Responses of fish communities to sustained removals of perch (*Perca fluviatilis*)

SCIENCE FOR CONSERVATION 210

Benjamin G. Ludgate and Gerard P. Closs

Published by
Department of Conservation
PO Box 10-420
Wellington, New Zealand

Science for Conservation is a scientific monograph series presenting research funded by New Zealand Department of Conservation (DOC). Manuscripts are internally and externally peer-reviewed; resulting publications are considered part of the formal international scientific literature.
Titles are listed in the DOC Science Publishing catalogue on the departmental website http://www.doc.govt.nz and printed copies can be purchased from science.publications@doc.govt.nz

ISSN 1173-2946
ISBN 0-478-22339-0

This report was prepared for publication by DOC Science Publishing, Science & Research Unit; editing by Ian Mackenzie and layout by Ruth Munro. Publication was approved by the Manager, Science & Research Unit, Science Technology and Information Services, Department of Conservation, Wellington.

CONTENTS

Responses of fish communities to sustained removals of perch (*Perca fluviatilis*)

Benjamin G. Ludgate and Gerard P. Closs

Department of Zoology, University of Otago, PO Box 56, Dunedin, New Zealand

ABSTRACT

Over a two-year period, adult perch (*Perca fluviatilis*) were regularly caught and removed from three coastal wetland ponds (removal ponds) in Otago, South Island, New Zealand. Resulting changes in the fish community in the ponds from which perch were removed were compared with fish communities in three similar ponds (control ponds) from which perch were not removed. At the start of the experiment, fish communities in both the removal and control ponds were similar, being dominated by a relatively small number of large adult perch and low numbers of common bullies (*Gobiomorphus cotidianus*). Few young of year (YOY) perch were present in the ponds suggesting that cannibalism was a significant factor regulating perch population dynamics. Periodic removal of adult perch from the removal ponds using gill and fyke nets significantly reduced adult perch abundance. In response, the abundance of common bully increased significantly in the two smallest removal ponds. However, in the largest pond perch successfully spawned either just prior to or during the initial removal and reduced adult perch abundance following removal resulted in increased YOY perch survival. By the end of the experiment, the fish community in this pond was dominated by YOY perch and common bully abundance remained low. In contrast to the changes that occurred in the removal ponds over the course of the experiment, no significant changes in the fish communities of the control ponds were observed. The results of the study suggest that perch have a significant negative impact on the abundance of common bully, and that cannibalism plays a significant role in regulating the population dynamics of perch in small lentic habitats. Physical removal of perch using gill and fyke nets may offer a potential control option in small lentic water bodies. However, incomplete removal of adults may still allow spawning. Due to a reduction in cannibalism by adult perch, increased survival of YOY perch resulting in high numerical abundance of YOY perch may subsequently occur.

Keywords: Freshwater fish, introduced species, exotic species, common bullies, *Gobiomorphus cotidianus*, lentic, *Perca fluviatilis*, perch, fish removal, netting

Ludgate, B.G.; Closs, G.P. 2003: Responses of fish communities to sustained removals of perch (*Perca fluviatilis*). *Science for Conservation 210*. 38 p.

1. Introduction

1.1 RATIONALE FOR STUDY

At least 20 species of freshwater fish have been introduced into New Zealand. Of these, brown and rainbow trout, quinnat salmon, koi carp, rudd, tench, goldfish, *Gambusia* and perch have established self-sustaining populations across large areas of either the North or South Island, or both (McDowall 1990). In many waterbodies introduced species such as brown or rainbow trout, perch, rudd, or koi carp now dominate the local ichthyofauna, both in terms of absolute numbers and biomass (McDowall 1990). Several of these introduced fish are recognised by law as sportsfish, including the various species of salmonid, perch, tench and rudd (in the Auckland–Waikato region). Little is known of the impact of introduced fish species on New Zealand freshwater ecosystems, although some evidence suggests it can be significant. Brown trout are known to eliminate small, non-diadromous galaxiid fish in small streams (Townsend & Crowl 1991; Crowl et al. 1992), a result that has consequences for periphyton, invertebrates and stream productivity (Flecker & Townsend 1994; McIntosh & Townsend 1995; Huryn 1996). However, other than trout, the impact of various introduced fish species on native freshwater ecosystems is not well known.

Perch are a freshwater fish species that was introduced into New Zealand in 1868 as an angling species (McDowall 1990). They are a relatively large predatory fish (commonly to 450 mm long) and now occur in a wide variety of lowland freshwater systems across both the North and South Islands of New Zealand (McDowall 1990). Based on European studies, perch have the potential to have a significant impact on the ecology of the systems into which they have been introduced, directly influencing zooplankton, macroinvertebrate, and fish populations (Persson & Greenberg 1990a; Tonn et al. 1992; Persson & Eklöv 1995). At present, only limited studies of the perch diet, spawning and habitat use have been reported from New Zealand systems (Duncan 1967; Griffiths 1976; Jellyman 1980). No information exists as to their impact on native fish, invertebrates, or other components of native freshwater ecosystems.

There is growing recognition and concern regarding the spread of introduced fish species across New Zealand. Information on their distribution, impact, and potential control methods is required in order to prioritise control strategies for various species and regions. In the case of a widely distributed and abundant species such as perch, eradication throughout New Zealand is not a realistic option. However, some biologically significant wetland areas remain free of any introduced fish species including perch. Understanding the potential impacts of various exotic freshwater species should they enter areas of high conservation significance, and refining potential methods for localized eradication is essential if control strategies are to be developed. The need to understand the likely impacts of perch and develop strategies for localised control or eradication provides the impetus for this study.

1.2 ECOLOGY OF PERCH

Perch belong to the Family Percidae, a group consisting of around 60 freshwater fish species that occur naturally in still or slow-flowing temperate waters throughout the Northern Hemisphere (McDowall 1990). The general biology of perch is well known in its native European environment, with research having been conducted into perch diet (e.g. Craig 1978; Mehner 1993), habitat use (e.g. Persson & Greenberg 1990b; Bean & Winfield 1995), predation effects (e.g. Tonn et al. 1992; Persson & Eklöv 1995) and competition (e.g. Persson & Greenberg 1990a). Coupled with this is extensive research into perch population size-structure, and population dynamics (e.g. Treasurer et al. 1992; Treasurer 1993; Persson et al. 2000).

Perch spawn in spring, where the fish begin a life cycle potentially involving three ontogenetic diet and habitat shifts (Persson 1988; Persson et al. 2000). Initially, perch are primarily planktivorous, feeding mostly on pelagic zooplankton at sizes up to 80 mm. They then switch to feeding primarily on macroinvertebrates and increase their use of littoral habitats. Intense intraspecific competition for zooplankton may force juvenile perch to switch from feeding on zooplankton to macroinvertebrates prematurely, resulting in reduced rates of growth (Persson 1988). A final shift to piscivory occurs for those perch that grow to a sufficient size, usually at around 150 mm long (Persson 1988).

As a result of the piscivorous nature of larger perch, cannibalistic adult perch have the potential to play an important role in structuring perch populations (Claessen et al. 2000). Cannibalism in perch affects mainly the young-of-the-year (YOY) class (Persson et al. 2000). Cannibalism of larval and juvenile perch has been reported from many perch populations and can play a significant role in reducing the intensity of intra-specific competition amongst juvenile perch (Persson 1988; Treasurer 1993; Persson et al. 2000; Wahlström et al. 2000). The effects of cannibalism are most commonly seen in systems lacking other top piscivores (Treasurer 1993; Wahlström et al. 2000). However, cannibalism can still play a major role in structuring perch populations when other top predators such as pike are present (Treasurer et al. 1992).

1.3 PERCH IN NEW ZEALAND

Perch are now distributed widely throughout New Zealand, with centres of abundance in Northland, Auckland, Hawke's Bay, Taranaki, Wellington, Hokitika, central Canterbury, Otago, and Southland (Fig. 1A; McDowall 2000). They have recently been recorded from Motueka (Shaw & Studholme 2001). In New Zealand perch up to 400–450 mm and 1–2 kg are regularly encountered, however many populations are dominated by smaller fish (McDowall 1990). They have been recorded to attain a maximum size of 675 mm and approximately 4 kg in New Zealand (McDowall 1990). They may grow to a larger size with fish in excess of 4 kg having been recorded elsewhere (McDowall 1990).

Research on perch in New Zealand is limited, with only three major studies investigating their biology. Jellyman (1980) examined perch life history and found that perch spawn in spring (September–November) with high larval and juvenile growth rates during the first six months followed by slower growth rates, especially during winter months. Duncan (1967) and Griffiths (1976) primarily examined perch diet, with only a minor interest in population structure. However, both studies noted the presence of common bullies (*Gobiomorphus cotidianus*) in the diet of perch. Common bully are widely distributed through the lowland habitats in which perch typically occur (McDowall 1990). High rates of predation on common bully could have major impacts on the abundance and behaviour of this small native fish.

Cannibalism by adult perch has been reported in the Northern Hemisphere on many occasions (Persson 1988; Treasurer 1993; Persson et al. 2000; Wahlström et al. 2000). In New Zealand, Duncan (1967) also noted young perch in the stomachs of large perch. In the absence of other piscivorous fish, it is likely that cannibalism has a significant influence on perch population dynamics in New Zealand. Cannibalism could potentially maintain low abundance and stabilise the structure of perch populations as is seen in the Northern Hemisphere (Treasurer 1993).

2. Aims and predictions

This study represents the first experimental study examining the impact of perch on native fish in New Zealand. The aims of this study were to determine whether eradication of perch from small wetland ponds could be achieved using netting and trapping. If adult perch could be either eradicated or significantly reduced, would this influence survival and recruitment of juvenile perch, and the abundance and population structure of common bully. Prior to removal it was predicted that, in response to the removal, numbers of adult perch in the remaining population would decline. In response to reduced numbers of adult perch, numbers of YOY perch following the removal would either be low because of an absence of spawning or increase because of a reduction in cannibalism hence survival of juvenile fish. It was also predicted that the numbers of common bullies would increase in the removal ponds relative to the control ponds because of reduced predation pressure from adult perch on this small native fish species.

3. Methods

3.1 STUDY SITE

The Waihola/Waipori Wetland Complex is located 33 km south-west of Dunedin in the South Island of New Zealand (45 59′ S, 170 06′ E) and covers approximately 2000 hectares of the Taieri plains (Fig. 1). The wetland is bordered by Lakes Waihola and Waipori and all are drained by the Waipori River and smaller streams. Areas of the wetland receive regular intrusions of saline water from the tidally influenced lower Waipori River, which joins the lower Taieri River on its way to Taieri Mouth, approximately 10 km downstream. The wetlands once formed part of a much larger wetland complex that extended throughout much of the lower Taieri River plain.

The Waihola/Waipori wetland has been significantly reduced in area since European colonisation by drainage for agricultural use. Although earlier unsuccessful attempts were made to drain and develop the area, the present wetland complex has not been altered since 1956, (Q.E.II National Trust 1997). Regular inundation of the area by high river levels during floods is ongoing, with the last major inundation prior to this study occurring in 1994. The wetland comprises

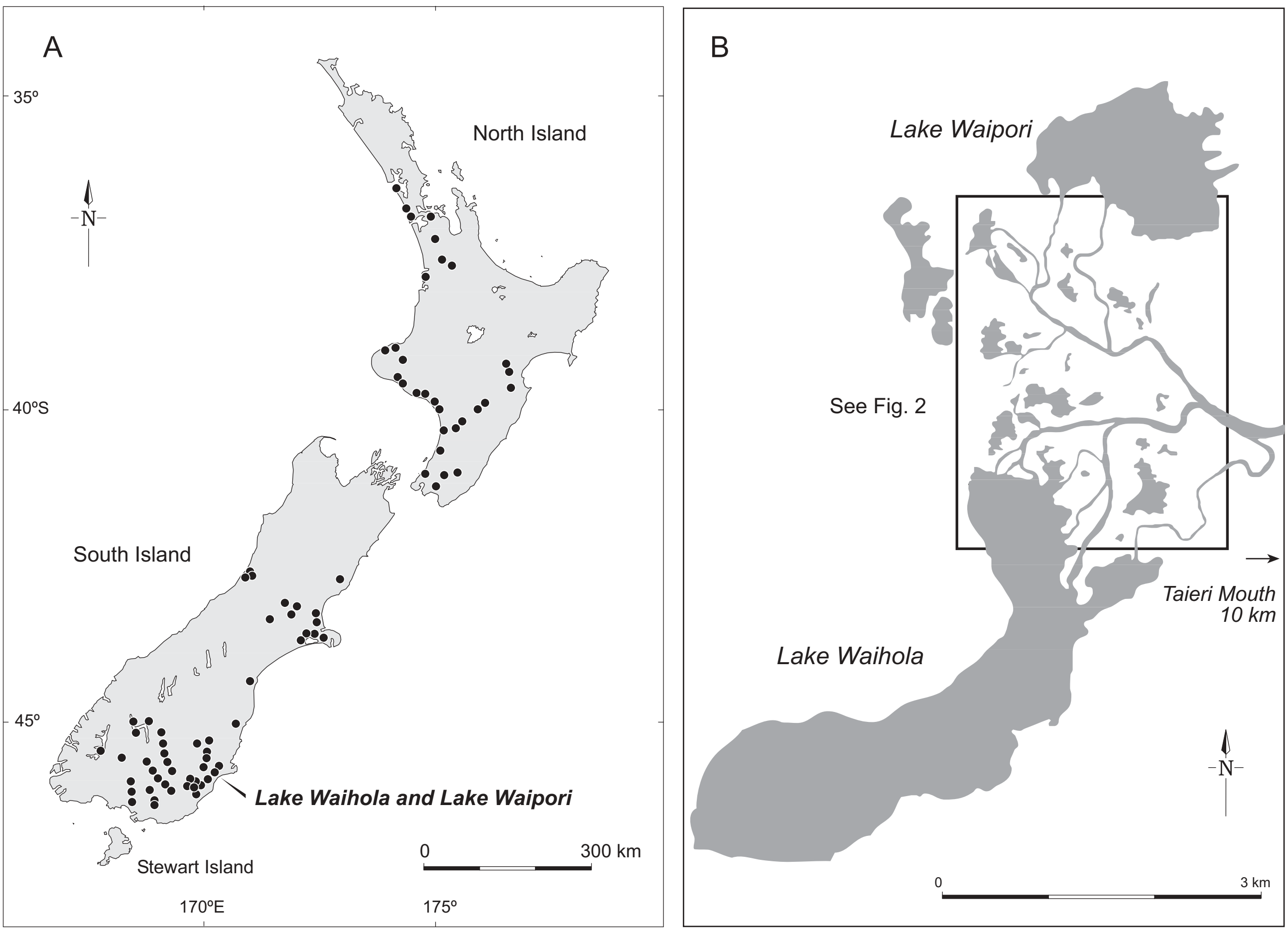


Figure 1. (A) Distribution of perch in New Zealand (adapted from New Zealand Freshwater Fish Database). (B) Map of the Waihola/Waipori wetlands.

numerous tidal channels and ponds (ranging from 0.2–8.9 hectares). Many isolated ponds do not receive water directly from the tidal flows. Levels in these are presumably maintained by groundwater intrusion and rainfall. Communities in these ponds are only connected to other waterbodies during major floods. The ponds within the wetlands were possibly formed following the collapse of peat bogs (Q.E.II National Trust 1997), and are structurally simple, lacking sloping shallow littoral areas and exhibiting only limited variation in depth.

