Native fish requirements for water intakes in Canterbury

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Department of Conservation
Te Papa Atawhai

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        Part 6—Fish passage

1. Background

There are several development pressures currently facing Canterbury's waterways and their associated instream values. One of these is water abstraction.

There are several risks to native fish species from screens, water intakes, and water races including that:

- Fish habitat can deteriorate or be lost with the removal of water from the natural system
- Fish may be entrained into water races, resulting in fish being impeded from completing their migrations, or the intake system can become an invasion pathway for fish to enter waterways where they do not already occur (Allibone 2000).
- Fish may die on intake structures (e.g. become impinged on the screens) or in water races if they are dewatered. Spawning sites may also be de-watered in water races.
- Populations of non-diadromous species may establish within water races and cause sinks and/or hybrid populations owing to a lack of mixing (Allibone 2000). This could also result in continuous loss of fish in the natural stream to the water race.
- Native species may be exposed to greater risk of predation and/ or competition in water races and intake structures.
- Water races might not provide appropriate habitat for survival of the species e.g. slow growth, poor spawning and poor rearing habitat.

Some of these risks may be compounded by repeated exposure to water races and/or intake structures.

The management and protection of freshwater systems and their species are of concern to the Department of Conservation (the department) and other environmental agencies. The department also has a statutory duty to protect freshwater systems and species.

The issues surrounding water intakes and impingement and entrainment of fish have received considerable research overseas (e.g. USBR 2006; DWA 2005), but little work has been carried out in New Zealand, especially on native species. In one of the few New Zealand studies, Unwin et al. (2005) found that a major unscreened take from the Rangitata River (approximately 31 m^3/s) entrained a large number of juvenile salmon into irrigation and hydroelectric canals. During the irrigation season and when the power station is not operating, there is no route by which unused water can be discharged back to natural waterways in this scheme. Therefore, any fish passing through this intake system during this period are a complete loss to the fishery. As part of the same study, Webb (1999) also noted significant losses of native fish. Torrentfish, upland bully, longfin eel, unidentified galaxiids and koura were caught (from 48 mm (upland bully) to 1000 mm (eel)), with torrentfish and longfin eel being the most commonly caught (Webb 1999). Smaller native fish were not caught probably owing to the trap mesh size of 3.4 mm. Therefore entrainment of fish into intake systems is likely to be having an affect, not only on recreational fish species, but also native fish populations throughout Canterbury. This study provides local evidence of the need for water intakes to be designed to prevent fish from being entrained.

Appropriately designed intakes and fish screens could minimise some of these current affects and/or prevent entrainment of many fish. The importance of considering water intake requirements of native fish relates not only to their intrinsic biodiversity value and legal considerations relating to fish passage, but also to recreational, cultural, and commercial fisheries (especially eels and whitebait), and as a food source for the sport fisheries (primarily salmonids in Canterbury). In 2004 Environment Canterbury initiated a process for formulating guidelines and standards for flowing water intakes in Canterbury. As part of this process, Fish and Game NZ produced criteria for sports fish based on both New Zealand and overseas literature (Bejakovich 2005). More recently the department was asked to contribute to this process by preparing this document with the aim of identifying water intake requirements that would protect native fish. This report focuses on native fish species that spend a significant part of their lifecycle in freshwater. It does not cover invertebrates, plants or other instream life also present in Canterbury waterways that could be affected by entrainment, impingement and/or passage. This information will be combined with results in Bejakovich (2005) by Environment Canterbury to prescribe standard intake and screening requirements that will protect freshwater fish communities in Canterbury waterways.

2. Freshwater responsibilities

Management of all fisheries types in New Zealand is governed by the Conservation Act 1987, which includes the Freshwater Fish Regulations 1983 (section 48a Conservation Act), and the Fisheries Act 1983. In relation to fish passage, the department's responsibilities include:

- Protecting freshwater fish habitats (s.6ab; Conservation Act 1987).
- Advocating the conservation of aquatic life and freshwater fisheries generally (s.53 (3) (d); Conservation Act, 1987).
- Administering the fish passage provisions (Part VI) of the Freshwater Fisheries Regulations 1983.

These functions are closely related to those of other agencies including the Ministry of Fisheries, regional councils and Fish and Game New Zealand, which also have specific functions in freshwater management in New Zealand. In Canterbury, both Environment Canterbury and the department have specific responsibilities with regard to fish passage.

Part VI (Regulation 41-50) of the Freshwater Fisheries Regulations 1983 states that:

- The Director General of Conservation may require that any dam or diversion structure has a fish facility (fish pass, fish screen or similar) included and can set conditions on its design and performance.
- Culverts and fords may not be built in such a way as to impede fish passage, without a permit from the Director General of Conservation.

(Full details see Appendix 1).

Consequently the regulations provide an opportunity for more detailed design, management and maintenance of structures to facilitate, and sometimes restrict, the passage of fish within waterways and/or to and from the sea. One reason for sometimes restricting access is to prohibit entrainment into water intake systems and the other is because some species have been found to have a negative impact on some native fish communities. Invading fish populations may compete, predate or potentially hybridise with resident native fish species (Allibone 2000).

Generally, these Freshwater Fisheries Regulations requirements apply to all defined structures unless they were built prior to 1 January 1984 and were authorized under the then Water and Soil Conservation Act 1967. This Act was the primary legislation governing the use of water resources prior to the enactment of the Resource Management Act (RMA) controls on water management and use.

Under the RMA, Environment Canterbury is responsible for the sustainable management of natural and physical resources including water, and land covered by water, in Canterbury. Therefore, environmental effects relating to the construction of structures in river and stream beds are controlled under the RMA, and these include consideration of water quality, aquatic life, erosion and habitat of aquatic and terrestrial flora and fauna, including passage of fish. Under the RMA, the department has an advocacy role only.

The department previously considered the RMA responsibilities covered most of its concerns, however, recently an Environment Court decision noted that the department's authorizations, for fish passage, as mentioned above, are required regardless of any other consent (RMA, Building Act etc.) or landowner approvals (Auckland Regional Council Environment Court Decision, A33/02).

Therefore, the intention of this report is to give guidance to applicants on the requirements and potential considerations for designing structures to protect native fish from entrainment and impingement on intake systems in Canterbury. The department envisages that standard requirements identified within this report will be adopted in Environment Canterbury's Natural Resources Regional Plan (NRRP) to help applicants meet both RMA and Freshwater Fisheries Regulations requirements.

Every person proposing a dam or diversion structure in waters containing fish must notify the department and seek approval or dispensation from the requirements of the regulations. This is independent of any RMA requirements or permitted activity rules in the NRRP.

3. Freshwater values in New Zealand

New Zealand has many different freshwater ecosystems, including more than 70 major river systems, 770 lakes and at least 73 significant wetlands (Cromarty and Scott 1995; Department of Conservation and Ministry for the Environment 2000). They provide habitat for a diverse range of indigenous aquatic flora and fauna including 38 endemic species of water plants (Coffey and Clayton 1988), hundreds of native aquatic and semi-aquatic invertebrates from 11 orders (Collier 1993; Winterbourn 2000) and at least 38 species of native fish (R. M. McDowall pers. comm.). In addition, Collier (1994) estimated that more than 228 species of aquatic animals and plants have also been introduced into New Zealand, of which just over 20 of those are introduced fish.

New Zealand's freshwater natural heritage is being increasingly threatened by a large number of different factors including increasing demand for water (for irrigation and energy generation); deterioration in water quality (as a result of increasing nutrient loading associated with changes in land use), degradation of aquatic habitat value, and the impacts of alien species (as a result of illegal spread). These pressures currently facing freshwater biodiversity and ecosystems have all had considerable negative consequences, with one third of the 38 described indigenous fish species now being categorised as nationally threatened, and most freshwater environments significantly modified and dominated by introduced plant and fish species (Department of Conservation and Ministry for the Environment 2000). In addition, several species of indigenous invertebrates and plants are also found within New Zealand's waterways and many are also threatened. However, this report focuses on native freshwater fish species.

4. Canterbury native fish

In Canterbury there are 27 native fish species recognised, 11 of these are threatened nationally (Hitchmough and Bull, in press) (Table 1). Several different groups of native species are represented including bullies, eels, lamprey, torrentfish and galaxiids. Canterbury supports a rich array of unusual species including a unique, unpigmented, landlocked, lake-dwelling koaro in Lake Pukaki, Stokell's smelt and Canterbury mudfish, and several species of non-migratory galaxiid species that have limited distributions.

Most native freshwater fish species are relatively small, predominantly nocturnal and highly secretive. Of the indigenous species recognised in New Zealand, over half are diadromous (migratory), requiring access to and from the sea to complete their lifecycles. It is commonly known that eels and whitebait (five different galaxiid species) migrate to and from the sea; however, it is not so well known that four species of bully, two species of smelt, and torrentfish also undertake such migrations. Some species (e.g. koaro) that are normally diadromous have also been found to be able to form self-sustaining land-locked populations (McDowall 1990).

In addition to the more strictly freshwater fishes there are also a small number of species that often find their way into the lower reaches of rivers but usually don't stay permanently or complete their lifecycles in freshwater e.g. kahawai, stargazers, cockabully. These species, that are not considered to undertake a significant part of their life in freshwater and do not penetrate far inland, are not included within this report.

Native fish species found in Canterbury are not only treasured for their intrinsic value, but also for their food (exploitation) and cultural value, such as eels, lamprey, whitebait and smelt (McDowall 1990) (Table 1). There are traditional/cultural Maori and commercial wild eel fisheries, recreational and commercial whitebait fisheries, minor black flounder and yelloweye mullet commercial fisheries (e.g. Lake Ellesmere), and other species that are popular for recreational fishing (e.g. yelloweye mullet) in Canterbury. Ngai Tahu have also recognised several freshwater fish as taonga species including giant bully, Canterbury mudfish, common smelt, torrentfish and giant kokopu.

TABLE 1. NATIVE FISH SPECIES FOUND IN CANTERBURY WATERWAYS.

COMMON NAME	SCIENTIFIC NAME	THREAT RANKING[1] (SOURCE: HITCHMOUGH AND BULL IN PRESS)
Lowland longjaw galaxias	*Galaxias cobitinis*	Nationally critical
Canterbury mudfish	*Neochanna burrowsius*	Nationally endangered
Dwarf galaxias	*Galaxias divergens*	Gradual decline
Longfin eel	*Anguilla dieffenbachii*	Gradual decline
Giant kokopu	*Galaxias argenteus*	Gradual decline
Bignose galaxias	*Galaxias macronasus*	Gradual decline
Upland longjaw galaxias	*Galaxias prognathus*	Gradual decline
Shortjaw kokopu	*Galaxias postvectis*	Sparse
Lamprey	*Geotria australis*	Sparse
Stokell's smelt	*Stokellia anisodon*	Range restricted
Northern flathead galaxias	*Galaxias vulgaris* type fish * data poor	Range restricted
Shortfin eel	*Anguilla australis*	Not threatened
Torrentfish	*Cheimarrichthys fosteri*	Not threatened
Koaro	*Galaxias brevipinnis*	Not threatened
Banded kokopu	*Galaxias fasciatus*	Not threatened
Inanga	*Galaxias maculatus*	Not threatened
Alpine galaxias	*Galaxias paucispondylus*	Not threatened
Canterbury galaxias	*Galaxias vulgaris*	Not threatened
Upland bully	*Gobiomorphus breviceps*	Not threatened
Common bully	*Gobiomorphus cotidianus*	Not threatened
Giant bully	*Gobiomorphus gobioides*	Not threatened
Bluegill bully	*Gobiomorphus hubbsi*	Not threatened
Redfin bully	*Gobiomorphus huttoni*	Not threatened
Yelloweye mullet	*Aldrichetta forsteri*	Not threatened
Common smelt	*Retropinna retropinna*	Not threatened
Black flounder	*Rhombosolea retiaria*	Not threatened
Yellowbelly flounder	*Rhombosolea leporina*	Not threatened

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[1] "Acutely threatened" (nationally critical, nationally endangered and nationally vulnerable) species face a very high risk of extinction in the wild and generally have a small population and a moderate to large recent or predicted decline.

