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NEW ZEALAND FRESHWATER FISHERIES MISCELLANEOUS REPORT NO. 41

ENVIRONMENTAL TOLERANCES OF NATIVE FISH SPECIES: A LITERATURE REVIEW

by

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ROTORUA

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NEW ZEALAND FRESHWATER FISHERIES MISCELLANEOUS REPORTS

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1. INTRODUCTION

Fisheries managers are frequently called on to judge the value of water or riparian habitat. Development or change may improve or decrease fisheries values or fish stocks. Managers need informed arguments, but the information on fish requirements is scattered throughout many reports, journals, and papers. The reports, like the fish that they describe, can be small, retiring, and well hidden.

Apart from whitebait, eels, smelt, and, perhaps bullies, New Zealand's native fish species are not well known. Of the 26 indigenous species, the grayling is extinct, and five are rare; the remainder may be widespread, but the abundance of all species has probably declined since agricultural and urban development (McDowall 1990a).

Some knowledge of fish life history and habitat requirements is essential to understand the effects of environmental modification. A brief synopsis of native fish life history is given in Section 2 below. Similarly, Section 3 gives limited information on how "environmental tolerance" can be measured.

A comprehensive discussion of tolerance and environmental factors would fill many pages. To keep this report short, Section 4 briefly reviews fish requirements. I have listed the seven most important issues and factors, as perceived by fisheries and environmental managers, and set a "flag" for each issue to alert managers to potential damage, but there are many other factors that affect fish populations.

2. SUMMARY OF SPECIES

There are two main groups of native freshwater fish: diadromous species that migrate between fresh water and the sea at some point in their life cycle (16 species, e.g., eels and whitebait), and those that complete their entire life cycle within fresh water (10 species, e.g., upland bully and alpine galaxias) (Table 1). A further five species (e.g., mullet and kawahai) are frequent in estuarine and brackish water, and sometimes penetrate far inland.

Migratory and non-migratory species are both affected by habitat change or loss, and by variations in water quality.

2.1 Migratory Species

Species which migrate between fresh and salt water during part of their life cycle are known as diadromous. For example, adult eels migrate to sea, spawn, and die, and elvers (young eels) migrate to fresh water.

TABLE 1. Summary of features of New Zealand's native fish species. (Adapted from Table 3, Jellyman 1985.)

Species	Scientific name	Require access to the sea	Distribution		Abundance	Importance	
			North Island	South Island		Recreation	Commecial
MARINE STRAGGLERS							
Grey mullet	*Mugil cephalus*	Yes	+ + +	+ +	+ +	+	+ +
Kahawai	*Arripis trutta*	Yes	+ + +	+ + +	+ + +	+ + +	+ + +
Yellowbelly flounder	*Rhombosolea leporina*	Yes	+ + +	+ + +	+ +	+ +	+ +
Cockabully	*Tripterygion nigripenne*	Yes	+ + +	+ + +	+ + +	-	-
Stargazer	*Leptoscopus macropygus*	Yes	+ + +	+ + +	+ +	-	+
Yelloweyed mullet	*Aldrichetta forsteri*	Yes	+ + +	+ + +	+ + +	+ +	+ +
TRUE MIGRATORY SPECIES							
Banded kokopu # *	*Galaxias fasciatus*	Yes	+ + +	+ + +	+	+	+
Giant kokopu # *	*Galaxias argenteus*	Yes	+ +	+ + +	+	+	+
Shortjawed kokopu *	*Galaxias postvectis*	Yes	+ + +	+ + +	+	+	+
Inanga	*Galaxias maculatus*	Yes	+ + +	+ + +	+ + +	+ + +	+ + +
Koaro #	*Galaxias brevipinnis*	Yes	+ + +	+ + +	+ +	+ +	+ +
Lamprey	*Geotria australis*	Yes	+ + +	+ + +	+	+	-
Longfinned eel *	*Anguilla dieffenbachii*	Yes	+ + +	+ + +	+ + +	+	+ + +
Shortfinned eel	*Anguilla australis*	Yes	+ + +	+ + +	+ + +	+	+ + +
Common smelt # *	*Retropinna retropinna*	Yes	+ + +	+ + +	+ +	+	+
Stokell's smelt *	*Stokellia anisodon*	Yes	0	+ +	+ + +	+ + +	+ + +
Black flounder *	*Rhombosolea retiaria*	Yes	+ + +	+ + +	+ +	+ +	+ +
Bluegilled bully *	*Gobiomorphus hubbsi*	Yes	+ + +	+ + +	+ +	-	-
Giant bully *	*Gobiomorphus gobioides*	Yes	+ + +	+ + +	+	-	-
Redfinned bully *	*Gobiomorphus huttoni*	Yes	+ + +	+ + +	+ +	-	-
Torrentfish *	*Cheimarrichthys fosteri*	Yes	+ + +	+ + +	+ +	-	-
NON-MIGRATORY SPECIES							
Common river galaxias *	*Galaxias vulgaris*	No	0	+ + +	+ +	-	-
Longjawed galaxias *	*Galaxias prognathus*	No	0	+	+	-	-
Alpine galaxias *	*Galaxias paucispondylus*	No	0	+ +	+	-	-
Dwarf galaxias *	*Galaxias divergens*	No	+ +	+ +	+	-	-
Common bully # *	*Gobiomorphus cotidianus*	No	+ + +	+ + +	+ + +	-	-
Upland bully *	*Gobiomorphus breviceps*	No	+ +	+ + +	+ +	-	-
Cran's bully *	*Gobiomorphus basalis*	No	+ + +	+	+ +	-	-
Dwarf inanga *	*Galaxias gracilis*	No	+	0	+	-	-
Brown mudfish *	*Neochanna apoda*	No	+ +	+ +	+	-	-
Black mudfish *	*Neochanna diversus*	No	+	0	+	-	-
Canterbury mudfish *	*Neochanna burrowsius*	No	0	+ +	+	-	-