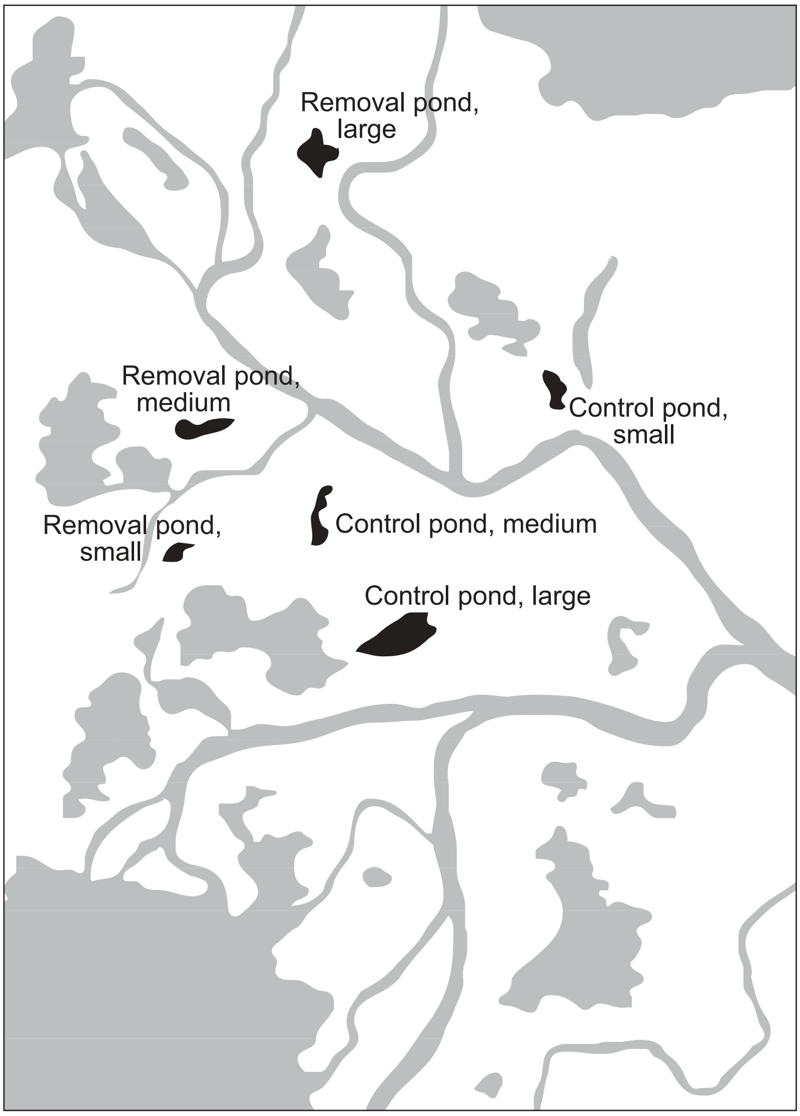
The vegetation of the area is relatively uniform, with the majority of the wetland area being covered by native plants such as flax (*Phormium tenax*), sedges (*Carex* spp.), raupo (*Typha orientalis*), interspersed with coprosma shrubs (*Coprosma propinqua*). Invasion by exotic plants has been a feature in recent years, with crack willow (*Salix fragilis*) and sweetgrass (*Glyceria maxima*) spreading throughout the wetland and increasingly crowding the waterways and waterbodies (Q.E.II National Trust 1997). The aquatic vegetation is mainly comprised of pondweeds (*Potamogeton* spp.), buttercups (*Ranunculus* spp.), *Myriophyllum* spp., free-floating ferns (*Azolla* spp.), and duckweed (*Lemna* spp.). The composition and density of vegetation between and within ponds varies considerably between years.

The fish community of the area is diverse by New Zealand standards. Perch are widespread throughout the wetlands, being found in both Lakes Waihola and Waipori, as well as in numerous smaller ponds and channels (Q.E.II National Trust 1997; Kattel 1999; David 2002). They are abundant in the Waipori and Taieri Rivers where they are regularly sought by anglers. The common bully is abundant throughout the wetland complex and is found in the connected and isolated ponds, as well as the lakes and channels (Kattel 1999; David 2002). Both longfin (*Anguilla dieffenbachii*) and shortfin eels (*A. australis*) are found within the wetlands in reasonable numbers (David 2002). Galaxiids are present in the area with inanga (*Galaxias maculatus*) being the most abundant, while giant kokopu (*G. argenteus*) are present in some areas in low numbers (David 2002). Due to the tidal nature of the Waipori and Taieri rivers, the wetlands are an important breeding ground for inanga (Sutherland & Closs 2001). Inanga are found predominantly in the connected ponds and channels, with low numbers present in some of the isolated ponds (David 2002). Populations of inanga in isolated ponds are presumably relict populations surviving since the ponds were last connected during floods (David 2002). Introduced brown trout are present in the wetland channels and connected lakes (David 2002). Other fish species occasionally observed in the tidal channels include smelt (*Retropinna retropinna*), lamprey (*Geotria australis*) and black flounder (*Rhombosolea retiaria;* Q.E.II National Trust 1997).

3.2 EXPERIMENTAL DESIGN

Six ponds were selected for this study from approximately 70 ponds contained within the wetlands (Fig. 2). Selection of the ponds was primarily based on four factors that were: the presence of perch and common bullies, pond size, location, and the absence of any connection with the main channels or the Waipori River. Fish composition was determined by examining data collected during a previous fish survey of the area (David 2002), and data collected in a

Figure 2. Location of the study ponds in the Waihola/Waipori wetlands.



preliminary survey of the ponds prior to this study. Relatively small ponds were selected to allow intensive netting of each pond. The ponds also had to be reasonably accessible through the rough boggy terrain of the wetland. Isolated ponds were required to prevent the movement of fish from other areas obscuring experimental effects. At the start of this study these ponds had been isolated since a large flood in 1994. Part way through the study in August 2000, flooding of the wetland area occurred and resulted in varying degrees of reconnection of the ponds to the wider floodplain.

The six ponds selected for this study were grouped into three paired size classes: small, medium, and large (Fig. 2). One pond from each size class was allocated to one of two treatments: perch removal (small, medium and large pond areas of 0.17, 0.46 and 0.79 hectares respectively) and control (small, medium and large pond areas of 0.33, 0.54 and 1.53 hectares respectively). The perch removal treatment consisted of three ponds where progressive removal of one-year and older perch was undertaken. Juveniles were not removed because of limitations of the sampling equipment. The control treatment consisted of the three ponds in which no perch removal was undertaken.

The sampling undertaken in this study involved a preliminary survey of the study ponds in October 1999; perch removals in November/December 1999 and December 2000; monitoring of the fish community monthly from November 1999 to April 2000. Sampling in the first season indicated rapid changes in fish community structure were unlikely hence sampling intensity was reduced in the second field season. Sampling was undertaken in November 2000, January 2001, and March 2001. A final gill and fyke net survey of all the ponds completed the study in April 2001 (Table 1).

3.3 PRELIMINARY SURVEY

A preliminary survey of the fish communities was undertaken across all six study ponds in early October (Table 1). Fyke nets (wing length 4.5 m, stretched mesh 20 mm) were set for five nights in each pond. Higher numbers of nets were used in larger ponds to maintain sampling effort with respect to pond size. Four fyke nets were used in the small control pond, six fyke nets in the medium control pond and seven fyke nets in the large control pond. In the small and medium perch removal ponds four fyke nets were used, while five fyke nets were used in the large perch removal pond. Fyke nets were set by attaching the floating top line of the wing to the bank (by tying to nearby vegetation, e.g. flax) then extending the net at an angle of 45 to the bank and anchoring the end using heavy chain. All fish caught were identified to species, measured to the nearest millimeter, and then released. Eels were identified to species level and immediately released without measurement (due to difficulties associated with handling and accurate measurement).

TABLE 1. DATES OF SAMPLING UNDERTAKEN IN THIS STUDY.
Note that the perch removals were only undertaken in the perch removal ponds, while the surveys and monitoring were undertaken in all six study ponds.

SAMPLING	START DATE	END DATE
1999/2000		
Preliminary survey	27/9/99	16/10/99
November monitoring	16/11/99	22/11/99
Perch removal (Small and medium)	19/11/99	22/11/99
Perch removal (Large)	10/12/99	17/12/99
December monitoring	11/12/99	18/12/99
January monitoring	29/1/00	3/2/00
February monitoring	1/3/00	6/3/00
March monitoring	20/3/00	26/3/00
April monitoring	15/4/00	19/4/00
2000/2001		
November monitoring	8/11/00	11/11/00
Perch removal (All three ponds)	4/12/00	7/12/00
January monitoring	28/1/01	31/1/01
March monitoring	28/3/01	31/3/01
Final survey	2/4/01	5/4/01

3.4 PHYSICO-CHEMICAL ANALYSIS

Measurement of the physico-chemical characteristics of the six study ponds was undertaken on eight occasions during the course of this study (monthly from November 1999 to April 2000, January 2001 and March 2001). Water chemistry analysis was not conducted in November 2000 because of equipment breakdown. One set of measurements was taken per pond on each of these occasions. The analysis was undertaken prior to fish sampling in each pond to reduce the influence of sediment disturbance on water quality measurements. Variables were measured in the center and edge of the ponds, with pH, conductivity, salinity, dissolved oxygen and temperature being measured from the top and bottom 20 cm of the water column.

Measurements taken were: depth (centimetres), water transparency (centimetres), pH, conductivity (micro-Siemens), salinity (parts per thousand), dissolved oxygen (milligrams per litre), and water temperature (degrees Celsius). Water transparency was measured using a Secchi disc. The secchi measurement was taken from the average of two measurements: one taken as the disc disappeared from view as it was lowered into the water column, the other taken as it reappeared as it was raised up the water column (McMahon et al. 1996). The pH measurement was taken using a pHep3 portable field pH meter. Conductivity, salinity, dissolved oxygen and water temperature were measured using a Yellow Springs Instruments (YSI) Model 85 meter. Air temperature and rainfall data over the study period were obtained from the National Institute of Water and Atmospheric Research (NIWA) weather station located at Dunedin Airport, approximately 5 km away.

3.5 PERCH REMOVAL 1999

The initial removal of perch from the three removal ponds was conducted in mid November and December 1999 (Table 1). The removals in the small and medium ponds were conducted simultaneously. The removal in the large pond was carried out when all nets were available to deploy in the one pond. The removals were initially planned to occur in late September/October, which would allow adult perch to be removed before spawning occurred or newly recruited YOY fish were present. These new recruits would be smaller than the minimum size possible for capture using the sampling methods utilised during the removal period, and would also be potentially present in very high numbers. It was reasoned that a pre-spawning removal would maximise the chances of achieving a successful removal. However, results from the preliminary survey suggested that capture rates of perch were reduced in water less than 10°C (see also Hokanson 1977). Subsequent delays due to weather resulted in the perch removal from the large removal pond being conducted in December 1999, probably after spawning had occurred.

The removal of perch was conducted using overnight sets of gill and fyke nets over a period of three to six nights for each removal pond. A total of nine 27 m multi-mesh gill nets (panel height 3 m, panel length 4.5 m, stretched mesh sizes: 25, 45, 55, 70, 85 and 115 mm) and nine fyke nets (wing length 4.5 m, stretched mesh 20 mm) were available to deploy across the ponds. In the small pond five fyke nets and three gill nets were used over a three night period. In the medium pond four fyke nets and six gill nets were used over a three-night period. In the large pond eight fyke nets and eight gill nets were used over a three-night period. Six fyke nets were also used continuously over a further three-night period in this pond. Gill nets were set by attaching one end of the floated top line to the bank and extending the net perpendicularly into the centre of the pond. Fyke nets were set as per the method described in the preliminary survey. All equipment was set within 4 hrs prior to sunset with some variation between ponds due to travel times between sites.

Equipment was retrieved within 4 hrs after sunrise, again with some variation between ponds due to variable travel times between sites. All perch captured were killed immediately using either the anaesthetic 2n-phenoxyethanol administered at a lethal dose, or by delivering a sharp blow to the head. All fish (excluding eels) were weighed to the nearest tenth of a gram and measured to the nearest millimetre. Eels were identified to species level. All fish other than perch were then immediately released.

3.6 FISH POPULATION MONITORING 1999/2000

Sampling of the fish population in each pond was conducted monthly from November 1999 through to April 2000 (six sampling occasions). All ponds were sampled using identical methods, and monitoring was completed in all six ponds over a maximum of seven days each month. Times of equipment set and retrieval were similar to times used in the preliminary survey. Variation in set times was accommodated by reporting all catches as 'catch per unit effort' (CPUE). Collapsible, rectangular 'Gansell bait fish' minnow traps (stretched nylon mesh 5 mm, 45 × 25 × 25 cm with 7 cm opening) and fyke nets (wing length 4.5 m, stretched mesh 20 mm) were used to monitor the fish populations. Minnow traps were used to target bullies and YOY perch. Fyke nets were primarily used to capture larger perch and eels. Gill nets could not be used during the monitoring given the need to return perch captured in the control ponds alive and in good condition, and the need to maintain a consistent sampling effort across all ponds.

