Controlling European perch (*Perca fluviatilis*): lessons from an experimental removal

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ABSTRACT

Over a 2-year period, we progressively removed perch from three ponds using a combination of gill and fyke nets and small minnow traps. Resulting changes in the fish community were compared with three control ponds. Large adult perch dominated communities in the control ponds, suggesting cannibalism was regulating these populations. In two of the removal ponds, perch removal was largely successful, and a marked increase in the abundance of common bullies occurred. In the third removal pond high juvenile perch recruitment occurred, presumably because of the absence of cannibalistic adult fish. Physical removal appears to be an option for perch control in relatively small lentic habitats and where desirable non-target fish species are present. It is recommended that removals be conducted in autumn to reduce the risk of high juvenile recruitment.

Keywords: common bullies, fish, *Gobiomorphus*, introduced species, lentic, *Perca fluviatilis*, perch

1. INTRODUCTION

Perch (*Perca fluviatilis*) were introduced to New Zealand in 1868 as an angling species (McDowall 1990). As a predator upon zooplankton, macroinvertebrates and fish, perch have the potential to significantly alter native freshwater communities. Consequently, understanding their impact and identifying possible control methods is of importance to managers of freshwater systems.

Perch belong to the family Percidae, consisting of around 60 freshwater fish species that occur naturally in still or slow-flowing temperate waters throughout the Northern Hemisphere (McDowall 1990). Perch have adapted well to New Zealand's environment, possessing high fecundity and flexibility in behaviour and habitat requirements (Hutchison & Armstrong 1993). They are spread widely throughout both the North and South Islands although the species' distribution is intermittent, with centres of high abundance in Northland, Auckland, Hawke's Bay, Taranaki, Wellington, Hokitika, central Canterbury, Otago and Southland (McDowall 2000).

Perch in New Zealand have an average adult size of 400–450 mm and 1–2 kg (McDowall 1990). Spawning occurs during spring (September–November) with the majority of males spawning in their first year but most females not until their second (Jellyman 1980). Larval perch grow quickly during their first 6 months and then growth slows, with negligible growth occurring during winter months (Jellyman 1980). As New Zealand's winters are milder and of shorter duration than those of many Northern Hemisphere countries, perch in New Zealand are probably capable of more rapid growth, experiencing lower associated overwinter mortality than that in Northern Hemisphere habitats.

During development, perch undergo three major shifts in diet and habitat use. Larval perch (5–30 mm) are pelagic zooplankton feeders, then at intermediate sizes (30–80 mm) shift to feeding on benthic macroinvertebrates. Lastly, perch over c. 130–180 mm are mainly piscivorous (Craig 1978; Le Cren 1987; Persson 1988). Diets of piscivorous perch in New Zealand are known to include smelt, eels and common bullies (Duncan 1967; Griffiths 1976), although other small fish species encountered by piscivorous perch are also likely to be vulnerable to predation. Cannibalisation of small perch, as observed in their native environs (e.g. Persson et al. 1999; Persson et al. 2000) also occurs in New Zealand (Duncan 1967). Cannibalism typically commences when perch are about 160–180 mm in length (Treasurer 1993). In small lentic habitats where perch are the only significant piscivorous predator, cannibalism by adult fish may drive population dynamics (Treasurer 1993, Wahlström et al. 2000). In such habitats, a relatively small number of piscivorous adult fish may limit juvenile recruitment, resulting in a low overall abundance and a population dominated by larger size classes (Treasurer 1993). In contrast, in habitats where larger perch are selectively removed (e.g. due to angling), high juvenile survival may lead to intense intraspecific competition and stunting (Treasurer 1993). Spawning success and the survival of larval and juvenile fish are also greatly influenced by environmental conditions, particularly temperature (Treasurer 1993).

