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10.2 COMPETITION AND PREDATION

Analysis of NZFFD records indicates that *Neochanna* species occurred in habitats without any other fish species on more than half of the occasions they were recorded (Table 10). Although a wide variety of other fish species may sometimes co-occur with *Neochanna* species, the incidence of co-occurrence is typically low except for one or two species. It is thought that *Neochanna* species are generally intolerant of competition because of their small size, general lack of aggression, small mouth and low metabolic rate, all of which may reduce their potential to be dominant competitors (Meredith 1985). While *Neochanna* are not inherently territorial or aggressive towards con-specifics, Barrier & Hicks (1994) reported that adult *N. diversus* were aggressive towards *G. affinis*, and Eldon (1969) found *N. apoda* were aggressive when outnumbered, or in the presence of a multitude of species in aquaria (Eldon 1969). It has also been suggested (Meredith 1985) that *Neochanna* species may lack predator-avoidance mechanisms. However, when disturbed suddenly, *N. cleaveri* can jump to a height of 50–60 mm above the water before immediately diving down to the pool bottom. Fish may repeat this manoeuvre two or three times in quick succession and it is likely used to facilitate their escape from aquatic predators (Andrews 1991). Juvenile *N. burrowsius* exhibit a similar behaviour when startled, although not jumping as high (L. O'Brien, pers. obs.). The following sections provide further information on commonly occurring inter-specific interactions.

10.2.1 *Anguilla* species

Eels (Anguillidae; *Anguilla*) prey on *Neochanna*, including larger (120 mm) individuals (Mitchell 1995; Eldon 1978b, 1979a), and there is a surprisingly low level of co-occurrence between *Neochanna* species and eels, considering the ubiquitous distribution of *Anguilla* species (Table 10). McDowall (1982) posed the question of whether this low level of co-existence between *Anguilla* and *Neochanna* arises from *Anguilla* species having a detrimental impact on *Neochanna* populations, e.g. through predation; or whether *Neochanna* species are able to tolerate harsher conditions, and thus largely avoid interactions with other species. This is still to be fully tested. However, where *N. burrowsius* and *Anguilla* species do co-exist, small-scale patterns of distribution within sites suggest that *Anguilla* influences *N. burrowsius* abundance (O'Brien 2005). Furthermore, in sites experiencing hydrological extremes, disturbance-mediated co-existence is likely to be occurring, e.g. in Tutaepatu Lagoon, Mid Canterbury, where extreme drought in 1972 and 1998 largely eliminated the *Anguilla australis* population, whereas *N. burrowsius* is thought to have survived (Glova & Hulley 1998; Main & Meredith 1999).

10.2.2 *Galaxias* species

NZFFD records indicate that all New Zealand *Neochanna* except for *N. rekohua* may co-occur with *Galaxias* species (Table 10). However, the incidence of co-occurrence is low and may be habitat-mediated. For example, a survey by Eldon (1968) of thirteen sites containing *N. apoda* on the West Coast of the South Island found co-occurrence with *Galaxias* on only one occasion, despite various galaxiids being found in adjacent habitats. This co-occurrence was with two *Galaxias fasciatus* that were found in deeper parts of a pool, with *N. apoda* occupying the shallow end (Eldon 1968). Eldon (1979a) reported co-occurrence

TABLE 10. PERCENTAGE OF NZFFD RECORDS SHOWING *Neochanna* SPECIES FOUND ALONE, AND IN THE PRESENCE OF OTHER IDENTIFIED SPECIES. AS *Neochanna* MAY CO-OCCUR WITH MORE THAN ONE OTHER SPECIES AT A GIVEN LOCATION, TOTALS DO NOT NECESSARILY ADD UP TO 100.

COMMON NAME	SPECIES NAME	*N. burrowsius*	*N. diversus*	*N. heleios*	*N. apoda*
Alone		59.7	59.3	72.7	67.1
Eel	*Anguilla* spp.	0.8	4.4	2.3	0.9
Longfin eel	*Anguilla dieffenbachii*	3.4	2.2		4.2
Shortfin eel	*Anguilla australis*	6.7	21.4	15.9	11.3
Galaxias	*Galaxias* spp.		0.5		
Giant kokopu	*Galaxias argenteus*				0.9
Banded kokopu	*Galaxias fasciatus*		3.8	9.1	4.2
Canterbury galaxias	*Galaxias vulgaris*	3.4			
Inanga	*Galaxias maculatus*	1.7	2.2		2.8
Torrentfish	*Cheimarrichthys fosteri*		0.5		
Common bully	*Gobiomorphus cotidianus*	7.6	3.3		0.9
Upland bully	*Gobiomorphus breviceps*	23.5			1.4
Brown trout	*Salmo trutta*	1.6			0.5
Brown bullhead catfish	*Ameiurus nebulosus*		1.6		
Goldfish	*Carassius auratus*		1.6		
Koi carp	*Cyprinus carpio*		1.1		
Rudd	*Scardinius erythrophthalmus*		0.5		
Gambusia	*Gambusia affinis*		18.1	6.8	
Perch	*Perca fluviatilis*	1.7			
Koura	*Paranephrops* spp.	0.8	1.1		20.2

of *N. burrowsius* with *G. maculatus* in Buchanans Creek, South Canterbury where, during spring, *N. burrowsius* juveniles 'mingled' with *G. maculatus* juveniles recently arrived from the sea. It is likely that competition for food occurs in such situations.