"Chronically threatened" (serious decline, gradual decline) face extinction but are buffered by either a large total population or a slow decline rate.

"At risk" (range restricted, sparse) have either restricted ranges or small scattered sub populations, and have a risk of decline.

4.1 GENERAL DISTRIBUTION AND IMPORTANT HABITATS OF NATIVE FISH

General distribution and commonly occupied habitats for each fish species currently found in Canterbury waterways is summarised in Table 2[2] (these descriptions are focussed on diadromous populations). Although this information is current and a lot has been learnt about freshwater fish in recent years, it is important to recognise that this information could change as there are still knowledge gaps for many species.

As detailed in Table 2, several species are found throughout New Zealand (e.g. common bully, shortfin eel); some are predominantly found only in Canterbury (e.g. Canterbury mudfish, Stokell's smelt); some have very restricted distributions but are found in neighbouring regions as well (e.g. lowland longjaw galaxias and upland longjaw galaxias); and some are found only in small parts of Canterbury (e.g. bignose galaxias). All species with restricted distributions, including those found predominantly or only in Canterbury, are endangered nationally and thus protecting these species over their full geographic range is vital for their future survival.

Native fish species in Canterbury inhabit a wide range of habitats including braided rivers, lakes, wetlands, small spring fed streams and tributaries (Table 2). Small freshwater habitats are often the areas that support the greatest native fish biodiversity by providing a natural environment and refuge from introduced species and natural predators. This highlights an important feature of native fish communities, that they are not restricted to 'big' waters, and their most important habitats are often small tributary streams and wetlands. In effect, consideration of native fish requirements is critical in water intake design in all sized waterways, from small ephemeral streams to large braided rivers.

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[2] Sources: McDowall 1965; Jowett and Richardson 1995; Allibone and Caskey 2000; McDowall 2000, Charteris 2002; McDowall and Waters 2002; McDowall and Waters 2003; Charteris et al. 2003; Bowie 2004; Jellyman 2004; Elkington and Charteris 2005

Native fish have also been found to occur in a wide range of habitat types from still or slow moving habitats (e.g. giant kokopu), to fast riffle habitats (e.g. torrentfish) (Table 2). Jowett and Richardson (1995) found that fish densities of resident common riverine native fish species were higher in riffles than in runs and are most abundant along river margins in depths of less than 0.25 m. They found optimum depths for small shortfin eel (< 200 mm) and for small longfin eel (<200 mm). The optimum depth for common bullies, upland bullies and Canterbury galaxias was less than 0.1 m. Torrentfish and bluegill bully were fast water species that preferred high water velocities and depths greater than 0.2 m. In contrast, upland bully and Canterbury galaxias were edge dwellers found in shallow slow-flowing margins. Redfin bully and common bully utilised intermediate habitat, with the former preferring deeper, slow flowing water and the latter swifter, shallower water.

Glova and Duncan (1984) also investigated depth preferences for several native fish species using habitat suitability curves with information collected from the Rakaia River. They found similar results to that of Jowett and Richardson (1994) with torrentfish and bluegill bully but for upland bully the optimum depth was 0.3 m and for juvenile longfin eels it was 0.5 m. Schicker et al. (1989) found that elvers migrate along the river margins and across the bottom of the river channel, with the greatest concentration recorded in the river margins at mid water depths. Boubẽe et al. (1986) found that downstream adult and upstream juvenile torrentfish were caught only in the main channel, not the edge habitats.

Jellyman (2004) found slow backwater habitat to be very important for young galaxiids, Canterbury galaxias and alpine galaxias, with these species found to have a low velocity tolerance (10 mm fry are able to hold station against a velocity of only 0.1 ms-1). Investigation of the Otago population of lowland longjaw galaxias found juveniles in depths of 0.2 - 0.3 m, with an average depth of 0.21 m. In contrast adult lowland longjaw galaxias used significantly shallower depths with a mean depth of 0.11 m (Baker et al. 2003).

These studies reveal that several native fish prefer to live near the bottom in shallow habitats, often in the edges of waterways but not always. Information on where native fish are found within the water column is detailed in Section 4.1.1.

To further complicate things, many native fish move between habitats as part of their lifecycle. Some make big changes by moving from freshwater to the sea; others make smaller movements from slow backwaters when juveniles, to fast water as adults, and some move up and down rivers to find favoured spawning or feeding habitats (Table 2). The fish species found in Canterbury can be spilt into a number of communities (Table 2).

- Migratory lowland to mid-country species (e.g. smelt, inanga and giant kokopu) which are found only in the lower altitude freshwater habitats.
- Resident lowland to mid-country species which are species that don't migrate and are resident only in lower altitudes (e.g. Canterbury mudfish).
- Climbers (e.g. eels, lamprey, banded kokopu, koaro) which are predominantly found higher up in the catchments, when adults, but can be found generally throughout catchments.
- High country species (e.g. alpine galaxias, bignose galaxias, upland longjaw galaxias) which are species that are resident in the high country and don't have to migrate to the sea.
- Generalist (e.g. upland bully, common bully, Canterbury galaxias) are found throughout most habitats.

(Modified from Boubée et al. 1999)

These groupings highlight that different species have different movement patterns within catchments. This distribution and habitat information is relevant when designing a water intake system. Applicants can then identify what species are found in the catchment and therefore could use the site (e.g. during migration), and can consider what habitat types are commonly occupied, so critical and most common habitats can be avoided, where possible, to limit entrainment. Further information on the timing of major migrations and key spawning times for each species are detailed in section 4.2.

TABLE 2. DISTRIBUTION AND HABITATS OF NATIVE FISH FOUND IN CANTERBURY

COMMON NAME *NATIONALLY THREATENED	DIADROMOUS (D)/ OR NON-DIADROMOUS OR LANDLOCKED (N)	DISTRIBUTION		FISH COMMUNITY 1.LOWLAND (MIGRATORY) 2.LOWLAND RESIDENT 3.CLIMBERS 4.MID -HIGH COUNTRY 5.GENERALIST	HABITATS COMMONLY OCCUPIED	
		NATIONAL	CANTERBURY		ADULTS	LARVAE/JUVENILE
Lamprey*	D	Throughout	Throughout; penetrates long distances inland.	3	Variety of habitats including streams, rivers, braided rivers and lagoons during its passage upstream from the sea to breed.	Sandy/silty areas along stream margins during its migration downstream to sea.
Longfin eel*	D	Throughout	Throughout; penetrates long distances inland.	3	Variety of habitats from lowlands to long distances inland- including lakes, pools in small streams, rivers and wetlands.	When <300 mm found mostly in boulder/cobble riffles in rivers.
Shortfin eel	D	Throughout	Throughout; generally more coastal but can penetrate long distances inland.	3	Variety of habitats, generally low elevation rivers, streams, wetlands and lakes.	When <300 mm found mostly in boulder/cobble riffles in rivers.
Giant kokopu*	D and N	Throughout; rare on east coast.	Sparse; generally only at low elevations (Banks Peninsula, Cam River, Timaru/Temuka area, Kaikoura (Kowhai).	1	Favours small to medium, deep gently-flowing streams, wetlands and lagoons.	Goes to sea after hatching then returns to river mouths, as whitebait, months later and migrates upstream along the river margins to find adult habitat,
Shortjaw kokopu*	D	Throughout; less common on the east coast.	Rare; found in only a few streams in Kaikoura (Ohau Stream, Blue Duck Creek).	3	Penetrates inland, commonly in small stable boulder streams. Often pool dwellers.	Goes to sea after hatching then returns to river mouths, as whitebait, months later and migrates upstream along the river margins to find adult habitat,
Koaro	D and N	Throughout	Widespread from sea to inland, but favours small tributaries at higher elevations.	3	Boulder/cobble streams and landlocked high country lakes.	Goes to sea after hatching then returns to river mouths, as whitebait, months later and migrates upstream along the river margins to find adult habitat.

Banded kokopu	D	Throughout; less common on the east coast	Sparse; found only in Banks Peninsula and South Canterbury streams.	3	Penetrates inland; commonly small forested streams and rivers. Often pool dwellers.	Goes to sea after hatching then returns to river mouths, as whitebait, months later and migrates upstream along the river margins to find adult habitat.
Inanga	D and N	Throughout	Widespread at low elevations.	1	Gently flowing to still estuaries, rivers, streams and wetlands.	Goes to sea after hatching then returns to river mouths, as whitebait, months later and migrates upstream along the river margins to find adult habitat.
Lowland longjaw galaxias*	N	Kauru/Kakanui (Otago) and mid and upper Waitaki (Canterbury).	Hakataramea, Edwards, Otamatapaio, Ahuriri, Ohau, Ruataniwha and Fraser catchments.	2 Otago 4 Canterbury	Small braided rivers, streams and spring-fed streams and wetlands. Riffle and run dwellers generally.	Juveniles do not migrate. Stationary and slow flowing habitats e.g. backwaters.
Dwarf galaxias*	N	North Island -widespread but somewhat intermittent; South Island - Marlborough, Nelson, upper Canterbury and upper West Coast.	Clarence	4	Riffle and flowing margins of larger rivers and streams.	Juveniles do not migrate. Stream margins in slow-moving habitats e.g. backwaters.
Upland Longjaw galaxias*	N	Intermittent and fragmented populations in South Island high country rivers and streams (Maruia, Hurunui, Rakaia, Rangitata and Waitaki catchments only).	Intermittent populations in Hurunui, Rakaia, Rangitata and Waitaki catchments.	4	Riffles and runs of streams and rivers in the high country.	Juveniles do not migrate. Slow-moving habitats.
Bignose galaxias*	N	Mackenzie Basin (Canterbury)	Throughout the Mackenzie Basin, however, seem to be restricted to areas of wetlands, springs or streams below the glacial lakes of Tekapo, Pukaki, and Ohau and above the hydropower lake of Benmore.	4	Small riffle and run habitat in small streams and rivers. Often also in areas of slow or no flow, including some wetland ponds.	Juveniles do not migrate. Slow-moving habitats.
Alpine galaxias	N	Only in the South Island high country. Distribution is intermittent and fragmented.	Intermittent populations in high country streams in the main river catchments from the Clarence to Waitaki River.	4	Rivers at high elevations amongst foothills in swiftly flowing habitat, especially riffles and runs.	Juveniles do not migrate. Slow-moving habitats.
Canterbury galaxias	N	Widespread throughout Canterbury and some parts of Marlborough and Otago.	Widespread throughout all main catchments.	4	Flowing rivers and tributaries. Prefer cobble substrate.	Juveniles do not migrate. Gently-flowing margins.
Northern flathead galaxias*	N	Upper South Island	Clarence, Conway and Kowhai (Kaikoura) catchments.	4	Flowing rivers and streams.	Juveniles do not migrate. Gently-flowing margins.

