A calendar of fish migrations through New Zealand river mouths

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prepared for Waiau River Working Party

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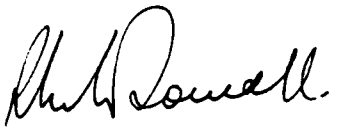
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1.0 EXECUTIVE SUMMARY

Diadromous fishes are migrating between New Zealand coastal seas and the rivers that drain into them, at almost all times of the year. There is clear seasonal partitioning, however, in the directions of these migrations, with much more upstream migration taking place during the spring, and downstream migration occurring during summer through into early winter. Patterns of migration in the Waiau River (Southland) are similar to the above.

2.0 INTRODUCTION

Sixteen of New Zealand's extant freshwater fishes, plus one extinct species (the grayling, *Prototroctes oxyrhynchus*) have diadromous life cycles. Though there are some countries with very small freshwater fish faunas (such as Hawaii — six species, and Iceland — three species), which have freshwater fish faunas that are entirely diadromous, New Zealand, with a larger though still rather impoverished freshwater fish fauna, has a greater proportion of diadromous species than any fauna of comparable or greater size. Reasons for this high proportion probably relate to New Zealand's great geographical isolation from other substantial land masses, and to its long tectonic and geomorphological instability, with violent volcanic activity, extensive marine submergence of now emergent land, mountain building, and so on (Fleming 1979; McDowall 1990).

New Zealand's diadromous freshwater fishes, with familial affiliations, scientific and common names, are listed in Table 1. Common names will be used hereafter in this report.

TABLE 1. Diadromous freshwater fish species in New Zealand

Family Geotriidae	*Geotria australis* - lamprey*
Family Anguillidae	*Anguilla dieffenbachii* - longfinned eel*
	Anguilla australis - shortfinned eel*
Family Retropinnidae	*Retropinna retropinna* - common smelt*
	Stokellia anisodon - Stokell's smelt
Family Galaxiidae	*Galaxias maculatus* - inanga*
	Galaxias argenteus - giant kokopu
	Galaxias fasciatus - banded kokopu*
	Galaxias postvectis - shortjawed kokopu
	Galaxias brevipinnis - koaro*
Family Pinguipedidae	*Cheimarrichthys fosteri* - torrentfish*
Family Eleotridae	*Gobiomorphus huttoni* - redfinned bully*
	Gobiomorphus cotidianus - common bully*
	Gobiomorphus hubbsi - bluegilled bully*
	Gobiomorphus gobioides - giant bully
Family Pleuronectidae	*Rhombosolea retiaria* - black flounder*

* - species recorded as diadromous in the Waiau River

The movements of fish between rivers and the sea vary in character, but whatever the details, they involve movements through river mouths, and for this reason maintenance of open river mouths is critically important for the well-being of fish populations, especially for those in which the migration is an obligatory feature of the life cycle.

- There are some, mostly marine, species that opportunistically enter river estuaries to find favourable feeding grounds, or shed freshwater intolerant ectoparasites, or for other purposes, if and when the opportunity presents itself — they are highly facultative;
    - In almost all instances these facultative movements involve basically marine fish entering fresh waters and very seldom the reverse;
    - The movement typically involves only a small proportion of the overall population of the species;
    - It may occur at various life stages within and among species;
    - The movement is often tidally related;
    - The duration of freshwater life is often brief and it may be for only a short distance up stream, into the river estuary or perhaps the lower river reaches;
    - They seem to be able to move in and out of rivers at highly variable life stages and seasons of the year;
    - Prevention of migration does not disrupt completion of the species' life cycle;
    - Typically, too, the species cannot survive indefinitely in fresh water, but the migrants must return at least to the estuary if not to sea, for longterm survival; this may be at intervals as short as tidally or daily.
- Other migratory fish move between rivers and the sea as a regular, often obligatory, behaviour which is essential for completion of the life cycle;
    - Most if not all individuals in the population undertake the migration;
    - It takes place at a definite, well-defined life stage (larva, juvenile, adult);
    - The various life stages are well-adapted to living in fresh water or the sea, and can continue to do so through completion of that and sometimes other life stages;
    - Migration may be possible only at well-defined life stages and seasons, and be mediated by precisely timed physiological changes in the fish;
    - An inability to undertaken this migration severely disrupts completion of the species' life cycle, and is likely to lead to local extirpation if the migration is prevented.

Species in the first category, above, are best described as **facultative marine wanderers** while those in the second are classified as **diadromous** (McDowall 1988); the latter are the primary concern of this report. Because these migrations are, more or less, obligatory in diadromous species, the possibility of river mouth closure has the potential to disrupt completion of the species' life cycles. If mouth closure is prolonged, or is intermittent but because of timing coincidences repeatedly prevents a seasonal migration of species, there is potential for that species to become extirpated in such a river. Where river mouth closure is caused by seasonal climatic events, such as winter low flows, or autumnal droughts, there is a real likelihood that natural events causing mouth closure could lead to local extirpation of a species in a river system.