Overnight sets of minnow traps and fyke nets were used for one night per pond on each sampling occasion. On one occasion, in April 2000, nets were left for two nights because weather and assistant injury prevented access to the ponds (CPUE adjusted accordingly). On each night, 4 minnow traps were set in each of four primary microhabitats within each pond (16 traps per pond): center surface (greater than 2 m from bank and floating in top 20 cm of water column); center bottom (greater than two metres from bank and resting on substrate); edge (adjacent to bank, resting on substrate); 1 m from edge (1 m from bank, resting on substrate). Two fyke nets were used per pond for monitoring trips in November and December. Three fyke nets were set in each pond from January onwards as additional equipment became available. Traps and fyke nets were set randomly with no selection for areas with or without macrophytes.

3.7 PERCH REMOVAL 2000

A second perch removal in the perch removal ponds was completed in December 2000 (Table 1). Again removals were initially planned for October 2000, prior to perch spawning. However, delays due to weather (i.e. water temperatures <10°C) resulted in the removals most probably being completed after perch spawning. This removal used similar methods to the 1999 removal, with the addition of 12 m long fine monofilament multi-mesh gill nets that had become available (panel height 1.7 m, panel length 3 m, stretched mesh sizes: 30, 50, 65, 85 mm). Two of these nets per pond were used in conjunction with the gill and fyke nets described previously. Removals across all three ponds were conducted simultaneously. Netting was conducted over a three-night period for each pond.

In the small pond four fyke nets, one 27 m gill net and two 12 m gill nets were used over a three-night period. In the medium pond four fyke nets, three 27 m gill nets and two 12 m gill nets were used over a three-night period. In the large pond three fyke nets, five 27 m gill nets and two 12 m gill nets were used over a three-night period. The setting and retrieval of the nets was conducted as per the methods used in the 1999 removal period.

3.8 FISH POPULATION MONITORING 2000/2001

Sampling of the fish populations was conducted in November 2000, January 2001, and March 2001 (Table 1). Methods used on each occasion were identical to those in the 1999/2000 season.

3.9 FINAL SURVEY

A final survey using overnight sets of gill and fyke nets was conducted across all six ponds in early April 2001. Gill and fyke nets were used in all ponds to provide directly comparable estimates of abundance across the full size range of perch in all of the study ponds. Two 15 m multi-mesh gill nets (panel height 1.7 m, panel length 3 m, stretched mesh sizes: 10, 30, 50, 65, 85 mm) were used in each pond. One 27 m gill net was also used in each pond. In the small pond three fyke nets were used, and in the medium and large removal ponds four fyke nets were used. Three fyke nets were used in the small control pond, one fyke net in the medium, and four fyke nets were used in the large control pond. A misunderstanding between survey teams resulted in fewer nets being available to survey the medium control pond otherwise variation in numbers of fyke nets per ponds allowed for some maintenance of sampling effort across the different sized ponds. The setting and retrieval of the nets was identical to methods used in the 1999 and 2000 removal periods. All fish collected in the control ponds and all fish other than perch in the removal ponds were immediately released following recording.

3.10 DATA ANALYSIS

Statistical analysis of the physico-chemical data was conducted using one-way ANOVAs using Systat Version 9.0 to determine if any differences in physico-chemical parameters existed between ponds.

The catch selectivity of gill and fyke netting for different size classes of perch was examined using size-frequency histograms. Catch rates of perch using the two sampling methods were compared by pooling all fish caught during the first and second removals and the final gill netting/fyke netting. These represent the sampling times during which gill and fyke nets were used simultaneously, hence catches at these times are directly comparable.

For analysis of perch population structure across the control and removal ponds, perch populations were divided into two functional groups based on length, i.e. YOY and large. The YOY group comprised perch less than 80 mm in total length. Eighty millimetres was the maximum size observed in perch in their first year of life in this study, and it was assumed that at this size perch were not significant piscivores. Perch larger than 80 mm in length were assumed to be piscivorous (Mittlebach & Persson 1998). Catch rates at each removal and in the final netting are presented graphically. For the fish community monitoring, independence of samples was assumed and equal replication of nets and traps per pond occurred, hence a statistical analysis was completed.

Catch data was converted to catch per unit effort (CPUE: No. fish hr^{-1} net^{-1} or No. fish hr^{-1} $trap^{-1}$) to accommodate variation in the time that each net was set. Because of the non-normal distribution of the data, randomisation tests (Manly 1991) were used to compare catch rates across ponds at each time. Randomisation tests were completed using Microsoft Excel 2001.

The size distribution of the common bully population in the control and removal ponds was compared using a two-sample Kolmogorov-Smirnov test (Sokal & Rohlf 1995), performed using Systat Version 9.0. Length data was pooled across the three ponds in each treatment to differentiate between early-spawning and late-spawning periods for the common bully. As common bullies are known to spawn from late spring to autumn, (Stephens 1982; McDowall 1990) the data was pooled into the following groups: November 1999–January 2000 (early spawning); February 2000–April 2000 (late spawning); November 2000 and January 2001 (early spawning); and March 2001 (late spawning).

Data collected on the other fish populations present in the study ponds (long and shortfin eels, and inanga) were grouped by year and variation in CPUE by pond was tested using the randomisation tests. The pooling of yearly data was performed to exclude seasonal changes from the analysis, and to allow simple comparison of the abundance of each species in each year across ponds.

4. Results

4.1 PRELIMINARY SURVEY

The preliminary survey of the six study ponds in October 1999 established that perch were present in all six ponds (Table 2). Perch were relatively abundant in three ponds, with 105 perch being caught and released in the large control pond, 38 perch in the small removal pond, and 18 in the medium removal pond. Few common bullies were caught in any ponds, 10 in the medium removal pond being the highest number observed. Eels were abundant with 117 being caught from the medium control pond. Inanga were only observed in the small control pond. As all fish were caught and released, fish may have been caught more than once over successive nights.

TABLE 2. TOTAL NUMBER OF FISH CAUGHT AND RELEASED OVER A FIVE NIGHT PERIOD FOR EACH POND USING FYKE AND MINNOW TRAPS DURING THE PRELIMINARY SURVEY OF ALL SIX STUDY PONDS IN OCTOBER 1999.

	PERCH	COMMON BULLY	LONGFIN EELS	SHORTFIN EELS	INANGA
Control					
Small	5	0	0	54	1
Medium	7	1	51	66	0
Large	105	1	12	10	0
Perch removal					
Small	38	1	13	11	0
Medium	18	10	28	61	0
Large	1	1	8	19	0

4.2 PHYSICO-CHEMICAL ANALYSIS

Air temperatures over the study period were similar between years. However, the winter of 1999 was observed as being very dry, and the summer of 1999/2000 being very wet (Table 3). Rainfall was more evenly distributed through winter and summer 2000/2001, with summer being marginally wetter than winter.

Depth, water transparency, salinity and conductivity levels differed significantly between ponds (Table 4). The large removal pond was deeper and clearer than the other ponds. The small control pond was more saline and had a higher conductivity than the other ponds. The levels of pH, water temperature, and dissolved oxygen were similar across all six study ponds throughout the study period (Table 4).

TABLE 3. DAILY AIR TEMPERATURES (°C) AND RAINFALL (mm) RECORDED AT DUNEDIN AIRPORT.
'Winter' = May–September (i.e. between field seasons), 'Summer' = October–April (i.e. field seasons).

	TEMPERATURE (°C) AVERAGE (RANGE)	RAINFALL (mm) AVERAGE (RANGE)	TOTAL
1999–2000			
'Winter'	7.7 (–6.5 – 25.2)	1.3 (0.0 – 21.0)	196.8
'Summer'	12.8 (–2.3 – 31.9)	2.4 (0.0 – 67.0)	515.2
2000–2001			
'Winter'	7.5 (–7.4 – 24.3)	2.0 (0.0 – 56.0)	306.2
'Summer'	13.1 (–4.5 – 31.2)	1.8 (0.0 – 25.0)	379.0

TABLE 4. MEAN AND RANGE (MINIMUM, MAXIMUM) OF PHYSICOCHEMICAL CONDITIONS OF THE SIX STUDY PONDS.
The data was taken from eight sampling occasions (November 1999 to April 2000, January 2001, March 2001).

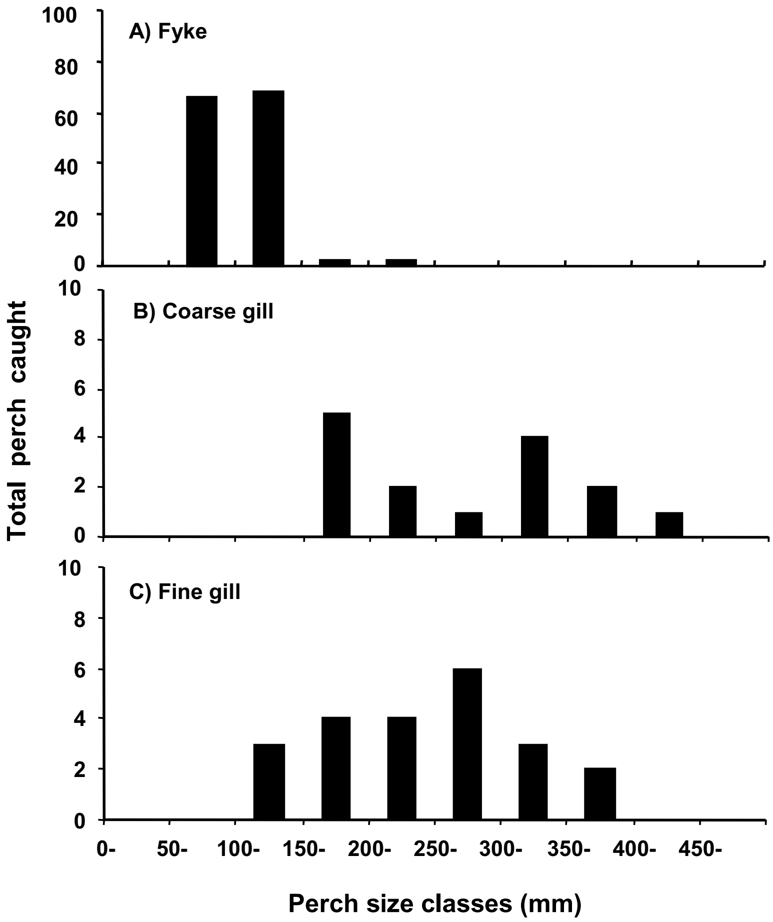
	CONTROL			PERCH REMOVAL		
	SMALL	MEDIUM	LARGE	SMALL	MEDIUM	LARGE
Depth (cm) *	62.1	77.0	77.8	84.0	72.1	86.3
	(46.0, 75.0)	(37.0, 96.0)	(62.0, 109.0)	(69.0, 99.0)	(56.0, 81.0)	(72.0, 95.0)
pH	7.3	7.6	7.5	7.3	7.4	7.4
	(6.7, 7.6)	(6.8, 8.8)	(6.8, 8.3)	(6.8, 7.9)	(6.8, 8.3)	(6.8, 8)
Water transparency *	30.2	35.8	22.0	34.0	36.6	47.8
(cm)	(27.0, Sub.)	(24.0, Sub.)	(12.0, Sub.)	(16.0, 46.0)	(20.0, Sub.)	(45.0, Sub.)
Salinity (ppt) *	1.5	0.6	1.2	1.1	0.7	0.7
	(0.1, 2.3)	(0.4, 0.9)	(0.6, 2.2)	(0.6, 1.9)	(0.5, 1.0)	(0.3, 1.1)
Conductivity (μS) *	2468	1043	1938	1800	1163	1175
	(818, 3832)	(667, 1731)	(925, 3611)	(1092, 3298)	(825, 1655)	(507, 1947)
Dissolved oxygen	6.0	6.4	5.5	6.1	6.5	7.6
(mg/L)	(1.9, 10.5)	(0.8, 11.2)	(3.1, 8.3)	(0.3, 12.7)	(0.4, 10.2)	(5.3, 10.1)
Water temperature (°C)	16.5	16.2	14.8	16.9	16.6	15.8
	(11.2, 21.8)	(11.6, 22.8)	(9.8, 18.2)	(11.4, 22.0)	(11.8, 22.8)	(12.9, 21.2)

* Indicates significant at P = 0.05 level. Sub. indicates bottom substrate visible.

4.3 CATCH SELECTIVITY OF GILL AND FYKE NETS IN RELATION TO PERCH SIZE

Fyke nets were clearly selective for smaller perch, catching a total of 134 perch in the 50 to 149 mm size range over the course of the removals and final survey (Fig. 3). Only four fish longer than 150 mm were caught in fyke nets during the removals and final survey. In contrast the gill nets mostly caught fish over 150 mm in length, the largest being a 410 mm perch.

Figure 3. Total number of perch caught by size classes in (A) fyke nets, (B) coarse monofilament gill net and (C) fine monofilament gill net during perch removals and final survey.



4.4 FISH COMMUNITY 1999/2000

Sampling of the study ponds before perch removal using fyke nets and minnow traps (November 1999) indicated the presence of low numbers of large perch in the small control and the large removal ponds, while 18 large perch were captured in the large control pond (Fig. 4). Only one YOY perch was recorded. Common bullies were collected in three of the ponds (large control, small and medium removals) in low numbers at this time.

The initial removal of perch using fyke and gill nets from the three perch removal ponds in late November/early December indicated that reasonable populations of perch had been present in all three removal ponds (Fig. 5). Six perch were removed from the small removal pond, with all perch captured being between 103–116 mm in length. Similarly, in the medium removal pond two perch (111 and 327 mm in length) were removed. In the large removal pond 55 perch were removed ranging in size from 50–449 mm. Of these perch, 47 were in the 100–149 mm size range.

Few large perch were subsequently caught during routine monitoring following the removals in the small and medium removal ponds (Fig. 6). Apart from one large perch that was caught and removed in the medium removal pond in December 1999, no large perch were caught in either the small or medium removal ponds for the rest of the 1999–2000 season. The large removal pond showed similar trends, with only two large perch caught and removed in

Figure 4. CPUE (No. fish hr^{-1} net^{-1}) of fish in November 1999 prior to perch removal: (A) large perch, (B) YOY perch, and (C) common bullies. Error bars are +1 SE. Numbers above bars represent the total number of fish caught. Letters indicate significant differences at 5% level. Note different scales on y-axes.