Canterbury mudfish*	N	Canterbury and northern Otago.	Intermittent and fragmented populations at low elevations, from Oxford (Ashley River) to just south of the Waitaki River	2	Springs, creeks, drains and around the margins of wetlands. Only movement within catchments would be from flood flows.	Juveniles do not migrate. Open water habitats.
Stokell's smelt*	D	Canterbury River lagoons.	Waiau, Rakaia, Ashburton, Rangitata and Waitaki lagoons.	1	Low elevation estuaries and streams.	Sea
Common smelt	D	Throughout, however, less common in the South Island. Found generally at low elevation, but can move upstream in low elevation rivers. Also several landlocked lake populations.	Throughout. A few inland populations in the Hurunui, Ashburton and Waitaki Rivers that could be landlocked.	1	Estuaries and lowland rivers, usually still or gently-flowing waters.	Go to sea after hatching, returning to river months later as juveniles or adults.
Black flounder	D	Throughout; penetrates long distances inland.	Throughout	1	Common in estuaries, lowland lakes and in rivers in both gentle and swift-flowing habitats.	Spawn at sea, migrate into freshwater in spring.
Yellowbelly flounder	D	Throughout	Widespread	1	River estuaries and lowland lakes.	Sea
Torrentfish	D	Widespread from sea level to inland, however, sparse in Otago and Southland.	Throughout	3	Rivers, often braided, generally in swift riffle habitats. It is thought that the females occupy upper reaches of rivers and males the lower.	Larvae go to sea. Juveniles migrate into rivers, moving along the bottom, some months later
Upland bully	N	North Island - south west intermittent distribution. South Island - widespread mainly eastern, southern and the upper West Coast.	Widespread	5	Varied habitats including wetlands, lakes, ponds, drains, streams and rivers, usually where flow is gentle. Prefer coarser substrates.	Stream margins and lake shallows.
Common bully	D and N	Throughout in streams and lakes.	Widespread	5	Varied habitats including lakes, wetland margins, streams and rivers in gentle flowing areas. Prefer finer substrate.	Gentle-flowing habitats.
Giant bully	D	Throughout at low elevations.	Throughout	1	Streams	Larvae go to sea and return to rivers in spring as juveniles.
Bluegill bully	D	Throughout from the sea to inland.	Throughout	1	Swift flowing riffles, often in the larger braided rivers. Prefer coarser substrates.	Larvae go to sea and return to rivers in spring as juveniles.
Redfin bully	D	Throughout from sea level to well inland; less common on the east coast.	Uncommon in Canterbury. Found around Kaikoura, Ashley, Waimakariri, Banks Peninsula and Waitaki catchment areas.	1	Cobble/boulder streams usually in swift flows.	Larvae go to sea and return to rivers in spring as juveniles.

4.1.1 Location of native fish within the water column

While native fish species migrate in both an upstream and downstream direction, movement within the water column also occurs. Migrating fish vary in size from large eels to tiny whitebait larvae heading to sea, to small bully and whitebait migrating upstream into freshwater (further information on fish size see section 4.4).

Limited work has been carried out looking at where in the water column the different fish species are found when migrating and swimming at their different life stages. Information on the location of fish within the water column is useful in identifying the placement of the intake system to prevent entrainment.

4.1.1.1 Generalist species

Most native fish species are small, cryptic and benthic, generally being found near the substrate in the water column (McDowall 1990), for example koaro were found commonly swimming close to, or resting on the substrate in a study in the Ryton River in Canterbury (Moffat 1984).

Also, as mentioned in Section 4.1, several native fish have been found to prefer shallow water less than 0.25 m (Jowett and Richardson 1995), both during flood and in normal flows (Jowett and Richardson 1994). Limited studies have been carried out investigating what native fish do in flood flows, but Jowett and Richardson (1994) suggested that the edge dwelling fish species respond quickly to flow changes, moving with the river margins to minimise any change in depth. David and Closs (2002) found giant kokopu moved within stream habitats to lower flow refuge areas during flood events; due to previous cover locations being exposed to increased flows.

4.1.1.2 Non-migratory galaxiids

Hopkins (1971) found that juvenile dwarf galaxias tend to hold station in the water column during their early life, but become more benthic at between 25-35 mm. This is probably consistent with other non migratory galaxiids.

4.1.1.3 Migratory species – downstream migrants

Meredith et al. (1989) found that larvae of smelt, bully and kokopu (whitebait) species resist downstream movement in daylight and may be resident on the river bottom. High larval densities, recorded on the river margins (bullies) and in mid river (smelt and bullies), were found commonly near the river bottom at night. Low densities were recorded in the river channels, especially the upper layers of the water column. Smelt larvae were concentrated in the middle of the river on the shallow areas (possibly the spawning habitat). These distributions were largely related to both position of spawning sites, and larval behaviour patterns (A. Meredith pers. obs.). In daylight most native fish larvae (bullies, galaxiids, smelt) were found to be negatively phototactic (swim away from light), and negatively thigmotactic (swim against currents) (Meredith et al. 1989). These behaviours effectively concentrate larvae on the river bottom. However, at night the larvae generally become inactive and are swept up into the water column as passive particles.

Adult migrating eels have been found to swim downstream with the main flow at night, predominantly at the surface (top 2 to 4 m of the water column) and during or soon after rainfall events (Boubée 2001; Watene 2001).

4.1.1.4 Migratory Species – upstream migrants

Juvenile smelt have been found to migrate upstream during the day and often cross the main channel of the Waikato River (Stancliff et al. 1988). Stancliff et al. (1988) also found that whitebait (inanga, giant kokopu, banded kokopu and koaro) and smelt moved almost exclusively in the upper-most metre of the water column, along the river margins. Highest densities of common bully and shrimp were found in the top 2 m of the water column along river margins but substantial numbers moved upstream along the bottom. Juvenile torrentfish were largely found to move upstream along the river bottom across the main channel (Boubée et al. 1986)

As mentioned in the previous section, elvers have been found to migrate across the bottom of the river channel at mid water depths (Schicker et al. 1989).

Of the limited investigations that have been undertaken downstream and upstream, migrants are either generally near the surface or the bottom of the water column, thus water intake systems would be best placed to avoid these locations. However, there are currently limited New Zealand wide observations, with investigations predominantly having been undertaken on the native fish in the Waikato River. It is unknown whether the migrations differ appreciably around the country, but there is no reason to believe that they should do so.

4.2 MIGRATION AND SPAWNING TIMING

Many native fish species undertake migrations between freshwater and the sea requiring migrations in both directions to complete their life cycles. This indicates extensive fish movements are occurring within our waterways from high country to the estuaries. Uninhibited passage between freshwater and marine habitats in our Canterbury waterways (large and small) is therefore crucial for the survival of many species in this region. Generally most significant migrations of native fish species tend to be associated with spawning (McDowall 1990), and for several species, especially migratory species (e.g. banded kokopu, shortjaw kokopu) this is associated with elevated or flood flows (Mitchell and Penlington 1982; Mitchell 1991; Charteris et al. 2003). Palmer et al. (1987) found eels, whitebait species, bully species, smelt and torrentfish were all found impinged on screens, especially during or immediately following floods that coincided with migration or increased activity. From these investigations, it was concluded that future water abstraction structures should incorporate passive intake screens, through which water will pass at a low velocity (Palmer et al. 1987). This report identifies the need to consider peak migration and spawning timing when designing intake systems.

It must be noted that non-migratory species do not make an extensive journey to the sea and back but these fish may still migrate within waterways, and therefore also require uninhibited passage.

Some diadromous species may establish ‘landlocked’ populations in some situations. These species are normally obliged to go to sea as part of their life cycle, but when prevented from doing so may use lakes or ponds instead for the ‘marine’ phase. Only some species (and only in some situations) have been found to successfully do this, notably giant kokopu, koaro, common bully, inanga, common smelt and banded kokopu.

As mentioned previously, Webb (1999) found torrentfish, upland bully, longfin eel, unidentified galaxiids and koura entrained into a large unscreened take in Canterbury. He found that all the torrentfish caught were full of eggs and concluded they were caught within the unscreened intake, as female are thought to undertake a spawning migration, and that when full of eggs, torrentfish loose their streamlined body shape and have difficulty holding station in fast water (Webb 1999). Trapping was undertaken monthly from September to April; upland bully were caught in October, December and January; longfin eel were caught in most months of the survey but predominantly in November, December and February; galaxiids were caught in September and October, and torrentfish in all months. In comparison with what is shown in Table 3, these results show that native fish are not likely to get entrained only during their spawning or main migrations times.

Most native fish migrations (and spawning) occur during spring and autumn, although there are some fish moving at almost all times of the year (Table 3[3]). The nature of these migrations varies considerably, however it should be noted that most downstream migration occurs during floods. Some species spawn in freshwater (e.g. whitebait, bullies, smelt), and their larvae are swept to sea where they feed and grow before migrating back into freshwater. While other species breed in the sea (e.g. eel, mullet and black flounder), where young migrate from the sea into freshwater to find a place to mature before heading out to sea again to breed.

It appears there is a clear shift from a predominance of upstream migrations during the spring, to a predominance of downstream migration in the summer through to mid winter (Table 3). Therefore no real conclusion can be drawn as to any particular period being more or less important; it depends on what species are present or are using the catchment under consideration. However, the shift from spring upstream to summer/winter downstream migration seems likely.

It should be noted that:

- There are still gaps in the knowledge of fish migration for many native fish species.
- The timing of migrations is not fixed and may vary considerably from year to year; migrations may be drawn out over many months.
- There may be more than one migration each year for some species. For example, juvenile torrentfish migrations up rivers, such as the Rakaia, have been reported to occur in both spring and autumn (Eldon and Greager 1983).

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[3] Sources: Schicker et al. 1989; McDowall 1995; Allibone and Caskey 2000; McDowall 2000; Charteris 2002; McDowall and Waters 2002; Charteris et al. 2003; Bowie 2004; Elkington and Charteris 2005; Ward et al. 2005

- Spawning migrations may also be delayed or happen sooner if conditions are not suitable.

So the timing of spawning (and migration) is important when designing a water intake system as spawning habitats and main migration pathways should be avoided, where possible, to prevent entrainment of these migrating and spawning fish.