Movements of larger piscivorous perch are related to feeding activity. In summer, Jellyman (1980) observed schools of uniformly sized perch feeding during daylight in the shallows (0.5–2.0 m) of Lake Pounui, Wairarapa, then moving into deeper water (1.5–3.0 m) in early evening to feed on small fish around macrophytes. At night perch schools broke down, with individual perch resting on the bottom in open water. During autumn to winter, perch were associated with macrophytes at depths of 2.0–3.5 m, and also around spawning in spring (Jellyman 1980). However, whilst the general patterns of movement of different size classes of perch have been described, factors determining habitat selection within these broader habitat categories have not been studied.

Despite a lack of detailed research on the ecology of perch in New Zealand, there is growing recognition by freshwater fishery managers of the potential of perch to negatively impact native fish. So far, neither active control of perch populations nor studies of their impact on native fish and invertebrate communities has been attempted. Reviews of various methods employed to control pest fish species suggest biological control (specifically a pathogen), poisoning and physical removal as possible options for perch control (see Roberts & Tilzey 1997).

Perch are particularly susceptible to the epizootic haematopoietic necrosis virus (EHN) (Bucke et al. 1979). However, this virus is unlikely to prove useful in the control of perch. The virus was accidentally introduced to Australia in the

1980s. Since then, outbreaks of the disease have periodically resulted in significant kills of perch, particularly when high fish densities have existed (e.g. Lake Burley Griffith in Canberra). However, recovery of perch populations is frequently rapid (ACT Government 2000). EHN is not an appropriate biological control option for perch populations in New Zealand given that salmonid and galaxiid fish species have also been shown to be susceptible (ACT Government 2000).

A variety of chemicals have been used to control or eradicate pest fish from fresh waters, the most well known being rotenone. However, the use of such poisons may be limited in many habitats by the presence of desirable non-target species such as giant kokopu (*Galaxias argenteus*), e.g. Lake Luxmore, Te Anau. An unfavourable socio-political attitude to the use of poisons may also render chemical removal of fish an unacceptable option for perch control.

The remaining option for the control of perch populations is physical removal, including the use of electrofishing, netting and trapping. As with poisoning and biological control, there are obvious associated risks to non-target species and of unfavourable public perception. However, careful selection and use of equipment can reduce these risks.

In this study, we report on the results of a progressive removal of perch from small lentic habitats in Otago. A primary aim of this study was to evaluate the potential of physical removal by netting and trapping to control perch populations in small-sized lentic habitats. Specifically, in this paper we examine (1) the impact of progressive removal on perch population dynamics and structure and (2) the responses of native fish (specifically common bullies, *Gobiomorphus cotidianus*) to that removal. Prior to the start of the removal, we predicted that numbers of large perch would decline in response to removal. In response to a decline in numbers of large perch, numbers of young-of-the-year (YOY) perch would either be low because of an absence of spawning, or increase because of a reduction in cannibalism. We expected numbers of common bullies to increase in the removal ponds relative to the control ponds as a result of reduced predation pressure on this small fish species.

2. METHODS

The Waihola and Waipori Wetland Complex is located 33 km southwest of Dunedin city in the South Island of New Zealand (45°59′S, 170°06′E). Six ponds contained within these wetlands were used in this study, their selection based primarily on three factors: presence of perch and common bullies, absence of connectivity to river and stream channels, and pond size. These six ponds were grouped into three size-classes (small, medium and large).

Two treatments were established: perch removal and control. The perch removal treatment was undertaken in three ponds where 1-year and older perch were progressively removed. The control treatment consisted of three ponds in which no perch removals were undertaken. Each treatment contained one pond from each of the small, medium and large size classes. The three ponds used in the perch removal treatment ranged in size from 0.17 ha to 0.79 ha, and the three control ponds from 0.33 ha to 1.5 ha. All ponds had similar physico-chemical characteristics (depth, salinity, temperature, dissolved oxygen) and macrophyte communities.

The initial removal of perch from the three perch removal ponds was conducted in mid November and December, 1999. The timing of removal was initially planned to occur prior to perch spawning in late September/October. At this time the numbers of YOY fish would be at a minimum after a full year of cannibalism by adult perch. Unfavourable conditions delayed removal until November/December, with removals in the largest pond being conducted last, because of the need for additional nets to sample its larger area. Consequently, the removals across the ponds were conducted just before, during or after the spawning period.