10.2.3 Salmonid species

Co-occurrence of *Neochanna* and salmonid species (Salmonidae: *Salmo*, *Oncorhynchus*, *Salvelinus*) is low (Table 10), likely because of differing habitat preferences and the piscivorous nature of larger salmonids (McDowall 2006). Eldon (1979a) reported on the affect that seven *Salmo trutta* (brown trout) had on the Buchanans Creek (South Canterbury) *N. burrowsius* population, when they invaded upstream reaches during a spawning migration. These *S. trutta* consumed 19 *N. burrowsius*, whereas one *S. trutta* that had not moved upstream had only consumed invertebrates. This population of *N. burrowsius* may only have persisted because of frequent habitat drying, which removed the trout (Eldon 1993). McDowall (2006) reviewed the impacts of salmonids on galaxioid fishes, including *Neochanna* species, and highlighted the serious nature of this threat.

10.2.4 Coarse fish species

Only *N. burrowsius* and *N. diversus* are recorded as co-occurring with coarse fishes (Ameiuridae: *Ameiurus*; Cyprinidae: *Carassius*, *Cyprinus*, *Scardinius*; and Percidae: *Perca* species). Eldon (1979a) found *Perca fluviatilis* preyed on

N. burrowsius when co-occurring in pools of an intermittent stream south of Otaio, South Canterbury. *Neochanna diversus* co-occurs in Awaroa Stream with both *Ameiurus nebulosus* (brown bullhead catfish) and *Scardinius erythrophthalmus* (rudd) and with the former species in Whangamarino Wetland, Waikato (NZFFD records). It is unclear whether *N. diversus* is negatively affected by these species. This requires further investigation, as coarse fish species are implicated in reducing aquatic macrophyte cover and increasing turbidity (Chadderton 2001; Dean 2001), activities that could influence *N. diversus* habitat suitability.

10.2.5 *Gambusia affinis*

The introduced fish *Gambusia affinis* (Poeciliidae), also called mosquitofish, occurs in both *N. diversus* and *N. heleios* habitats (Table 10). *Gambusia affinis* attack other fish, particularly their fins, causing mortality (Baker et al. 2004). Such behaviour has seen *G. affinis* 'implicated in the displacement, decline, or elimination of numerous native fish and amphibian species in many countries where they have been introduced' Ling (2004: 474). In New Zealand, *G. affinis* is classified as a noxious and unwanted fish species (Chadderton 2001; Dean 2001).

Kerr & McGlynn (2001) attributed the high abundance of *N. heleios* at Ngawha, Northland, to the absence of *G. affinis*. Moreover, behavioural investigations into the interactions between *G. affinis* and *N. diversus* indicated that foraging behaviour and prey capture rates of *N. diversus* altered in the presence of *G. affinis* (Barrier & Hicks 1994). Further, Barrier & Hicks (1994) emphasised that *G. affinis* could induce changes in the zooplankton community, which is an important component of the diet of *N. apoda*. However, the predominant threat arising from *G. affinis* is their predation of *Neochanna* fry. This could threaten recruitment into *Neochanna* populations, and their long-term persistence (Hicks & Barrier 1996; Ling 2004). However, *Neochanna* have a greater tolerance of seasonal dry periods, which regularly remove *G. affinis*, so co-existence within large wetland complexes is determined by hydrological dynamics. The severity of the threat posed to *N. diversus* by *G. affinis* may also be reduced by the two species spawning in different seasons, with *N. diversus* fry being abundant when *G. affinis* numbers are low (Barrier & Hicks 1994; Ling 2004). Nonetheless, use of the piscicide rotenone has been considered (Willis & Ling 2000; Ling 2003) as a means of controlling *G. affinis* numbers and thus protecting *N. diversus* and *N. heleios* populations.

10.2.6 *Gobiomorphus breviceps*

Neochanna burrowsius often co-exists with *Gobiomorphus breviceps* (Gobiidae; upland bully) (Table 10). However, habitat separation occurs between the two species, with more *N. burrowsius* being found in macrophyte patches, and more *G. breviceps* in open areas (Eldon 1979a; O'Brien 2005). In outdoor experiments it was found that *G. breviceps* competed aggressively for space; however, competition for food resources may be reduced by temporal differences in foraging between the species, and increased foraging activity by *N. burrowsius* (O'Brien 2005). In the wild, co-existence between *G. breviceps* and *N. burrowsius* may be promoted in situations where *G. breviceps* populations are limited by factors such as environmental stress, a lack of spawning substrate, or sedimentation (Jowett & Boustead 2001; O'Brien 2005).

10.2.7 Frogs

There have been no specific studies into interactions between introduced frogs and *Neochanna* species, but there is some suggestion that negative interactions may occur. Eldon (1978b) found *N. apoda* fry and *Hyla ewingi* (whistling frog) tadpoles in stump holes in the same area; however, they did not appear to coexist in the same holes. Further, observations of distinct distributions in Dog Kennel Stream, South Canterbury, suggest negative interactions between *N. burrowsius* and introduced *Litoria aurea* (golden bell frog) (S. Harraway, DOC, pers. comm.). Such interactions require further study as bell frogs (*Litoria aurea, L. raniformis*) commonly occur in *N. burrowsius* habitat (L. O'Brien, pers. obs.). *Limnodynastes dumerilii grayi* (eastern banjo frog), discovered in Northland in 1999, may represent a future threat to *N. diversus* and *N. heleios* if it establishes and spreads. Classified as an unwanted organism, this frog can excrete a poisonous substance and breeds in wetland habitats similar to those of *Neochanna* species.

10.2.8 Avian interactions

Birds may influence *Neochanna* through habitat degradation or direct predation. Eldon (1993) discussed the impact that excessive numbers of water fowl can have on *Neochanna* habitat through consumption of aquatic plants. *Neochanna* eggs may also be consumed 'accidentally' by waterfowl, if they are scattered amongst vegetation at the water surface. Large flocks of waterfowl have been observed in *Neochanna* habitats by Francis (2000a) and O'Brien (2005), the latter witnessing many hundreds of waterfowl being attracted by supplementary grain to a pond prior to the duck shooting season. This influx of birds was thought to have fouled the water, leading to widespread bacterial infection of *N. burrowsius* also present in the pond (O'Brien 2005).