TABLE 3. MAIN SPAWNING AND MIGRATION PERIODS FOR NATIVE FISH SPECIES FOUND IN CANTERBURY (FOCUSSING ON DIADROMOUS POPULATIONS) (BLACK= DOWNSTREAM MOVEMENT; STRIPED = UPSTREAM MOVEMENT; GREY = NON DIADROMOUS)

Species	Moving	Life Stage	Dec	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov
			Summer	Summer	Summer	Autumn	Autumn	Autumn	Winter	Winter	Winter	Spring	Spring	Spring
Lamprey	Up	Adult	▤	▤					▤	▤	▤	▤	▤	
	Down	Juvenile				■	■	■	■	■	■			
Longfin eel	Up	Juvenile								▤	▤	▤	▤	▤
	Down	Adult			■	■	■	■	■					
Shortfin eel	Up	Juvenile								▤	▤	▤	▤	▤
	Down	Adult			■	■	■	■	■					
Giant kokopu	Up	Juvenile	▤										▤	▤
	Down	Larva					? ■	? ■	? ■	? ■	? ■			
Shortjaw kokopu	Up	Juvenile									▤	▤	▤	
	Down	Larva					■	■	■					
Koaro	Up	Juvenile									▤	▤	▤	
	Down	Larva				■	■	■	■					
Banded kokopu	Up	Juvenile										▤	▤	▤
	Down	Larva					■	■	■	■				
Inanga	Up	Juvenile								▤	▤	▤	▤	▤
	Down	Larva		■	■	■	■							
Stokell's smelt	Up	Adult	▤	▤	▤	▤						▤	▤	▤
	Down	Larva	■	■	■	■		■	■					
Common Smelt	Up	Adult	▤	▤	▤	▤	▤				▤	▤	▤	▤
	Down	larva	■	■	■	■	■							■
Black flounder	Up	Juvenile										▤	▤	▤
	Down	Adult							■	■	■			
Yellowbelly flounder	Up		▤										▤	▤
	Down													
Torrentfish	Up	Juvenile						▤	▤	▤	▤	▤	▤	▤
	Down	Larva			■	■	■	■						
Common bully	Up	Juvenile	▤	▤	▤	▤						▤	▤	▤
	Down	Larva	■	■	■									■
Giant bully	Up	Juvenile	? ▤	? ▤										? ▤
	Down	Larva	■										■	■
Bluegill bully	Up	Juvenile	▤											▤
	Down	Larva	■	■	■							■	■	■
Redfin bully	Up	Juvenile	▤	▤								▤	▤	▤
	Down	Larva										■	■	■
Lowland longjaw galaxias			? ░	? ░					?	?	?	? ░	? ░	
Dwarf galaxias			░	░		? ░	? ░	? ░				░	░	░
Upland longjaw galaxias						? ░	? ░	? ░			░	░	░	
Bignose galaxias						? ░	? ░	? ░		? ░	? ░	? ░		
Alpine galaxias										? ░	? ░	? ░	? ░	? ░
Canterbury galaxias			░									░	░	░
Canterbury mudfish			░								░	░	░	░
Upland bully			░	░							░	░	░	░

4.3 FISH SWIMMING ABILITY

Fish swimming ability is related mainly to fish size, although water velocity, temperature and gradient are also factors (Boubẽe et al. 1999). Fish swimming ability is important in water intake design as it could prevent entrainment or impingement. If approach velocity (water velocity approaching the intake system, flow into or perpendicular to the face of the intake) is less than native fish swimming abilities then fish can swim away from intake. In contrast, if sweep velocity (velocity going across the front of the intake) is kept high then any fish near the screen will be swept past. So to protect fish from impingement or entrainment, the approach velocity should not exceed certain values based on the swimming mode of the fish present in the waterway.

Some native fish are good climbers (e.g. juvenile eels and some galaxiid species) and are able to penetrate well upstream and to high elevations. These species are capable, especially juvenile fish, of climbing significant barriers, such as waterfalls, by progressing along wetted perimeters outside the areas of high water velocity. In contrast other native fish are not good climbers and need low water velocity to progress up or down waterways. However, climbing is not indicative of good swimming ability and native fish are generally considered to be poor swimmers compared with salmon and trout (Mitchell, 1989).

A fish's ability to avoid or escape from dangers imposed by irrigation intake structures, therefore, partly depends on its swimming ability. This ability falls into one of four categories (Table 4).

TABLE 4. SWIMMING ABILITY CLASSIFICATIONS OF SOME NATIVE FISH SPECIES (MODIFIED FROM BOUBÉE ET AL.1999)

SWIMMING ABILITY CLASSIFICATION	SPECIES
Anguilliforms – able to worm their way through spaces in stones or vegetation, in or out of water.	Shortfin eel and longfin eel, and to some extent juvenile whitebait (banded kokopu, giant kokopu, shortjaw kokopu and koaro).
Climbers – able to climb the wetted margins of waterfall, rapids and spillways using fins, adhering to surface tension of water films.	Lamprey, elvers (longfin and shortfin), juvenile whitebait (banded kokopu, shortjaw kokopu, giant kokopu and koaro), juvenile common and redfin bully (limited extent).
Jumpers – able to leap using the waves at waterfall and rapids.	Smelt, inanga.
Swimmers – usually swim around obstacles. Rely on areas of low velocity.	Inanga, smelt, bullies, torrentfish. Adults of most native fish species.

However, fish behaviour, including where fish live within the water column (Section 4.1.1), as well as responses to water velocity, temperature and gradient are also factors that influence the ability of fish to migrate and move within waterways (Boubée et al. 1999). Therefore, in addition to swimming ability, behaviour, especially for smaller life stages, also needs to be considered in water intake design.

There are two types of swimming abilities recognised in native fish:

- Sustained speed, which is the swimming speed the fish can maintain for long periods (hours)
- Burst speed, which is the swimming speed that fish can maintain only for seconds (Boubée et al. 1999). Fish use this type of swimming to escape danger, catch prey or negotiate small areas of fast-flowing water.

In a review of fish swimming performance, Hunter and Major (1986) fitted logarithmic curves to swimming speed data from a number of authors to give two formulae that modelled the sustained and burst swimming ability. Further work by NIWA has progressed from this to create formulae for some native fish species (Table 5). Little difference was found between swimming ability of bullies, smelt and inanga. So Boubée et al. (1999) concluded the same formula could be used for all of these groups. However, the swimming ability of eels was found to be lower than most other freshwater fish species because of their eel-like swimming motion (Boubée et al. 1999).

TABLE 5. RELATIONSHIP BETWEEN SWIMMING SPEEDS (VF M/S), FISH LENGTH (L M) AND TIME (T SECS) (BOUBÉE ET AL.1999)

	EELS	INANGA/SMELT/BULLIES
SUSTAINED VF	1.87L^0.5t^-0.13	5.29L^0.63t^-0.16
BURST VF	5.6L^0.5t^-0.33	14.4L^0.63t^-0.43

Water temperature has also been found to influence swimming ability with a greater ability at high temperatures up to optima, because of the increased metabolic rate capacity (Boubée et al. 1999; Brett and Glass 1973). Temperature is thought to affect sustained swimming capacity more than burst swimming. Brett and Glass (1973) found an increase of 5°C in water temperature increased the maximum sustained swimming speed of sockeye salmon by about 20%. For fish in Canterbury waterways, their decreased swimming performance at low temperatures (e.g. < 10°C) may be of significance; in winter and early spring, fish may be unable to avoid/escape from intake structures. (Temperature, however, was not considered in the creation of the formula in Table 5).

Another parameter not considered in the creation of the formula was depth. This has been found to alter swimming speeds only when the water was less than 0.3 times the depth of the fish. In this case, Webb et al. (1991) found swimming speeds were around 30-50% lower than the maximum speeds attained in deep water (Boubée et al. 1999). There are also other parameters (e.g. oxygen saturation) that could influence swimming ability.

Velocity requirements for native fish have not been researched to the same extent as they have been for salmonids overseas, but some swimming abilities for a range of native fish have been determined, mostly for juvenile stages (Table 6[4]). Some specific experiments have been carried out to investigate velocity preferences for some species (e.g. Jowett and Richardson 1995), while other information describes what velocities are commonly found in sites where these species occur (e.g. McDowall et al. 1996) (Table 6). Table 6 is predominantly composed of data from sustained swimming speed investigations.

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[4] Sources; Sorensen 1951; Moffat 1984; Glova and Duncan 1985; Mitchell 1989; Stancliff et al 1988; Mitchell 1990; Boubée et al. 1992; Jowett and Richardson 1995; Mitchell and Boubée 1995; McDowall et al 1996; Knights and White 1998; McCullough 1998; Bonnett and Sykes 2002; David and Closs 2002; Jowett 2002; Baker et al. 2003; Nikora et al. 2003; Jellyman 2004

TABLE 6. SWIMMING VELOCITY PREFERENCES (SUSTAINED SWIMMING SPEEDS) FOR SPECIES FOUND IN CANTERBURY WATERWAYS (M/S^{-1}) (*= FIGURES GENERALISED FROM RESULTS OF INVESTIGATIONS).

COMMON NAME	SWIMMING VELOCITY GENERAL (ADULT)	SWIMMING VELOCITY GENERAL (JUVENILE)	SWIMMING VELOCITY OVER <15M (JUVENILE)	SWIMMING VELOCITY OVER >15 M (JUVENILE)
Eels	<1.5-2	<0.2-0.5 Preferred <0.3		
Shortfin eel		0.15->0.6*	<0.3	<0.25
Longfin eel		<0.15->1.0*		
Giant kokopu	<0.1			
Shortjaw kokopu	<0.05			
Koaro	<0.8*	0.1-0.24*		
Banded kokopu	0-0.05	0.04-0.29	<0.3	<0.25
Inanga	<0.15-0.36 0.07 preferred	0.007-0.39	<0.3	<0.25
Lowland longjaw galaxias	0.1-0.5	0.1 (fry)		
Alpine galaxias		0.1 (fry)		
Canterbury galaxias	<0.15-0.6*	0.1 (fry)		
Torrentfish	0.3-<1.1*			
Common bully	0.15-0.6*	0.24-0.28	<0.3	<0.25
Upland bully	<0.15-0.7*			
Bluegill bully	0.3->1.0*			
Redfin bully	<0.15-0.6*			
Common smelt	0.15-0.6*	0.19-0.27	<0.3	<0.25
Mean NZ species (based on observation obtained with juvenile shortfin eel, common bully, common smelt, inanga and banded kokopu)		0.2-0.32		

The only specific study to mention burst speed was Mitchell (1989) who found shortfin eel could swim at 0.2 ms^{-1} for longer than 20 minutes and at more than 0.5 ms^{-1} for only a short period, and Nikora et al. (2003) who reported inanga burst velocity was within the range of 0.47-1.35 ms^{-1}.

Moffat (1984) investigated sustained swimming ability, including critical swimming speeds, of koaro in Ryton River and in experimental flumes. He studied koaro from 50-100 mm in length and found that their critical swimming speed (flow that caused greater than 60 % mortality on the electrified screens in the flume) over a 12 hour period was 0.4-0.8 ms^{-1} (8 bls^{-1}(body lengths per second)). In addition, he concluded from his experimental studies that 0.1 to 0.2 ms^{-1} (2 bls^{-1} for 50-100 mm koaro) caused minimal levels of mortality. Therefore, flows should ideally be kept below 0.2 ms^{-1} so fish can swim away from intakes and should avoid flows greater than 0.4 ms^{-1} to minimise entrainment and mortality.

Most species occur over a wide range of velocities (Table 6), for example torrentfish and bluegill bully prefer high velocity water, whereas the other bully species prefer low velocity water.