Overnight sets of 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 fyke nets (wing length 4.5 m, stretched mesh 20 mm) were used for the perch removal, over a period of three-to-six nights for each pond. For the small pond, five fyke nets and three gill nets were used over a three-night period. For the medium pond, four fyke nets and six gill nets were used over a three-night period. For the large pond, eight fyke nets and eight gill nets were used over a three-night period, then six fyke nets were used continuously over a further three-night period. Gill nets were set by attaching the net to the bank, then stretching the net out perpendicular to the bank and into the pond centre. Fyke nets were set by attaching the wing to the bank, setting at an angle of 45° to the bank, and anchoring with weights.

Sampling of the fish population was conducted monthly from November 1999 through to April 2000 (six sampling occasions). Minnow traps (stretched mesh 5 mm) and fyke nets (same mesh sizes as for the 1999 perch removal) were used to monitor the perch population. Overnight sets of these nets were used for one night per pond on each sampling occasion. Sixteen minnow traps were used per pond for each sampling occasion. Traps were set in four different habitats: centre top (area >2 m from the pond bank, and just submerged), centre bottom (area >2 m from the pond bank, and on pond substrate), edge (area immediately adjacent to pond bank) and 1 m from the edge (area 1 m from the pond bank, parallel to the bank). These habitats were selected to ensure sampling of all primary microhabitats within each pond. Minnow traps were either floated on the pond surface using two floats per net, or weighted using chain links.

A second perch removal was undertaken in December 2000. Again removal was delayed because of inclement weather, resulting in adult removal being conducted probably just after the spring spawning period. This removal used similar methods to the 1999 removal, with gill and fyke netting being conducted over a three-night period for each pond. An additional two 12-m-long fine monofilament multi-mesh gill nets (panel height 1.7 m, panel length 3 m, stretched mesh sizes: 30, 50, 65, 85 mm) were used in each pond during this second removal period. For the small pond four fyke nets, one 27-m gill net and two 12-m gill nets were used. For the medium pond four fyke nets, three 27-m gill nets and two 12-m gill nets were used. For the large pond three fyke nets, five 27-m gill nets and two 12-m gill nets were used.

In the second field season, sampling of the fish population was conducted bimonthly from November 2000 through to March 2000 (three sampling occasions). Methods used were identical to those in the 1999/2000 season.

A final survey of fish communities across all six ponds using equivalent methods (gill and fyke netting) was conducted in early April 2001. Overnight sets of 27-m and 15-m multi-mesh gill (panel height 1.7 m, panel length 3 m, stretched mesh sizes: 10, 30, 50, 65, 85 mm) and fyke nets were used. For the small control pond three fyke nets, one 27-m gill net and two 15-m gill nets were used. For the medium control pond one fyke net, one 27-m gill net and two 15-m gill nets were used. For the large control pond four fyke nets, one 27-m gill net and two 15-m gill nets were used. The setting and retrieval of nets was conducted as per methods used to survey fish through 1999 and 2000.

All fish captured were measured to the nearest millimetre from snout to tail using a standard 300-mm fish board. In perch removal ponds all perch captured were killed immediately using either the anaesthetic 2n-phenoxyethanol administered in a lethal dose or by a sharp blow to the head, and then preserved in formaldehyde for later diet analysis.

Catch rates were expressed as catch per unit effort (CPUE) which is defined here as the number of fish caught per net per hour. The terms YOY and large are used throughout this study to describe the size and age of the perch caught. YOY are defined as those fish < 80 mm in total length, and represent the current year's recruitment into the perch population. Large fish are defined as those fish > 80 mm in total length, and represent those fish 1 year old and older. This 80 mm boundary provides the best representation of the size at which different year classes were found, according to the observations made during this study, and by comparing these data with those collected by Jellyman (1980). Also, Mehner et al. (1998) observed a maximum size of YOY perch of 74 mm at the end of the growing season, which is comparable to the value used here.