\- = species is not exploited.
\# = normally migratory, but some freshwater-limited stocks exist, based in lakes.
* = species found only in New Zealand.

Distribution: + + + widepsread
+ + regional
+ localised
0 absent

Abundance: + + + abundant
+ + moderate
+ low

Importance: + + + high
+ + + moderate
+ low

If migration routes are blocked by natural or unnatural barriers (physical, biological, or chemical), then the population upstream of the barrier will decrease. Dams, poorly designed culverts, flood gates, or other barriers block access to upstream areas. Simple changes in water quality (e.g., the thermal discharge from Huntly power station), can radically alter fish behaviour and block access for part or all of the year.

Five of the diadromous species (common smelt, koaro, banded and giant kokopu, and common bully) can spawn either in lakes or their tributaries, and a journey to the sea is not always necessary. For instance, in the lower Waikato there are distinct lake and sea-run populations of common smelt.

Juveniles of inanga, koaro, and the three species of kokopu contribute to the whitebait fishery. The inanga is by far the most important component of the fishery, but koaro and banded kokopu may be abundant in some places (Saxton *et al.* 1987). All three species of kokopu are rare in catchments without indigenous forest (Hanchet 1988). Giant kokopu are found mainly in lowland waters with plenty of instream cover, and may occur in exotic forest. There are several lake-limited populations of giant kokopu in the South Island. This fish seems to tolerate warmer temperatures than the other species of kokopu (Taylor 1988). Banded kokopu may occur upstream of giant kokopu in more confined waters, but also may be common at low altitudes where small forested streams flow directly to the sea. There are a few lake-limited populations in both the North and South Islands. In south Westland, Taylor (1988) found shortjawed kokopu at higher altitudes in cool clear waters.

Koaro penetrate much further inland than any of the kokopu species. There are many lake and alpine-tarn populations, and koaro whitebait were once an important food of the Maori people, especially around Taupo. The great inland penetration of this species does not preclude it from occupying lowland forested streams that enter the sea, directly, and in such places the fish may occur only metres above the surf.

Banded kokopu, shortjawed kokopu, and koaro whitebait are good climbers and can climb waterfalls. Inanga don't usually penetrate more than a few kilometres inland from the sea unless the slope is gentle. They spawn in estuaries at the limit of salt water influence.

Eels form a valuable recreational and commercial resource and, together with lampreys, have significant cultural values. Both species must migrate to and from the sea to spawn.

Of the two smelt species, Stokell's smelt is confined to Canterbury and does not penetrate far inland (McMillan 1961). Common smelt, the "no. 2" whitebait of the Waikato, is widespread throughout both islands and spawns in rivers and lakes. Common smelt have been introduced widely in both the North and South Islands as forage fish for trout.

Little is known about the biology of most of the bullies; the redfinned bully is better understood than the other species (McDowall 1964, 1965a, 1965b). The common bully appears almost everywhere at low altitudes and there are some lake populations at higher altitudes. We presume that most common bullies and bluegilled bullies are diadromous, as their juveniles are known from the whitebait catch. The giant bully probably spends part of its juvenile life at sea, and seldom penetrates far inland.

Flounder usually are confined to lowland waters, but black flounder can penetrate well upstream. Torrentfish live in fast flowing waters up to about 600m a.s.l.

2.2 Non-migratory species

The three mudfish species and dwarf inanga are all rare. The draining or "improvement" of wetlands is the major threat to the three mudfish species. Dwarf inanga has been recorded from 10 Northland lakes, but is abundant in only three.

Other galaxiids (dwarf, common river, alpine, and longjawed) are more widely distributed. The dwarf galaxias (not to be confused with dwarf inanga) is found in forested hill streams of both main islands. The geographic distribution of dwarf galaxias is similar to brown mudfish. The common river galaxias occurs widely along the eastern slopes of the Southern Alps down to low altitudes. The alpine and longjawed galaxias have similar, but more restricted, distributions and are not found on the plains.

There are two species of non-migratory bully. Cran's bully is confined almost exclusively to the North Island. Hanchet (1988) never found Cran's bully in indigenous forest. Upland bully are found in the southern Northern Island and over much of the South Island, where they occupy all types of fresh water.

