculatus*, gillraker counts can be used to identify *G. gracilis* (McDowall 1990). However, landlocked *G. maculatus* may have up to 20 gillrakers, while *G. gracilis* may have as few as 17 (McDowall 1972). Therefore, identification of *G. gracilis* on the basis of gillraker counts is considered valid only when more than 20 gillrakers are present. Since there is no overlap in number of vertebrae between *G. gracilis* and landlocked lacustrine populations of *G. maculatus* in New Zealand (McDowall 1972), vertebral counts were used to confirm identifications based on gillraker counts. A number of fish (9–42) were taken from each of the lakes from which *G. gracilis* had not been identified, and were X-rayed. Vertebrae (excluding the hypural centra) were counted from the radiographs, and the frequency distributions of vertebral counts were compared with those for *G. gracilis* and *G. maculatus*. In accordance with McDowall (1972), fish with mean vertebral counts less than 51 were deemed to be *G. gracilis*, while those with mean vertebral counts over 54 were *G. maculatus*. Of the latter, those with 55–60 vertebrae were lacustrine stocks, while those with over 60 were diadromous.

The mean catch per unit effort (CPUE) for *G. gracilis* was calculated from the catch data for each lake (fish per net-night) and used to assess major differences in the relative abundance of *G. gracilis* between lakes. *G. gracilis* were deemed to be abundant in lakes where "large" schools could be readily observed around the littoral zone and where relative abundance as measured by CPUE exceeded 20 fish per net-night. In comparison, *G. gracilis* were deemed to be rare in lakes where they were never seen from the shore and where relative abundance was less than 10 fish per net-night. Where its relative abundance fell between these extremes, *G. gracilis* was deemed to be common.

RESULTS

The fish species recorded in each lake are listed in Table 3. No *Galaxias gracilis* were recorded in the three lakes surveyed in the far north, near Kaitaia. Landlocked *G. maculatus* were present in lakes Ngatu and Rotokawau. Smelt (*Retropinna retropinna* Richardson) were present in Lake Rotoroa. We found no galaxiids in lakes Te Riu, Tauanui, and Owhareiti near Kaikohe. Stocked populations of eels (mostly *Anguilla australis* Richardson), characterised by absence of juveniles and lack of variation in size, were apparent in many of the lakes lacking outlet streams (e.g., lakes Rotoroa, Owhareiti, Waikare, Taharoa, Kapoai, Parawanui, Rototuna, Phoebes, and Rotokawau). Self-recruiting populations of introduced exotic fish including rudd (*Scardinius erythrophthalamus* Linnaeus), perch (*Perca fluviatilis* Linnaeus), goldfish (*Carassius auratus* Linnaeus), and mosquito fish (*Gambusia affinis* Baird & Girard) were found in nine of the lakes. Lake Tauanui is the most northern of the known locations for perch in New Zealand.

Galaxias gracilis were not recorded in Shag Lake, in the Kai Iwi group, even though they were present in the three adjacent lakes. However, it appears that *G. gracilis* may once have occurred there. A relative of the landowner (D. Harrison) commented that "we caught whitebait in this lake when we were children". She indicated that she was a keen whitebaiter, and when questioned clearly knew the difference between juvenile galaxiids and bullies (*Gobiomorphus cotidianus* McDowall), the only other small fish present in Shag Lake. The only galaxiid likely to have been historically present in Shag Lake is *G. gracilis*.

No *G. gracilis* were recorded in lakes Wainui, Parawanui, and Kapoai, which lie between the Kai Iwi and Poutu lakes, within the known geographical range for this species, nor in the small unnamed lake 'Lake A' just north of Baylys Beach on the North Kaipara Head.

Unrecorded populations of *G. gracilis* were discovered in lakes Kahuparere and Rotopouua within the Poutu group of lakes. Identifications were confirmed by analysis of vertebral counts (Table 4). Rotopouua (surface area < 0.05 km^2) is the smallest lake known to contain these fish.

The galaxiids in Lake Mokeno were diadromous *G. maculatus* (Table 4), and there were no galaxiids in Lake Karaka.