Any information on swimming speeds should be used in two ways in designing fish intakes to protect native fish:

- The approach velocity (the speed of the water just in front of a screen) should be kept low enough to enable native fish to escape entrainment.
- The sweep velocity (the velocity of water across the screen) should be high enough that most fish will be sweep past the screens and intake.

Information collated above suggests that velocities < 0.3 ms^{-1} approaching water intakes would minimise involuntary entrainment of most juvenile and adult fish by intake structures. This conclusion is in line with conclusions from Mitchell (1989) and Boubée et al. (1999) in their native fish swimming investigations. However, if an area is important for spawning, or a main migration pathway for larvae, then velocities approaching water intakes will need to be set at ≤ 0.1 ms^{-1}.

In contrast, swimming performance experiments on five species of native fish found that water velocities greater than 1.5 ms^{-1} are likely to exclude all species except those that are capable of climbing or clinging; while water velocities down to 0.5 ms^{-1} could be expected to provide a species selective deterrent to migration depending on the distance over which the velocity is maintained (Mitchell 1989). Therefore consideration should be given as to what species use the area. However, from the current information available it appears that the sweep velocities should be set > 0.5 ms^{-1}.

4.4 FISH SIZE

Most freshwater fish species are quite small (<150 mm), generally with adults around 90-150 mm. However there are a few exceptions including the giant kokopu which can reach 580 mm, lamprey that can reach around 750 mm and eels that have been found up to 2000 mm (most commonly up to 1 m) (Table 7[5]). Table 7 indicates there are still many gaps in knowledge on size of some native fish species at different life stages.

TABLE 7. COMMON NATIVE FISH SIZE RANGES FOR EACH LIFE STAGE

COMMON NAME	**APPROXIMATE SIZE RANGES (MM)**			
	ON HATCHING	**JUVENILE**	**ADULT**	**EGGS**
Lamprey	11	90-100	200-750	1
Longfin eel	6-9	60-200	400-1500	n/a
Shortfin eel	6-9	50-200	400-1200	n/a
Giant kokopu	9	45-50	70-580	2
Shortjaw kokopu	9	45-50	70-350	2
Koaro	9	45-50	70-290	2
Banded kokopu	8	40-45	70-260	2
Inanga	7	50-65	70-150	2
Lowland longjaw galaxias	7	15-20	60-90	
Dwarf galaxias		20-30	60-90	2
Upland longjaw galaxias		30-55	60-90	2
Bignose galaxias		15-30	60-80	
Alpine galaxias		20-35	60-110	2
Canterbury galaxias	7	20-35	70-150	2.5
Canterbury mudfish	6	35-50	70-150	1.5
Stokell's smelt	5	50-60	70-100	0.7
Common smelt	5	45-55	60-120	1
Black flounder			200-300	n/a
Yellowbelly flounder			200-500	n/a
Torrentfish		16-20	60-160	
Upland bully		10-20	60-130	2
Common bully	3	10-20	60-150	1
Giant bully		10-20	70-240	1
Bluegill bully	3	20	50-90	1
Redfin bully	3	15-20	60-120	1

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[5] Sources: Schicker et al. 1989; McDowall 1995; Allibone and Caskey 2000; McDowall 2000; Charteris 2002; McDowall and Waters 2002; Charteris et al. 2003; Bowie 2004; Elkington and Charteris 2005; Ward et al. 2005; P. Ravenscroft pers. comm.

Native fish would be best protected if water intake systems in areas of importance for spawning and/or on main migration pathways prevented fish of 3-10 mm (the size of the smallest life stage) from passing through (Table 7).

5. Species of concern to the department with regard to freshwater intake systems in Canterbury

The information in section 4 illustrates that native fish have varying requirements including swimming ability, migration times and size range. The department appreciates that it would be very difficult to provide protection to all species from water intakes and screens, so it is important to identify those species it sees as being the most at risk.

All freshwater species and stocks are important to the department, however, of most concern are:

1. Nationally threatened species, and therefore those at risk of extinction (e.g. lowland longjaw galaxias);
2. Species found within restricted ranges, especially those found only in Canterbury (e.g. bignose galaxias);
3. Species found only in New Zealand waters (e.g. giant kokopu);
4. Species that make up the whitebait fishery (e.g. inanga);
5. Migratory species that could be at most risk of entrainment during migrations (e.g. lamprey);
6. Species recognised as a taonga species (culturally important) (e.g. torrentfish);
7. Existing genetically distinct populations of species, known as Evolutionary Significant Units (ESUs).

Table 8 lists the species found in Canterbury waterways and their importance for protection from loss on or through fish screens and intakes.

TABLE 8. SPECIES FOUND IN CANTERBURY WATERWAYS AND THEIR IMPORTANCE IN PROTECTION FROM TAKES

COMMON NAME	REASONS WHY A CONCERN (FROM LIST ABOVE)
Lowland longjaw galaxias	1,2,3,7
Canterbury mudfish	1,2,3,6,7
Dwarf galaxias	1,3,7
Longfin eel	1,3, 5
Giant kokopu	1,3,4,5,6
Bignose galaxias	1,2,3,7
Upland longjaw galaxias	1,2,3,7
Shortjaw kokopu	1,3,4,5
Lamprey	1,3,5
Stokell's smelt	1,2,3,4
Northern flathead galaxias	1,2,3,7
Shortfin eel	5
Torrentfish	3,5,6
Koaro	4,5
Banded kokopu	3,4,5
Inanga	4
Alpine galaxias	2,3,7
Canterbury galaxias	2,3,7
Upland bully	3
Common bully	3,5
Giant bully	3,6
Bluegill bully	3,5
Redfin bully	3,5
Yelloweye mullet	3
Common smelt	3,6
Black flounder	3,5
Yellowbelly flounder	3

The native fish species that are most at risk of extinction (nationally threatened – category 1) and meet a higher number of categories would be deemed the most critical to protect from water intakes (Table 8).

Taking into consideration all the biological information collated earlier in this report and the value of each fish species, it seems that the groups most at risk of entrainment and impingement on water intake systems are:

- Downstream migrating juveniles (e.g. lamprey);
- Downstream migrating larvae (e.g. banded kokopu, shortjaw kokopu, giant kokopu);
- Upstream migrating juveniles (e.g. elvers, bluegill bully, redfin bully, torrentfish);
- Resident larvae and juveniles of threatened non diadromous native fish species (e.g. lowland longjaw galaxias, bignose galaxias, upland longjaw galaxias, northern flathead galaxias).

6. Water intake requirements

There are currently many gaps in the knowledge of intake requirements to protect native fish, so it is not possible to specify what percentage exclusion is deemed to be sufficient for their protection. However this would be deemed to have been achieved if the criteria for water intakes and screens have been met and monitoring results are positive.

To protect native fish, especially those identified as being at highest risk, the following approach should be used. First, fish species that are present and use the area need to be identified. Then information on those species' requirements needs to be considered in designing intake structures that will protect those species (sections 4, 5 and 6 of this report and any new information available). If the area is generally important for native fish, and there are not specific species that are of concern, then the parameters identified in section 6.2-6.7 should be followed.

6.1 SOURCES OF INFORMATION ON NATIVE FISH DISTRIBUTION IN CANTERBURY

There are many gaps in the knowledge on the distribution of native fish species throughout Canterbury waterways, and some of our smaller species are very difficult to identify. However, in addition to using the information shown in Table 2, below is a list of sources of information which contain information or methods used to identify the species currently found in or using a waterway:

- New Zealand Freshwater Fish Database (NZFFD) (http://fwdb.niwa.cri.nz/). Anyone can get access to this database. Many organisations and individuals submit fish survey results to this database which is maintained by the National Institute of Water and Atmospheric Research (NIWA).
- Freshwater Biodata Information System – A relatively new database which holds records of New Zealand's freshwater fish, invertebrates, algae and other aquatic plants (https://secure.niwa.co.nz/fbis/index.do).
- Daly, A. 2004. Inventory of instream values for rivers and lakes of Canterbury – a desktop review. Environment Canterbury Report U04/13. This gives a description of instream values in each major river and lake catchment as at 2004.
- Talk to your local Department of Conservation or Environment Canterbury office.

Freshwater fish surveys are continually being undertaken. Probably the most up to date source of information is the NZFFD.

6.2 SCREEN (MESH SIZE)

The size of the upstream and downstream migrant fish needs to be considered in setting mesh size to exclude native fish from water intake systems. The largest downstream migrants are likely to be the eel species, and these are probably easily excluded. However, most freshwater fish species are smaller (< 150 mm adult; < 10 mm juvenile), and it is generally these smaller species and the juvenile stage of all native fish species that need to be kept out of intake systems.

In New Zealand few investigations have been undertaken to define mesh size required to protect different native fish species and fish communities from entrainment. The few studies that have been undertaken generally looked at net mesh size that retained the species during capture.

Stancliff et al. (1989) found that whitebait (juvenile inanga and banded kokopu), common bully and shrimps were all caught and retained successfully using 2 mm mesh nets; 1-1.5 mm mesh had to be used to retain juvenile eels (elvers) (Schicker et al. 1989).

Overseas studies have found screen mesh size less than 20 mm, at a velocity of less than $0.5 ms^{-1}$, will avoid entrainment and/or impingement of European eels (550-750 mm in length) (Adam and Schwevers 1997). A study in New Zealand has suggested that the smallest adult migrating eels, shortfin eels, would be excluded by bar-spacing of less than 25 mm, at a velocity of less than $0.3\ ms^{-1}$ (Mitchell 1990). Boubée and Williams (2006) concluded from investigations that 30 mm screens would exclude eels longer than 1000 mm and therefore would protect only part of the migrant stock. Recently Jacques Boubée (NIWA unpublished data) has suggested 20 mm gaps would likely exclude adult migrating eels. This is backed up by overseas work that has also suggested 20 mm gaps (Adam and Schwevers 1997, DWA 2005). However, work undertaken at hydro dams over recent years has found migrant eels generally avoid intakes and search for safer passage in some situations (Watene et al. 2003).

MacLean (1986) compared 0.525 mm with 0.3 mm mesh nets in the Waikato River and found the larger mesh caught very few larvae, while the 0.3 mm nets caught high numbers of several species of larval native fish.

Mesh size of Gee minnow traps has been found to have a large influence on the effectiveness of capturing native fish, especially mudfish species (Dean 1995; Francis 2000; O'Brien 2005). The use of 2-3 mm gap mesh size has been found to be preferable to larger gaps, as Dean (1995) and O'Brien (2005) have found juvenile mudfish often escape through 6 mm mesh, depending upon their size at capture. O'Brien (2005) has also found that Canterbury mudfish are more likely to be caught and in higher numbers in 2 mm mesh size traps than in larger mesh traps (O'Brien, unpublished data). Therefore a 2-3 mm gap appears to be effective at containing a variety of different sized mudfish species and other native fish.

As mentioned previously, in a study undertaken to look at fish entrainment in a large unscreened water-take in Canterbury, native fish ranging in size from 48 to 1000 mm were caught using traps with a mesh gap of 3.4 and 8.9 mm (Webb 1999).