Evidence of *Ardea novaehollandiae novaehollandiae* (white-faced heron) predation on *N. burrowsius*, in the form of wounded dead fish, and live fish with bitten tails, was common in shallow weedy habitats (O'Brien 2005). In Canterbury, herons commonly congregate around drains following aquatic plant removal for drain maintenance (M. & H. Redworth, formerly St Andrews, pers. comm.). Thompson (1987) reported that a *Botaurus stellaris poiciloptilus* (bittern) had regurgitated a c. 100-mm-long *N. diversus*. *Halcyon sancta vegans* (kingfishers) and *Porphyrio melanotus* (pukeko) have also been implicated as predators of *Neochanna* species (Eldon 1978b; Hicks & Barrier 1996) The level of predation by birds is likely to be high in some circumstances, although the cryptic, nocturnal habits of adult *Neochanna* may mitigate this risk.

10.3 FACTORS AFFECTING FISH 'HEALTH'

Disease and parasitic infection can affect both growth rates and survival of individual *Neochanna* and entire populations. The prevalence of these potentially debilitating factors often varies between populations (Eldon 1978b; O'Brien 2005). Stress applied by the environment can cause outbreaks of infectious diseases in fishes. Stresses include temperature changes, low dissolved oxygen, eutrophication, sewage, and synthetic pollution (Snieszko 1974). However, fish regularly encounter pathogens in their habitats and generally have adequate resistance to bacteria, unless weakened by stress or injury. Infection by parasites has been related to the abundance of intermittent hosts, often prey species, such as snails, which are consumed, thereby transferring the parasite to fish (Eldon 1978b; McDowall 1990).

10.3.1 Disease

Eldon (1978b) reported that few *N. apoda* he examined showed any outward sign of sickness. The exception was a fish caught shortly after a dry summer, which had a large bacterial (*Pseudomonas* sp.) infection. O'Brien (2005) found a higher incidence of bacterial infection in *N. burrowsius*, especially from habitat with poor water quality. The percentage of healthy *N. burrowsius* in a population with no external indication of disease or infection varied from 15% to 80%.

Determining the level of threat to *Neochanna* posed by chytrid fungus was identified by DOC (2003) as a research priority. Chytrid fungi occur commonly in both soil and water, and some are known to have severe impacts on frog populations. In tadpoles, fungi largely attack the keratin present in the skin and mouthparts, with most mortality occurring during metamorphosis into adults. Meredith (1985) found that the epidermis of *N. burrowsius* has no kerainisation, so it is possible that chytrid fungi will not threaten *Neochanna* species. However, this requires further investigation.

10.3.2 Parasites

Parasites are attached either internally or externally to their host. External parasites are more likely to cause the death of their host, as their own survival is not necessarily dependent on that of the host (O'Brien 2005). In fish, the most common external parasite is the ciliate protozoan *Ichthyophthirius multifiliis* (white spot or 'ich') which has caused mass mortality in fish overseas (e.g. Wurtsbaugh & Tapia 1988). External examinations by O'Brien (2005) indicated that whitespot was present in all *burrowsius* populations she studied; however, it reached a potentially epidemic level in Hororata Spring (mid Canterbury), where 50% of *N. burrowsius* captured carried at least one cyst, and some individuals carried more than 20. Eldon (1978b) examined the stomachs and gonads of *N. apoda* from several sites around the Wairarapa. The internal parasitic nematode *Hedruris spinigera* was prevalent in stomachs. In one population, 63% of fish examined carried a nematode, with a maximum parasite load of 14 in one individual (Eldon 1978b). The incidence of infection was related to the prevalence of amphipods, the nematodes' intermediate host, in the diet of *N. apoda*. Cysts of the digenean fluke *Telogaster opisthorchis* (Trematoda) were found in the gonads of *N. apoda* and infection rates ranged from 16% to 21% of individuals. Eldon (1978b, p. 38) also noted that 'some males were so heavily infested that at first glance they appeared to be females'. Internal parasites have not been recorded in other *Neochanna* species, most likely because only small numbers of fish have been examined (Blair 1984).

11. Conservation initiatives

European settlement of New Zealand resulted in rapid changes in many lowland areas. For example, J. Hector (in his letter to Günther, printed in Günther 1867: 307) stated that the type locality of *N. apoda* now lay beneath the goldfields township of Kanieri but that '… little more than two years ago it was a swamp covered in dense forest.' Much of this landscape change is irreversible. However, if conservation actions are carried out now, it may be possible to preserve and restore the remaining lowland habitat of *Neochanna* species. This chapter discusses recovery plans, methods of determining distribution and conservation priority, habitat protection and restoration, reserve design, and establishing new populations.

11.1 RECOVERY PLANS

Guidelines towards a conservation strategy for *N. burrowsius* were produced by Eldon (1993), and a recovery plan for *N. apoda* was written by Francis (2000b). The most recent and, so far, most comprehensive plan is the the New Zealand *Neochanna* species recovery plan published by DOC (2003). This plan sets out actions thought neccesary over ten years to ensure the recovery of these species. The long-term goal of this plan is 'that the geographic range, habitat, and genetic diversity of all mudfish species are maintained and improved' (DOC 2003: 12). Five objectives were identified for the term of the plan (2003–2013). These are:

- The protection and management of *Neochanna* habitats
- Monitoring of population trends
- Advocacy for the protection and sustainable management of habitats
- Maintenance and increase of populations
- Involvement of iwi in the implementation of the plan

Objective 4 of the recovery plan (DOC 2003) intended that the endangered species classifications of *N. burrowsius* and *N. heleios* be improved to the status of 'Serious Decline' or better, and that *N. diversus* and *N. apoda* remain at 'Gradual Decline' or improve by 2013.