The lakes sampled in 1985 were ranked according to the relative abundance of *G. gracilis* as measured by mean CPUE (Fig. 1a). At that time *G. gracilis* were most abundant in Lake Humuhumu, and Lake Kanono ranked second. The relative abundance of *G. gracilis* in lakes Kahuparere, Rototuna, and Rotokawau was less than half that in Lake Kanono. No *G. gracilis* were caught in lakes Waingata and Roto-otuauru.

By 1993 the relative abundance of adult *G. gracilis* in lakes Kanono, Rototuna, and Waingata was higher than in 1985 (Fig. 1b), so these fish were probably more abundant in all the Poutu lakes. Nevertheless, the relative abundance of *G. gracilis* in Lake Kanono was still more than double that in the other lakes surveyed at this time, and the ranking of lakes

Table 3 Occurrence of fish species in 25 Northland lakes surveyed in 1991 and 1992. Abbreviations: p = present; a = absent; s = stocked population; 1 = *Carassias auratus*; 2 = *Retropinna retropinna*; 3 = *Perca fluviatilis*; 4 = *Cyprinus carpio*; * exotic species.

	Anguilla australis	*Anguilla dieffenbachii*	*Gobiomorphus cotidianus*	*Galaxias gracilis*	*Galaxias maculatus*	*Oncorhynchus mykiss**	*Gambusia affinis**	*Scardinius erythrophthalmus**	Other exotics
Kaitaia Lakes									
Rotokawau	p	p	p	a	p	a	a	a	
Ngatu	a	a	p	a	p	s	p	a	1
Rotoroa	s	s	p	a	a	a	a	a	2
Kaikohe Lakes									
Te Riu	p	p	p	a	a	a	a	a	
Owhareiti	s	a	p	a	a	a	a	a	
Tauanui	a	a	a	a	a	a	a	a	3
Kai Iwi Lakes									
Shag	p	p	p	a	a	a	p	a	
Waikere	s	s	p	p	a	s	p	a	
Taharoa	s	a	p	p	a	s	p	a	
Kai Iwi	a	a	p	p	a	s	p	a	
Poutu Lakes									
Lake A	a	a	a	a	a	a	a	a	
Kapoai	s	a	p	a	a	a	a	p	
Parawanui	s	a	p	a	a	a	a	p	4
Wainui	a	a	a	a	a	a	a	a	
Rototuna	s	a	p	p	a	a	a	p	
Phoebes	s	a	a	a	a	a	a	a	
Rotopouua	a	a	p	p	a	a	a	a	
Humuhumu	a	a	p	p	a	a	a	a	
Roto-otuauru	p	p	p	p	a	a	a	a	
Rotokawau	s	a	p	p	a	a	a	a	
Waingata	a	a	p	p	a	a	a	a	
Kanono	a	a	p	p	a	a	a	a	
Kahuparere	a	a	p	p	a	a	a	a	
Mokeno	p	p	p	a	p	a	a	a	
Karaka	p	p	p	a	a	a	a	a	

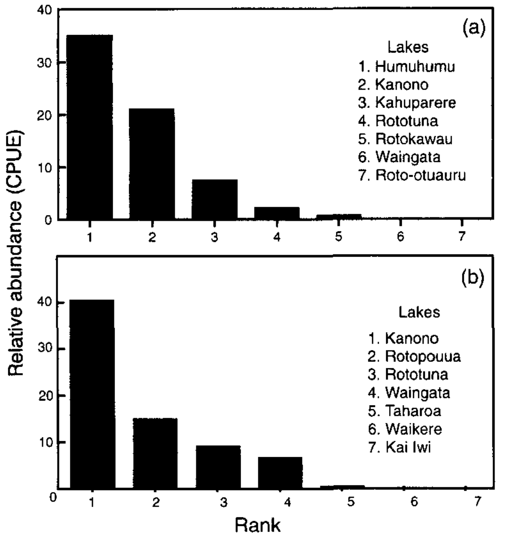

Fig. 1 Ranking of lakes containing populations of *Galaxias gracilis* on the basis of relative abundance, as measured by mean catch per unit effort (fish per net-night): (a) 1985 survey; (b) 1991–93 survey.