2.3 Further information

Further information on fish life cycles and habitat is available in McDowall (1990b), Hanchet (1988), and Taylor (1988).

3. ENVIRONMENTAL TOLERANCES

3.1 Water Quality and Tolerance

In most discussions on "water quality", discussion is limited to physical or chemical parameters, e.g., temperature or heavy metal concentrations. However, any complete discussion on water quality requirements for fish must consider fish habitat. The various issues related to water quality cannot be examined in isolation from the available fish habitat. For example, a pesticide spillage or effluent discharge from a factory may cause a significant and sensational fish kill. Yet in the long-term, such an accident may have no effect on fish populations, providing that there is no repetition.

Conversely, the construction of an impassable barrier (e.g., a small culvert with a 10 cm overhanging lip), may kill no fish yet exclude all migratory fish species from the catchment upstream. Similarly, exotic forest plantations or agricultural development alter fish habitat. The conversion of bush to pine forest, or wetland to pasture, may change the relative abundance of fish species, even if all species still occur in the catchment.

In other words, setting water quality parameters by basing them on a set of environmental tolerances is only part of the approach to conserving fish populations.

3.2 Measuring Tolerance

3.2.1 Methods

There are several approaches to the problem of measuring and setting limits to environmental tolerances of fish species. In the first, the lethality of a particular environmental factor is tested against a sample of animals, and the death rate is measured. For example, a number of inanga are placed in a water bath, and the temperature is raised until 50% die. The temperature at which this occurs is called Lethal Temperature 50 (LT50) (Simons 1984, 1986a, 1986b).

A second approach is to examine fish populations at many sites. As many physical variables as feasible are measured, and statistical techniques are used to pick out critical factors controlling distribution and abundance. Environmental tolerances can only be inferred from this approach. A third method attempts to discover the environmental preferences of individual species in the laboratory. The success of any approach depends on the ability to forecast the effects of environmental change.

3.2.2 Lethality Testing

Lethality testing is particular useful for setting limits to discharges of potentially toxic or acutely toxic substances (e.g., arsenic or hydrocarbons). This is the most common approach used to set water quality standards by overseas agencies (US Environmental Protection Agency (USEPA) 1976, Canadian Water Quality Guidelines 1987). Quality standards frequently are expressed both by maxima that cannot be exceeded at any time, and by an average that cannot be exceeded within a 24-hour period. Not all agencies adopt this approach. Wherever possible, tolerances are based on experiments with different animals and plants, particularly invertebrates.

However, this approach has disadvantages. Firstly, it is expensive and time consuming to test individual pollutants and the results are not always clear cut.

Secondly, it is important to distinguish between acute toxicity and the effects of continuous, low-level, or background contamination. For example, continuous leaching of agricultural and domestic sewage has radically altered the ecology of Lake Rotorua. Water quality standards may attempt to deal with acute pollution by setting dilution factors and flushing rates, but low level contamination is difficult to control.

Aquatic organisms may concentrate or accumulate toxic leachate (e.g., mercury in trout). The only method of measuring such long-term environmental degradation is by biological monitoring (Pridmore and Cooper 1985), but there are few current monitoring programmes. Moreover, fish are not necessarily the best means of monitoring community change, as New Zealand species tend to be uncommon, and difficult to capture and maintain in the laboratory.

Thirdly, most effluents are not single compounds, but mixtures with ingredients that may be innocuous singly, but lethal in combination. The interaction between two or more chemicals may either increase or decrease overall toxicity. For example, simultaneous exposure of fathead minnows to parathion and linear-alkyl-benzene-sulfonate doubled the toxicity of parathion to the fish (Murty 1986). In general, the few data available suggest that the long-term, joint effect on fish for mixtures of toxicants commonly found in sewage and industrial effluents, " . . .may be markedly more than additive" (Alabaster and Lloyd 1982). Lastly, continuous exposure to pollutants or stress may increase the susceptibility of fish to disease or predation.

4. PRINCIPAL ENVIRONMENTAL FACTORS

Church *et al.* (1979) reviewed the habitat requirements for fish in New Zealand rivers. They discussed stream flow and fish passage requirements, some aspects of food and habitat, and physiological requirements, and noted that "... not enough information is readily available about the habitat needs of New Zealand fishes ...". Although some progress has been made in the development of techniques and collection of data, I doubt that there ever will be a completely satisfactory means of predicting habitat change for fish.

The abstraction of water for use by agriculture or industry is a frequent cause of modification to fish habitat. Abstraction reduces water depth, discharge, channel width, and variability, and may reduce food production, rearing, or feeding areas. Changes in fish habitat can be predicted to a limited degree by the Instream Flow Incremental Methodology (IFIM). For example, flood control works may increase the suitability of some streams for fish by reducing the frequency of destructive flooding, whereas excessive abstraction may reduce feeding and rearing areas for fish. IFIM and low flows are discussed in papers in McColl (1982).