3. RESULTS

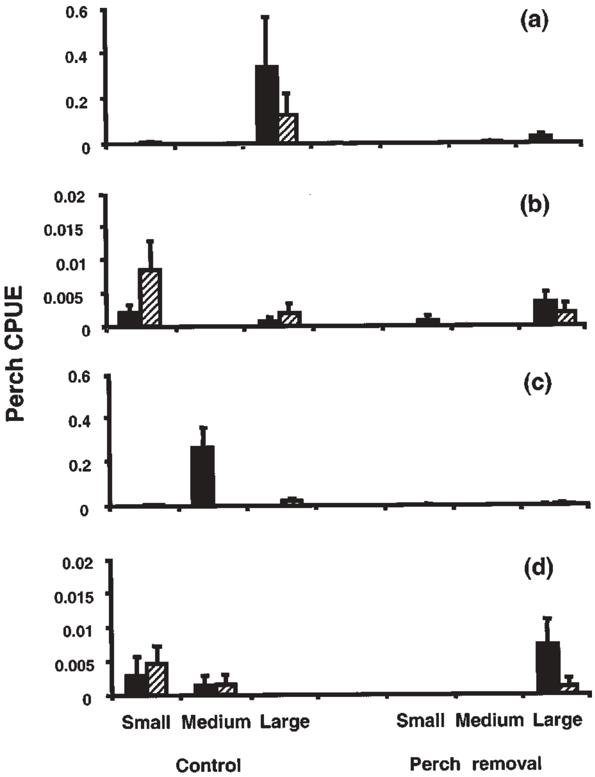
Over the study period a total of nine large perch were removed from each of the small and medium removal ponds, and 23 YOY and 89 large perch from the large removal pond (Table 1). Relative to removal ponds, a greater number of perch were collected in control ponds (Table 1). However, a number of these fish may have been captured more than once given that most of these fish were returned alive.

In control ponds, perch population dynamics were characterised by populations of both YOY and larger perch at various times (Table 1, Fig. 1). The highest catch rates of YOY perch occurred during immediate post-spawning sampling periods (Fig. 1A, C). Variation in spawning success was evident, with high densities of YOY perch being observed in the large control pond in spring 1999 (Fig. 1A) and in the medium pond in spring 2000 (Fig. 1C). The catch rates of YOY perch declined rapidly through summer and autumn, with larger fish tending to dominate catches of perch in control ponds in both summer/autumn 2000 and 2001 (Fig. 1B, C). Catches of large perch were variable across ponds, with only one large perch ever being caught in the medium control pond,

TABLE 1. TOTAL NUMBERS OF YOUNG-OF-THE-YEAR (YOY) AND ADULT PERCH CAPTURED PER POND THROUGHOUT THE STUDY (1999–2001).
Note that sampling times differ for the two treatments: control pond data were derived from the nine monitoring trips (1999/2000 and 2000/01); perch removal pond data were derived from the nine monitoring trips and the two perch removal periods (1999 and 2000).

		PERCH	
TREATMENT	POND SIZE	YOY	LARGE
Control	Small	5	21
	Medium	109	1
	Large	126	76
Perch Removal	Small	0	9
	Medium	0	9
	Large	23	89

Figure 1. Average CPUE (fish per net per hour) of YOY (solid bars) and large perch (striped bars) in all six study ponds in (a) spring/early summer 1999 (December sampling trip); (b) summer/autumn 2000 (January to April sampling trips combined); (c) spring/early summer 2000 (December sampling trip), and (d) summer/autumn 2001 (January and March sampling trips combined). Figures derived from data for all nets. Error bars are standard errors.



although the occurrence of large numbers of YOY fish in spring 2001 (Fig. 1C) clearly indicated that more than one large perch was present in this pond.

Initial removals and catches of large perch in 2000 indicated that large perch were initially present in all perch removal ponds (Table 1, Fig. 1). However, in small and medium removal ponds, the catch rates of large perch dropped rapidly after the initial removal period (Fig. 1). In contrast, large perch were caught in the largest removal pond into the summer/autumn period of 2001. Corresponding with an apparent absence of large perch in the small and medium removal ponds was the failure to catch any YOY perch in either 2000 or 2001 (Fig. 1). In contrast, YOY perch were observed in the largest removal pond in both 2000 and 2001. Significantly, survival of high numbers of YOY fish occurred through the summer/autumn period of 2001 (Fig. 1D).