Rototuna and Waingata was unchanged. Very few *G. gracilis* were caught in lakes Taharoa, Waikere and Kai Iwi during the 1991–93 survey.

Today *G. gracilis* are abundant in lakes Humuhumu and Kanono and in the recently stocked Lake Ototoa, but densities are lower in all other lakes. The species is deemed to be common in lakes Rotopouua and Kahuparere, but comparatively rare in Rototuna, Waingata, Rotokawau, Taharoa, and Waikere. No *G. gracilis* were caught in Lake Roto-otuauru, Lake Kai Iwi, or Shag Lake during our surveys, and Lake Rototuna (Lower) no longer exists.

DISCUSSION

Galaxias gracilis were found in two more lakes within the species' known geographical range given in McDowall & Richardson (1986). No new populations were found in any lakes beyond this range. The only galaxiid present in lakes Kuwakatai and Ototoa (=Rototoa) before

Table 4 Variation in vertebral number and differences in mean number of vertebrae for *Galaxias* species in Northland dune lakes. Data from: [1]McDowall (1967); [2]McDowall (1972).

		Number of vertebrae																	
		47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	Mean no.
***G. maculatus* (catadromous)**																			
Mokeno	1985													1	8	19	17	2	61.2
***G. maculatus* (landlocked)**																			
Waiparera[1]	1967								2	5	10	12	9	3					56.7
Ngatu	1992								1	1	1								55.0
G. gracilis																			
Kahuparere	1985				4	3	2	1											51.0
Kanono[2]	1972			3	6	7	6	2											50.9
Kanono	1985		2	1	17	14	8												50.6
Waingata[2]	1972	1	0	7	9	3													49.7
Waingata	1992			2	6														49.8
Rotokawau[2]	1972		1	6	10	3													49.8
Roto-otauuru[2]	1972		3	14	6	1													49.2
Humuhumu	1985	2	9	19	10														48.9
Rotopouua	1992	1	3	7	3														48.9
Rototuna[1]	1967	1	16	24	9														48.8
Rototuna	1985		1	4															48.8
Waikere[2]	1972		6	13	1														48.8