There is a considerable amount of research effort currently being directed at developing IFIM-type techniques for New Zealand conditions. These are:

- development of models to predict the impact of flow or catchment modifications on brown trout populations (S7050/337);
- development of suitability of use curves for New Zealand benthic invertebrates (S5065/334);
- physical characteristis of the feeding habitat of large brown trout in New Zealand rivers (S7050/344).

Studies to date indicate that the overseas data available for use in the IFIM often are not appropriate for New Zealand rivers and streams.

Abstraction or reduced water flow may lead to subsequent changes in water quality (Biggs 1982). For example, sedimentation may impact indirectly on fish habitat by clogging gravel river bed or by shading plants. Reduced flows also may increase water temperature and decrease dissolved oxygen, both of which have direct effects on fish physiology.

The body temperature of fish closely follows the temperature of the surrounding water. All fish have an optimum temperature range, but their exact response to temperature change depends on species, life stage, and historical water temperatures. For example, eggs and embryoes may be either more or less sensitive to temperature change than adults or fingerlings, and that sensitivity may vary depending on the water temperature at which the animal has been living.

Decreases in dissolved oxygen are closely associated with increased temperature. (N.B., the concentration of oxygen in water is measured in parts per million, whereas air contains twenty parts per hundred - a ten-thousand-fold difference.) Oxygen concentration varies greatly, both between sites and diurnally, particularly in enriched or eutrophic waters. Salmonids and most galaxiid species require more than 6 mg/l (Scott 1982). Only eels and mudfish are likely to tolerate low oxygen for any period, and neither will withstand the low oxygen conditions caused by pollution.

The tolerance of New Zealand fish to common pollutants and their response to habitat degradation is largely unknown. Thus, absolute standards and rules are probably impossible. As an alternative, I have suggested a set of "flags" for the most common, potential degraders for fish species. If a discharge or modification is above a certain limit, DOC managers should consider whether or not to take further action.

These "flags" were derived from existing water quality standards and standard practices within DSIR and regional water authorities. The previous National Water and Soil Conservation Organisation (NWASCO) produced a compilation of the United States Environmental Protection Agency's 1980 ambient water quality criteria (Smith 1986a), and noted that the Water and Soil Conservation Act 1967 requires that "waters shall not ... contain toxic substances to the extent that they are unsafe for consumption by human or farm animals ..." and that "There shall be no destruction of natural aquatic life by reason of a concentration of toxic substances." NWASCO did not recommend standards for New Zealand, but encouraged the use of USEPA standards for " ... initial guidance." Smith (1986b) completed a review of heavy metals in the New Zealand aquatic environment, which is discussed in Section 4.7. As these reports may not be readily available, a table of "limits" from the Canadian Water Quality Guidelines is reproduced as Appendix I.

The following environmental issues (in order of priority) are perceived by water quality and fisheries staff as the most common threats to fish.

4.1 Barriers

Given that 16 of the 26 indigenous fish species are migratory, small, and rather inconspicuous, barriers and culverts may prevent access to over half New Zealand's fish fauna. For fisheries conservation, perhaps the single most beneficial activity that DOC field staff could undertake would be to inspect road bridges and forest culverts for reasonable fish passage. For example, Hicks (1984) found 27 dams and weirs in Taranaki, excluding hydro-electric dams, which impeded fish passage to upstream sections.

In some circumstances, it may be simple and inexpensive to install fish passes over low weirs (Mitchell in prep.). However, such mechanisms need to be maintained after their installation. There is an urgent need to develop guidelines and mechanisms for fish passage.

4.2 Suspended Sediment

Sediment continuously enters streams and rivers, both from natural sources and because of human activity. Agriculture, mining, and forest clearance all cause sediment run off, and sediment is discharged in farm, domestic, and industrial effluents.

Coarse particles soon settle out of suspension onto the stream bed. The rate of precipitation depends on the size of the particle, current, and turbulence. Precipitated sediment may plug the interstices of stony rivers, and reduce interstitial flow, invertebrate production, and fish habitat.

Moderate levels of suspended sediment may be less of a problem than sediment that precipitates onto river beds. But high levels may indirectly affect fish populations by reducing light transmission, and hence periphyton productivity and invertebrate populations.

Suspended sediment concentrations greater than 100 mg/l may have direct deleterious effects on fish (e.g., by clogging the gills), but the effect depends on particle size. For some effluents, 20-40 mg/l may significantly degrade riverine invertebrate fauna, and a reduction in fish biomass may occur at lower concentrations (C.W. Hickey, DSIR Water Quality Centre, pers. comm.). For European fisheries, which comprise both coarse and game fish species, Alabaster and Lloyd (1982) suggested that water containing 25 - 80 mg/l should maintain "good or moderate" fisheries. For salmonid habitats in Alaska, Lloyd (1987) noted that a high level of protection is afforded by levels of up to 25 mg/l, which approximates to drinking water standards.