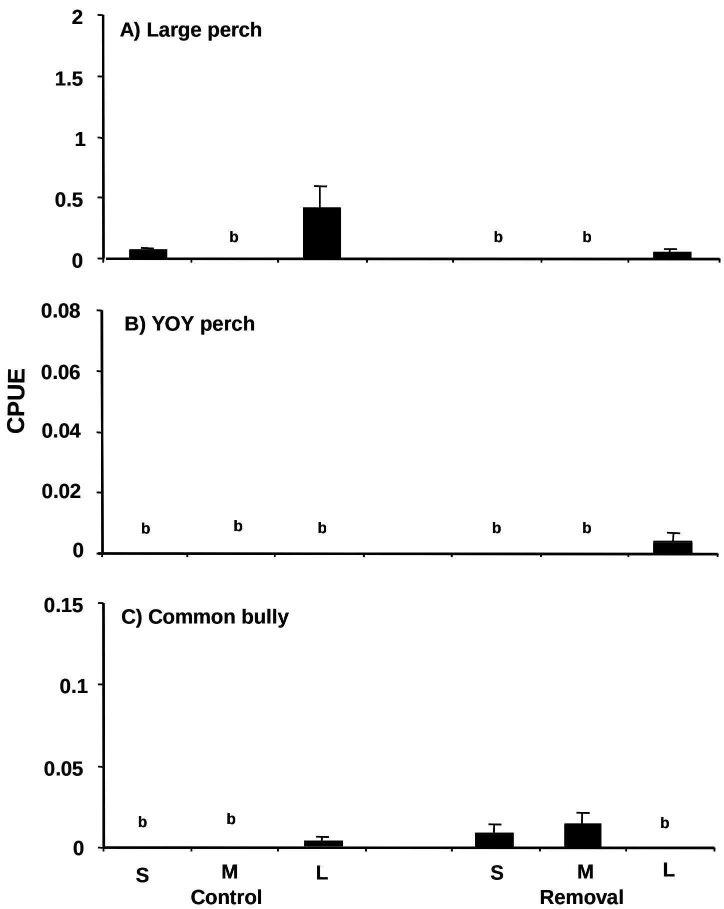
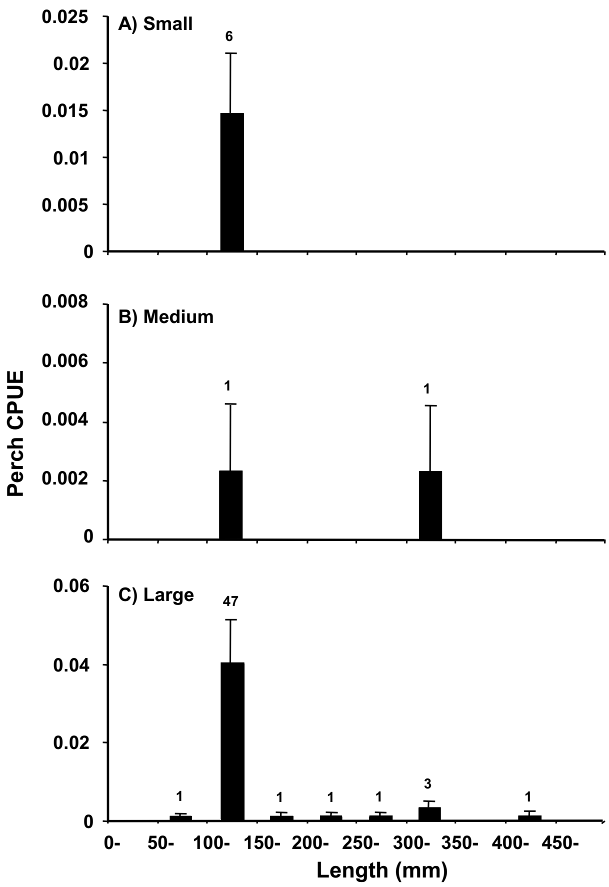


Figure 5. CPUE (No. fish hr^{-1} net^{-1}) of 50 mm length classes of perch caught during the 1999 perch removal in the (A) small, (B) medium and (C) large perch removal ponds. Error bars are +1 SE. Numbers above bars represent the total number of fish caught. Note different scales on y-axes.



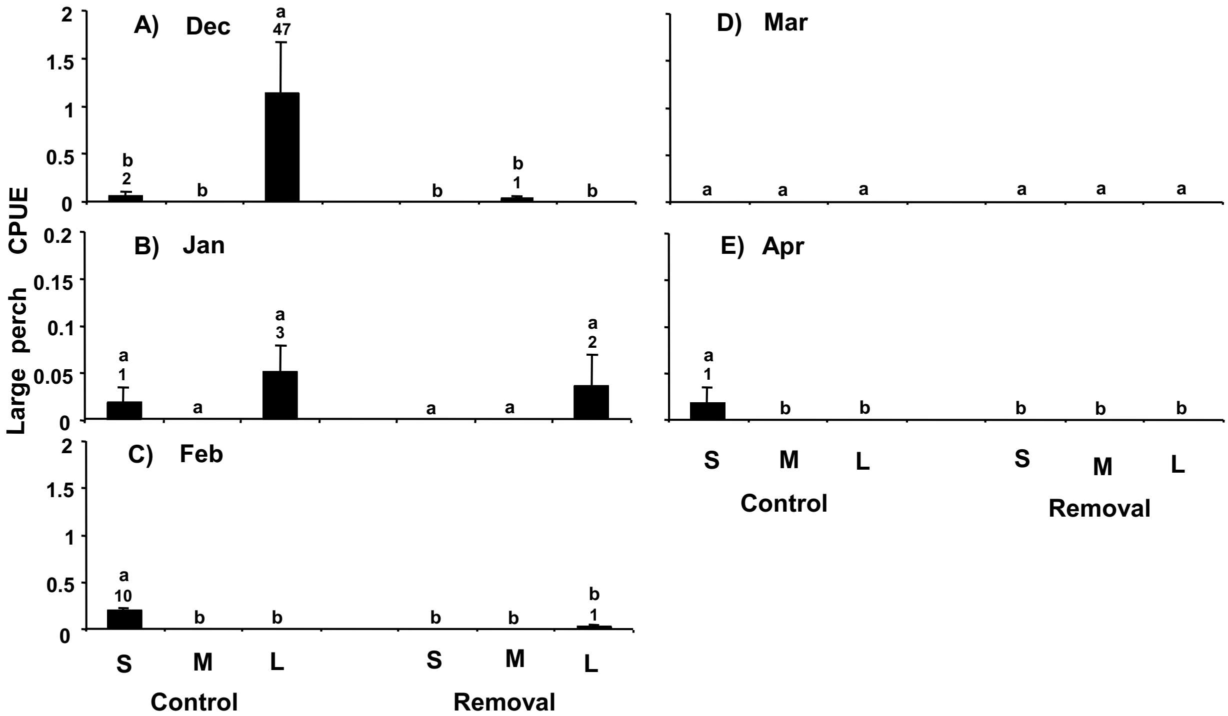


Figure 6. CPUE (No. fish hr^{-1} net^{-1}) of large perch (>80 mm) in (A) December 1999, (B) January 2000, (C) February 2000, (D) March 2000 and (E) April 2000. Error bars are +1 SE. Numbers above bars represent the total number of fish caught. Letters indicate significant differences at 5% level. Note different scales in (B) January 2000 and (E) April 2000.

January 2000 and one in February 2000. Large perch were caught more frequently in the control ponds, with significantly higher numbers of large perch being caught in the large control pond in December 1999 compared with the other ponds. Large perch were caught in reasonable numbers in January 2000 in the small and large control ponds, while in February 2000 ten large perch were caught in the small control pond. The numbers of large perch caught and released subsequently decreased, with no large perch captured in any ponds in March 2000, and only one large perch caught in the small control pond in April 2000.

Following the pre-spawning perch removals in the small and medium removal ponds in late November no YOY perch were observed at any time in these ponds during the 1999–2000 season (Fig. 7). However, in December 1999 ten YOY perch were caught in the large removal pond, indicating that the perch removal had either been only partly successful or had occurred after spawning. Capture rates of YOY perch were also high in the large control pond at this time, but decreased dramatically by January 2000, when only one YOY perch was caught in this pond. Similarly, the small control pond had low numbers of YOY perch present in January 2000, and these also had decreased in abundance by the following sampling date. YOY perch were not caught in any of the control ponds from the March sampling onwards, while the large removal pond supported low numbers of YOY perch in both March and April.

The low abundance of common bullies in December 1999 was similar to the patterns observed prior to the perch removals in November 1999 (Fig. 4C and 8A). However, no common bullies were observed in the large control pond at

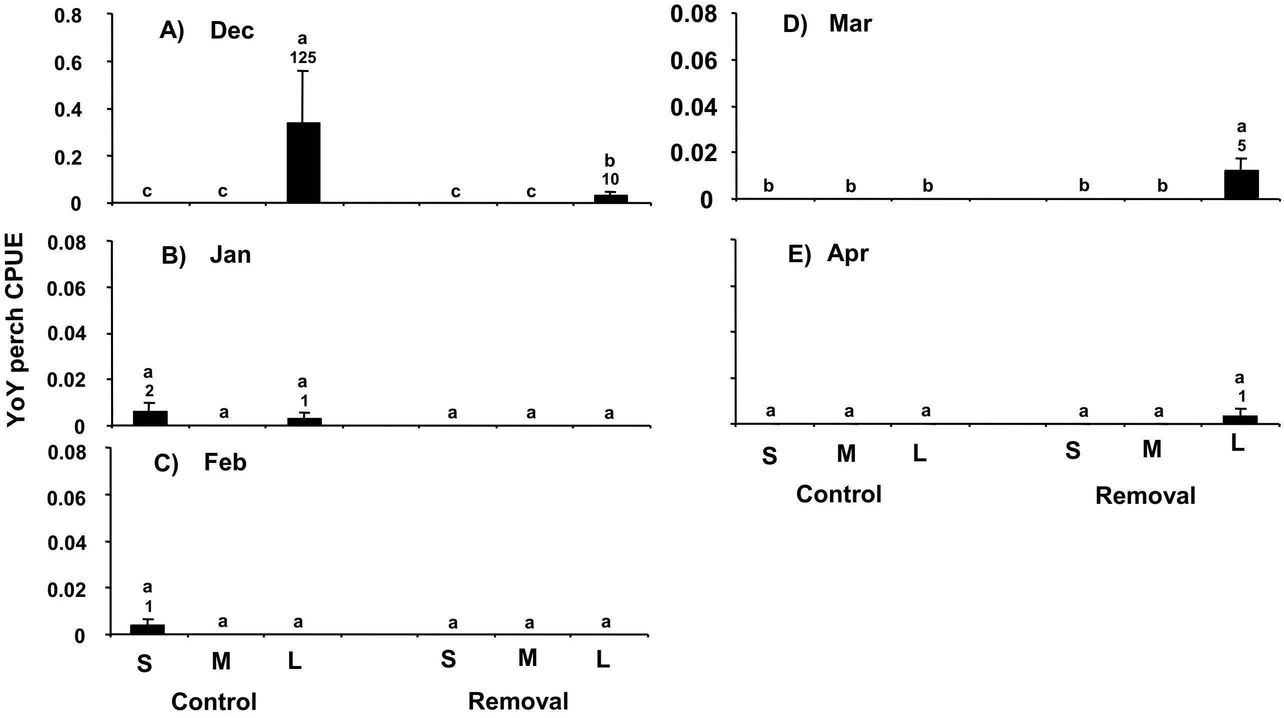


Figure 7. CPUE (No. fish hr^{-1} net^{-1}) of YOY perch (<80 mm) in (A) December 1999, (B) January 2000, (C) February 2000, (D) March 2000 and (E) April 2000. Error bars are +1 SE. Numbers above bars represent the total number of fish caught. Letters indicate significant differences at 5% level. Note different scale in (A) December 1999

these times. By January 2000 the CPUE of bullies in the small and medium removal ponds had increased, as did the CPUE of common bullies in the medium control pond (Fig. 8). February 2000 saw significantly higher numbers of bullies caught in the small and medium removal ponds, with low numbers observed in all the other ponds and none in the large control pond. By the main bully spawning period of March, bully abundance was significantly higher in the small and medium removal ponds, as well as in the medium control pond compared with all other ponds. This pattern was also seen in April 2000 where the highest numbers of bullies in the 1999–2000 season were observed in the medium control, and the small and medium removal ponds. No significant differences in bully CPUE occurred between these three ponds at this time.

4.5 FISH COMMUNITY 2000/2001

During the monitoring (November 2000) prior to the second round of perch removal, eight large perch were caught in the large control pond, with only one and two perch caught in the small and large removal ponds respectively (Fig. 9). Two large perch were caught in the small control pond. Large numbers of YOY perch were caught in the medium control pond indicating a successful spawning event in this pond. Prior to this catch few perch had been caught from this pond. One YOY perch was also caught in the large removal pond. Common bullies were caught in relatively high numbers in the small and medium removal ponds in November 2000, as well as in the medium control pond.