Keeping a river mouth open is a consequence of the interaction of opposing sets of forces. The flow of water from a river to sea tends to sweep gravels and sands out of the lower river, estuary, and mouth, thereby maintaining the mouth opening. But coastal drift of sands and gravels along the ocean beach caused by ocean currents and prevailing wind-driven surf tends to deposit these materials in the river mouth and thereby close it. Whether the mouth is open or closed depends on which of these forces is the greatest. River mouth closure is a natural phenomenon, e.g. Lake Ellesmere and numerous small rivers along the Canterbury coast have apparently always suffered mouth closure owing to gravel deposition at their outlets. Closure has become a more common phenomenon in New Zealand rivers as a consequence of the human manipulation of river flows, and frequent closure of the mouths of rivers such as the Ashburton and Opihi probably can be attributed to reduced flows from these rivers as a result of water abstraction for irrigation.

2.1 Waiau River

The Waiau River (Southland) has undergone major reduction in flows as a result of diversion through the Manapouri Power Station and into Doubtful Sound of water, that formerly flowed down the river from Lake Manapouri. Flows from the lake and down the Waiau River formerly exceeded 400 m^3s^{-1}, but after construction of the Lake Manapouri Control Structure (hereinafter called the Mararoa Weir), flows at the weir amounted to only 0.3 m^3s-1; flows in the river channel are gradually restored by the entry of numerous, mostly small, tributaries below the weir, but even so, normal flows at the mouth are reduced to only about 78 m^3s^{-1} (Riddell *et al.* 1993). Flows are often greater than this, as a result of floods in the tributaries of the river below the Weir, or when water is discharged across the weir to avoid excessive water levels in Lake Manapouri, or to avoid turbid water from the Mararoa River entering the lake. Nevertheless, there is the potential for extended periods of low flow, and for this to result in mouth closure of the Waiau - especially if low flows endure for a long time and there is simultaneous strong coastal drift of sand and gravel. Closure of the Waiau River mouth has occurred since construction of the Mararoa Weir.

The Waiau River Working Party (WRWP) was convened by the Electricity Corporation of New Zealand to identify and evaluate various possible impacts of impoundment and diversion of water at the Mararoa Weir. Since one of the potential effects of the management of the Waiau River is reduced flows leading to mouth closure, the WRWP commissioned

preparation of this calendar of fish migrations so that the most critical periods for maintenance of mouth opening can be identified.

3.0 TYPES OF DIADROMOUS MIGRATIONS

The life stages, at which migrations between fresh waters and the sea take place, vary between species, and fall into three fairly distinct categories. It is important to understand these if the impacts of mouth closure are also to be understood.

3.1 Anadromous species

Some diadromous species spend most of their lives at sea. They migrate into river estuaries and lower rivers as mature to ripe adults, and spawn there after periods of varying duration, after which the spent adults often die (always in anadromous New Zealand species). The eggs develop in fresh water, and either the newly hatched larvae go to sea, or there is a period of rearing in fresh water before the juveniles go to sea. In either case, most feeding, growth and maturation takes place in the sea. The defining feature of anadromous fishes is that: **the adults leave the sea and move into fresh water to spawn.** Examples in New Zealand are lamprey, and common and Stokell's smelts.

3.2 Catadromous species

Other diadromous species spend most of their lives in fresh water. They enter fresh water as small juveniles, and spend one to many years feeding, growing and maturing in rivers and lakes, before they migrate downstream as mature adults, and go to sea, spawn and (usually) die. Egg development is at sea, and small juveniles return to fresh water to complete the cycle. The defining feature of catadromous fishes is that: **the adults leave fresh water and move to sea to spawn.** Examples in New Zealand are eels and black flounder; inanga are regarded as marginally catadromous (see **Inanga**, below)

3.3 Amphidromous species

Yet other species have migrations that do not fit either of the above categories. Typically, the adults spawn in fresh water after a long period (several months to years) of feeding and growing in fresh water. Spawning and egg development take place in fresh water, and the tiny larvae are swept to sea soon after hatching. They grow and develop in the oceanic plankton for several months before they return to fresh water as small juveniles. They resume feeding and growing there, to adulthood, thus completing the cycle. The defining feature of amphidromous species is that: **there is no adult spawning migration between fresh water and the sea; migration bears no direct relation to spawning activity.** Examples in New Zealand are the whitebait of koaro, various kokopu, plus juveniles of torrentfish and various bullies.

4.0 DATA AND ANALYSIS

The freshwater fish fauna of the Waiau River was described in McDowall (1994), in which 12 of the 16 extant diadromous fish species known from New Zealand waters, were reported. Additional diadromous species possibly are present but not yet recorded. Partly for this reason, all 16 diadromous New Zealand freshwater fishes are considered in this report. In addition, the calendar is then relevant to all New Zealand rivers, and therefore of wider utility in determining the potential impacts of mouth closures. Data are derived from published reports of the life histories of the species concerned.

Knowledge of the timing of migrations of New Zealand's diadromous fish species is incomplete, meaning that preparation of a calendar of migrations, as attempted here, will be subject to amendment as knowledge of the nature and timing of fish migrations increases. However, it provides an estimate of migration patterns and therefrom an ability to predict what periods of the year are likely to be more or less critical for fish migration in and out of rivers such as the Waiau. It is critical to recognise that for all diadromous species there are both **upstream** and **downstream** migrations which are of equal importance to maintaining their populations. In the discussion that follows, I have attempted to define the migration periods of the various life stages, as well as possible, from published literature. Boundaries of the migration periods are certainly arguable and will be subject to refinement or even major adjustment when further information is available; but those used are a best estimate on the basis of existing knowledge. Migration periods are summaried by species and life stage in Figure 1.