However, the issue is complex and the effects of even moderate discharges of sediment can not always be predicted. For example, Boubee (1990) found that inanga juveniles avoid high concentrations of silt, but, in most natural situations, silt levels are not high enough to cause avoidance behaviour. Hayes (1989) reported that the effect of a decline in water quality in Lake Waahi on lake populations of fish was not as severe as expected. Apart from lacustrine common smelt, the biomass of fish species increased in lakes with higher suspended sediment concentrations. In Waahi, loss of cover and food for fish (provided by submerged macrophytes) appears to have been compensated for by increased turbidity and an associated increase in biomass of the common prey species, mysid shrimps.

Although the suspended sediment concentration in Lake Waahi (20-40 mg/l) is sufficient to cause a marked decline in water clarity, it is still less than the legislative requirement (100 mg/l) or Alabaster and Lloyd's (1982) suggested maximum for moderate fisheries.

Suspended solids are unlikely to have such a moderate impact on river fisheries. Bluegilled bully, torrentfish, and koaro are all characteristic of stony, boulder rivers, and do not tolerate high levels of deposited silt. Further information is needed on the life cycles and habitat requirements of these species.

Discharges of less than 20 mg/l to lowland rivers that tend to have high natural suspended sediment levels are unlikely to have a detrimental effect, providing that dilution of the receiving water is high. Suspended sediment concentration in rivers varies greatly with discharge. The validity of this "flag" (20 mg/l suspended sediment) depends on the circumstances of discharge and receiving water, and needs to be verified on a case-by-case basis.

Legislative requirements for discharges are under review. The present legislation stipulates that:

(a) discharges should not increase suspended sediment of receiving waters to more than 100 mg/l, and

(b) natural colour and clarity of receiving waters should not be changed to a conspicuous extent.

In practice, much lower concentrations (10-20 mg/l) of suspended sediment may alter clarity and colour. Many water authorities are satisfied with a limit of 20-

30 mg/l suspended sediment in effluent, given reasonable dilution at the point of discharge.

4.3 Organic Effluent and Nutrient Enrichment

Most water right applications are to discharge organic effluent to rivers from dairy sheds or domestic oxidation pond systems (Hickey, DSIR, pers comm.; Kokich, Northland Regional Council, pers. comm.; Becker, Auckland Regional Council, pers. comm.). For example, there are about 7000 dairy sheds in the Waikato area, and Hickey *et al.* (1990) noted poor effluent quality from dairy sheds in comparison with domestic sewage oxidation ponds.

Organic effluents also are discharged from meatworks and dairy factories. Other agricultural activities may discharge nitrogen and phosphorus to aquatic ecosystems from direct run off and leaching (McColl and Hughes 1981, Smith 1989). The collective influence of agricultural activity on water quality and fish habitat is far greater than point source pollution from other industry.

Discharges of organic matter and nutrients have three primary effects on aquatic ecosystems:

i) enriched water promotes microbial, algal, macrophyte, and fungal growth, which in turn increases plant and microbial respiration, and hence biological oxygen demand (BOD). Highly eutrophic water may become deoxygenated at night;

ii) changes in plant and fungal communities radically alter fish habitat, smother some benthic invertebrates, and promote populations of others (Hickey and Rutherford 1986);

iii) ammonia is extremely toxic to fish. The most frequent sources of ammonia are sewage and oxidation ponds, but the ammonia usually is converted rapidly to nitrite and nitrate. Excessive quantities of ammonia may be discharged if oxidation ponds or sewage works are overloaded or under stress. Ammonia also is produced from silage and manure.

NWASCO (1981) recommended that the concentration of dissolved oxygen should exceed 5 mg/l, and the average five-day biochemical oxygen demand at 20°C should not exceed 2-5 mg/l, depending on water classification. These limits usually would prevent deleterious effects to receiving waters. However, dairy factory waste water promotes faster growth of sewage fungus and requires a lower limit (Quinn and Hickey 1987).

Ammonia is more toxic at high pH. European standards are 0.025 mg/l at pH 8.5 (Alabaster and Lloyd 1982). In New Zealand waters, direct toxic effects are unlikely where the ammonia concentration is less than 0.01 mg/l, provided that pH is less than 9.0.

There is little information on the acute or long-term effects of organic discharges on New Zealand fish or benthic invertebrates (Hickey and Rutherford 1986). Swift and stony rivers appear to be more susceptible to change than slow, silty, or muddy rivers. Although organic waste loads have decreased significantly in recent years, there is room for considerable improvement. In particular, Hickey *et al* (1990) considered that " ... dairy shed ponds are generally performing poorly in comparison with ... domestic sewage oxidation ponds...".

4.4 Temperature

Simons (1984, 1986) determined thermal tolerances for eight species of native fish and two species of crustacea. Critical thermal maximum values ranged between 31.8° C and 38.5° C, with thermal tolerance increasing in the following order: smelt, freshwater crayfish, juvenile banded kokopu, freshwater shrimp, inanga, Cran's bully, common bully, shortfinned eel elvers.

Smelt larvae were one of the more sensitive species tested. Fish acclimated to 18° C and 22° C were relatively unaffected by 3.5 days exposure to 26° C. The less sensitive species were more resistant to high temperatures.