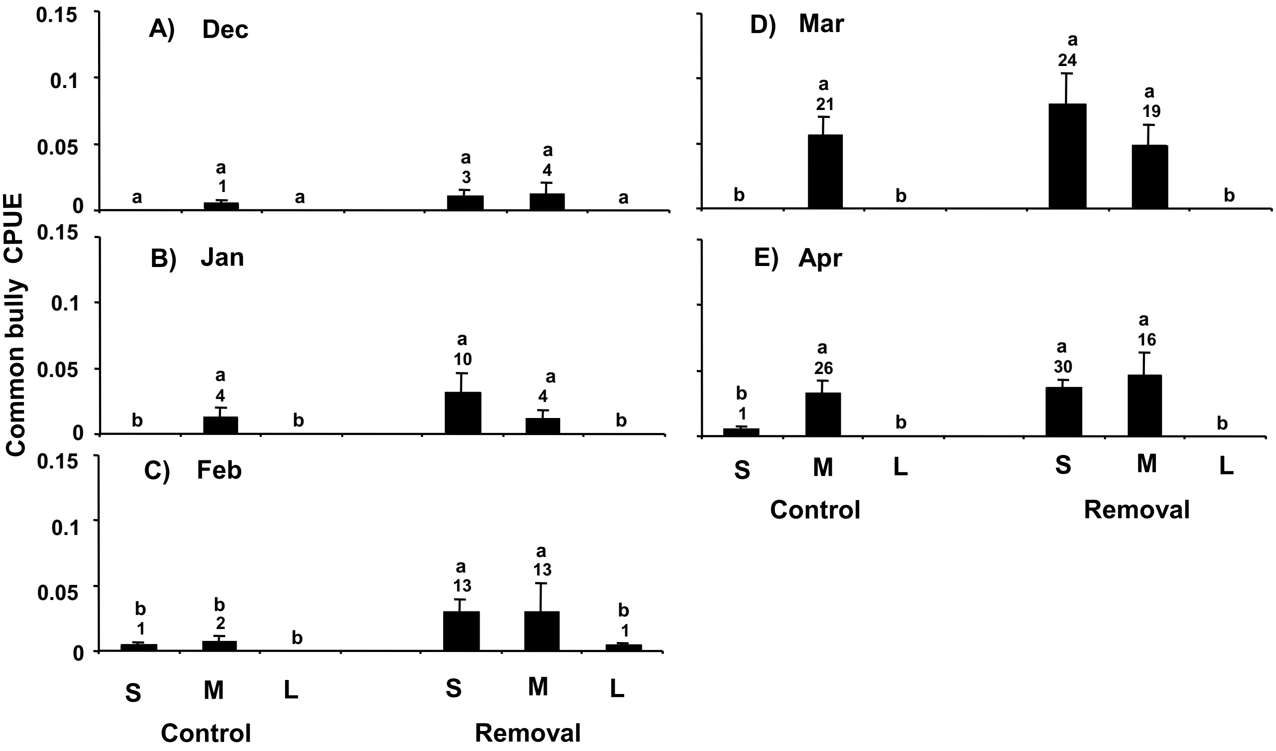
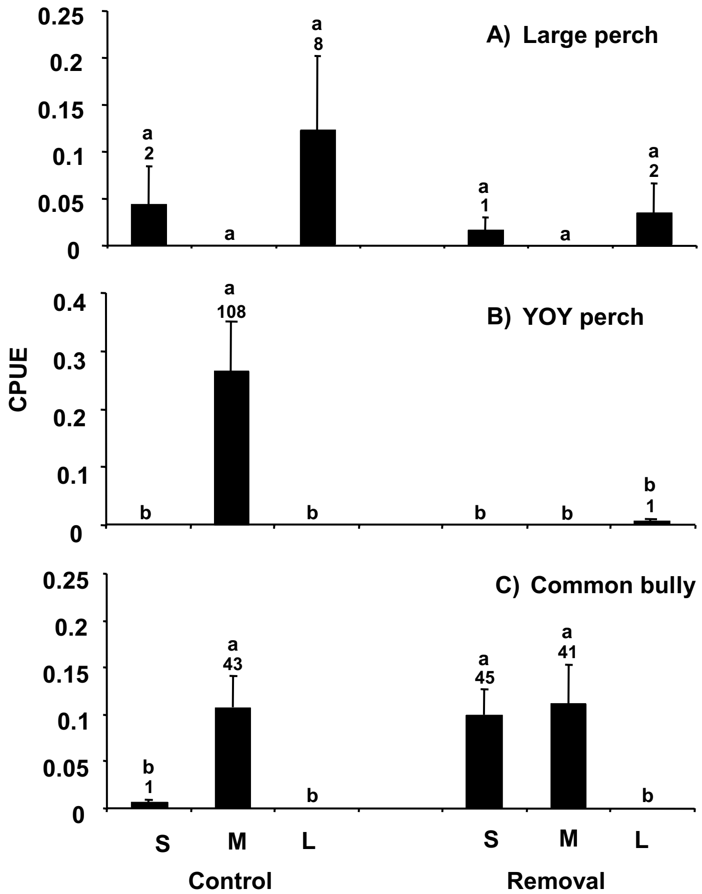


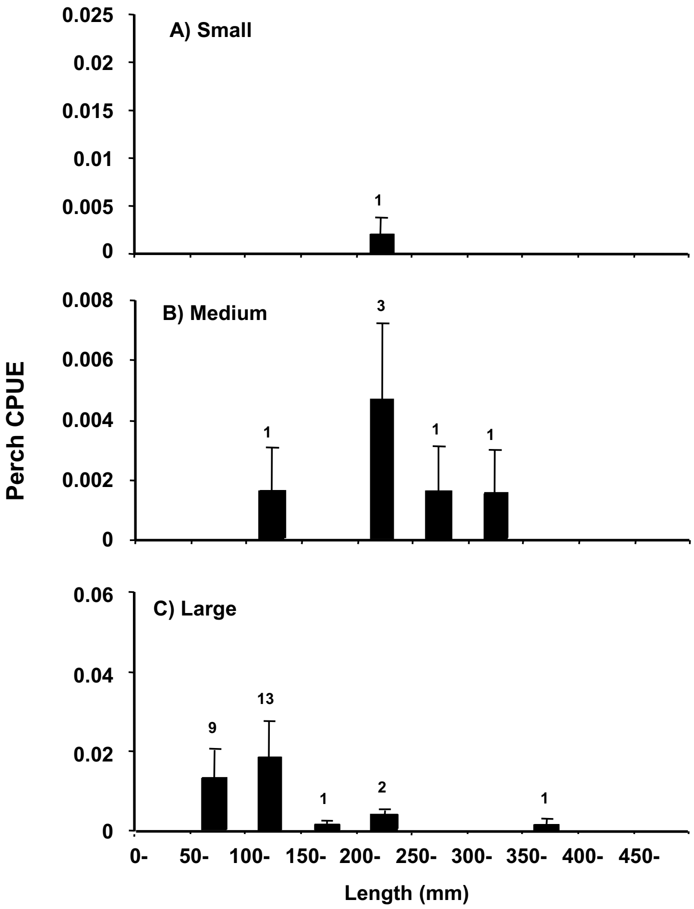
Figure 8. CPUE (No. fish hr^{-1} net^{-1}) of common bullies in (A) December 1999, (B) January 2000, (C) February 2000, (D) March 2000 and (E) April 2000. Error bars are +1 SE. Numbers above bars represent the total number of fish caught. Letters indicate significant differences at 5% level.

Figure 9. CPUE (No. fish hr^{-1} net^{-1}) of fish in November 2000: (A) large perch, (B) YOY perch and (C) common bullies. Error bars are +1 SE. Numbers above bars represent the total number of fish caught. Letters indicate significant differences at 5% level. Note different scale in (B) YOY perch.



The perch removal conducted in early December 2000 recorded low abundances of perch in the small and medium removal pond, with higher numbers of perch in the large perch removal pond (Fig. 10). When compared to the first perch removal in 1999 (Fig. 5), the catch rate of perch from the medium removal pond was higher in the second removal. Catch rates during the second removal were clearly improved by the use of the six 12 m long fine monofilament multi-mesh gill nets, which accounted for 70% of the total catch of perch from gill nets at this time. In the small removal pond only one perch was captured, with a length of 201 mm, and in the medium removal pond six perch were caught, ranging in length from 124–313 mm. However, in the large removal pond 26 perch were caught with 22 being less than 150 mm, indicating survival of significant numbers of YOY perch from the previous year.

Figure 10. CPUE (No. fish hr^{-1} net^{-1}) of 50 mm length classes of perch caught during the 2000 perch removal in the (A) small, (B) medium and (C) large removal ponds. Error bars are +1 SE. Numbers above bars represent the total number of fish caught. Note different scales on y-axes.



In January and March 2001, no large perch were captured in any of the removal ponds (Fig. 11). In January 2001 no large perch were captured in the control ponds, but in March 2001 low numbers were caught in the small and medium control ponds.

YOY perch were caught in low numbers in the small and medium control ponds and the large removal pond in January 2001 (Fig. 12) indicating that spawning had occurred in these ponds at some time. However, by March 2001 no YOY perch were caught in the control ponds, while in the large removal pond YOY perch were still present.

Figure 11. CPUE (No. fish hr^{-1} net^{-1}) of large perch in (A) January 2001 and (B) March 2001. Error bars are +1 SE. Numbers above bars represent the total number of fish caught. Letters indicate significant differences at 5% level.

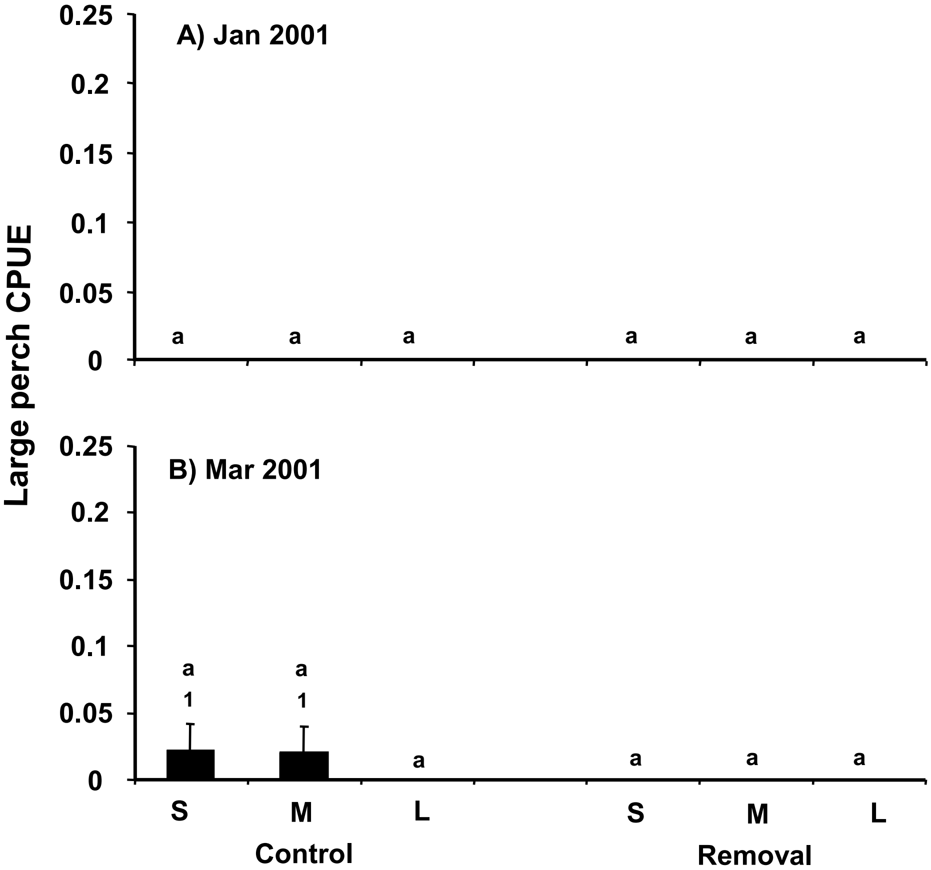
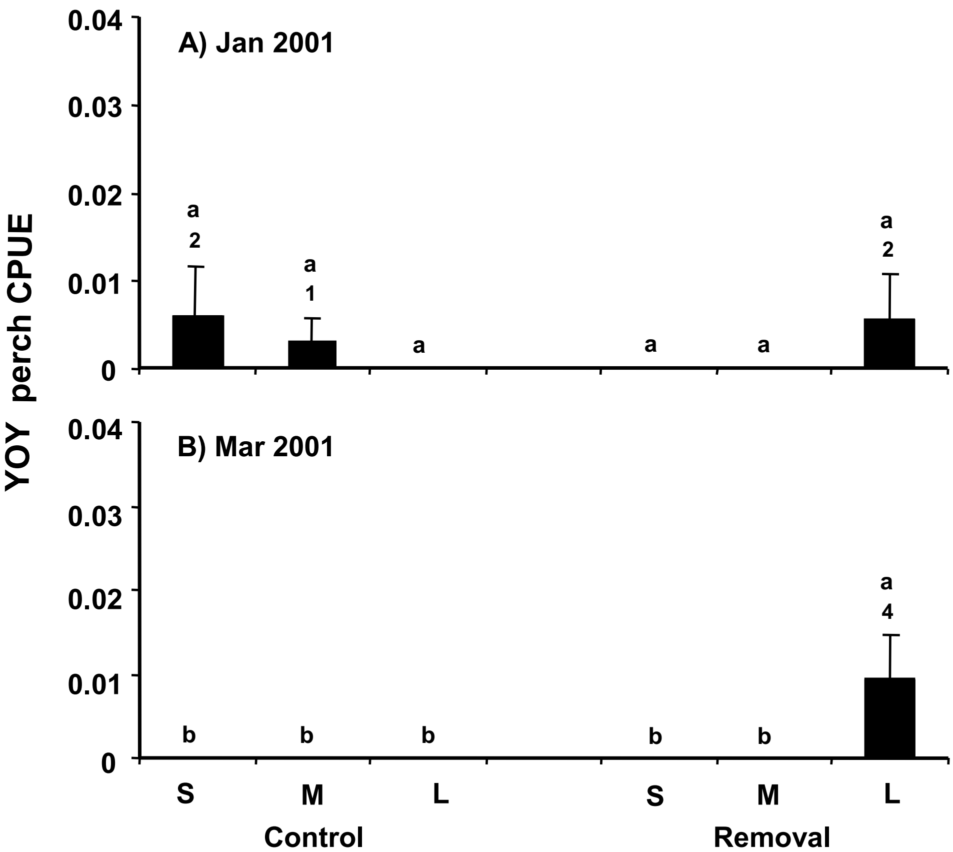


Figure 12. CPUE (No. fish hr^{-1} net^{-1}) of YOY perch in (A) January 2001 and (B) March 2001. Error bars are +1 SE. Numbers above bars represent the total number of fish caught. Letters indicate significant differences at 5% level.



Similar to November 2000 (Fig. 9C), the abundance of common bullies was high in January 2001 in the small and medium removal ponds, and in the medium control pond (Fig. 13). However, by March 2001 the catch rates of bullies had decreased in the medium control pond, but had increased dramatically in the small and medium removal ponds. The CPUE of bullies in the large removal pond remained low.

4.6 OTHER FISH

In 1999/2000 significantly more longfin eels were found in the medium control pond compared with the other ponds, whereas the abundance of shortfin eels was significantly greater in the small and medium control ponds (Fig. 14). In the 2000/2001 period significantly more shortfin eels were caught in the medium control pond, while the large control pond contained considerably higher numbers of inanga relative to the other ponds.