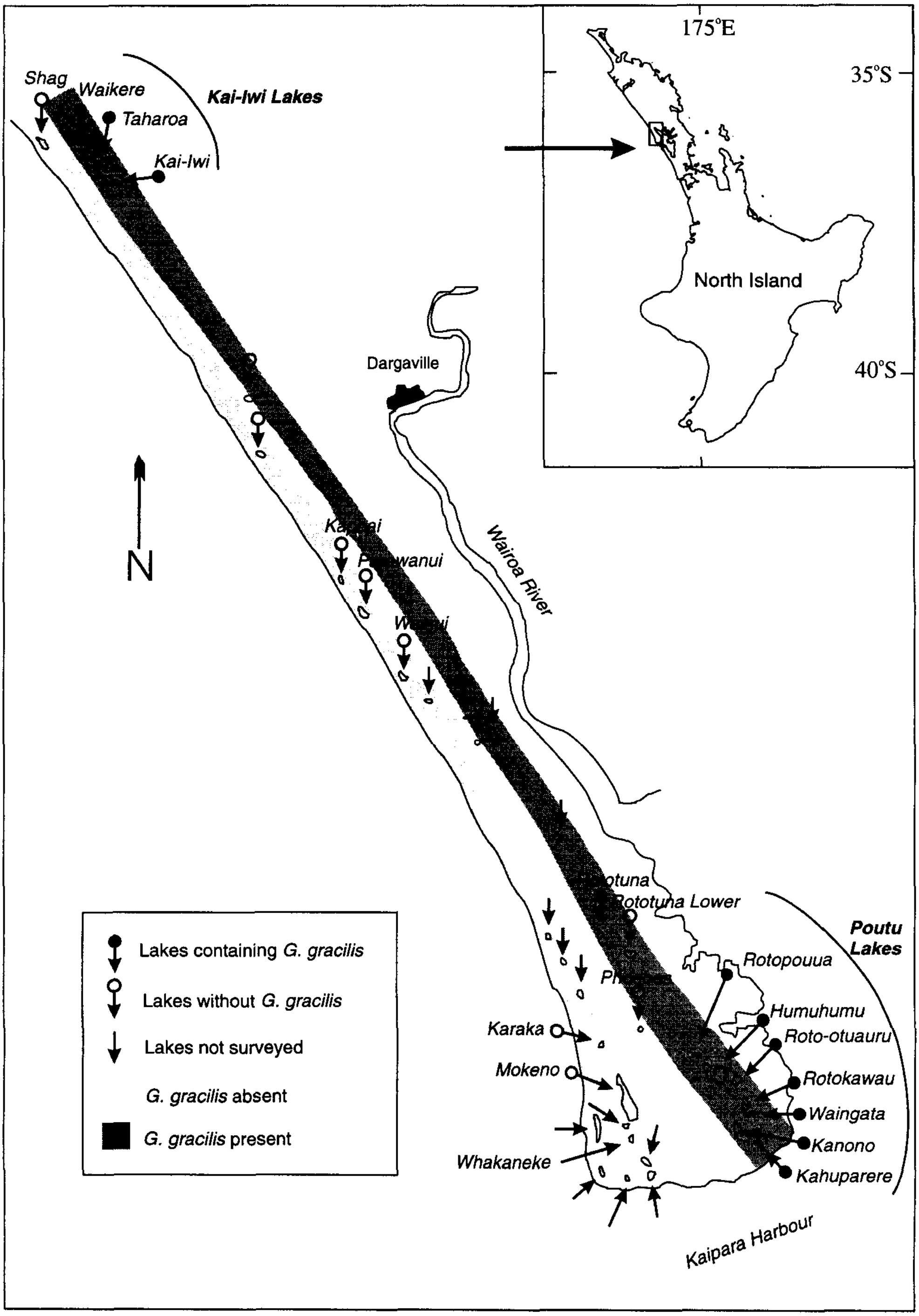

Fig. 2 Location of lakes on the North Kaipara Head containing *Galaxias gracilis* populations.

1986 was *G. fasciatus* (Schipper 1979; Thompson 1989). *Galaxias gracilis* was not present in lakes on the South Kaipara Head before 1986, nor was it present in lakes north of the Kai Iwi group, or in inland lakes east of Dargaville. The geographical distribution of *G. gracilis* as at 1986 is shown in Fig. 2.

The presence of *G. gracilis* in the Kai Iwi lakes north of Dargaville and in the Poutu lakes south of Dargaville requires some explanation, as these two groups of lakes are 80 km apart and differ in time of formation by about 5000 years (Lowe & Green 1987). McDowall (1990) noted this difference in distribution and, while indicating that *G. gracilis* probably diverged from landlocked *G. maculatus*, suggested that there may have been more than one speciation. This would explain the presence of *G. gracilis* in these two groups of lakes and their absence from the three lakes (Parawanui, Wainui, and Kapoai) between the two groups.

However, it is also possible that *G. gracilis* were transported from one group of lakes to the other by pre-European Maori. This species can be readily introduced into new lakes (Thompson 1989), and Maori had the knowledge, experience, and capability to carry out such introductions (Strickland 1993). The variation in mean vertebral count between fish from different lakes (Table 4) provides some evidence for population differences. However, this phenotypic variation may be due to latitudinally varying factors such as daylength and/or water temperature. Identification of genetic relationships between the lake populations will depend on analysis of DNA.

Galaxias gracilis was not present in three lakes of mid-Holocene origin, nor in two late-Holocene lakes (Table 5), so its distribution is not related to lake age, at least in geological terms. However, *G. gracilis* occurred in all lakes lying within the eastern chain along the North Kaipara Head, and in none of the lakes in the western chain (Table 6). Thus there is an association between lakes containing *G. gracilis* and distance from the sea. This may be coincidental, but lakes close to the sea are likely to be chemically and biologically different from more inland lakes, so may be less suitable for survival of some fish species. Lakes which are near the coast and exposed to the prevailing westerly winds, which carry sea spray inland from the coast, have elevated sodium, magnesium and chloride ion concentrations (Cunningham et al. 1953; Timperley 1987). In addition, such lakes may be more accessible to eels, which would be expected to prey on *G. gracilis*. As most of the dune lakes on the North Kaipara Head have no outlet streams, natural colonisation by eels will depend on overland movement from nearby watercourses. This will be more feasible for the lower-altitude lakes nearer the coast than for the higher-altitude, inland ones.