11.2 DETERMINING DISTRIBUTION

To conserve a threatened species, it is important to evaluate its distribution and abundance using reliable measures. Unfortunately, as a species becomes increasingly rare, it becomes more difficult to detect and sample adequately. This problem is compounded for *Neochanna* species by the general difficulty in capturing them (Eldon 1992). Because of the 'marginal' nature of many *Neochanna* habitats, regional-scale fish surveys have only rarely found *Neochanna* species (McDowall et al. 1977; Main 1989). Comprehensive surveys targeted at *Neochanna* species have been conducted successfully throughout their ranges (section 2.3). Even so, when potentially suitable habitat is specifically sampled, the success rate for finding *Neochanna* species is seldom more than 50% (Table 11).

A variety of methods have been employed to capture *Neochanna* species, with Gee-minnow traps being the most common (Table 12). However, methods used for sampling different species have varied subtly due to differences in habitat type and surveyor preference. Other commonly used capture methods include fyke nets for *N. rekohua*, electric fishing and push nets for *N. burrowsius*, a combination of passive trapping methods for *N. diversus*, Kilwell bait traps for *N. heleios*, and hand nets for *N. apoda* (Table 12). Comparisons of data collected using different methods can be problematic. Thus, standardised methods for surveying and monitoring *Neochanna* species have been proposed (DOC 2003).

TABLE 11. PERCENTAGES OF SITES AT WHICH *Neochanna* SPECIES WERE ENCOUNTERED DURING SURVEY WORK SPECIFICALLY FOCUSED ON FINDING THEM.

SPECIES	TOTAL NUMBER OF SITES SURVEYED	NUMBER OF SITES WITH *Neochanna*	PERCENTAGE OF SITES WITH *Neochanna*	SOURCE
N. burrowsius	21	7	33	Cadwallader (1973)
	65	22	34	Harraway (2000)
	90	21	23	Eldon (unpubl. data)
N. diversus	35	4	11	McGlynn & Booth (2002)
	180	31	17	Kerr & McGlynn (2001)
	94	29	31	University of Waikato*
N. heleios	35	10	29	McGlynn & Booth (2002)
	180	19	11	Kerr & McGlynn (2001)
	94	3	3	University of Waikato*
N. apoda	26	7	27	Francis (2000a)
	31	23	74	Rebergen (1997)
	26	8	31	Butler (1999)
	14	4	29	Caskey (1996)
	7	1	14	Caskey (1997)
	33	11	33	Grainger (2000)

* Data given in Kerr & McGlynn (2001).

TABLE 12. ANALYSIS OF COLLECTION METHODS USED TO CAPTURE *Neochanna* SPECIES AS INDICATED BY NZFFD RECORDS. VALUES ARE PERCENTAGES FOR EACH FISH SPECIES.

COLLECTION METHOD	*N. rekohua*	*N. burrowsius*	*N. diversus*	*N. heleios*	*N. apoda*
Gee-minnow trap	57.1	59.4	57.9	90.9	59.5
Passive methods combined*	14.3	6.9	13.5	2.3	8.2
Fyke net	28.6	3.0	2.3		0.5
Hand net		7.9	12.3	2.3	10.3
Electric fishing		8.9	5.3		5.6
Kilwell bait trap			5.3	4.5	7.7
Push net		8.9	2.3		0.5
Observation		4.0	1.2		6.2
Passive and active methods combined†		1.0			1.0
Spotlighting					0.5

* Records based on a combination of net types, net/trap combination, Kilwell/Gee-minnow combination, or a combination of trap type methods.

† Records based on electric fishing/trap combinations, or net/electric fishing combinations.

Past survey work on *Neochanna* species (and freshwater fish in general) has generated site-specific point data. However, there is a growing need for detailed information on the small-scale, continuous distribution of species, particularly for planning and resource consent purposes. Thus, the management of freshwater fish using geographical mapping and modelling techniques has increasingly been recognised; for example, by Joy & Death (2000, 2002, 2004) who have successfully developed models to predict fish community composition in New Zealand streams. However, these models have predominantly focused on migratory species, and have not included rare species (occurring at < 5% of sites) such as *Neochanna*.

11.3 DETERMINING PRIORITY

Objective 1 of the *Neochanna* recovery plan (DOC 2003: 13) is to '**protect and manage habitats with key mudfish populations**', with criteria to define key populations being listed as: preservation of large populations or habitats, unique or key scientific sites, maintenance of the geographic range, and genetic and biological diversity within each species. Priority setting has often relied heavily on the considered opinions of experts. However, quantitative methods, by which sites can be ranked to set conservation priorities, are increasingly important in conservation science (Minns 1987). The identification of effective assessment indicators, which require only basic monitoring data, will be essential for on-going conservation efforts. Increasingly, volunteer groups, non-scientific agencies, and quickly trained personnel using simple methods are conducting monitoring. This should be welcomed, as it may be a necessity for undertaking large-scale monitoring. However, it is important that the data collected yield meaningful information, in addition to the techniques being straightforward. There is, therefore, a need for transparent criteria that even persons with limited expertise can use (Minns 1987).

Ranking diverse habitats and *Neochanna* species populations is difficult. There is a tendency to rank habitats on the basis of the level of modification or agricultural influence, with 'good' habitat being judged to be sites that retain perceived 'naturalness'. However, aesthetically 'natural' sites may not sustain the densest populations (Eldon 1978b; O'Brien 2005). For example, Barrier (1993) recorded the highest catch per unit effort (CPUE) of *N. diversus* in a roadside drain. Similarly, Francis (2000a) found the occurrence of *N. apoda* increased in areas of higher agricultural activity in the Wairarapa. Thus, population characteristics should be considered to identify key populations, as well as habitat values.