Figure 13. CPUE (No. fish hr^{-1} net^{-1}) of common bullies in (A) January 2001 and (B) March 2001. Error bars are +1 SE. Numbers above bars represent the total number of fish caught. Letters indicate significant differences at 5% level.

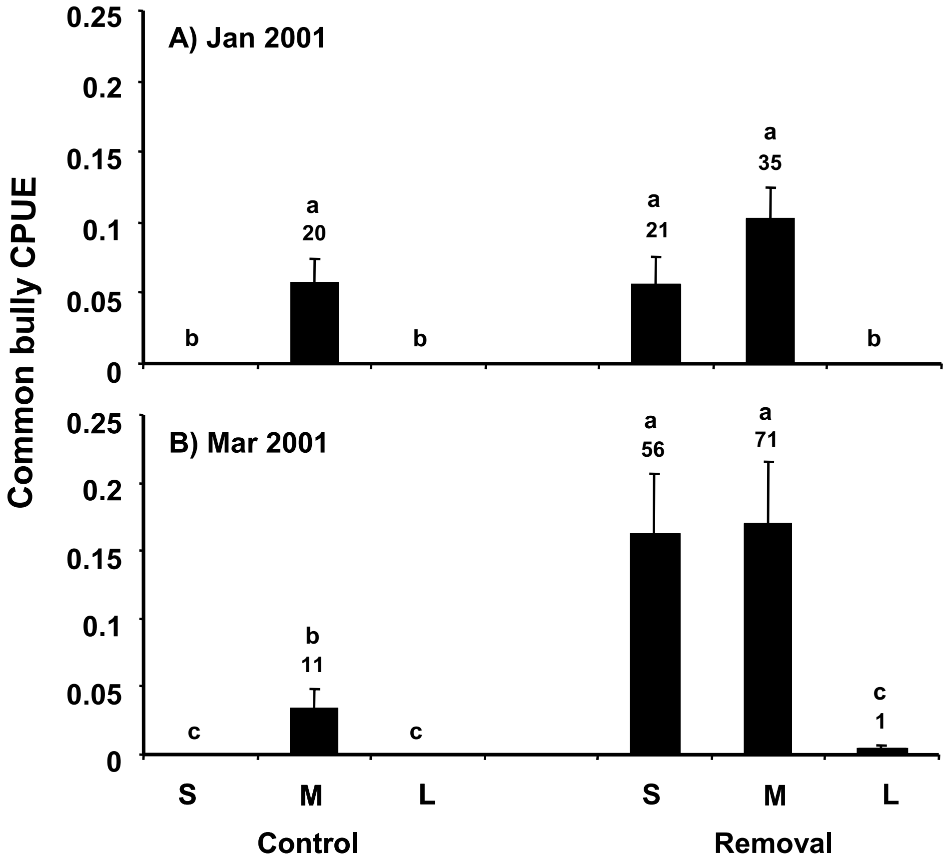
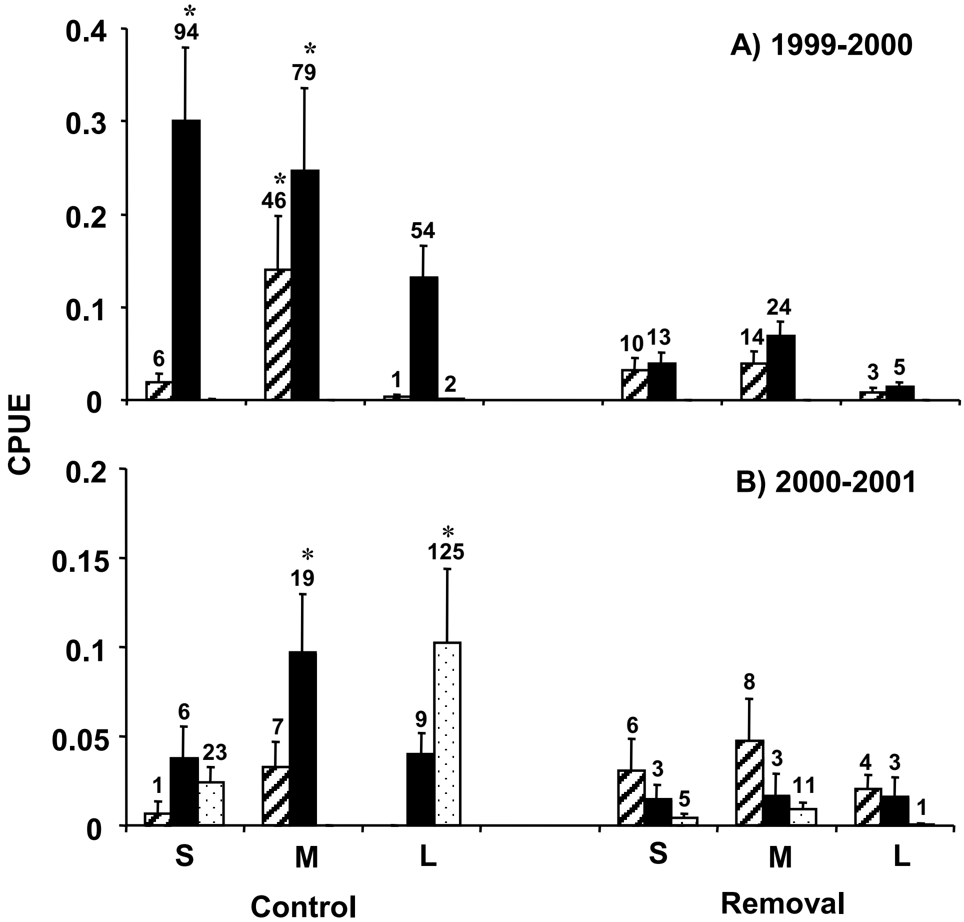


Figure 14. CPUE (No. fish hr^{-1} net^{-1}) per pond for (A) 1999–2000 and (B) 2000–2001. Fish species shown are long-finned eels (diagonals), short-finned eels (solid) and inanga (spots). Eel data from fyke nets only; inanga data from minnow and fyke nets. Error bars are +1 SE. Numbers above bars represent the total number of fish caught. Asterisk above bar represents significant difference between ponds at 5% level. Note different scales on y-axes.



4.7 FINAL SURVEY

The patterns in perch population structure observed through January and March 2000 were supported by the results of the final gill and fyke net survey across all of the ponds (Fig. 15). Perch ranging from 101–355 mm were observed in all three of the control ponds, with no YOY perch being observed at this time. No perch were captured in the small removal pond, and only one 173 mm perch was removed from the medium removal pond. In contrast, large numbers of YOY perch were collected from the large removal pond, with only one 214 mm perch being captured at this time.

4.8 COMMON BULLY SIZE DISTRIBUTION

In the early spawning period of 1999/2000 bullies were found in low numbers in ponds across both treatments (Fig. 16). The length distribution of bullies did not differ significantly between the treatments (Kolmogorov-Smirnov test: D = 0.393, P = 0.46). However, in the late spawning period bully size distributions did differ (K.-S. test: D = 0.346, P < 0.0001) with larger bullies and a greater size range present in the removal ponds.

The distributions of bully lengths differed between the control and perch removal ponds in the early spawning 2000/2001 period (K.-S. test: D = 0.206, P

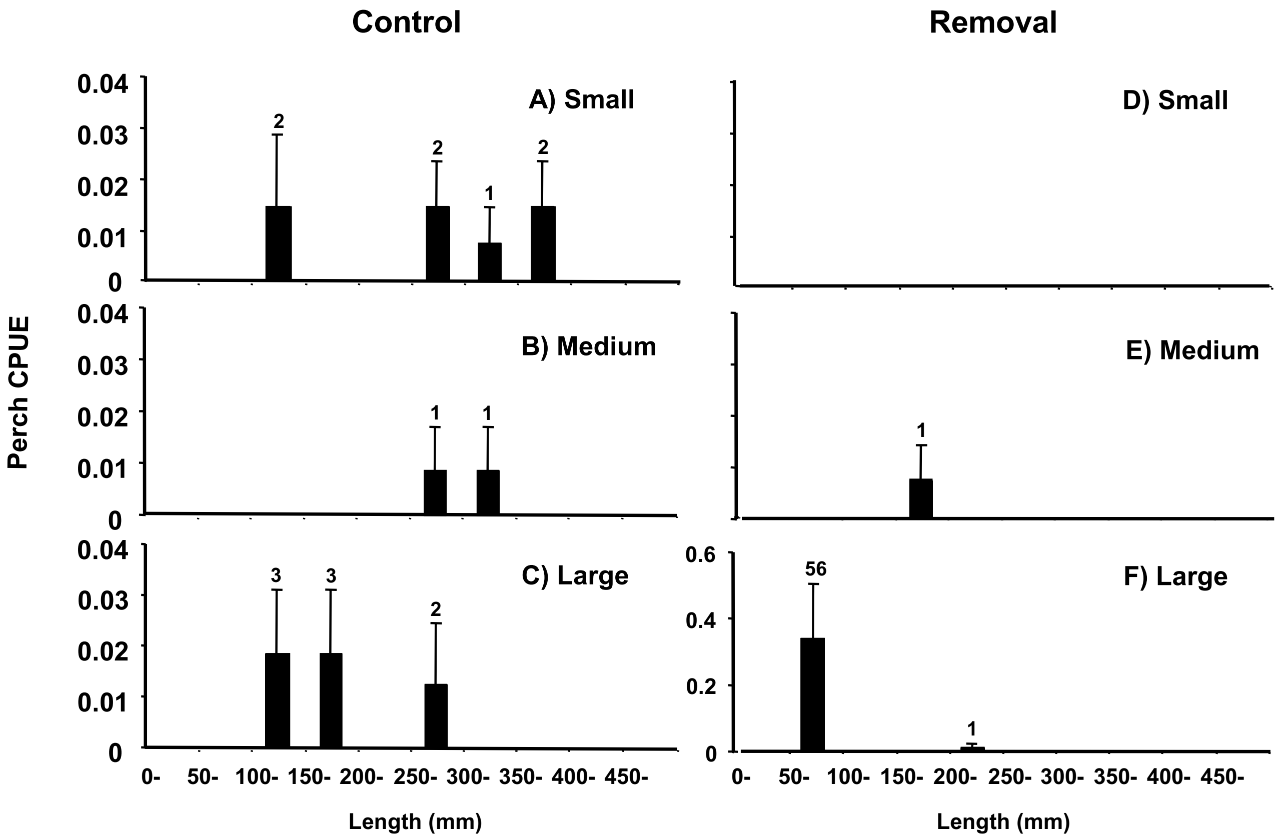


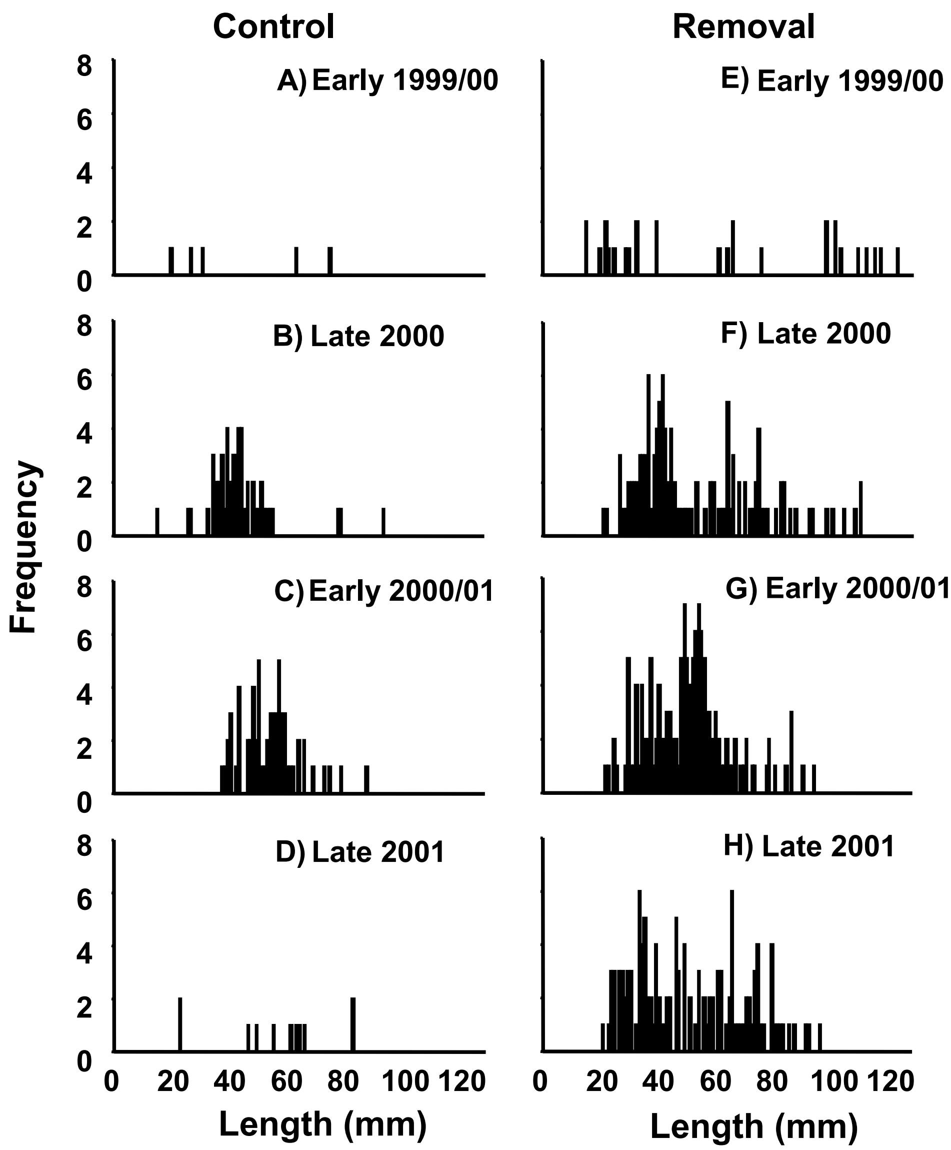
Figure 15. CPUE (No. fish hr^{-1} net^{-1}) of perch from the final survey in April 2001 in the control ponds: (A) small, (B) medium and (C) large; and the perch removal ponds: (D) small, (E) medium and (F) large. Error bars +1 SE. Numbers above bars represent the total number of fish caught. Note different scale on y-axis of (F) large perch removal pond.