4.1 Lamprey (anadromous)

Migrations of mature adults into fresh water are known to take place during winter, beginning as early as June and possibly continuing through September. Precise definition of the period of passage from the sea is somewhat confused by the fact that adult lampreys take many months to mature, after moving into rivers, and so are found there over much longer periods than the actual migration period (Kelso and Glova 1993).

Lampreys emigrate from fresh water as miniatures of the adult, known as macrophthalmia. These transform from the eyeless ammocoete during the summer and autumn and migrate downstream to the sea during at least July and August (Empson and Meredith 1987), though probably more widely, Todd and Kelso (1993) concluded that the emigration takes place between January and May, judging from the presence of transformed macrophthalmia in a small Canterbury stream (greatest numbers observed in March). However, Todd and Kelso (1993) did not allow for the time taken for transformation to run its full course, nor for any period of residence in fresh water by macrophthalmia prior to emigration, and so I suspect their dating of the beginning of the migration may be significantly too early. Potter *et al.* (1980) dated the emigrations of macrophthalmia from Western Australian rivers as occurring over about six weeks (in July-August), and a similarly narrower emigration period may apply in New Zealand rivers.

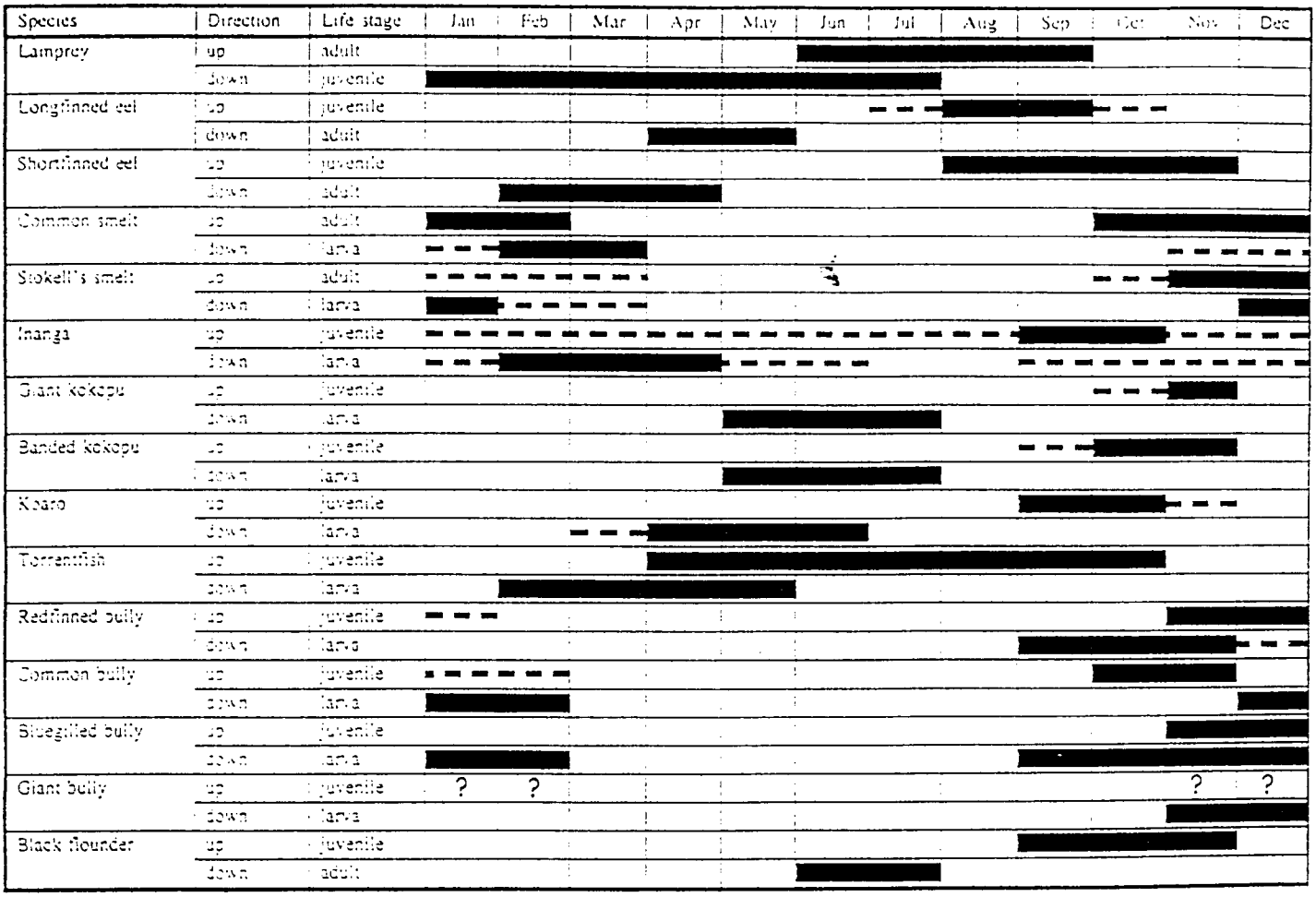


FIGURE 1. Summary of migration periods of New Zealand's diadromous freshwater fish species (continuous lines indicate probable main periods of migration and discontinuous lines periods of less intense migratory activity).