In addition to its restricted geographical distribution, *G. gracilis* has few populations. This species is now present in just 11 lakes on the North

Table 5 Time of formation of lakes on the North Kaipara Head. Sources: [1]Lowe & Green (1987); [2]Cassie & Freeman (1980); [3]McLellan (1985).

	Time of formation	*G. gracilis* present
Rototuna	Pleistocene[3]	Yes
Roto-otuauru	Pleistocene[3]	Yes
Rotokawau	Pleistocene[3]	Yes
Waingata	Pleistocene[2,3]	Yes
Waikere	Mid Holocene[1]	Yes
Taharoa	Mid Holocene[1]	Yes
Kai Iwi	Mid Holocene[1]	Yes
Parawanui	Mid Holocene[3]	No
Kapoai	Mid Holocene	No
Wainui	Mid Holocene	No
Humuhumu	Late Holocene[1]	Yes
Kanono	Late Holocene[1]	Yes
Kahuparere	Late Holocene[1]	Yes
Rotopouua	Late Holocene	Yes
Karaka	Late Holocene[1]	No
Mokeno	Late Holocene[1]	No

Table 6 Occurrence of *G. gracilis* in the eastern and western chains of lakes on the North Kaipara Head (see also Fig. 2).

Lake group	Lakes > 0.5 ha n	Lakes surveyed to date n	%	Lakes with *G. gracilis* n	%
Western chain	18	7	38.9	0	0
Eastern chain	13	13	100	12	92.3

Kaipara Head, and it is unlikely that others will be found. Anecdotal evidence indicates that it was once present in Shag Lake in the Kai Iwi group and in Lake Rototuna (Lower) (see Fig. 2), before it was drained. The total number of pre-European locations for this species could therefore have been as high as 13.

Historically, densities of *G. gracilis* were probably high in all these lakes because relatively high densities have been observed in lakes differing markedly in size, water clarity, and productivity. For example, Lake Taharoa is oligotrophic, with a relatively large surface area (2.37 km^2) and maximum depth (35 m). Its secchi disc depth ranges from 7.0 to 11.0 m (Kokich 1991). Before the introduction of trout to this lake, Cudby & Ewing (1968) reported "many large schools of galaxiids around the lake margin", and Cudby et al. (1969) also noted "numerous shoals in the shallows" just after trout were introduced. In the much smaller Lake Waingata (surface area 0.12 km^2, maximum depth 7 m) which Fish (1966) described as turbid and fertile, large schools of *G. gracilis* were observed from a boat all around the shoreline, outside the weed beds (A. Parker, pers. comm., 1984). In comparison, Lake Ototoa (1.39 km^2, maximum depth 28 m), has secchi disc values of 5–9 m (Green 1975), and schools of *G. gracilis* can be observed every 5–10 m around the shoreline (B. Wilson, pers. comm., 1994). This species was therefore relatively abundant in these lakes before the introduction of other fish, and/or habitat modification, and there is no reason why they should not have been equally abundant in all other lakes where they occurred.

Galaxias gracilis are now abundant in only two of the lakes (Humuhumu and Kanono) where they occurred before 1986, but are now also abundant in Lake Ototoa, where an introduced population has become established. They are relatively common in another two lakes, rare in five, and extinct or close to it in three to four lakes. Although the establishment of a new population in Lake Ototoa has extended this species' geographic range, *G. gracilis* have declined in abundance in most (>80%) of the dune lakes where they occurred in pre-European times.