11.3.1 Methods of ranking populations

It is important when assessing a population's status that results are compared against overall standards and/or guidelines. This ensures a comparable ranking system across the entire range of habitats within a species' range. In studies of *Neochanna* populations, the most commonly used estimate of density is CPUE data, using Gee-minnow traps and calculated as number of fish caught per trap per night. Analysis of NZFFD records using Gee-minnow traps (and which also state the effort used) indicate that the majority of sites have relatively low catch rates, i.e. 50% of populations sampled resulted in a CPUE of less than one, except for *N. burrowsius* (Fig. 15). *Neochanna burrowsius* populations consistently exhibited higher CPUE, and thus likely higher densities. This could be related to their generally higher fecundity (Fig. 9). *Neochanna diversus* populations usually yield the lowest CPUE of the mainland species (Fig. 15).

Another important characteristic of a population is the size of individuals. Maximum lengths of *Neochanna* in New Zealand, recorded as total length, are: *N. rekohua*—175 mm, *N. burrowsius*—157 mm, *N. diversus*—165 mm, *N. heleios*—134 mm, and *N. apoda*—200 mm (Eldon 1979c; McDowall 2004; NZFFD records). These differences in size attained are likely associated with differences in growth rate and/or longevity among species (section 6). Within species, adult size, especially that of females, has important consequences for population dynamics, principally because fecundity increases with size (Eldon 1978b, 1979c; Fig. 9). Thus, a population containing large females may produce a greater number of offspring, which increases the chance that some will survive, than a similar-sized population of small fish.

We suggest that *Neochanna* populations can be comparatively ranked, using the population attributes of CPUE and maximum fish length which are often recorded in the NZFFD. For example, cumulative graphs of fish density (CPUE; Fig. 15) obtained from Gee-minnow trap collections and the length of the largest fish captured (Fig. 16) could be used to rank sampled populations against the results of all other populations and sampling occasions. Specifically, this could be done by assigning a ranking, from 1 to 3, based on where the sample population fits in relation to records from other populations of that species. Rank classes are defined by the range of values, obtained from Figs 15 and 16, representing

Figure. 15. Cumulative frequency of *Neochanna* population densities in terms of catch per unit effort (CPUE) using Gee-minnow traps, as given in the NZFFD at 30 July 2004.

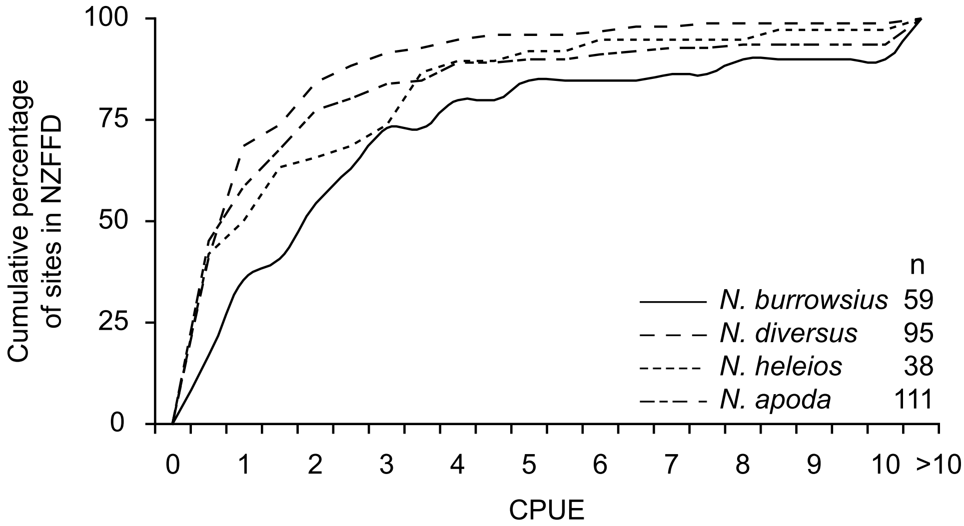
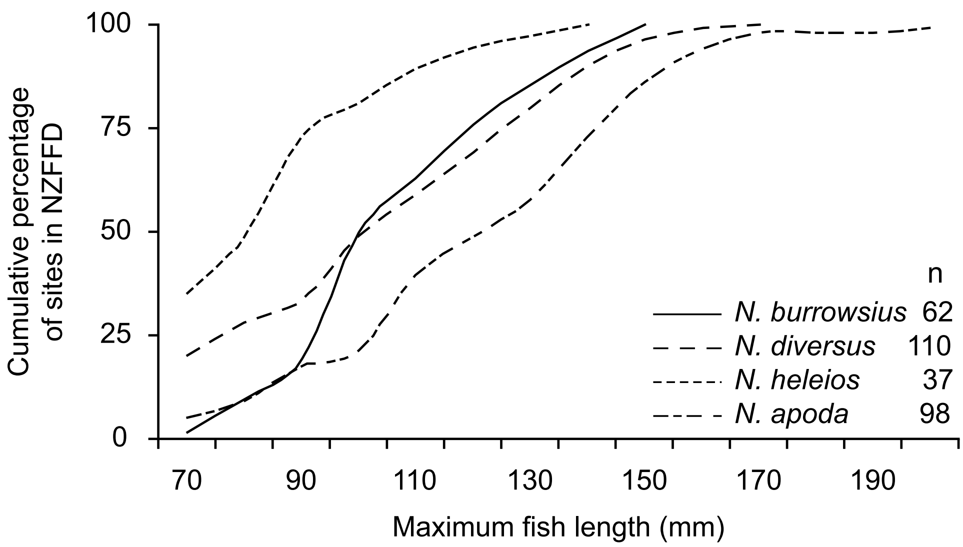


Figure 16. Cumulative frequency of maximum *Neochanna* lengths (mm) at all sites reported in the NZFFD as at 30 July 2004.



the 75–100 percentile (Rank 1), 50–75 percentile (Rank 2), and 0–50 percentile (Rank 3). This method of population assessment compares relatively well with more subjective assessments used by various authors. For example, Barrier et al. (1996) classed high catch rates for *N. diversus* as 1–8 fish per trap per night and low catch rates as 0.4, and Kerr & McGlynn (2001, p. 28) stated that 'good sites often have greater than 4 fish per trap'. Using CPUE data presented by Hicks & Barrier (1996) as an example, the suggested classification scheme would give a top ranking to eight of the 39 sites where *N. diversus* were found, and a second ranking to five of the sites. Use of such a ranking method to identify key sites objectively is important, as highly ranked populations are likely to be a source of recruits to surrounding habitats.