4.2 Longfinned eel (catadromous)

Emigrations of adult eels to sea are well known autumn phenomena, with the adults departing for sea mostly during April and May (Cairns 1941; Hobbs 1947; Burnet 1969; Todd 1981).

Migrations of juvenile longfin glass eels back into fresh water occur from about July to December, with greatest numbers arriving in August and September (Jellyman 1987).

4.3 Shortfinned eel (catadromous)

Seaward migrations of the mature adults are recorded in February through March and into early April (Cairns 1941; Hobbs 1947; Burnet 1969; Todd 1981).

The migrations of shortfin glass eels into rivers takes place during August to October (Jellyman 1987).

4.4 Common smelt (is regarded as anadromous though its migrations seem regionally variable and complex)

Eldon and Greager (1983) recorded common smelt in the Rakaia River lagoon in all months, but greatest abundance in March; in the nearby Waimakariri (Eldon and Kelly 1985) it was commonest during spring (October-November). Whitebaiters in West Coast rivers encounter mature adults entering rivers during the spring, beginning about October, and they probably continue to run over the entire summer.

Spawning of common smelt takes place mostly in autumn; larval smelt were encountered emigrating from the Waikato River mostly during March to June by Meredith, *et al.* (1989), though some emigration was observed in all months of the year.

4.5 Stokell's smelt (anadromous)

Eldon and Greager (1983) found Stokell's smelt in the Rakaia lagoon in large numbers from October to March, with peak influx in November and December.

Spawning by Stokell's smelt is not well-defined, but occurs in fresh/estuarine waters (McMillan 1961) and thus presumably coincides with part of the period when the fish occupy river estuaries, probably December-January, tapering off into March.

4.6 Inanga (regarded as "marginally catadromous")

Mature adults certainly undergo a downstream spawning migration, though this ends in the tidal estuary rather than at sea (which it ought, to be truly catadromous). However, successful spawning probably depends on the stimulus of tidal fluctuations, and for these to

occur an open river mouth is highly desirable. There are rare instances of inanga spawning where there is no tidal influence, though after a minor fresh (Hefford 1933). Spawning by inanga was recorded in every month of the year from September to June by McDowall (1968), but it is predominantly in the autumn months of March and April. Taylor *et al.* (1992) recorded spawning in South Island rivers between December and May, with the main period being February to April, giving close agreement with McDowall (1968). Hatching takes 2-6 weeks from spawning, depending on water temperatures with development slower at cooler temperatures (Benzie 1968). Newly hatched larval must therefore be leaving rivers during many months, though especially in autumn, from February to April.

Inanga return to rivers from the sea, also over a very prolonged period, as some fresh-run "whitebait" juveniles have been recorded in all months of the year (McDowall 1968). However, the migration has a very strong seasonal component with a maximum during September and October (McDowall 1968; McDowall and Eldon 1980).

4.7 Koaro (amphidromous)

Spawning takes place in fresh water, probably during the late autumn and winter. McDowall (1990) suggested an autumn to early winter spawning period for koaro, based on collections of mature to ripe adults. McDowall *et al.* (1994) calculated a hatch date of early April to mid June, which equates to the period when larval koaro would be going to sea. Larvae, thought to be of koaro, were captured in late March, moving downstream in a tributary of the Taramakau River (A.M. Suren, pers. comm.). Koehn and O'Connor (1992) described koaro spawning in Australia (Victoria) during May-June.

The most intensive return migrations of whitebait juveniles of koaro occur during September and October (McDowall and Eldon 1980).

4.8 Banded kokopu (amphidromous):

The spawning period of banded kokopu was described as late April to late June by Hopkins (1979); this is consistent with Mitchell and Penlington's (1982) observations of actual spawning in early June, and Ots and Eldon's (1975) report of downstream movement of newly hatched larvae in late June. Hatch date for this species was estimated as mid-May to mid-July from counts of daily growth rings by McDowall *et al.* (1994). From this rather diverse, limited, but relatively consistent set of data, emigrations of larval banded kokopu from rivers seem likely during June and July.

Whitebait juveniles of banded kokopu were recorded returning to New Zealand rivers from about mid-October through November (McDowall and Eldon 1980); however sampling was terminated in late November, so that migration may extend through November into December, and perhaps beyond.

4.9 Giant kokopu (amphidromous)

The spawning site of giant kokopu has never been observed, though ripe adults have been captured during winter (June to August), and this coincides with periods of greater activity by giant kokopu encountered by eel fishers (McDowall 1990). Very sparse data on hatch date determined by back-calculation from daily growth rings in otoliths indicated a hatch date in mid-July (McDowall *et al.* 1994).