Therefore from current limited information the mesh sizes required for exclusion are:

GROUP	MESH SIZE (MM)
Native larval fish	0.3
Whitebait (banded kokopu, inanga), common bully, shrimp	2.0
Canterbury mudfish	2.0
Glass eels/elvers	1.5
Eels (adults)	20-25

Swimming speeds (water velocity) is important in relation to the fish screen size and ability of the species to escape entrainment, so any consideration of mesh size should be considered together with swimming ability of the species and thus water velocity at intakes. The fact that some native fish species (e.g. eels and whitebait) will increase in size as they migrate upstream should also be considered.

6.3 LOCATION

Important native fish populations occur in a variety of habitats from large braided rivers to small streams (Section 4.1). Small streams often provide very important and highly valued native fish habitat, while salmonids become of decreasing abundance or importance in smaller streams. In particular, many of the regionally and nationally threatened or rare native fish occur in small streams, particularly in areas such as high country springs and wetlands (e.g. in the Mackenzie Basin), and small streams (e.g. Banks Peninsula or Kaikoura). However larger habitats, such as braided rivers, are also important because they provide an alternative fish habitat commonly used by different native species and also provide the main pathway to and from the sea for migratory species. Therefore screening requirements for native fish need to be considered in all freshwater habitats.

6.4 STRUCTURE PLACEMENT

6.4.1 Timing

Section 4.2 shows that most migrations occur during spring and autumn, although there are some fish moving in one direction or another at almost all times of the year. There appears to be a clear shift from a predominance of upstream migrations during the spring to a predominance of downstream migrations from summer through to mid winter. Considering water abstraction is likely during most months of the year and generally peaks during irrigation season (September to April), water abstraction can pose a significant risk to fish migrations that occur during those times in Canterbury waterways.

The risk of species being transferred can be decreased if abstractions avoid water removal during periods when fish are migrating (Allibone 2000). Even changes in the time of day water is abstracted may reduce the movement of fish [e.g. whitebait migrate more during daylight hours (McDowall 1990)]. However, it is acknowledged that limiting the timing of abstraction is not always possible.

Fish migrating upstream may encounter screens or intake structures, especially those positioned at the lower sections of a river. These fish would benefit from the provision of diversion channels with weirs or drops, diversion incentives or, conversely, allowance for easy passage up diversion channels and past screens back to the river. Poorly designed diversion channels can trap fish and expose native fish to predation from larger fish and/or birds.

Therefore consideration of what species are present or are using the catchment, and in what direction they are migrating, needs to be taken into account in the design of any water intake system.

6.4.2 Location within the water body

Sections 4.1 and 4.2 show that different species migrate and use different areas of a water body. Where the intake and screens should be placed will depend on what species are likely to use the area of the intake. However, further work is required on this aspect to assess species not considered in the studies carried out to date and to test recommendations made.

It is also important that all water takes do not divert the majority of water into the actual intake and that the majority of water is maintained within the bypass channel. Another point that needs consideration when designing a water intake is that the proportion of the abstraction may be more critical at low level flows as fish may make the decision to go through to escape low water levels. Hopefully, however, all takes will cease in these situations owing to restrictions set on consents.

The understanding of the risks to native fish from intake structures is incomplete, however, the following summarised 'rules of thumb' should minimise the risks:

- The intake should be sited as close as possible to the intake point, and the screen surface should be oriented as close as possible to parallel with the water flow, so that water is abstracted through the screen at right angles to the flow. This is to aid in preventing, or at least minimising, entrainment into the intake system.
- Native fish species have been found to migrate during all hours of the day and night. Therefore it is important that all intake systems are maintained 24 hours a day.
- For areas of dense native fish populations, it might be best to position intakes in the mid to surface water, preferably in fast flowing areas and away from favoured adult and juvenile habitat.
- For upstream migrant fish, intakes should be placed to abstract mid- water column water, away from the surface, bottom and margins of the channel, so as to keep the migration pathways clear.
- If a take location is important for larval fish and downstream migrants, then bottom and edge water-takes should be avoided, where possible, and intakes could be sited in mid-channel or deeper water areas near the water surface. While this may pose a risk to adult eel downstream migration, these fish are large (> 600 mm) and may be effectively screened with coarse mesh (approximately 20-25 mm).

It is acknowledged that it is seldom possible to restrict or prevent abstraction during key migration months, however, it is thought that fish should be screened out or deterred from entering intakes wherever possible but especially in areas where the most 'at risk' species occur. The species most at risk have been identified in Section 5. Consideration of the species' migration times, together with their size and information, as given above, relating to where intakes should be located within the water column, is necessary when designing screens and intake systems.

6.5 WATER VELOCITY

Dams, weirs and flood gates form velocity barriers which have been found to exclude native fish from some areas (Mitchell 1989). Therefore it is important to identify velocity limits for native species so that limits can be set at water intakes and screens which allow native fish to avoid/escape entrainment and impingement.

Only a few native fish found in Canterbury have been investigated for their swimming performance (Table 6), and of those studied, only one life stage (the life stage they are in when they undertake migration) has commonly been investigated.

Some formulae have been produced that calculate swimming ability of eel, whitebait, bullies and smelt (Table 5), and information on swimming ability of several native fish has been investigated (Table 6). These two sources should be used when setting water velocities at water intakes. Consideration should be given to what species use the area, however, from the information collated in section 4.3 to protect native fish, sweep velocity should be set $> 0.5\ ms^{-1}$ and the approach velocity should be set below $0.3\ ms^{-1}$. However, if the intake site is important for spawning or is a main migration pathway, then the approach velocity should be set $\leq 0.1\ ms^{-1}$.

6.6 BYPASS AND ESCAPE ROUTES

6.6.1 Exclusion

Although screens will be an effective method of keeping fish out of water races, any design feature that prevents fish from approaching screens or intake structures is desirable. For example, louvers placed at the intake should divert fish away from the intake.

Allibone (2000) suggests structural methods for prevention of fish passage are best at preventing upstream movement. Natural or artificial barriers made of bedrock or concrete and greater than 3 m in height are likely to prevent most swimming species (e.g. inanga), however, this is not likely to prevent climbing species (e.g. koaro and eels).

6.6.2 Bypass routes

Fish that are excluded from the intakes by screens need unimpeded passage/diversion back to the main stream; it is not sufficient merely to exclude fish if they remain exposed to increased predation risk (and possibly poor water quality) near the intake structure.

Limited studies have been undertaken to investigate the size of a bypass. However, in a recent New Zealand study, Boubée and Williams (2006) have found that to ensure the safe passage of large migrant eels via power dams, bypasses of 150-250 mm in diameter are required. As this study focussed on eels, the largest native fish, this is a good indication of the size required to help native fish.

6.7 MONITORING AND MAINTENANCE

There is a need for regular monitoring and maintenance of all water intakes and screens to ensure design criteria are effective at protecting native fish. Monitoring should be a condition of the resource consent for the water take. Monitoring conditions should also be standardised and be easily measurable.

Monitoring outcomes should include, but not be limited to:

- Effectiveness of the screen system in preventing native fish entrainment (including approach velocity, sweep velocity, screen angle, screen mesh size and bypass system).
- Monitoring of numbers of native fish impinged during peak migration periods.
- Ensuring unimpeded fish passage where required.

6.8 SUMMARY

From the information collated above, a good fish screen and intake system for native fish is thought to be one that:

- Has a structure that fish can detect during their approach, and which allows orientation, approach, and escape velocities within the fishes swimming ability.
- Provides a suitable escape path or bypass so fish don't get entrained in the intake.
- Has a screen mesh size that is effective at physically excluding the species.
- Has a screen located at or as close as practical to the point of diversion.
- Is constructed as far as practical from the preferred migration path or position.

Possibly also a screen and intake system that:

- Has structures (e.g. louvers) set up so that native fish will avoid the path into the screens and intake.

7. Gaps in current knowledge

It is difficult to establish criteria for screening of native fish at water intakes as there is a lack of published information and research on native fish requirements. Much of the existing information is included within wider or ongoing research projects and still needs further testing.

The following areas have been identified in this document as requiring further investigation:

- Testing of the recommendations concluded in this report (Section 6). This may largely arise from specific effectiveness testing of some screen designs.
- Testing the current efficiency of screens and take designs found in Canterbury waterways in relation to native fish protection (e.g. use underwater cameras to assess behaviour of fish species around intakes; record native fish numbers entrained or dead on intakes and the affects of those losses on the local population).
- Freshwater fish migration timing of those species that remain unknown (Section 4.2).
- Further studies on preferred residency or migration positions of fish species within the water column, several species remain unstudied (Section 4.1).
- Studies on the relative effects of temperature and depth on native fish swimming ability (Section 4.3).
- Further confirmation of all the main native fish groups swimming abilities (all life stages including larvae, juvenile and adults) including both burst and sustained swimming speeds (Section 4.3).
- Determining effective mesh size to exclude all native fish groups, especially migratory species.
- The effectiveness of screens (including mesh size) for entrainment, avoidance and mortality of all main freshwater fish groups found in Canterbury waterways.
- Testing of the effectiveness of using exclusion barriers to prevent native fish.
- Invertebrate requirements for intake systems (e.g. koura).

8. Conclusion

The department and Environment Canterbury both have roles in freshwater fisheries management including fish passage. In relation to water abstraction the Director General of Conservation may require any diversion structure to have a fish facility included and can set conditions for design and performance. This report therefore provides guidance to applicants on design requirements to help protect native fish.

Twenty seven species of native fish are recognised in Canterbury freshwater; of those 11 are nationally threatened. They occur in a variety of habitats from small streams to large braided rivers, and several species have to undertake migrations between freshwater and marine to complete their lifecycles. All native fish species are of concern to the department. However, of most concern are those species that are nationally threatened, have restricted ranges, are migratory and are culturally important.

Known information on native fish species in relation to spawning, swimming ability, movement and size is collated in this report (Section 4). This highlights that different species have different requirements and that several native fish are small, undertake significant migrations and need relatively low velocity to avoid structures. There are large gaps in information on native fish and their requirements.

In comparison to salmonids, limited information about intake and screen requirements to protect native fish is available. However the information that is known is collated in this report and should be used to protect native fish at water intakes.

Taking into account all the biological information collated earlier in this report, and the value of each fish species, it seems that the species and life stages most at risk of entrainment and impingement on water intake systems are downstream migrating juveniles (e.g. lamprey) and larvae (e.g. whitebait species) and upstream migrating juveniles (e.g. whitebait and bullies).

The following factors are identified as being important in protecting native fish from entrainment into intakes:

- All streams and rivers are important for native fish including small streams.
- Screens need to be maintained 24 hours a day, not just in daylight or at night, as fish are moving within waterways at all times.

- The location of the intake and screen system should be as close as possible to the intake point and the screen surface should be oriented as close as possible to parallel with the water flow. Specific location will depend on what species use the area.
- Approach velocity to the intake will depend on which species use the area, however, water velocities kept below 0.3 ms^{-1} (and 0.1 ms^{-1} for important spawning or migration pathways) will minimise involuntary entrainment of most native fish that have been investigated.
- Sweep velocity across the screen will depend on what species use the area, however, water velocities set > 0.5 ms^{-1} have been found to deter most species that have been studied.
- Sweep velocity should exceed approach velocity so fish are not exposed to approach velocity and ultimately screen impingement.
- Maximum mesh size for exclusion will depend on what species use the area (0.3-25 mm dependent on the species).
- Exclusion incentives could be used to deter native fish species from entering intakes (e.g. louvers).
- Bypasses need to be situated as close as possible to the take, need to maintain the majority of water where possible, and need to provide free unimpeded passage back to the main stem.
- Monitoring and maintenance are vital to ensure the proposed parameters are met. Screens should be checked and maintained before and during the irrigation season.