However, Town (1982) showed that summer acclimated (22-23° C) freshwater shrimps suffered high mortalities at temperatures above 27.5° C. Winter-acclimated shrimps tolerated 23-24° C, but heavy mortality occurred when temperatures exceeded 25° C.

All eight species tested by Simons, except banded kokopu, tend to occur in lowland areas (Taylor 1988), and, together with giant kokopu, longfinned eel, giant bully, and flounder, can be described as a "warm water" group. Development proposals in lowland areas should be treated with caution if river temperatures are likely to be raised above 25° C.

Koaro, banded and shortjawed kokopu, lamprey, longfinned eel, bluegilled bully, and torrentfish are probably less tolerant of warm water. Inanga will select temperatures of about 20° C (Boubee, MAF Fisheries, pers. comm.). As a result, a lower "flag" is necessary, say 21° C, although there is no clear justification for choosing this limit.

There are three main causes of water temperature increases:

(a) direct heating by industry or power stations, but this is comparatively rare, as New Zealand is less industrialised than other western nations;

(b) removal of overhead vegetation, which can significantly increase summer water temperatures, particularly in small streams. Temperature change in individual rivers can be predicted with reasonable accuracy, if the hydrology is known;

(c) flash flooding across dry river beds during summer, which may raise the water temperature high enough to kill fish (Spooner, Hawkes Bay Acclimatisation Society, pers. comm.).

The criteria and classifications set by the 1967 Water and Soil Conservation Act were superseded by the report of the Water Quality Working Party (NWASCO 1981) and may be modified further by the Resource Management Law Reform Bill. For most water classifications, the Bill proposes that changes of 3°C are permitted, to an upper limit of 25°C; for salmonid spawning, the temperature may not exceed 13°C; for coastal waters, the natural water temperature should not be changed by more than 3°C; the quality of " ... water which is protected for an outstanding special purpose of a scenic, scientific or recreational character (Class S) ..." should not be significantly altered "... in those characteristics which have a direct bearing on the suitability of the water for the specific use or uses designated."

These definitions unfortunately leave plenty of room for argument. For example, does the change in temperature refer to average or maximum temperatures? Also, they may not always be realistic. For example, although the Waikato River rarely exceeds 24°C, small streams in Northland, Bay of Plenty, and Hawkes Bay may reach 30°C (Mosley 1982). In the South Island, temperatures exceeding 24°C are unusual. USEPA and Canadian Water Quality guidelines set both a maximum that cannot be exceeded at any time, and a weekly average that should not be exceeded.

4.5 Agricultural Chemicals

Despite strict rules and regulations, there is a feeling of unease amongst many water quality and fisheries personnel about the potential for agricultural chemicals to appear in water. In horticultural areas, growers use pesticides, fungicides, and herbicides intensively, not always according to instructions. Used correctly, agricultural chemicals may not be detrimental to fish populations (Wilcock and Fox 1987), but incorrect use or widespread use leading to low, persistent, background levels of chemicals may be harmful.

4.6 Acidity and Alkalinity

The natural pH of streams varies geographically according to the geology of a region, and diurnally as a consequence of the respiration of stream animals and plants. There is no specific pH level beyond which toxic effects on fish occur, rather a gradual deterioration at pH values beyond the normal range (Alabaster and Lloyd 1982). A safe range is between 5 and 9 and good fisheries occur between 6.3 and 8.5.

Many forest and swamp streams in New Zealand have naturally low pH (Main *et al.* 1985). Giant kokopu, inanga, koaro, and shortfinned and longfinned eels are all found in waters down to pH 5.9 (Taylor 1988). Other species are more common in neutral waters. The exact tolerance of New Zealand species is unknown.

Most industrial discharges should be close to neutral. In peat areas, acid discharges can follow heavy rain. Acids also are associated with run-off from some mines. Acid rain is, fortunately, not yet a New Zealand problem. Extremely high or low pH is unlikely to be a significant factor limiting fish populations in New Zealand.

4.7 Industrial Chemicals and Heavy Metals

Most of the heavy metals in the New Zealand environment derive from geothermal or natural activity (Smith 1986b). Agriculture (including dairy and meat processing), urban run-off, refuse tips, mines, and industry are other potential sources.

Despite high levels of heavy metals in geothermal areas (leading to high levels of mercury in trout), background concentrations and discharges are low. Heavy metal contamination is not usually a problem in the New Zealand environment (Hickey, DSIR pers. comm). The exceptions would be individual industrial processes using large quantities of heavy metal salts, e.g., timber processing.

The range of possible contaminants is so great that the only feasible approach is to use overseas water quality standards as guidelines for existing and proposed discharges (Appendix I). Where point source pollution from industry is a likely threat, individual discharges should be monitored regularly. There are facilities available at MAF Fisheries Freshwater Fisheries laboratory in Rotorua to test toxic effluent. Staff have tested some pulp and paper effluent for the timber industry, but there are no data on native fish tolerances to heavy metals. Testing individual pollutants is not considered to be a high priority at present.