Migrations back into fresh water from the sea by giant kokopu whitebait were observed mostly during November, in a sampling programme undertaken from the beginning of September to the end of November (McDowall and Eldon 1980); extension of the season through at least into early December seems likely.

4.10 Shortjawed kokopu (amphidromous)

Even less is known about the life history and migrations of shortjawed kokopu. The spawning site is unknown, and the spawning season seems likely to be in autumn-winter - ripe adults have been collected in at least March through April (McDowall 1990; NIWA, unpublished data), while back calculation from very few juveniles indicated a hatch date of mid-July (McDowall *et al.* 1994).

Juvenile shortjawed kokopu come back from the sea into fresh water as whitebait during the spring, but the present inability to distinguish them from the whitebait of koaro makes it impossible to determine the period of migration; it is presumably coincident with part of migration period described for koaro.

Because the periods of migration for this species are so uncertain, they are not included in the data analysis. What little is known, however, suggests that addition of data for shortjawed kokopu is likely to reinforce patterns of downstream movements in summer through winter, and upstream movements in spring.

4.11 Torrentfish (amphidromous)

Spawning is thought likely to occur in fresh water, though it has never been observed or its location described. Mature to ripe fish are found in rivers over a prolonged period, and spawning was estimated as occurring in the Rakaia and Ashley Rivers from January to April (Scrimgeour and Eldon 1989). Presumably a seaward migration of larvae took place during or slightly later than this period, say February to May, giving time for egg development in the colder months of the year.

Juvenile torrentfish return to rivers from the sea over a prolonged period. Eldon and Greager (1983) recorded them entering the Rakaia lagoon from the sea in all months from April to November, and Eldon and Kelly (1985) into the Waimakariri estuary in the same months.

4.12 Redfinned bully (amphidromous)

Spawning of redfins takes place during late winter to early spring (July until November—McDowall 1965). Larvae go to sea on hatching, from about August to December.

Return migrations of juvenile redfinned bullies into rivers from the sea take place from late spring, from about November, and probably through into the early summer (January), though there are few data.

4.13 Common bully (amphidromous)

Spawning occurs from spring probably through summer - perhaps October to February. Meredith *et al.* (1989) reported peak numbers of bully larvae emigrating down the Waikato River at Huntly to occur in October and November. They did not identify these larvae as common bullies; however, it is the predominant diadromous bully species in the Waikato, with redfinned bullies occurring only intermittently, and there is little doubt that most of the bully larvae collected by Meredith *et al.* (1989) were common bully.

Juvenile common bullies return to fresh water from the sea during the summer - late December through February (Stancliff *et al.* 1988).

4.14 Bluegilled bully (amphidromous)

Virtually nothing is published on the life history of the bluegilled bully. Juvenile bluegills are known to migrate into river mouths from the sea during the late spring, and probably well through the summer.

Spawning has been observed from early spring through summer, and larval bluegills are probably moving to sea from October through February.

4.15 Giant bully (is believed to be amphidromous, though data on its life history are very sparse)

Adults are mature during the spring (November and December), so that an emigration of newly hatched larvae from river estuaries where giant bullies are found, is likely through about this period. Nothing is known about their return to fresh water.

4.16 Black flounder (catadromous)

Black flounder adults probably mature and migrate to sea during the winter (Davis *et al.* 1983). Eldon and Greager (1983) reported an increased numbers of adults in the Rakaia

River in early May, followed by a decline; they cited a report of downstream movements of adult black flounders in the Waitaki River in June-July.

Flounders begin their lives as normal, vertically oriented larval fish in the marine plankton, but undergo a metamorphosis during which they adopt the distinctive practice of lying on one side, and the eye on that side migrates to join the other on what becomes the fish's upper (ocular) surface. Newly metamorphosed larval black flounder are found making their way into fresh waters during spring (September in the Rakaia River - Eldon and Greager 1983; October-December in the Waimakariri River - Eldon and Kelly 1985).

5.0 DISCUSSION

The data from these various informal and narrative accounts of native fish migrations have been transformed into Figure 1 in which the most important months for migrations up and down stream are indicated by continuous lines. Periods outside these months, when some migration is known or suspected, are shown as discontinuous lines. Table 2 shows the estimated number of species that is likely to be migrating up stream, down stream and in total, in any month of the year for both New Zealand wide river systems and the Waiau River; these data are displayed in Figure 2 (New Zealand-wide patterns of migration, by month) and Figure 3 (Waiau River patterns of migration by month). In all these, 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 is obvious. Total migration intensity was greatest in spring, though not greatly higher than the autumn peak. Thus there is no consistent period of significantly less total migratory activity than at other times in the New Zealand-wide dataset. Increased reliability of the data upon which Table 2 is based is likely to incrementally modify migration periods for many species but seems unlikely to fundamentally alter the patterns of upstream and downstream migration. At present, no argument can be made for any particular period being more or less important for migration, overall. However, the shift evident from spring upstream to summer-winter downstream migration seems likely to be real. For species important to fish populations in the Waiau River (Southland), which is the primary concern of WRWP which commissioned this report, the pattern is much the same (Table 2).