= 0.05; Fig. 16). A change occurred in the late spawning period in 2000/2001 when the number of bullies dropped in the control ponds, but the small and medium removal ponds contained large numbers of bullies across a wide size range. However, at this time there was no significant difference in the size distribution despite the considerable difference in abundance (K.-S. test: D = 0.263, P = 0.42).

4.9 SUMMARY OF FISH COMMUNITY DYNAMICS (1999–2001)

Large perch were caught in all six of the study ponds in the preliminary survey and were caught in all three of the control ponds at some stage during the fish community monitoring. However, large perch were rarely caught in the three perch removal ponds after the initial removal, with no large perch being caught following the second perch removal in these ponds in December 2000. The results of the final survey also indicated that large perch were still present in reasonable numbers in the control ponds, but few were present in the removal ponds. YOY perch were observed for short periods in December and January in the control ponds, but were caught over the entire study in the large perch removal pond. YOY perch were not caught at any time in the small and medium

Figure 16. Lengths of common bullies in the control ponds: (A) early spawning 1999/2000, (B) late spawning 2000, (C) early spawning 2000/2001 and (D) late spawning 2001; and the perch removal ponds: (E) early spawning 1999/2000, (F) late spawning 2000, (G) early spawning 2000/2001 and (H) late spawning 2001. Early spawning times are November to January. Late spawning times are February to April.



removal ponds. Common bullies were abundant in the small and medium removal ponds and the medium control pond. In the 2000/2001 monitoring season the abundance of bullies in the small and medium removal ponds increased dramatically, while the population in the medium control pond decreased. The size structure of the bullies changed in the control and removal ponds throughout the study, with a greater number of small and large bullies observed in the small and medium removal ponds. Longfin eels were present in greater numbers in the medium control pond in 1999/2000 compared with the other ponds, while shortfin eels were more abundant in all three of the control ponds in 1999/2000. Inanga were more abundant in the large control pond than the other ponds in the 2000/2001 monitoring season.

5. Discussion

5.1 PHYSICO-CHEMICAL PARAMETERS

Depth, water transparency, salinity and conductivity levels differed significantly between ponds during this study. Salinity and conductivity levels observed remained within the tolerance limits of the fish species present (Thorpe 1977; McDowall 1990). The differences in the depth and water transparency observed between the ponds in this study were unlikely to have influenced the dynamics of the fish communities.

Water temperature, pH and dissolved oxygen did not differ significantly between ponds. Dissolved oxygen levels as low as 0.3 mg L-1 were observed at various locations within certain ponds. Levels of less than 1 mg L-1 is a lethal oxygen level for many fish species (Matthews 1998), however these readings were only observed around the edges and the bottom areas of the ponds. All measurements taken from the pond surface were greater than 1 mg L-1. The pH and water temperatures observed in the ponds remained within tolerance limits of the fish species in the ponds (Thorpe 1977; Richardson et al. 1994).

5.2 CATCH SELECTIVITY OF GILL AND FYKE NETS

Selectivity for particular sizes of perch was evident in the catch by either fyke or gill nets, with fyke nets tending to catch smaller fish relative to the gill nets. A degree of selectivity is an inevitable feature of any passive sampling device (Hubert 1996), and the patterns of perch capture over the course of this study must be interpreted in light of likely sampling bias at any particular time. With the exception of the final survey, gill nets were only used to capture perch in the removal ponds. Typically, the efficiency of gill nets is relatively high but is also often associated with some fish injury and mortality (Hubert 1996). Consequently, gill nets could not be used in the control ponds, where the intention was to maintain natural perch populations, and so required the return of all captured fish alive and in good condition. Hence, we could use only fyke nets during the regular monitoring of fish populations. As a result, perch catch rates during the regular monitoring from the medium and small control ponds were low, given that perch populations in these ponds were dominated by a small number of large perch. In the large control pond, mostly small perch were captured during the regular monitoring in the summers of both 1999/2000 and 2000/2001. However, it is important that large perch (>300 mm long) were captured from all three control ponds when gill nets were used along with fyke nets during the final survey in April 2001. In contrast, no large perch were captured from any of the removal ponds during the final fyke and gill net survey in April 2001. Given that perch over 300 mm long are likely to be over 4 years old (Jellyman 1980), the final gill and fyke net survey confirmed that large adult perch were present in all of the control ponds over the course of the study.

5.3 IMPACT OF REMOVALS ON PERCH POPULATION STRUCTURE AND DYNAMICS

The pattern of population dynamics observed in response to either the removal or non-removal of adult perch are comparable to patterns of perch population dynamics seen in Northern Hemisphere perch populations (Treasurer 1993; Wahlström et al. 2000). Perch spawning in spring (September–November) resulted in a marked increase in the numbers of YOY fish in the control ponds, although the success of the various spawning events was variable across different years. However, in the control ponds where adult perch were present, subsequent survival of YOY perch was low suggesting cannibalism was regulating the population (Treasurer 1993; Persson et al. 2000; Wahlström et al. 2000). In contrast, the YOY perch observed in the large perch removal pond in November 1999 and 2000 were still present in April 2000 and March 2001 respectively, suggesting that cannibalism was reduced, presumably due to the previous removal of large piscivorous perch from this pond.

The importance of cannibalism in controlling recruitment of perch populations is well known in the Northern Hemisphere (e.g. Treasurer 1993; Mehner 1993; Wahlström et al. 2000). In a small Scottish lake with intensive angling pressure and hence removal of larger perch, Treasurer (1993) found that YOY perch survival was greater compared with another lake where no angling occurred and adult perch were more numerous. In larger lakes, Wang & Eckmann (1994) observed that cannibalism of young perch by adults occurred when the two age classes co-occurred in the same habitats. Size-selective predation on larval perch has also been found to be a determining factor in the strength of perch year-classes (Mehner 1993; Sanderson et al. 1999)

The success of perch spawning and subsequent recruitment was variable between ponds across the different years in this study. A variety of factors may influence patterns of perch recruitment including the number of eggs produced, and egg and larval perch survival (Le Cren 1955; Koonce et al. 1977; Treasurer et al. 1992). Environmental factors, such as wind and temperature, can limit survival during the early stages of larval development (Koonce et al. 1977; Treasurer et al. 1992). Predation on larval perch may also be significant (Sanderson et al. 1999). Further, it is possible that in the ponds where evidence of perch spawning was not observed, the YOY perch may have already declined in abundance prior to sampling due to cannibalism by the large piscivorous perch present (Treasurer et al. 1992). Predation rates are likely to have been relatively high due to the limited refuge areas available and the high encounter rates that would be expected to occur in the relatively small ponds.

5.4 IMPACT OF PERCH REMOVAL ON COMMON BULLIES

Marked increases in the numbers of common bullies occurred in the small and medium removal ponds. Removal of adult perch from these ponds appeared to be relatively successful with no adult perch being captured in either of these ponds after the perch removal in November 2000. In contrast, bully numbers remained low in two of the control ponds and in the large removal pond where perch remained abundant. In the medium control pond the number of bullies increased during the first year of this study before declining in the second when perch spawned successfully and the abundance of YOY perch was high. The results suggest that the presence of either YOY or large perch reduces the abundance of common bullies. Perch have been implicated in the decline of native fish species in both Australia and New Zealand (Cadwallader & Backhouse 1983; McDowall 1990; Pen & Potter 1992; McDowall 1996), although experimental studies have not previously been conducted to determine the strength of interactions between perch and native species (McDowall 1987). This study represents the first direct evidence of a possible negative effect of perch on a native fish species in New Zealand.

The mechanisms that may contribute to the observed negative relationship between perch and bullies are probably a combination of direct predation and competition (Persson 1988). Given the piscivorous nature of large perch (Persson 1988) and previous observations of predation on bullies by perch (Duncan 1967; Griffiths 1976), we consider predation is likely to be the primary mechanism by which perch reduce bully numbers. However, predation of bullies by juvenile perch could also have contributed to the suppression of common bully numbers seen in this study. Because there is a difference in the main spawning times of perch (September–November) and the common bully (March–April) observed in this study, it is possible that some of the juvenile perch developed to a size where they could be potential predators of larval bullies (Brabrand 1995, 2001; Borcherding et al. 2000). This could have contributed to the low abundance of bullies seen in the large removal pond, where large numbers of YOY perch were observed throughout the study following the removal of adult perch.

Competitive interactions between the two fish species may also contribute to the suppression of common bullies by perch (Eklöv & Persson 1995). This interspecific competition could potentially be for food resources or favoured habitats. Ontogenetic diet and habitat shifts by perch include periods where they feed predominantly on pelagic zooplankton and benthic macroinvertebrates in either the pelagic or littoral habitats respectively (Persson 1988). These invertebrate groups dominate the diet of common bullies throughout their life history, and pelagic and benthic littoral habitats are used by juvenile and adult bullies respectively (McDowall 1990; Rowe & Chisnall 1996). Occupation of similar pelagic and littoral habitats by juvenile perch may bring them into direct competition with bullies for both food and habitat.

5.5 PRESENCE OF OTHER FISH

Three fish species other than perch and common bullies were recorded in all ponds throughout the study. Longfin eels were present in greater numbers in the medium control pond in 1999/2000 than in the other ponds, but by 2000/2001 the abundance across all of the ponds was similar. Shortfin eels were abundant in all ponds throughout the study, with greater numbers seen in all three of the control ponds in 1999/2000. No obvious reason for this difference could be confidently identified. The eel populations in the study ponds were initially abundant, but declined in the second year of this study across all ponds. The mechanism for this decline is also unknown. Rowe (1999) suggested that the presence of eels in lakes possibly reduced the abundance of common bullies, however there were no consistent relationships between the abundance of eels and the abundance of perch and common bullies. In this study, high bully abundance was observed in conjunction with a high abundance of eels in the medium control pond.

Relatively higher numbers of inanga were observed in 2000/2001, particularly in the large control pond. This increase was almost certainly due to the movement of juvenile inanga into the ponds during the minor flood across the area in August 2000. Following the entry of these inanga into the ponds in August 2000, numbers of inanga did not appear to change in relation to the number of perch or bullies present in the ponds. Significantly, the flood did not appear to alter the abundance of perch and common bullies given that similar patterns of relative abundance were evident across each pond between April and November 2000. The absence of changes in the abundance of perch and common bullies in relation to the flood was most probably due to the limited activity exhibited by these fish species during winter and the absence of juveniles which might be more likely to be passively transported by flood waters.

5.6 USE OF GILL AND FYKE NETTING AS A METHOD OF PERCH REDUCTION AND ERADICATION

This study demonstrates that perch numbers can be reduced, and perhaps even eradicated successfully from small lentic habitats using gill and fyke netting. Such a result is important, given that many of the more recent records of new perch occurrence in New Zealand are in relatively small lentic habitats. Use of gill and fyke nets in our study had little or no impact on the abundance of bullies, suggesting that physical removal may be a useful control option where certain native fish are present. However, our attempts to remove adult perch were obviously less successful in the large removal pond where spawning occurred. Further, small perch were also captured in the medium removal pond during the final survey in April 2001 (and have since been caught in December 2001). As pond/lake size increases, increased habitat heterogeneity and the difficulty associated with attempting to net a larger area are likely to contribute to reduced catch efficiency. This is a factor that is likely to severely limit the usefulness of gill and fyke netting as a perch eradication technique.

An aspect of perch ecology that may facilitate successful removal is the tendency of perch populations in small lentic habitats to be cannibalistic and hence be dominated by a relatively small number of large fish. Targeting these large fish in late autumn would appear to offer the greatest chances of successful perch control. In autumn, water temperatures are still relatively high, hence perch are still active and likely to be caught using passive trapping techniques. More importantly, juvenile perch are less abundant at this time hence less sampling effort is required to remove the remaining adult perch.

An increase in YOY survival resulting in increased perch population densities is an obvious risk factor to consider when removing larger piscivorous perch (Treasurer 1993). In this study, the post-spawning removal of large perch in the large removal pond produced a fish community that numerically contained higher numbers of perch compared with the community present at the start of the study. Increased recruitment will very quickly negate the value of any removal attempt as the juvenile fish will attain adult sizes within three years, and may commence spawning even earlier (McDowall 1990). Timing of removal is therefore crucial to avoid increased YOY survival. Again, attempting removals in autumn would appear likely to minimize the risk of increased juvenile survival, given that previous predation on YOY fish by piscivorous adults is likely to have reduced juvenile numbers (as observed in this study). Alternatively, a short window of opportunity also exists in spring (September–October) as warmer water temperatures result in increased fish movement, thus rendering them vulnerable to passive sampling techniques. However, cold weather conditions (such as those encountered in this study) can result in low catch efficiencies or force the delay of removal attempts until after spawning.

Methods to suppress the recruitment of juvenile perch following adult perch removal are clearly an area requiring further research. A possible strategy to explore is the introduction of sterile large perch into habitats from which fertile large perch have been removed. Sterile fish will not contribute offspring to existing fish populations, but through cannibalism will serve to limit subsequent YOY survival should successful spawning occur between any remaining adult non-sterile fish. Sterile fish could subsequently be removed when the absence of juvenile perch suggests that all fertile perch in the population have been eliminated. The successful production of sterile triploid fish by heat or pressure shocking of eggs in the closely related yellow perch (*Perca flavescens*) suggests such an approach may be feasible (Malison et al. 1993a, b).

Our attempts to successfully target perch in small lentic habitats would be greatly assisted by improved knowledge of perch microhabitat selection, and patterns of diel movement and activity. Whilst our understanding of the broad habitats used by perch at various life-history stages is good (Wang & Eckmann 1994; Imbrock et al. 1996), to our knowledge there are no detailed studies of the factors that determine microhabitat selection within these broader habitat catagories. Patterns of diel activity have been documented in large lakes (Imbrock et al. 1996), however, again there are no studies of diel activity in smaller lentic habitats or river systems. Further, patterns of movement, home range, and hunting strategies of individual fish have not been examined. Understanding such patterns of habitat use and activity could be greatly enhanced through the use of radio telemetry. Knowledge of the movements of perch within a specific habitat could improve subsequent capture rates through informed placement of nets and other trapping devices. Such information will be crucial to successful perch control in larger habitats. Radio telemetry also offers scope for exploring additional approaches to perch control. Given that perch are typically a shoaling species (Imbrock et al. 1996), radiotagged perch could be released and at a later time relocated thus revealing the position of a perch shoal.