Several knowledge gaps were identified throughout this report. These need to be considered in any water intake management decisions. For instance, further investigation is required into mesh size required for screens, location of species within the water column and testing of all current findings to see how effective they are at protecting native fish.

If it is not possible to successfully screen out native fish using these methods mentioned above, then appropriate mitigation for any loss needs to be identified and undertaken as part of the consent or approval. This could include providing uninhibited passage between intakes and natural systems, creating appropriate habitat for native fish species, considering species in any maintenance of the water intake scheme and protecting key populations.

Only native fish were considered in this report. Consideration should also be given to other instream values like plants and invertebrates especially some larger species e.g. koura and freshwater mussels. There are 13 aquatic plants and at least 13 species of invertebrates that are nationally threatened and found in Canterbury waterways (Hitchmough and Bull, in press; Nick Head pers. comm.). The possible risk of spread of pest species, such as a recent biosecurity risk identified in the South Island with didymo (rock snot), also needs to be considered when transfers of water between catchments are being contemplated.

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10. References

Allibone, R.M. 2000: Water abstraction impacts on non-migratory galaxiids of Otago Streams. *Science for Conservation* 147, Department of Conservation, 43p

Allibone, R.M.; Caskey, D. 2000: Timing and habitat of koaro (*Galaxias brevipinnis*) spawning in streams draining Mt Taranaki, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 34: 593 – 595.

Auckland Regional Council. 2002: Auckland Regional Council – (2002) NZRMA 241, *Environment Court Decision*, Auckland.

Baker, C.F.; Jowett, I.G.; Allibone, R.M. 2003: Habitat use by non-migratory Otago galaxiids and implications for water management. *Science for Conservation* 221, Department of Conservation. Wellington.34p

Bejakovich, D. 2005. Criteria for Fish Screen Design in Canterbury. New Zealand Fish and Game Council, Christchurch. 16p

Bonnett, M.L.; Sykes, J.R.E. 2002: Habitat preferences of giant kokopu, *Galaxias argenteus*. New Zealand Journal of Marine and Freshwater Research 36:13-24

Boubée, J.A.T.; Williams, E.K. 2006: Downstream passage of silver eels at a small hydroelectric facility. *Fisheries Management and Ecology*, 13, 165-176.

Boubée, J.A.T: Protection of downstream migrating eels at hydro-dams.2001: In Williams, E.K. and Boubẽe, J.A.T. (editors) Proceedings of the Eel Passage Workshop. NIWA publication, Hamilton, 156p.

Boubée, J.A.T.; Jowett, I.; Nichols, S.; Williams, E.1999: Fish passage at culverts – a review, with possible solutions for New Zealand indigenous species. Department of Conservation. Wellington, New Zealand.

Boubée, J.A.T.; West, D.W.; Mora, A.L. 1992: Awakino River Whitebait Fishery. *New Zealand Freshwater Fisheries Miscellaneous Report* No. 129. MAF Fisheries, Christchurch.

Bowie, S. 2004: Bignose galaxias (*Galaxias macronasus*) survey in the Mackenzie Basin, Canterbury, New Zealand. Department of Conservation. Christchurch, New Zealand, 32p.

Brett, J.R.; Glass, N.R. 1973. Metabolic rates and critical swimming speeds of sockeye salmon (*Oncorhynchus nerka*) in relation to size and temperature. Journal of the Fisheries Research Board of Canada 30: 379-387.

Charteris, S.C. 2002: Spawning, egg development and recruitment of diadromous galaxiids in Taranaki, New Zealand. Unpublished MSc thesis, Massey University, Palmerston North, New Zealand.

Charteris, S.C.; Allibone, R. M.; Death, R.G. 2003: Spawning site selection, egg development, and larval drift of *Galaxias postvectis* and *G. fasciatus* in a New Zealand Stream. *New Zealand Journal of Marine and Freshwater Research* 37: 493-505.

Coffey, B.T.; Clayton, J.S. 1988: New Zealand water plants: A guide to plants found in New Zealand freshwaters. Ruakura Agriculture Centre. 65p

Collier, K.J. 1993: Review of the status, distribution, and conservation of freshwater invertebrates in New Zealand. *New Zealand Journal of Marine and Freshwater Research* 27:339-356.

Collier, K. J. (ed) 1994: Restoration of aquatic habitats. Selected papers from the second day of the New Zealand Limnological Society Conference, 1993.

Cromarty, P.; Scott, D. (Eds) 1995: A directory of wetlands in New Zealand. Department of Conservation, Wellington. 395p.

Daly, A. 2004: Inventory of instream values for Rivers and Lakes of Canterbury – a desktop review. Environment Canterbury Report U04/13.

David, B.O.; Closs, G.P. 2002: Behaviour of a stream dwelling fish before, during and after high discharge events. *Transactions of American Fish Society* 131: 762-777.

Dean, T.L. 1995. Environmental physiology of aquatic and aerial respiration in the black mudfish (*Neochanna diversus* Stokell, 1949). Unpublished M.Sc. Thesis, University of Waikato, Hamilton, New Zealand. 120 pp.

Department of Conservation. 2001: Managing invasive freshwater fish in New Zealand: proceedings of a workshop hosted by Department of Conservation, 10-12 May, 2001, Hamilton.

Department of Conservation and Ministry for the Environment. 2000: The New Zealand biodiversity strategy: our chance to turn the tide. Department of Conservation and Ministry for the Environment, Wellington. 145p.

Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. (German Association for Water, Wastewater and Waste) (D.W.A). 2006: Fish Protection Technologies and Downstream Fishways - Dimensioning, Design, Effectiveness Inspection, Hennef. 218p

Eldon, G.A.; Greager, A.J. 1983. Fishes of the Rakaia lagoon. New Zealand Ministry of Agriculture and Fisheries, *Fisheries Environmental Report* 30. 65p

Elkington, S.; Charteris, S.C. 2005: Freshwater Fish of the Upper Waitaki River. Department of Conservation, Christchurch, New Zealand, 31p.

Francis, K.A. 2000: Conservation of the brown mudfish (*Neochanna apoda*) in the Manawatu and Rangitikei regions. Unpublished BSc (Honours) project, Massey University, Palmerston North. 28p.

Glova, G.J.; Duncan, M.J. 1985: Potential effects of reduced flows on fish habitats in a large braided river, New Zealand. *Transactions of the American Fisheries Society* 114: 165-181.

Hitchmough, R.; Bull, L. (comp.) in press: New Zealand threat classification systems lists 2005. *Threatened Species Occasional Publication.* Department of Conservation, Wellington.

Hopkins, C.L. 1971: Life history of *Galaxias divergens* (Alamonoidea: Galaxiidae) New Zealand Journal of Marine and Freshwater Research 5:41-57

Hunter, L.A.; Major, L. 1986: Analysis of fish swimming performance data. Report for the Department of Fisheries and Oceans, Govt. of Canada and Alberta Department of Transportation.

Jowett, I. G.; Richardson, J. 1994: Comparison of habitat use by fish in normal and flood river conditions. *New Zealand Journal of Marine and Freshwater Research* 28:409-416.

Jowett, I. G., Richardson, J. 1995: Habitat preferences of common, riverine New Zealand native fishes and implications for flow management. *New Zealand Journal of Marine and Freshwater Research* 29:13-23.

Jowett, I.G. 2002: Instream habitat suitability criteria for feeding inanga (*Galaxias maculatus*). *New Zealand Journal of Marine and Freshwater Research* 36:399-407.

Joy, M. K.; Death, R. G. 2001: Control of freshwater fish and crayfish community structure in Taranaki, New Zealand: dams, diadromy or habitat structure? *Freshwater Biology* 46: 417-429.

Jellyman, P.G. 2004: Fry survival of alpine (*Galaxias pauscipondylus*) and Canterbury (*Galaxias vulgaris*) galaxiids. Unpublished BSc Hons thesis, University of Canterbury, Christchurch, NZ. 64p

Knights, B.; White, E.M. 1998: Enhancing immigration and recruitment of eels: the use of passes and associated trapping systems. *Fisheries Management and Ecology* 5, 459-471

MacLean, G.D. 1986: Ichthyoplankton Studies on the Waikato River at Huntly. Unpublished MSc thesis, University of Waikato, Hamilton.

McCullough, C.D. 1998: Abundance, behaviour and habitat requirements of the banded kokopu (*Galaxias fasciatus*). Unpublished MSc thesis, the University of Waikato, Hamilton, New Zealand

McDowall, R.M. 1965: Studies of the biology of the redfin bully, *Gobiomorphus huttoni* (Ogilby) II. Breeding and life history. *Transactions of the Royal Society of New Zealand* 5 (14): 177-196.

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

McDowall, R.M. 1994: A calendar of fish migrations through New Zealand river mouths. Consultancy Report, NIWA.

McDowall, R. M. 1995: Seasonal pulses in migrations of New Zealand diadromous fish and the potential impact of river mouth closure. New Zealand *Journal of Marine and Freshwater Research* 29, 517-526

McDowall R.M. 2000: The Reed Field Guide to New Zealand Freshwater Fish. Reed Books, Auckland, 224p.

McDowall, R. M.; Waters, J. M. 2002: A new longjaw galaxias species (Telostei: Galaxiidae) from the Kauru River, North Otago, New Zealand. *New Zealand Journal of Zoology*. 29:41-52.

McDowall, R.M.; Waters, J.M. 2003: A new species of Galaxias (Telostei: Galaxiidae) from the Mackenzie Basin, New Zealand. *Journal of the Royal Society of New Zealand*.33 (3): 675-691.

McDowall, R.; Eldon, G. 1980: The ecology of whitebait migrations (Galaxiidae: *Galaxias spp.*). New Zealand Ministry of Agriculture and Fisheries, *Fisheries Research Bulletin* 20.

McDowall, R. M.; Eldon, G.A.; Bonnett, M.L.; Sykes, J.R.E. 1996: Critical habitats for the conservation of short jawed kokopu, *Galaxias postvectis* Clarke. *Conservation Sciences Publications 5*, Department of Conservation, Wellington. 80p

Meredith, A.S.; Empson, P.W.; Boubée, J.A.T.; Mitchell, C.P. 1987: Ichthyoplankton studies on the lower Waikato River. I. Entrainment at Huntly power station. *New Zealand Freshwater Fisheries Report* 88

Meredith, A.S.; Empson, P.W.; Boubée, J.A.T.; Mitchell, C.P. 1989: Ichthyoplankton studies on the lower Waikato River. II. Larval Distributions at Huntly. *New Zealand Freshwater Fisheries Report* 109

Mitchell, C.P. 1989: Swimming performances of some native freshwater fishes. *New Zealand Journal of Marine and Freshwater Research* 23:181-187.