The Waiau River supports a regionally valued whitebait fishery (McDowall 1993), for which an open river mouth during August through mid-November is desirable. For the river to contribute its regional share to the maintenance of the fishery through reproduction in the river, mouth opening from about late February through May is desirable. Another important fishery resource in the river is its eel stocks; migrations of adult eels to spawn, and the return of juvenile eels to regenerate the stocks would be well accommodated by the same opening times as specified above for the whitebait fishery and stocks. A much less significant fishery resource is for black flounder; migration patterns of adult to sea to spawn are not well known, but seem likely to be in June and/or July, while return migrations of juveniles are probably September to November.

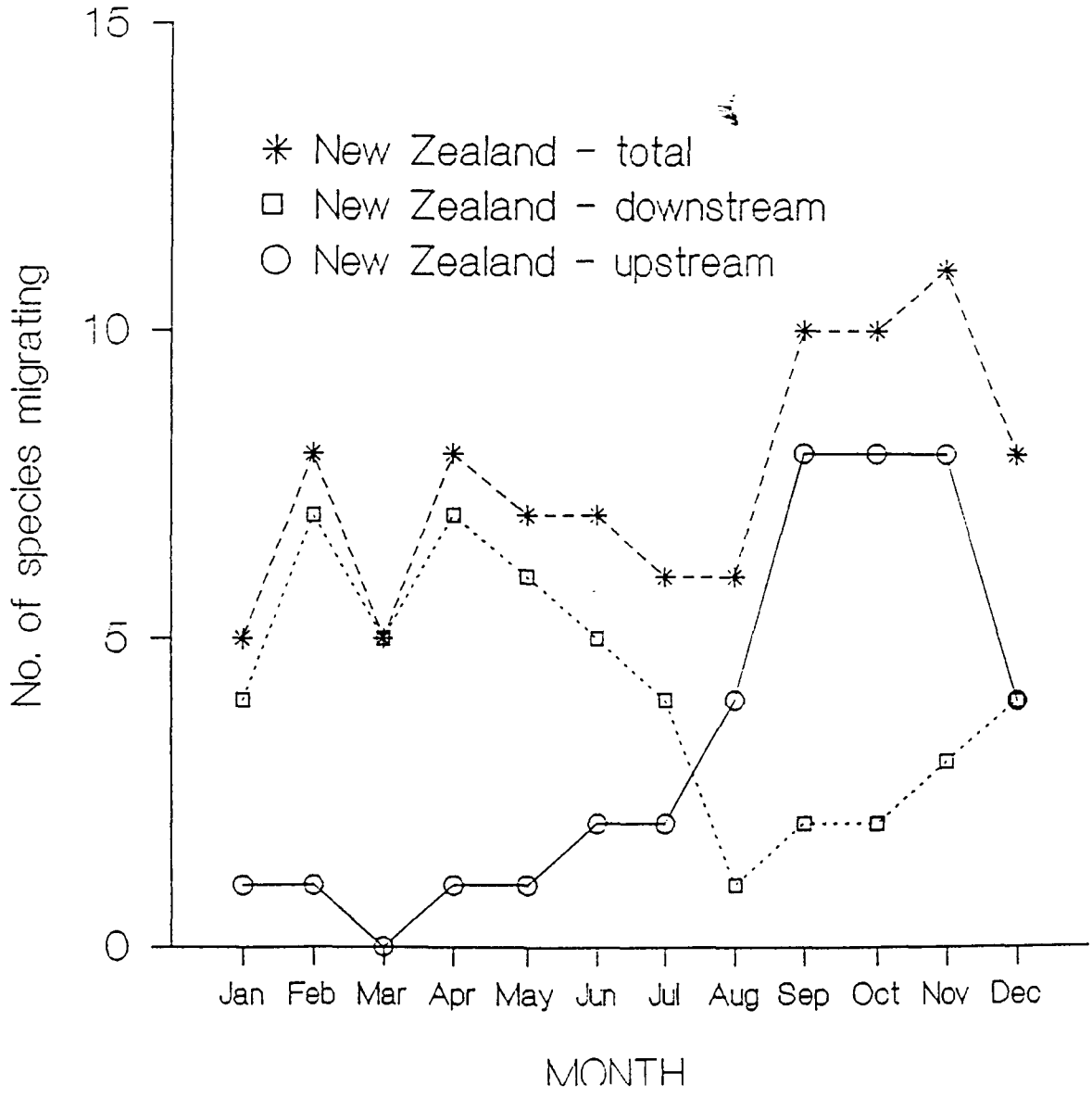


FIGURE 2. Monthly distribution of upstream, downstream, and total migratory activity by diadromous New Zealand freshwater fishes.