Patterns of perch population structure and population dynamics observed through the regular monitoring in 2001 were supported by the results of the final netting period (Fig. 2). Only large perch (up to 380 mm) were collected from the three control ponds in April 2001. No large or YOY perch were collected from the small removal pond, and only two large perch (both <120 mm long) were collected from the medium removal pond. In contrast, large numbers of YOY perch were collected from the large removal pond. Only a single large perch (again <120 mm) was collected from this pond.

Common bully numbers clearly responded to the successful removal of perch in the small and medium removal ponds (Fig. 3). The numbers of common bullies observed in spring 1999 were very low across all ponds. Only low numbers of bullies were recorded in the medium control pond, and the small and medium perch removal ponds (Fig. 3). The catch rates of common bullies remained low over the entire study period in all three control ponds, with only a small increase being observed in the medium control pond. The catch rate of common bullies also remained low in the largest removal pond where perch removal had been unsuccessful (Figs 2 and 3). In contrast, the catch rates of common bullies had increased dramatically in the small and medium removal ponds compared with the catch rates in the same ponds at the beginning of the study (Fig. 3).

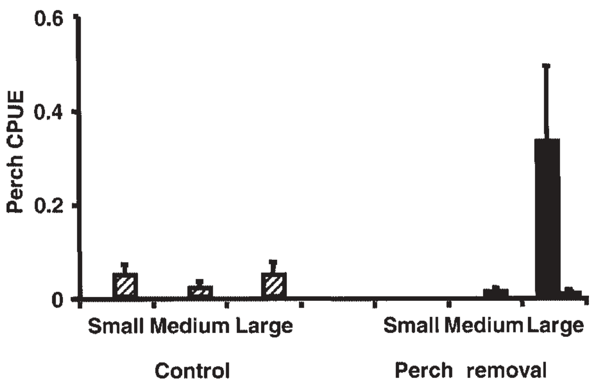


Figure 2. Average CPUE (fish per net per hour) of YOY (solid bars) and large perch (striped bars) in all six study ponds during the final netting trip in April 2001. Figures derived from data for all nets. Error bars are standard errors.

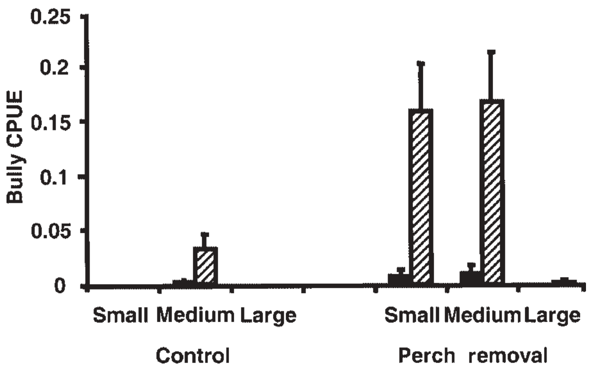


Figure 3. Average CPUE (fish per net per hour) of common bullies in all six study ponds in spring 1999 (December sampling trip, solid bars) and autumn 2001 (March sampling trip, striped bars). Figures derived from data for all nets. Error bars are standard errors.

4. DISCUSSION

4.1 Impact of removal on perch population structure and dynamics

The patterns 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 European perch populations (Treasurer 1993; Wahlström et al. 2000). Spawning in spring (September–November) resulted in a marked increase in the numbers of YOY fish, although the success of spawning events was variable between ponds across different years. Adverse environmental conditions (low temperatures and wind) can result in low survival rate in the eleutheroembryo (yolksac) phase, and food limitation can cause high mortality of larval fish (Treasurer et al. 1992).