11.4 HABITAT PROTECTION AND RESTORATION

Many *Neochanna* populations are protected by virtue of occurring in remnant wetlands that receive some form of protection, e.g. Ashhurst Domain, Whangamarino Wetland, Kopuatai Peat Dome, Mangarakau Wetland, and Fensham Reserve. However, populations on private land remain largely unprotected. In fact, analysis of DOC's National Database of Key Mudfish sites (DOC, unpubl. data, as at January 2004) shows that of 67 sites with land ownership given, 63% were on privately owned land. The use of covenants, such as that on Dog Kennel Stream, South Canterbury (which was the first to specifically protect a freshwater fish on private land; Gray 2000), is increasing, with 6% of sites included in the key *Neochanna* site database being under some form of protection. Although private ownership is sometimes an obstacle to conservation activities (e.g. DOC 2004a), the numbers of landowners interested in protecting *Neochanna* populations is increasing (DOC 2004b). There are many options for the protection of wetland habitat and they include both short-term and non-binding arrangements, and legal protection in perpetuity. Legal agreements (such as covenants) to protect land can be made between landowners and a number of organisations, including the Queen Elizabeth II National Trust, DOC, and local authorities. A variety of funds is also available to support conservation activities. Information on these can be obtained from DOC and local councils.

Many *Neochanna* habitats have undergone some form of restoration, mainly involving riparian planting (e.g. Caskey 2000). However, only a few studies comparing 'restored' and 'control' sites have been carried out, and one of these has suggested that dense plantings of trees and other vegetation in 'restored' sites may not always be beneficial to *Neochanna*. Leanne O'Brien (unpubl. data) compared *N. burrowsius* from similar pool habitats above, and within, a restored section of Dog Kennel Stream, South Canterbury, during 1999 and 2001. Juveniles from un-restored pools were generally longer and had greater condition than those in the restored pools. Although further studies are needed, this result does emphasise the importance of adequate monitoring when conducting habitat modification or restoration activities to ensure the outcomes are as envisioned and to guide future conservation efforts.

11.5 RESERVE DESIGN

Faunal reserves have been suggested as one way of ensuring the continued persistence of *Neochanna* species. McDowall (1984) described the appropriate criteria guiding reserve design for freshwater fish in New Zealand as naturalness, reserve size, permanence of water, absence of exotic species, absence of exploitation, and access to the sea. Although McDowall (1984) included the criterion of access to the sea primarily for diadromous species, which need access to it, this criteria is also important for *Neochanna*, but from the opposite perspective. Connections to the sea can be expected to increase the occurrence of other species which is not desirable. Reserves for *Neochanna* need to be of sufficient area to maintain the integrity of their hydrology (Close 1996; Hicks & Barrier 1996), and Hicks & Barrier (1996) considered buffer zones were needed between wetland reserves and surrounding pasture. Nevertheless, many *Neochanna* populations are able to persist in a very small habitats (McDowall 1984; Eldon 1986; Eastwood 1997), indicating that even small reserves may be effective.

The establishment of multiple, interconnected or 'complex' reserves may be desirable, as this would increase the probability of some individuals surviving severe disturbance and being able to repopulate habitat where populations have been lost. Several studies have demonstrated the ability of *Neochanna* to disperse widely and recolonise suitable habitats after disturbance (e.g. Eldon 1978b; Eldon et al. 1978; Main 1989; O'Brien 2000). Dispersal provides a mechanism whereby fish can naturally and rapidly recolonise streams following perturbation and local extinction (McDowall 1996b). Davey et al. (2003) considered that dispersal of *N. burrowsius* during flooding was an important component of its long-term persistence and that, where possible, dispersal routes between sites during flooded conditions should be identified and maintained to allow recolonisation of suitable habitats following local extinctions. Promoting the natural re-establishment of fish populations has particular advantages in that it occurs when habitat conditions are again suitable, colonising stocks are well adapted to local conditions, and it is inexpensive (McDowall 1996d).

11.6 ESTABLISHING NEW POPULATIONS

Throughout the world, captive breeding has brought many species back from the brink of extinction. In New Zealand, it is being used to increase population sizes, maintain genetic variability and as a source of translocation stock of threatened endemic fauna. Its potential for the conservation of threatened *Neochanna* species has been recognised and advocated, e.g. Eldon (1969, 1993) and Swales (1991), and general guidelines for the captive breeding, rearing and establishment of new *Neochanna* populations have been outlined (O'Brien & Dunn 2005). Successful captive breeding has been achieved for *N. burrowsius* (Cadwallader 1975a; Eldon 1979c; Gay 1999; O'Brien 2005), *N. diversus* (Gay 1999), and *N. apoda* (Eldon 1969, 1971). Further, Caskey (2002) and Perrie (2004) successfully reared *N. apoda* and *N. diversus* juveniles after attempts at breeding.