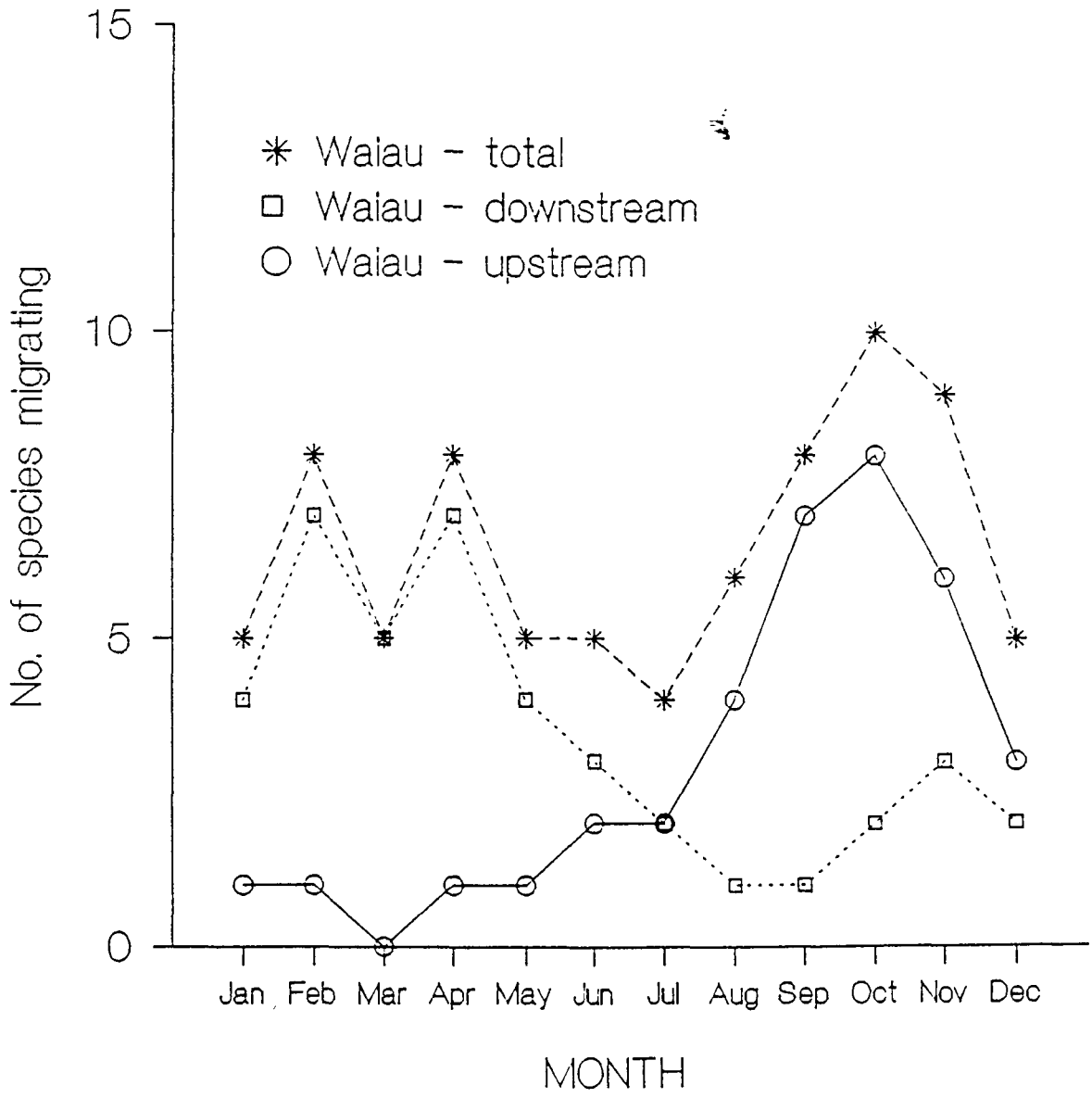


FIGURE 3. Monthly distribution of upstream, downstream, and total migratory activity by diadromous Waiau river freshwater fishes.

TABLE 2. Numbers of species migrating up and down stream through the mouths of New Zealand rivers, and through the Waiau River mouth (Southland)

	New Zealand			Waiau River		
	up	down	total	up	down	total
January	1	4	5	1	4	5
February	1	7	8	1	7	8
March		0	5	5	0	55
April	1	7	8	1	7	8
May	1	6	7	1	4	5
June	2	5	7	2	3	5
July	2	4	6	2	2	4
August	4	1	5	4	1	5
September	8	2	10	8	1	9
October	8	2	10	8	2	10
November	8	3	11	6	3	9
December	4	4	8	3	2	5

6.0 REFERENCES

Benzie, V. 1968. Some ecological aspects of the spawning behaviour and early development of the common whitebait, *Galaxias maculatus attenuatus* (Jenyns). *Proceedings of the New Zealand Ecological Society* 15: 31-39.

Burnet, A.M.R. 1969. Migrating eels in a Canterbury river, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 3(2): 230-244.

Cairns, D. 1941. Life-history of the two species of New Zealand fresh-water eel. Part I. Taxonomy, age, growth, migration, and distribution. *New Zealand Journal of Science and Technology* 23(1): 53-72.

Davis, S.F., Eldon, G.A., Glova, G.J. and Sagar, P.M. 1983. Fish populations of the lower Rakaia River. *New Zealand Ministry of Agriculture and Fisheries, Fisheries Environmental Report* 33: 1-109.

Eldon, G.A. and Greager, A.J. 1983. Fishes of the Rakaia Lagoon. *New Zealand Ministry of Agriculture and Fisheries, Fisheries Environmental Report* 30: 1-65.

Eldon, G.A. and Kelly, G.R. 1985. Fishes in the Waimakariri estuary. *New Zealand Ministry of Agriculture and Fisheries, Fisheries Environmental Report* 56: 1-59.