Irrespective of the success of spawning events in the control ponds, subsequent survival of YOY perch was low. Such a pattern suggests that cannibalism is playing a key role in regulating the population structure of perch in these ponds (see Treasurer 1993; Wahlström et al. 2000). This conclusion is further supported by the observation of high juvenile survival into April 2001 in the largest removal pond where a significant number of large perch had been previously removed. Due to the combined constraints of weather and equipment, removal in this pond was delayed until December, which resulted in removal being conducted in the immediate post-spawning period. Significantly, no perch likely to be cannibalistic (>160 mm) were caught in this pond after the removal in December 2000. Treasurer (1993) similarly observed high survival of juvenile perch in a small lake subjected to intensive angling and hence removal of larger cannibalistic fish.

4.2 Impact of removal on common bullies

Marked increases in numbers of common bullies appeared to be associated with the successful reduction of perch numbers in small and medium removal ponds. In contrast, the numbers of common bullies remained low in all three control ponds and in the large removal pond where perch remained abundant. Perch have been implicated in the decline of native fish species in both Australia and New Zealand (Cadwallader & Backhouse 1983; McDowall 1990, 1996). However, this study represents the first direct evidence of a likely negative impact that European perch may be having on small fish species and the juveniles of larger fish species in New Zealand. Given the substantial switch in the composition of the fish community following perch removal, the presence or absence of perch is likely to also have a significant impact on the structure of lentic invertebrate communities. The impact of this change in fish community composition on invertebrate communities will be reported in a subsequent paper. In New Zealand river systems, a change in fish communities previously dominated by galaxiids to one dominated by trout has had a variety of ecosystem level effects (Huryn 1998). Habitat use and the patterns of distribution of juvenile and adult perch and bullies through time and space are quite different (McDowall 1990), hence the two species are likely to exert quite different predatory pressures in the habitats in which they occur.

Direct predation is likely to be the main mechanism whereby perch are suppressing numbers of common bullies. In Australian billabong systems, gudgeons (*Hypseleotris* spp.) form a significant component in the diet of perch over 80 mm in length (Shirley 2001). In smaller experimental enclosures, common bullies also exhibit lower survival rates in the presence of adult perch (R. Goldsmith, unpubl. data). However, competition between juvenile perch and common bullies could also be significant (see Persson 1987a and references therein for examples of competitive interactions between perch and other European fish species).

4.3 Lessons to be learnt and knowledge gaps: implications for perch control

This study demonstrates that perch numbers can be significantly reduced, and perhaps even eradicated successfully from small lentic habitats. Such a result is significant given that many of the more recent records of new perch occurrence in New Zealand are in relatively small lentic habitats. In our study, physical removal using gill and fyke nets had little or no negative impact on the abundance of bullies, suggesting that physical removal is likely to be a useful control option where desirable native fish are present. Such targeted removal could be particularly important in habitats where perch and potentially threatened native fish such as giant kokopu occur together.

An aspect of perch ecology that may facilitate successful removal in small lentic habitats is the tendency of perch populations in such habitats to be cannibalistic and hence 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 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 fish 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. Timing of removal is therefore crucial to avoid increased YOY survival. Again, attempting removals in autumn would appear likely to minimise the risk of increased juvenile survival, given that predation on YOY fish by piscivorous adults had largely eliminated the YOY fish in the Sinclair Wetland ponds by this time. Alternatively, a short window of opportunity also exists in spring as warmer water temperatures result in increased fish movement. However, highly variable weather conditions (such as those encountered in this study) can either delay removal attempts until after spawning or, if attempted, result in low catch efficiencies.

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 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 limit subsequent YOY survival should successful spawning occur between any remaining adult non-sterile fish. Sterile fish could subsequently be removed when absence of juvenile perch suggests that all fertile perch in the population have been eliminated. The introduction of sterile fish may also serve to reduce successful spawning attempts between remaining adult fertile fish should the sterile fish be capable of exhibiting normal spawning behaviour, and thus attract fertile fish into non-productive mating. At present, to our knowledge, no attempts have been made to produce sterile perch, although sterile triploid salmonids are routinely produced (G. Young, pers. comm.)

Our attempts to successfully target perch in smaller 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 (Persson 1987b; Wang & Eckmann 1994; Imbrock et al. 1996), there appear to be no detailed studies of the factors that determine microhabitat selection within these broader habitats. 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 radiotelemetry. 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.