Mitchell, C.P. 1990: Fish passes for native fish: a guide for managers. *New Zealand Freshwater Fisheries Report* 45

Mitchell, C. P. 1991: Deposition of *Galaxias fasciatus* eggs with *Galaxias maculatus* eggs at a tidal site. *New Zealand Journal of Marine and Freshwater Research* 25: 201-205.

Mitchell, C. P.; Penlington, B. P. 1982: Spawning of *Galaxias fasciatus* Gray (Salmoniformes: Galaxiidae). *New Zealand Journal of Marine and Freshwater Research* 16: 131-133.

Mitchell, C. P. and Boubée, J.A.T. 1995: Evaluation of materials to allow fish passage past Huntly Power Station. *Report to ECNZ*. 10p.

Moffat, R. (1984). Aspects of spatial segregation of adult koaro (*Galaxias brevipinnis*) and juvenile trout (*Salmo trutta* and *Salmo gairdnerii*) in the Ryton River. Department of Zoology. Christchurch, University of Canterbury: 66.

Molley, J.; Bell, B.; Clout, M.; de Lange, P.; Gibbs, G.; Given, D.; Norton, D.; Smith, N.; Stephens, T. 2002: Classifying species according to threat of extinction – a system for New Zealand. *Threatened species occasional publication* 22. 26p.

Nikora, V.I.; Aberle, J.; Biggs, B.J.F.; Jowett, I.G.; Sykes, J.R.E. 2003: Effects of fish size, time to fatigue and turbulence on swimming performance: a case study of *Galaxias maculatus*. *Journal of Fish Biology*, 63, 1365-1382.

O'Brien, L. K. 2005: The conservation ecology of Canterbury mudfish (*Neochanna burrowsius*). Unpublished PhD thesis, University of Canterbury, Christchurch, New Zealand. 242p.

Palmer, P. 1991: DOC's role regarding the fish passage component of the Freshwater Fisheries Regulations 1983. *Unpublished Department of Conservation Memo*. Christchurch

Palmer, D.; Boubée, J.A.T.; Mitchell, C.P. 1987: Impingement of fish and crustacean at Huntly thermal power station. *New Zealand Freshwater Fisheries Report* 91.

Schicker, K.P.; Boubẽe, J.A.T.; Palmer, D.; Stancliff, A.G.; Mitchell, C.P. 1989: Elver movement in the Waikato River at Huntly. *New Zealand Freshwater Fisheries Report* 108

Sorenson, I. 1951: An investigation of some factors affecting the upstream migration of elvers of the American eel in a Rhode Island brook. *Transactions of the American fisheries Society* 115, 258-268

Stancliff, A.G.; Boubée, J.A.T.; Palmer, D.; Mitchell, C.P. 1988: Distribution of migratory fish and shrimps in the vicinity of the Waikato thermal power stations. *New Zealand Freshwater Fisheries Report* 99.

Stancliff, A.G.; Boubée, J.A.T.; Mitchell, C.P. 1989: Cross- channel movement of small migratory fish and shrimps in the Waikato River near Huntly thermal power station. *New Zealand Freshwater Fisheries Report* 107.

Unwin, M.J., Webb, M, Barker, R.J., Link, W.A. 2005: Quantifying production of salmon fry in an unscreened irrigation system: A case study on the Rangitata River, New Zealand. *North American Journal of Fisheries Management* 25:619-634.

United States Department of the Interior Bureau of Reclamation (Denver Fish) (U.S. B.R.). 2006: Protection at Water Diversions - A Guide for Planning and Designing Fish Exclusion Facilities, Colorado, 480p.

Ward, F.J.; Northcoate, T.G.; Boubée, J.A.T. 2005: Review Paper – the New Zealand common smelt: biology and ecology. *Journal of Fish Biology* 66, 1-32

Watene, E. M.; Boubée, J.A.T.; Haro, A. 2003: Downstream movement of mature eels in a hydroelectric reservoir in New Zealand. In: D.A. Dixon (ed.) Biology, *Management and Protection of Catadromous Eels, Symposium* 33.

Watene, E. 2001: Movement of migrant eels. In Williams, E.K. and Boubẽe, J.A.T. (Editors) *Proceedings of the Eel Passage Workshop. NIWA publication*, Hamilton, 156p.

Webb, P.W.; Sims, D.; Schulz, W.W.1991: The effects of an air/water surface on the fast-start performance of rainbow trout (Oncorhynchus mykiss). *Journal of Experimental Biology* 155: 219-226.

Webb, M.W. 1999: Diversion of juvenile salmon into the Rangitata Diversion Race and their fate for the 1998/99 irrigation season. *Fish and Game NZ publication*, Central South Island Region, Temuka. 50p.

Winterbourn, M.J. 2000: Feeding ecology. In Collier, K.J; and Winterbourn, M.J. (Editors) New Zealand stream invertebrates: ecology and implications for management. *New Zealand Limnological Society*, 415 p.

APPENDIX 1. Extracts of relevant sections of the Freshwater Fisheries Regulations (1983) with regard to fish passage provisions (as at December 2004)

DEFINITIONS (REGULATION 2)

dam means any structure designed to confine, direct, or control water, whether permanent or temporary; and includes weirs:

diversion structure means any structure designed to divert or abstract natural water from its natural channel or bed whether permanent or temporary:

fish facility means any structure or device, including any fish pass or fish screen inserted in or by any water course or lake, to stop, permit, or control the passage of fish through, around, or past any dam or other structure impeding the natural movement of fish upstream or downstream:

fish pass means any structure providing passage through or over any barrier to their passage:

fish screen means any device whether moving or stationary designed to impede or stop the passage of fish:

officer means a warranted officer within the meaning of the Act:

remedial works means any structures, channel modifications, or water flow provided to offset the effect of a dam or diversion structure:

RELEVANT REGULATIONS

Part 6—Fish passage

41 Scope

(1) This part of these regulations shall apply to every dam or diversion structure in any natural river, stream, or water.

(2) For the purposes of these regulations "dam or diversion structure" shall not include—

(a) Any net, trap, or structure erected and used solely for the purpose of taking or holding fish in accordance with the provisions of the Act, or of these regulations:

(b) Any dam constructed on dry or swampy land or ephemeral water courses for the express purpose of watering domestic stock or providing habitat for water birds:

(c) Any water diversion not being incorporated into or with a dam, that is solely and reasonably required for domestic needs or for the purposes of watering domestic stock and that empties, without dead ends, into any viable fish habitat:

(d) Any structure authorised by a Regional Water Board not requiring a water right that in no way impedes the passage of fish.

(3) For the purposes of this Part of these regulations, the term "occupier" includes the owner of any land when there is no apparent occupier; and also includes any person doing any work by contract for the occupier.

42 Culverts and fords

(1) Notwithstanding regulation 41 (2) (d) of these regulations, no person shall construct any culvert or ford in any natural river, stream, or water in such a way that the passage of fish would be impeded, without the written approval of the Director-General incorporating such conditions as the Director-General thinks appropriate.

(2) The occupier of any land shall maintain any culvert or ford in any natural river, stream, or water (including the bed of any such natural river, stream, or water in the vicinity of the culvert or ford) in such a way as to allow the free passage of fish:

Provided that this requirement shall cease if the culvert or ford is completely removed or a written exemption has been given by the Director-General.

43 Dams and diversion structures

(1) The Director-General may require that any dam or diversion structure proposed to be built include a fish facility:

Provided that this requirement shall not apply to any dam or diversion structure subject to a water right issued under the provisions of the Water and Soil Conservation Act 1967 prior to the 1st day of January 1984.

(2) Any person proposing to build such a dam or diversion structure shall notify the Director-General and forward a submission seeking the Director-General's approval or dispensation from the requirements of these regulations, shall supply to the Director-General such information as is reasonably required by the Director-General to assist him in deciding his requirements (including plans and specifications of the proposed structure and any proposed fish facility).

(3) Should the Director-General consider that the information supplied is inadequate, he shall, within 28 days, advise the applicant as to what further information is required.

44 Requirement for a fish facility

(1) If, in the opinion of the Director-General, a fish facility is required or dispensation from such a requirement is acceptable, the Director-General shall as soon as practical but in no case longer than 6 months if a fish facility is required from the date of receiving all information required, or 3 months where a fish facility is not required from the date of receiving all information required, forward his written requirement or dispensation to whomsoever made the submission.

(2) Where in the opinion of the Director-General a fish facility is required he shall specify what is required to enable fish to pass or stop the passage of fish, and while not limiting this general requirement may specify—

(a) The type, general dimensions, and general design of any fish pass to be utilised:

(b) The type, general dimensions, general design, and placement of any fish screen utilised.

(3) Subject to the Water and Soil Conservation Act 1967 and any determination under that Act, the Director-General may specify—

(a) The type and placement of any water intake to be utilised where fish screens are not required:

(b) The flow of water through any fish pass and the periods of the day and year when the pass must be operational:

(c) The volume, velocity, and placement of additional water to attract migrating fish to any fish pass:

(d) The type and scope of any remedial works in connection with any fish screen or fish pass to enable fish to approach the structure or to be returned to the normal course of the water channel:

(e) The volume or relative proportion of water that shall remain downstream of any dam or diversion structure and the period of day or year that such water flows shall be provided.

(4) Every approval given by the Director-General shall expire 3 years from the date of issue if the construction of the dam or diversion structure is not completed, or such longer time as he may allow.

(5) The manager of every dam or diversion structure in connection with which a fish facility is provided shall at all times keep such fish facility in good and satisfactory repair and order, so that fish may freely pass and return at all times or are prevented from passing as specified under these regulations.

45 Adequate water

The manager of every dam or diversion structure in connection with which a fish facility is provided shall, subject to the Water and Soil Conservation Act 1967 and any relevant determination under that Act, maintain a flow of water through or past such fish facility sufficient in quantity to allow the facility to function as specified at all times or periods specified; but no person shall be liable for a breach of this regulation due to drought, flood, or other sources beyond his control if the default is made good as soon as reasonably possible.

46 Required maintenance or repair

The Director-General may serve notice in writing to the manager of any fish facility notifying him of any defects or want of repair in such fish facility and requiring him within a reasonable time to be therein prescribed to remove any defect or make such repairs as may be required:

Provided that nothing in this regulation shall affect the liability of a manager under regulation 44 of these regulations.

47 Damage

No person shall wilfully injure or damage any fish facility.

48 Alterations

No person shall, without the written consent of the Director-General, make a structural alteration in any fish facility.

49 Inspection of fish facilities

Any Officer may at all reasonable times enter upon any fish facility and upon any remedial works or upon the land bordering such fish facility or remedial works for the purpose of their inspection.

50 Protection of fish

No person, other than an Officer acting in his official capacity, shall take or attempt to take any fish on its passage through a fish facility, or place any obstruction therein or within a radius of 50 m of any point of a fish facility, or shall within a radius of 50 m of any point of a fish facility use any contrivance whereby fish may be impeded in any way in freely entering or passing through or passing by a fish facility except as may be provided by the Director-General in writing to the manager of the fish facility.

Editorial Note: The Water and Soil Conservation Act 1967 was repealed on 1 October 1991 by s361 (1) of the Resource Management Act 1991 (1991 No. 69). References to the WSCA and related structures (water rights, regional water boards) are deemed to relate to their equivalents in the RMA (resource consents, regional councils).