Some translocations of *Neochanna* species to protected sites have been successful in New Zealand, especially efforts by G.A. Eldon with *N. burrowsius* during the 1980s (Eldon 1983, 1985, 1986, 1988a, 1988b, 1989, 1993; Eldon & Field-Dodgson 1983). Initial sites included the Christchurch botanical gardens, a small pond at Ohoka, an old borrow pit at Lowcliffe, and farm dams at Taiko (Eldon 1983). By 1985, however, *N. burrowsius* were found at only two of these four sites, and the liberated juveniles in one of them were in poor condition and showed no evidence of breeding (Eldon 1985). Further translocations have also had mixed success (Eldon 1989, 1993). More recently, DOC staff translocated *N. burrowsius* to the Willowby Local Purpose Reserve (S. Harraway, DOC, pers. comm.) and to an artificially constructed 8.3-ha wetland at Westerfield (South Branch Ashburton River) in February 2002. Only the latter translocation was successful. Attempts have also been made to establish *N. burrowsius* in a restored urban waterway (Hartley 2003). In the Stratford area, Caskey (1999, 2000) applied Eldon's (1993) translocation guidelines to *N. apoda*, which occurs in fragmented agricultural habitats. A media release (Stratford Press, August 5 1998) and previous survey data (Caskey 1996, 1997, 1998) were used to locate a suitable translocation habitat where juveniles were released (DOC 1999b, 2000e, f), but despite close monitoring, the population failed to establish (Caskey 2000, 2002; DOC 2000e, f, g).

Thus, despite considerable effort, few new *Neochanna* populations have been established. This emphasises the need to focus on the protection of habitats that currently contain *Neochanna.* Further understanding is also needed of the small-scale and long-term seasonal characteristics of *Neochanna* habitats, in order to better guide the identification of potential translocation sites for each species.

12. Information gaps

Since the 1960s, 22 peer-reviewed, scientific articles on New Zealand *Neochanna* species have been published, seven in international journals. These articles give 50 different keywords reflecting the topics most extensively studied. The majority of these referred to species investigated and localities. Of the keywords relating to subject areas covered, **habitat** is included in six papers, **conservation**, and **air-breathing** in three, and **behaviour**, **diet**, **distribution**, **population genetics**, **spawning**, and **taxonomy** in two. A review of the literature on *Neochanna* reveals that because of their discrete distributions, most research has been on single species, by researchers from universities in the vicinity of the particular study species or population. Few comparative studies have been made, despite *Neochanna* species forming a well-defined group with interesting similarities and dissimilarities. The domination of species-specific research has led to conclusions generated from work on a few species being applied to the genus as a whole, with much speculation. Despite this, many studies emphasise that *Neochanna* species are distinct and have unique characteristics. Rather than apply overall generalities, with provisos that some species are exceptions, the present review highlights the recognition of a continuum of characteristics found among them. Further, although many common characteristics—such as drought tolerance—have been identified, the exact mechanisms allowing *Neochanna* to persist require further study. Thus, there is a need to move from a descriptive to a mechanistic approach to research on *Neochanna* species. Understandably, the greatest information gaps are for the newly described or re-classified species, i.e. *N. heleios* and *N. rekohua*. However, further research into many aspects of basic biology and ecology is needed for all species to ensure there is adequate information to effectively undertake conservation management.

12.1 TRANSFORMATION SERIES

The transformation series (Fig. 3) initially proposed by McDowall (1997a) and substantiated by Water & McDowall (2005) is based on detailed knowledge of the morphological characteristics and phylogenetic relationships of the six species of *Neochanna*. The relationships are interpreted as indicating increasing adaptation to life in shallow, hydrologically fluctuating wetlands. Morphological, phylogenetic and ecological data continue to provide strong support for the placement of *Neochanna* species within the transformation series and its use as a general framework for generating hypotheses to guide further research of the genus. This review of *Neochanna* literature also supports an extension of the transformation series to include differences in life-history, fecundity, current habitat use, physiological adaptations and tolerances, and survival strategies. However, the lack of comparative research and inadequate data on many species means that definitive conclusions are not possible at present, and there is a need for:

- Comparative studies to determine the validity and generality of conclusions based on the transformation series.
- Improved understanding of the mechanisms by which particular habitats exert selective pressure on *Neochanna* species.
- Development of conservation guidelines that reflect species-specific characteristics and requirements, as indicated by the transformation series.

12.2 DISTRIBUTION

The boundaries of evolutionary significant units (ESUs) for each species have been identified and knowledge of the geographic extent of species distributions is good (Fig. 2). Further, as *Neochanna* species are restricted to low-lying areas, their distributions are unlikely to change substantially. Further areas of investigation relating to species distributions are:

- Mapping of small-scale distributions of *Neochanna* species in wetlands and agricultural drains in a form suitable for incorporation into GIS databases, to improve conservation management.
- Resurveying of sites sampled prior to c. 1995 to assess population persistence.
- Evaluation of local extinction events since records began to determine likely rate of recent decline.
- Determination of the ability of *Neochanna* species to disperse, and identification of factors that affect dispersal rates of all life stages.

12.3 HABITAT

Investigations to date have identified general habitat characteristics for many *Neochanna* species. Species appear to occur in habitat types across a hydrological continuum, which is likely to be related to adaptations indicated in the transformation series. Further investigations could focus on:

- Understanding habitat use by *Neochanna* species at all life stages, and the importance of ontogenetic shifts in habitat use.
- Understanding the role of hydrological fluctuation on distribution, persistence, and local adaptation of *Neochanna* species.
- Developing detailed models of habitat preference for *Neochanna* species, including aspects of hydrology, vegetation (terrestrial and aquatic), and community attributes (fish and invertebrate).
- Models have been developed for some species; however, these may require further testing at a wider range of sites (if these were not included in the original model) to determine their predictive ability.
- Developing simple and quick methods for initial habitat assessment.

12.4 FEEDING

There have been few extensive studies of *Neochanna* diet, due in part to the destructive methods usually required, which limit sample sizes. However, *Neochanna* species are regarded as generalist feeders, although there are likely to be differences in diet that relate to habitat type. In particular, investigation is required into:

- The role of differences in teeth and jaw morphology in diet and feeding mode.
- How changes in habitat hydrology influence prey species composition and thus *Neochanna* growth rates.
- The ability of *Neochanna* species to change diet or otherwise compensate for the presence of competing fish species.