5. CONCLUSIONS

In general, the quality of New Zealand's fresh water is exceptionally high by world standards (Organisation for Economic and Cultural Development 1980). New Zealand has few industries, is not subject to acid rain, and the standard of urban sewage treatment is relatively high. Point source pollution has been brought progressively under control, and water managers have been able to concentrate on pollution prevention through water right legislation.

Be that as it may, the populations of most native species of fish have declined in parallel with wholesale changes in habitat. Whitebait catches from the Waikato River have declined from about 60 tonnes in the 1930s to less than 16 tonnes in 1985 (Stancliff *et al.* 1988). Deforestation, and urban and agricultural development have reduced the habitat available for native fish. Whilst few species are rare, none are as widespread as in pre-European times (McDowall 1990a).

Freshwater ecosystems are on the receiving end of a large number of human activities. As such, the general health of freshwater fish and invertebrates is an indicator of wider well being. For example, the blooms and excessive growths of macrophytes in Lake Rotorua are murky indicators of eutrophication. The decline in water quality has occurred over many years, as agricultural and urban development has progressed.

This gradual deterioration in water quality and fish habitat is more common and a greater problem than sudden, catastrophic changes such as a fish kill. Fish kills are unusual events which may occur naturally following sudden storms or disease, or because of effluent discharges. Teirney *et al.* (1978) produced a manual to help with the investigation of fish kills. Although some sections of the manual are now out-of-date, and the document is not widely available, it may assist managers to identify the immediate cause of a fish kill.

In the longer term, there is a need for more research on the biology of our native fish. Good management is based on adequate information, and our knowledge of some species is woefully deficient. MAF Fisheries are investigating the temperature and silt tolerances of some species, and also has the facilities to test the effect of specific toxicants.

Given that over half of New Zealand's freshwater fish fauna is migratory, the need for adequate fish passage should be self evident. Further information on movement, swimming speeds, and fish pass design is needed to ensure that migratory species reach suitable habitats.

We are still unable to define adequately the "suitable habitat" for many species. For example, Hanchet (1988) showed the importance of bush catchments to native fish populations. But which features of bush catchments affect the distribution of native fish? Would riparian strips in exotic forests be sufficient to protect native fish communities? If so, how big should they be, and which plant species are most effective?

There are also questions about the responses of fish species to individual pollutants. Some toxicity information is adequately covered by overseas literature (Appendix I), but it is dangerous to rely too heavily on overseas data. Managers should have information available on the effect of the more common pollutants, such as suspended sediment and organic enrichment, on New Zealand species.

Despite the paucity of specific information, we are able to delineate policies and practices that will protect fish communities. Although some of our fish species occur elsewhere in the southern hemisphere, kokopu and galaxias are as unique to New Zealand as kakapo and kiwis. I hope this document provides some means to assist with the conservation of New Zealand's fish fauna.

6. ACKNOWLEDGEMENTS

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APPENDIX I. Canadian water quality guidelines for Freshwater aquatic life.

Parameter	Guideline	Comments
Inorganic parameters		
Aluminium	0.005 mg/l	pH6.5;[Ca2+]4.0 mg/l DOC2.0 mg/l
	0.1 mg/l	pH$\geq$6.5;[Ca2+]$\geq$4.0 mg/l; DOC$\geq$2.0 mg/l
Antimony	ID	
Arsenic	0.05 mg/l	
Beryllium	ID	
Cadmium	0.2 µg/l	Hardness 0-60 mg/l ($CaCO_3$)
	0.8 µg/l	Hardness 60-120 mg/l ($CaCO_3$)
	1.3 µg/l	Hardness 120-180 mg/l ($CaCO_3$)
	1.8 µg/l	Hardness >180 mg/l ($CaCO_3$)
Chlorine (total residual chlorine)	2.0 µg/l	Measured by amperometric or equivalent method
Chromium	0.02 mg/l	To protect fish
	2.0 µg/l	To protect aquatic life, including zooplankton and phytoplankton
Copper	2.0 µg/l	Hardness 0-60 mg/l ($CaCO_3$)
	2.0 µg/l	Hardness 60-120 mg/l ($CaCO_3$)
	3.0 µg/l	Hardness 120-180 mg/l ($CaCO_3$)
	4.0 µg/l	Hardness >180 mg/l ($CaCO_3$)
Cyanide	5.0 µg/l	Free cyanide as CN
Dissolved oxygen	6.0 mg/l	Warm-water biota - early life stages
	5.0 mg/l	- other life stages
	9.5 mg/l	Cold-water biota - early life stages
	6.5 mg/l	- other life stages
Iron	0.3 mg/l	
Lead	1.0 µg/l	Hardness 0-60 mg/l ($CaCO_3$)
	2.0 µg/l	Hardness 60-120 mg/l ($CaCO_3$)
	4.0 µg/l	Hardness 120-180 mg/l ($CaCO_3$)
	7.0 µg/l	Hardness >180 mg/l ($CaCO_3$)
Mercury	0.1 µg/l	
Nickel	25.0 µg/l	Hardness 0-60 mg/l ($CaCO_3$)
	65.0 µg/l	Hardness 60-120 mg/l ($CaCO_3$)
	110.0 µg/l	Hardness 120-180 mg/l ($CaCO_3$)
	150.0 mg/l	Hardness >180 mg/l ($CaCO_3$)

APPENDIX I. (Ctd.)