Trout stocking is thought to have been the major factor responsible for the decline of *G. gracilis* in the Kai Iwi Lakes and in Lake Waingata (McDowall 1990). Rainbow trout (*O. mykiss*) prey on this species, and a decline in *G. gracilis* has generally followed trout stocking. Fish (1966) recorded *G. gracilis* in 76% of the trout caught in Lake Waingata in 1962, but by 1963 *G. gracilis* were too scarce to be preyed on by trout. A similar decline occurred in Lakes Taharoa, Kai Iwi and Waikere following the introduction of trout. Cudby et al. (1969) reported *G. gracilis* in 22% of trout stomachs in 1969. However, they were not preyed on by any trout sampled in 1970 and 1971, and were rare in Lake Taharoa by 1970 (Cudby 1970; Allen & Turner 1971).

Although trout are effective predators of *G. gracilis*, and have been associated with their decline in several lakes, other observations suggest that *G. gracilis* populations can resist trout predation. For example, *G. gracilis* were still abundant in Lake Waingata in 1962 (Fish 1966), despite the fact that this lake had been stocked with trout each year between 1953 and 1959 (Cunningham 1957), and declined only after annual trout stocking resumed in 1962. Moreover, *G. gracilis* were relatively common in Lake Ototoa between 1991 and 1994 even though this lake was stocked with rainbow trout each year (B. Wilson, pers. comm., 1994).

Differences in trout stocking rates cannot account for the differences in abundance of *G. gracilis*. This species was rare in Lake Taharoa and common in Lake Ototoa between 1990 and 1993 when trout were stocked into Lake Taharoa at 11 fish per ha (M. Poynter, pers. comm., 1994) compared with 8 fish per ha in Lake Ototoa (B. Wilson, pers. comm., 1994). These rates are relatively low and similar, especially when compared with the initial annual trout stocking rates of 22–48 fish per ha (Fish 1966; Allen & Turner 1971). Clearly, trout predation is not the whole story, and other changes in lake ecology could be involved.

By 1962 the exotic macrophyte *Elodea canadensis* Micheaux was rapidly becoming established in the littoral zone of Lake Waingata, a change in the dominant phytoplankton species had occurred, and a decline in both the freshwater crab *Halicarcinus lacustris* Chilton and the crayfish *Paranephrops planifrons* White were noted (Fish 1966). Water quality in the lake was apparently declining by 1962 and the introduction of exotic species of plant and fish no doubt compounded the effect on the lakes' ecology of increased eutrophication. Therefore a number of ecological changes, apart from renewed trout stocking, coincided with the decline of *G. gracilis* in Lake Waingata in the early 1960s. Faunistic changes also coincided with the introduction of trout and the decline of *G. gracilis* in lakes Taharoa and Waikere. In particular, the mosquito fish (*Gambusia affinis*) was introduced into these lakes between 1970 and 1973 (Anon. 1973). Thus the role of trout predation in the decline of *G. gracilis* in these lakes is unknown, and any effect on *G. gracilis* may have been exacerbated by other factors.

Further evidence that trout predation is not the only factor affecting the density of *G. gracilis* comes from lakes where trout stocking has been discontinued, and from lakes never stocked with trout. Lake Waingata has not been stocked with trout for the past 20 years, yet *G. gracilis* are still rare there. Densities of *G. gracilis* in Lake Waingata were lower than in Lake Rototuna – where it is common, and which has never been stocked with trout – in both 1985 and in the early 1990s. Moreover, *G. gracilis* are relatively rare in lakes Rotokawau and Roto-otuauru which have never been stocked with trout.

CONCLUSION

Trout predation has undoubtedly affected *G. gracilis* densities in some lakes, but it appears that factors other than trout predation have reduced *G. gracilis* populations in others, and may have compounded the effects of trout predation on *G. gracilis* in Lake Waingata and in the Kai Iwi lakes. Until such other factors are identified and counteracted, the future of *G. gracilis* is precarious. Given the extremely restricted distribution of this endemic species, its few extant populations (12), and its decline in at least eight of these lakes, it is clearly a threatened species, worthy of IUCN listing, and in need of urgent conservation management. Studies are now underway to identify the factors responsible for its decline.

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