6. Conclusions

The results of this study indicate that perch are having a significant impact on the abundance of common bullies in shallow coastal lakes in New Zealand. In this study, the removal of adult perch from three small wetland ponds resulted in marked changes in the population and community structure of the fish communities in all three ponds over a two year period. In the two smallest removal ponds, perch removal appeared to be relatively successful with no adult perch caught in these ponds after November 2000. An increase in the abundance of common bullies was observed in both of these ponds from year one of the study, with bully numbers continuing to increase through the second year of the study. It is worth noting that bully catch rates in both of these ponds are lower than catch rates from other ponds in the area which are naturally perch free (David 2002). Consequently, we anticipate that bully abundance will continue to increase in these ponds provided they remain perch free. Long-term manipulations of predatory fish populations elsewhere have demonstrated that community responses may take several years to fully express themselves following the initial manipulation (McQueen et al. 2001). In contrast to the changes observed in the removal ponds, the fish communities remained relatively stable in three ponds where adult perch were not removed. Large adult perch continued to dominate the fish community in each of these ponds.

The impact of perch on New Zealand freshwater ecosystems is likely to be complex. Although the removal of adult perch was associated with an increase in the abundance of common bully in this study, such a response may not be repeated elsewhere. The impact of perch predation on native fish species other than common bullies either remains unknown or is limited. Several of these species, including giant kokopu, eels, smelt, and inanga, may either predate on common bully, or compete for various resources (McDowall 1990). Interactions between native fish have been previously implicated in the low abundance of koaro and common bully in various lentic habitats (Rowe 1999). Removal of perch from habitats where these species are currently sympatric would further our understanding of the impact of perch introduction on New Zealand's lowland freshwater ecosystems.

The use of gill and fyke netting does appear to be a potentially useful control option for perch in small lentic systems. However, the success of our attempts to remove perch from each pond system clearly declined as the size of the ponds increased. In larger ponds, we feel that it would be difficult to eradicate perch entirely without considerably greater effort. Unfortunately, as observed in this study, perch have the capacity to rapidly repopulate habitats in which piscivourous adult perch have been previously reduced. Research into methods which increase the efficiency of removal or which reduce the likelihood of successful spawning and recruitment is required.

7. Acknowledgements

This research was funded by the Department of Conservation (investigation no. 3246). We are grateful for permission to work in the Sinclair Wetlands from the Sinclair Wetlands Committee and Kai Tahu. Otago Fish and Game gave permission to remove perch. Thanks to all the people who assisted with field sampling, in particular Nathan Whitmore and Cath Hall. Comments by Richard Allibone, Ruth Goldsmith and Mark Lintermans on earlier drafts greatly improved this report. The research was conducted with the permission of University of Otago Animal Ethics Committee.

8. References

Bean, C.W.; Winfield, I.J. 1995: Habitat use and activity patterns of roach (*Rutilus rutilus* (L.)), rudd (*Scardinius erythrophthalmus* (L.)), perch (*Perca fluviatilis* L.) and pike (*Esox lucius* L.) in the laboratory: the role of predation threat and structural complexity. *Ecology of Freshwater Fish 4*: 37–46.

Borcherding, J.; Maw, S.K.; Tauber, S. 2000: Growth of 0+ perch (*Perca fluviatilis*) predating on 0+ bream (*Abramis brama*). *Ecology of Freshwater Fish 9*: 236–241.

Brabrand, Å. 1995: Intra-cohort cannibalism among larval stages of perch (*Perca fluviatilis*). *Ecology of Freshwater Fish 4*: 70–76.

Brabrand, Å. 2001: Piscivory in larval perch (*Perca fluviatilis*): mechanisms structuring larval roach (*Rutilus rutilus*) cohorts. *Ecology of Freshwater Fish 10*: 97–104.

Cadwallader, P.L.; Backhouse, G.N. 1983: A guide to the freshwater fish of Victoria. Victorian Government Printing Office, Melbourne. 249 p.

Claessen, D.; de Roos, A.M.; Persson, L. 2000: Dwarfs and giants: cannibalism and competition in size-structured populations. *The American Naturalist 155*: 219–237.

Craig, J.F. 1978: A study of the food and feeding of perch, *Perca fluviatilis* L., in Windermere. *Freshwater Biology 8*: 59–68.

Crowl, T.A.; Townsend, C.R.; McIintosh, A.R. 1992: The impact of introduced brown and rainbow trout on native fish: the case of Australasia. *Reviews in Fish Biology and Fisheries 2*: 217–241.

David, B.O. 2002: Ecology of giant kokopu. Ph.D. thesis (unpublished). University of Otago, Dunedin, New Zealand.

Duncan, K.W. 1967: The food and population structure of perch (*Perca fluviatilis* L.) in Lake Mahinerangi. *Transactions of the Royal Society of New Zealand, Zoology 9*: 45–52.

Eklöv, P.; Persson, L. 1995: Species-specific antipredator capacities and prey refuges: interactions between piscivorous perch (*Perca fluviatilis*) and juvenile perch and roach (*Rutlius rutilus*). *Behavioural Ecology and Sociobiology 37*: 169–178.

Flecker, A.S.; Townsend, C.R. 1994: Community wide consequences of trout introduction in New Zealand streams. *Ecological Applications 4*: 798–807.

Griffiths, W.E. 1976: Food and feeding habits of European perch in the Selwyn River, Canterbury, New Zealand. *New Zealand Journal of Marine and Freshwater Research 10*: 417–428.

Hokanson, K.E.F. 1977: Temperature requirements of some percids and adaptations to the seasonal temperature cycle. *Journal of the Fisheries Research Board of Canada 34*: 1524–1550.

Hubert, W.A. 1996: Passive capture techniques. Pp. 157–192 in Murphy, B.R.; Willis, D.W. (Eds): Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Huryn, A.D. 1996: An appraisal of the Allan paradox in a New Zealand trout stream. *Limnology & Oceanography 41*: 243–252.

Imbrock, F.; Appenzeller, A.; Eckmann, R. 1996: Diel and seasonal distribution of perch in Lake Constance: a hydroacoustic study and *in situ* observations. *Journal of Fish Biology 49*: 1–13.

Jellyman, D.J. 1980: Age, growth, and reproduction of perch, *Perca fluviatilis* L., in Lake Pounui. *New Zealand Journal of Marine and Freshwater Research 14*: 391–400.

Kattel, G.R. 1999: Seasonal and diel dynamics of pelagic fish and zooplankton populations in a shallow lowland South Island coastal lake New Zealand. MSc thesis (unpublished), University of Otago, Dunedin, New Zealand.

Koonce, J.F.; Bagenal, T.B.; Carline, R.F.; Hokanson, K.E.F.; Nagiec, M. 1977: Factors influencing year-class strength of percids: a summary and a model of temperature effects. *Journal of the Fisheries Research Board of Canada 34*: 1900–1909.

Le Cren, E.D. 1955: Year to year variation in the year-class strength of *Perca fluviatilis*. *Verhandlungen internationale Vereinigung für theoretische und angewandte Limnologie 12*: 187–192.

Malison, J.A.; Procarione, L.S.; Held, J.A.; Kayes, T.B.; Amundson, C.H. 1993a: The influence of triploidy and heat and hydrostatic pressure shocks on the growth and reproductive development of juvenile yellow perch (*Perca flavescens*). *Aquaculture 116*: 121–133.

Malison, J.A.; Kayes, T.B.; Held, J.A.; Barry, T.P.; Amundson, C.H. 1993b: Manipulation of ploidy in yellow perch (*Perca flavescens*) by heat shock, hydrostatic pressure shock, and spermatozoa inactivation. *Aquaculture 110*: 229–242.

Manly, B.F.J. 1991: Randomisation, bootstrap and Monte Carlo methods in biology. Chapman and Hall, London. 281 p.

Matthews, W.J. 1998: Patterns in freshwater fish ecology. Chapman and Hall, New York. 756 p.

McDowall, R.M. 1987: Impacts of exotic fishes on the native fauna. Pp. 333–347 in Viner, A.B. (Ed.): Inland waters of New Zealand. *DSIR Bulletin 241*, Wellington, Science Information Publishing Center.

McDowall, R.M. 1990: New Zealand freshwater fishes. A natural history and guide. Heinemann Reed, Auckland. 553 p.

McDowall, R.M. 1996: Freshwater perches. Pp. 183–185 in McDowall, R.M. (Ed.): Freshwater fishes of South-eastern Australia. Reed Books, Chatswood.

McDowall, R.M. 2000: The Reed field guide to New Zealand freshwater fishes. Reed Books, Auckland. 224 p.

McIntosh, A.R.; Townsend, C.R. 1995: Contrasting predation risks presented by introduced brown trout and native common river galaxias in New Zealand streams. *Canadian Journal of Fisheries and Aquatic Sciences 52*: 1821–1833.

McMahon, T.E.; Zale, A.V.; Orth, D.J. 1996: Aquatic habitat measurements. Pp. 83–120 in Murphy, B.R.; Willis, D.W. (Eds): Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

McQueen, D.J.; Ramcharan, C.W.; Yan, N.D.; Demers, E.; Perez-Fuentetaja, A.; Dillon, P.J. 2001: Summary and emergent properties. The Dorset food web piscivore manipulation project. *Archiv für Hydrobiologie—Special Issues: Advances in Limnology 56*: 257–288.

Mehner, T. 1993: Distribution and diet composition of 0+ herring (*Clupea harengus* L.) and perch (*Perca fluviatilis* L.) in a shallow estuary of the Southern Baltic. *Archiv für Hydrobiologie 128*: 309–316.

Mittlebach, G.; Persson, L. 1998: The ontogeny of piscivory and its ecological consequences. *Canadian Journal of Fisheries and Aquatic Sciences 55*: 1454–1465.

Pen, L.J.; Potter, I.C. 1992: Seasonal and size-related changes in the diet of perch, *Perca fluviatilis* L., in the shallows of an Australian river, and their implications for the conservation of indigenous teleosts. *Aquatic Conservation: Marine and Freshwater Ecosystems 2*: 243–253.

Persson, L. 1988: Asymmetries in competitive and predatory interactions in fish populations. Pp. 203–218 in Ebenman, B.; Persson, L. (Eds): Size-structured populations. Springer-Verlag, Berlin.

Persson, L.; Eklöv, P. 1995: Prey refuges affecting interactions between piscivorous perch and juvenile perch and roach. *Ecology 76*: 70–81.

Persson, L.; Greenberg, L.A. 1990a: Interspecific and intraspecific size class competition affecting resource use and growth of perch, *Perca fluviatilis*. *Oikos 59*: 97–106.

Persson, L.; Greenberg, L.A. 1990b: Optimal foraging and habitat shift in perch (*Perca fluviatilis*) in a resource gradient. *Ecology 71*: 1699–1713.

Persson, L.; Byström, P.; Wahlström, E. 2000: Cannibalism and competition in Eurasian perch: population dynamics of an ontogenetic omnivore. *Ecology 81*: 1058–1071.

Q.E.II National Trust. 1997: Sinclair Wetlands Management Plan. Ducks Unlimited New Zealand Inc. and Queen Elizabeth II National Trust.

Richardson, J.; Boubée, J.A.T.; West, D.W. 1994: Thermal tolerance and preference of some native New Zealand freshwater fish. *New Zealand Journal of Marine and Freshwater Research 28*: 399–407.

Rowe, D.K. 1999: Factors influencing the abundance of the common bully, *Gobiomorphus cotidianus* McDowall, in small, North Island, New Zealand, lakes. *Fisheries Management and Ecology 6*: 377–386.

Rowe, D.K.; Chisnall, B.L. 1996. Size-related differences in diel feeding activity, prey selection and nocturnal migration strategy for the planktonic larvae of *Gobiomorphus cotidianus* in Lake Rotoiti (NI), New Zealand. *Archiv für Hydrobiologie 135*: 485–497.

Sanderson, B.L.; Hrabik, T.R.; Magnuson, J.J.; Post, D.M. 1999: Cyclic dynamics of a yellow perch (*Perca flavescens*) population in an oligotrophic lake: evidence for the role of intraspecific interactions. *Canadian Journal of Fisheries and Aquatic Sciences 56*: 1534–1542.

Shaw, T.; Studholme, B. 2001: Koi carp and gambusia: survey for and eradication of *Gambusia* (*Gambusia affinis*) and koi carp (*Cyprinus carpio*) populations in the Nelson region 2000–2001. *Occasional Publication No. 52*. New Zealand Department of Conservation, Nelson/Marlborough Conservancy, Nelson.

Sokal, R.R.; Rohlf, F.J. 1995: Biometry. W.H. Freeman and Company, New York. 887 p.

Stephens, R.T.T. 1982: Reproduction, growth and mortality of the common bully, *Gobiomorphus cotidianus* McDowall, in a eutrophic New Zealand lake. *Journal of Fish Biology 20*: 259–270.

Sutherland, D.L.; Closs, G.P. 2001: Spatial and temporal variation in the abundance and composition of icthyoplankton in a large South Island, New Zealand river estuary. *New Zealand Journal of Marine and Freshwater Research 35*: 1061–1069.

Thorpe, J.E. 1977: Morphology, physiology, behavior, and ecology of *Perca fluviatilis* L. and *P. flavescens* Mitchill. *Journal of the Fisheries Research Board of Canada 34*: 1504–1514.

Tonn, W.M.; Paszkowski, C.A.; Holopainen, I.J. 1992: Piscivory and recruitment: mechanisms structuring prey populations in small lakes. *Ecology 73*: 951–958.

Townsend, C.R.; Crowl, T.A. 1991: Fragmented population structure in native New Zealand fish: an effect of introduced brown trout? *Oikos 61*: 347–354.

Treasurer, J. 1993: The population biology of perch, *Perca fluviatilis* L., in simple fish communities with no top piscivore. *Ecology of Freshwater Fish 2*: 16–22.

Treasurer, J.W.; Owen, R.; Bowers, E. 1992: The population dynamics of pike, *Esox lucius*, and perch, *Perca fluviatilis*, in a simple predator-prey system. *Environmental Biology of Fishes 34:* 65–78.

Wang, N.; Eckmann, R. 1994: Distribution of perch (*Perca fluviatilis* L.) during their first year of life in Lake Constance. *Hydrobiologia 277*: 135–143.

Wahlström, E.; Persson, L.; Diehl, S.; Byström, P. 2000: Size-dependent foraging efficiency, cannibalism and zooplankton community structure. *Oecologia 123*: 138–148.