12.5 REPRODUCTION

Although reproduction is a requirement for population persistence, it has not been well studied in *Neochanna* species, especially in *N. heleios* and *N. rekohua*. This is an essential area of future study, especially as *Neochanna* species appear to differ from one another in their reproductive characteristics. Investigations should focus on:

- Determining the timing, location and type of habitat used for spawning by all species.
- Verifying that *N. apoda* habitually scatter eggs above the water line and how they achieve this.
- Investigating the role of habitat quality and environmental cues in determining spawning in *Neochanna* species.
- Investigating the fecundity and early development of all species, including egg characteristics such as size ranges and development times.

- Assessing the effect of emersion and habitat factors on subsequent reproductive output.
- Determining the length of time that *Neochanna* species can retain viable eggs and the mechanisms by which they do so.

12.6 POPULATION CHARACTERISTICS

Population investigations are best approached through long-term study and monitoring at particular sites, and they require appropriate funding and time allocation to ensure that this happens. There is a need to:

- Investigate the relationship between recruitment, habitat capacity and population density.
- Investigate whether there are differences in patterns of growth between species which may reflect differences in somatic versus reproductive investment.
- Confirm the occurrence of stunting and determine factors suppressing growth and adult size in populations.

12.7 BEHAVIOUR

Much of the information regarding *Neochanna* behaviour is anecdotal and many field observations are necessarily serendipitous. Thus, there is a need for further laboratory- and field-based behavioural studies on:

- Species-specific survival strategies, and whether all species respond equally to emersion.
- Size-dependent responses to summer stress, as different-sized fish may require different summer refuges.
- Shelter-seeking behaviour, what triggers such behaviour, and how *Neochanna* species choose specific kinds of refuges.
- How capable *Neochanna* species are at burrowing, what type of substratum is required, and where in particular habitats they are likely to burrow.
- Social behaviour during periods of increased stress or threat, and its potential to improve survival.
- Behavioural studies of *Neochanna* in low-pH waters and under progressively hypoxic conditions.

12.8 PHYSIOLOGY

The mechanisms that enable *Neochanna* to survive without free water for extended periods are still not fully understood. Physiological investigations have focused on *N. burrowsius* and *N. diversus*, with conclusions obtained from studies of these species often being applied to the genus as a whole. There is a need, therefore, for more species-specific knowledge. Meredith (1985), Dean (1995), and Davidson (1999) all note subjects requiring further study, including direct comparisons of oxygen consumption, metabolic rate, critical oxygen values, and gill morphology. Further, investigations must employ standardised experimental procedures and acclimation times. Topics for research could include:

- Investigations of the physiological parameters of *Neochanna* during exposure to low-pH waters.
- Whether the water permeability of mucus changes upon desiccation.
- The role of mucous substances in aiding the disassociation of ammonium ions during emersion, and maintenance of a neutral skin pH.
- Comprehensive determination of blood characteristics of fish in aquatic and aerial conditions.
- Investigations of *Neochanna* circulatory systems; in particular, blood flow to the skin, to assess the ability of the species to undergo cutaneous vasoconstriction in response to hypoxia and emersion.
- Investigation of the ability of *Neochanna* species to lower their metabolic rates on emersion, and the limits of this ability.
- Whether *Neochanna* species are capable of switching from protein to lipid or glycogen metabolism.

12.9 THREATS

Major threats influencing *Neochanna* populations have been identified (Table 9), but how they actually affect individuals and populations is not well understood. In particular, there is a need to:

- Quantify and understand the threats posed to *Neochanna* populations by common land management and agricultural activities.
- Investigate and quantify the impact of drain maintenance on *Neochanna* populations, including direct and indirect factors.
- Develop environmentally and economically sustainable approaches that address the apparent conflict between intensive land management and the persistence of *Neochanna* populations.
- Investigate the effect of potential competitors and predators on the persistence and health of *Neochanna* populations.
- Investigate disturbance-mediated coexistence between *Neochanna* species and potential competitors and predators.
- Investigate internal parasites and disease to fully assess the vulnerability of *Neochanna* species to these.

12.10 CONSERVATION

Historically, much conservation work on *Neochanna* species has been relatively ad hoc. However, since the formation of the DOC mudfish recovery group and the development of a 10-year recovery plan (DOC 2003), initiatives have become increasingly co-ordinated. There is still a need to:

- Develop guidelines for assessing *Neochanna* habitats and applying appropriate conservation actions (such as revegetation).
- Determine whether agricultural drain networks can provide dispersal corridors between small reserves to allow gene flow, particularly in *N. burrowsius*.
- Develop quantitative and transparent (but straightforward) methods by which populations can be easily ranked, that can be used to set conservation priorities.

- Determine effective assessment indicators that require only basic monitoring data, to facilitate evaluation of on-going conservation work.
- Determine what information landowners need, and develop information packs with species-specific information and best practices for interested landowner groups.
- Develop guidelines for identifying potential sites for establishing new populations.
- Improve the procedures for pre-translocation proposals and post-translocation monitoring of sites, and assimilation of knowledge to aid further translocations.
- Investigate the factors responsible for the success or failure to establish of *Neochanna* populations.

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What is known about* Neochanna *species?

Neochanna *(mudfish) are small, cryptic fish of the Galaxiidae family that exhibit extraordinary survival ability and amphibious behaviour. Of the six* Neochanna *species, five are endemic to New Zealand.* Neochanna *species show a continuum of morphological transformation from* Galaxias*-like characteristics towards an anguilliform, or eel-like body plan. Overall, the taxonomic distinctiveness, general biogeography, and genetic structure of the genus* Neochanna *is fairly well known, but many aspects of the species' physiology, biology, and ecological situation require further study.*

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