Radiotelemetry also offers scope for exploring additional approaches to perch control. Given that perch are typically a shoaling species (Imbrock et al. 1996), radio-tagged perch could be released and at a later time relocated, revealing the position of a perch shoal. Nets can then be positioned accurately to intercept shoals, resulting in considerably increased catch rates. The use of radio-tagged 'Judas' individuals has been used to locate spawning aggregations of European carp in Lake St Clair, Tasmania (Inland Fisheries Service, Tasmania, 2001).

Finally, the impact of perch predation on fish species other than common bullies remains unknown. Obvious species upon which perch could be having a negative impact include giant kokopu, smelt and inanga, all of which occupy similar lowland habitats across some of their range (McDowall 1990). Removal of perch from habitats where these species are currently sympatric would begin to further our understanding of the impact of European perch introduction on New Zealand's lowland freshwater ecosystems.

5. ACKNOWLEDGEMENTS

This research was funded by the Department of Conservation (Project No. 3246). Kai Tahu and the Sinclair Wetlands Management Committee granted permission to work in the wetlands. Numerous field assistants worked in wet, muddy and often cold conditions in the ponds, swamps, bogs and mudholes that make up the Sinclair Wetlands. The Department of Zoology, University of Otago, provided additional resources. The research was conducted with the permission of the University of Otago Animal Ethics Committee.

6. REFERENCES

ACT Government. 2000: Fish stocking plan for the Australian Capital Territory 2001–2005. Environment ACT, Canberra.

Bucke, D.; Cawley, G.D.; Craig, J.F.; Pickering, A.D.; Willoughby, L.G. 1979: Further studies of an epizootic of perch, *Perca fluviatilis* L., of uncertain aetiology. *Journal of Fish Diseases 2*: 297–311.

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

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

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 9*: 45–52.

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.

Huryn, A.D. 1998: Ecosystem level evidence for top-down and bottom-up control of production in a grassland stream system. *Oecologia 115*: 173–183.

Hutchison, M.J.; Armstrong, P.H. 1993: The invasion of a south-western Australian river system by *Perca fluviatilis*: history and probable causes. *Global Ecology and Biogeography Letters 39*: 77–89.

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

Inland Fisheries Service, Tasmania. 2001: The Tasmanian carp program: program update. Inland Fisheries Service Publication, Moonah, Tasmania.

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.

Le Cren, E.D. 1987: Perch (*Perca fluviatilis*) and pike (*Esox lucius*) in Windermere from 1940 to 1985; studies in population dynamics. *Canadian Journal of Fisheries and Aquatic Sciences 44 (Supplement 2)*: 216–228.

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. 52–77 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, Auckland. 224 p.

Mehner, T.; Dörner, H.; Schultz, H. 1998: Factors determining the year-class strength of age-0 Eurasian perch (*Perca fluviatilis* L.) in a biomanipulated reservoir. *Archives for Fisheries and Marine Research 46*: 241–251.

Persson, L. 1987a: Effects of habitat and season on competitive interactions between roach (*Rutilus rutilus*) and perch (*Perca fluviatilis*). *Oecologia 73*: 170–177.

Persson, L. 1987b: The effect of resource availability and distribution on size class interactions in perch, *Perca fluviatilis*. *Oikos 48*: 148–160.

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

Persson, L.; Byström, P.; Wahlström, E.; Andersson, J.; Hjelm, J. 1999: Interactions among size-structured populations in a whole-lake experiment: size- and scale- dependent processes. *Oikos 87*: 139–156.

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

Roberts, J.; Tilzey, R. (eds) 1997: Controlling carp: exploring the options for Australia. Proceedings of a workshop 22–24 October 1996, Albury, NSW. CSIRO and Murray-Darling Basin Commission. 129 p.

Shirley, M.J. 2001: The ecology of billabong fish communities of the River Murray with a focus on the interactions of European perch (*Perca fluviatilis*). Unpublished PhD Thesis, Monash University, Australia.

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.; 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.

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

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