Parameter	Guideline	Comments
Nitrogen		
Ammonia (total)	2.2 mg/l	pH 6.5; temperature 10oC
	1.37 mg/l	pH 8.0; temperature 10oC
Nitrite	0.06 mg/l	
Nitrate		Concentrations that stimulate prolific weed growth should be avoided
Nitrosamines	ID	
pH	6.5-9.0	
Selenium	1.0 μg/l	
Silver	0.1 μg/l	
Thallium	ID	
Zinc	0.03 mg/l	
Organic parameters		
Acrolein	ID	
Aldrin/dieldrin	4.0 ng/l (dieldrin)	
Benzene	0.3 mg/l	
Chlordane	6.0 ng/l	
Chlorinated benzenes		
Monochlorobenzene	15.0 μg/l	
Dichlorobenzene		
1,2- and 1,3-	2.5 μg/l	
1,4-	4.0 μg/l	
Trichlorobenzene		
1,2,3-	0.9 μg/l	
1,2,4-	0.5 μg/l	
1,3,5-	0.65 μg/l	
Tetrachlorobenzene		
1,2,3,4-	0.10 μg/l	
1,2,3,5-	0.10 μg/l	
1,2,3,5-	0.15 μg/l	
Pentachlorobenzene	0.030 μg/l	
Hexachlorobenzene	0.0065 μg/l	
Chlorinated ethylenes		
Tetrachloroethylene	260 μg/l	
Di- and trichloroethylenes	ID	

APPENDIX I. (Ctd.)

Parameter	Guideline	Comments
Chlorinated phenols		
Monochlorophenols	7 μg/l	
Dichlorophenols	0.2 μg/l	
Trichlorophenols	18 μg/l	
Tetrachlorophenols	1 μg/l	
Pentachlorophenol	0.5 μg/l	
DDT	1 ng/l	
Dinitrotoluenes	ID	
Diphenylhydrazine	ID	
Endosulfan	0.02 μg/l	
Endrin	2.3 ng/l	
Ethylbenzene	0.7 mg/l	
Halogenated ethers	ID	
Heptachlor + Heptachlor epoxide	0.01 μg/l	
Hexachlorobutadiene	0.1 μg/l	
Hexachlorocyclohexane isomers	0.01 μg/l	
Hexachloro-cyclopentadiene	ID	
Phenols (total)	1 μg/l	
Nitrobenzene	ID	
Nitrophenols	ID	
Phenoxy herbicides (2, 4-D)	4.0 μg/l	
Phthalate esters		
DBP	4 μg/l	
DEHP	0.6 μg/l	
Other phthalate esters	0.2 μg/l	
Polychlorinated biphenyls (total)	1 ng/l	

APPENDIX I. (Ctd.)

Parameter	Guideline	Comments
Polycyclic aromatic hydrocarbons	ID	
Toluene	0.3 mg/l	
Toxaphene	8 ng/l	
Physical parameters		
Temperature		Thermal additions should not alter thermal stratification or turnover rates, exceed maximum weekly average temperatures, or exceed maximum short term temperatures.
Total suspended solids		
increase of 10.0 mg/l		Background suspended solids 100.0 mg/l
increase of 10% above background		Background suspended solids >100.0 mg/l

ID = Insufficient data to recommend a guideline.
mg/l = milligram per litre.
μg/l = microgram per litre.
ng/l = nanogram per litre.

APPENDIX II.

Further information on the environmental requirements of New Zealand's native fish fauna is available from:

MAF Fisheries, PO Box 8324, Riccarton, Christchurch (03) 3488-939

*Dr R.M. McDowall	(Manager) Native fish life histories and systematics; whitebait fishery
*E. Graynoth	Salmonid and exotic fish biology; impacts of forestry on stream ecology
I.G. Jowett	Hydraulic modelling of rivers; fish pass design; water temperature modelling
G.A. Eldon	Native fish biology

MAF Fisheries, PO Box 6016, Rotorua (073) 463 730

*N. McCarter	(Scientist-in-Charge) Fish feeding and growth; environmental tolerances
C.P. Mitchell	Fish passes; ecology of native fish
J. Richardson	Salmonid ecology and impact assessment

MAF Fisheries, Waikato Fisheries Consultants, PO Box 445, Hamilton (071) 548-203

*Dr J. Boubee	(Scientist-in-Charge) Impact assessment of thermal discharges; ecology of large rivers

Water Quality Centre, DSIR, PO Box 11115, Hamilton (071) 67-026

*Dr N. Burns	(Scientist-in-Charge).
Dr C. Hickey	Aquatic biochemistry; benthic microbial effects on river oxygen; aquatic ecotoxicity
Dr D. Smith	Water quality standards and monitoring; heavy metal toxicity in aquatic ecosystems; water quality indices; environmental impacts of coastal outfalls

* Contact person

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