Empson, P. and Meredith, A.S. 1987. Downstream movement of *Geotria australis* in the lower Waikato River. *New Zealand Journal of Marine and Freshwater Research* 21(4): 643-644.

Fleming, C.A. 1979. *The geological history of New Zealand and its life.* Auckland University Press, Auckland. 141 pp.

Hefford, A.E. 1933. Whitebait. *N.Z. Marine Department Annual Report on Fisheries* 1933: 13-14.

Hobbs, D.F. 1947. Migrating eels in Lake Ellesmere. *Transactions and Proceedings of the Royal Society of New Zealand* 77(5): 228-232.

Hopkins, C.L. 1979. Reproduction of *Galaxias fasciatus* Gray (Salmoniformes: Galaxiidae). *New Zealand Journal of Marine and Freshwater Research* 13(2): 225-230.

Jellyman, D.J. 1987. A review of the marine life history of the Australian temperate species of *Anguilla*. pp. 276-285 *in:* Dadswell M.J. *et al.* (Eds.). *American Fisheries Society Symposium: 1. Common strategies of anadromous and catadromous fishes.* American Fisheries Society, Bethesda.

Kelso, J.R.M. and Glova, G.J. 1993. Distribution, upstream migration and habitat selection of maturing lampreys, *Geotria australis*, in Pigeon Bay Stream, New Zealand. *Australian Journal of Marine and Freshwater Research* 44: 749-759.

Koehn, J.D. and O'Connor, W. 1992. *Galaxias brevipinnis*, this is your life ....cycle. *Australian Society for Fish Biology Newsletter* 22(2): 38.

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

McDowall, R.M. 1968. *Galaxias maculatus* (Jenyns), the New Zealand whitebait. *New Zealand Marine Department Fisheries Research Bulletin* 2: 1-84.

McDowall, R.M. 1988. *Diadromy in fishes: migrations between freshwater and marine environments.* London: Croom Helm.

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

McDowall, R.M. 1993. The Waiau River (Southland) whitebait fishery: a consideration of the impacts of the Mararoa Dam and flow diversion from the river. *N.Z. Freshwater Miscellaneous Report* 51: 1-11.

McDowall, R.M. 1994. Native fish populations of the Waiau River (Southland) and the impacts of the Lake Manapouri Control Structure (the Mararoa Weir). *NIWA Consultancy Report* SRC005: 1-58.

McDowall, R.M. and Eldon, G.A. 1980. The ecology of whitebait migrations (Galaxiidae, *Galaxias* spp.). *New Zealand Ministry of Agriculture and Fisheries, Fisheries Research Bulletin* 20: 1-171.

McDowall, R.M., Mitchell, C.P. and Brothers, E.B. 1994. Age at migration from the sea of juvenile *Galaxias* in New Zealand (Pisces: Galaxiidae). *Bulletin of Marine Science* 54(2): 385-402.

McMillan, H.M. 1961. An addition to the knowledge of the fish *Retropinna anisodon* Stockell (Retropinnidae). *Transactions of the Royal Society of New Zealand, Zoology* 1(10): 139-144.

Meredith, A.S., Empson, P.W., Boubée, J.A.T. and Mitchell, C.P. 1989. Ichthyoplankton studies on the lower Waikato River. II. Larval distributions at Huntly. *New Zealand Freshwater Fisheries Report* 109: 1-58.

Mitchell, C.P. and Penlington, B.P. 1982. Spawning of *Galaxias fasciatus* Gray (Salmoniformes: Galaxiidae). *New Zealand Journal of Marine and Freshwater Research* 16(1): 131-133.

Ots, J.P. and Eldon, G.A. 1975. Downstream movement of fry of *Galaxias fasciatus* Gray. *New Zealand Journal of Marine and Freshwater Research* 9(1): 97-99.

Potter, I.C., Hilliard, R.W. and Bird, D.J. 1980. Metamorphosis in the southern hemisphere lamprey, *Geotria australis*. *Journal of Zoology, London* 190: 405-430.

Riddell, D.C., Freestone, H. and Nutting, S. 1993. *Waiau River - hydrology: report to the Waiau River Working Party*. Invercargill: Southland Regional Council.

Scrimgeour, G.J. and Eldon, G.A. 1989. Aspects of the reproductive biology of torrentfish, *Cheimarrichthys fosteri* in two braided rivers of Canterbury, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 23(1): 19-25.

Stancliff, A.G., Boubée, J.A.T., Palmer, D. and 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: 1-31.

Taylor, M.J., Buckland, A.R. and Kelly, G.R. 1992. South Island inanga spawning surveys, 1988-1990. *New Zealand Freshwater Fisheries Report* 133: 1-69.

Todd, P.R. 1981. The timing and periodicity of migrating New Zealand freshwater eels (*Anguilla* spp.). *New Zealand Journal of Marine and Freshwater Research* 15(3): 225-235.

Todd, P.R. and Kelso, J.R.M. 1993. Distribution, growth and transformation timing of larval *Geotria australis* in New Zealand. *Ecology of Freshwater Fish* 2(3): 99-107.