43

NIWA

Taihoro Nukurangi

Effects of suspended solids on the feeding ability of five native fish species

D K Rowe
T Deans

NIWA Science and Technology Series No. 43

NIWA Science and Technology Series No. 43

Effects of suspended solids on the feeding ability of five native fish species

D K Rowe
T Deans

NIWA
Hamilton

September 1996

Cataloguing-in-publication

Rowe, D.
Effects of suspended solids on the feeding ability of five native fish species/D.K. Rowe, T. Deans Hamilton, NZ: National Institute of Water and atmospheric Research Ltd., 1996. (NIWA science and technology series ; 43)

ISSN 1173-0382
ISBN 0-478-08390-4

The *NIWA Science and Technology Series* is published by NIWA (the National Institute of Water and Atmospheric Research Ltd.), New Zealand. It supersedes *NIWA Ecosystems Publications* (ISSN 1172-3726; published by NIWA Ecosystems, Hamilton), *New Zealand Freshwater Research Reports* (ISSN 1171-9842; published by NIWA Freshwater, Christchurch) and *Miscellaneous Publications, New Zealand Oceanographic Institute* (ISSN 0510-0054).

Available from:

Publications
NIWA
PO BOX 8602
Christchurch
New Zealand
Ph. 03 348 8987
Fax 03 348 5548

or: Publications
NIWA Ecosystems
PO Box 11-115
Hamilton
New Zealand
Ph. 07 856 7026
Fax 07 856 0151

or: Publications
NIWA Marine
private Bag 14-901
Kilbirnie, Wellington
New Zealand
Ph. 04 386 1189
Fax 04 386 2153

NIWA specialises in meeting information needs for the sustainable development of water and atmospheric resources. It was established on 1 July 1992.

TABLE OF CONTENTS

1. Introduction

Lethal levels of inert suspended solids (SS) have been reported for a number of northern hemisphere fish species (Alabaster & Lloyd 1980, Newcombe & McDonald 1991). Lethal concentrations that cause death within a few days of continuous exposure are generally well over 1000 g m^{-3}, but such high concentrations are rarely encountered in New Zealand lakes and rivers. However, sublethal concentrations of SS can result in reduced feeding and growth, avoidance of affected waters, disruption of homing performance, or migration failure in fish (Alabaster & Lloyd 1980, Newcombe & McDonald 1991, Ryan 1991).

In New Zealand, there are few data on the effects of SS on native fish (Ryan 1991). However there is increasing evidence that sublethal levels of SS affect the upstream migrations of our native fish species. For example, McDowall & Eldon (1980) indicated that juvenile migrant koaro (*Galaxias brevipinnis*), inanga (*Galaxias maculatus*) and banded kokopu (*Galaxias fasciatus*) all avoided highly turbid waters occurring during flood conditions in rivers, but noted that the koaro was more tolerant of turbidity than the other two species. Later, Saxton et al. (1987) indicated that the relative scarcity of juvenile inanga entering the Motu River may have been due to the relatively high turbidity of this river. Similarly, Schicker et al. (1990) found that many juvenile migrant inanga in the Waikato River avoided the left bank just below the Waipa River confluence. Although this avoidance could have been due to differences in water depth, velocity, or water temperature between the left and right banks, the water from the Waipa River was more turbid than that in the Waikato River, and the numbers of inanga migrating dropped markedly when turbidity levels in the Waipa River rose following heavy rain (Schicker et al. 1990).

If upstream migrations of juvenile native fish were to be reduced by high levels of turbidity, then re-population of habitats in river tributaries would also be reduced and diadromous fish species could decline in affected catchments. Evidence for such a decline was provided by Rowe et al. (1989). They documented the absence of juvenile diadromous fish (eels, bullies, galaxiids) from pristine tributary streams above a major slip in the Retaruke River, which is a major tributary of the Whanganui River. Physical habitat and invertebrate densities in the tributary streams were excellent, but the only fish present were large (>1 m), hence relatively old, eels and riverine species (upland bullies) that don't have an obligatory marine phase in their life cycle. As the juveniles of the diadromous fish species were all present in other tributaries of the Whanganui River, some factor had clearly restricted their migrations into the Retaruke River. Rowe et al. (1989) indicated that the only factor that satisfactorily explained their absence in this river was solids pollution. The river substrate below the slip was heavily contaminated by silt and the water below the slip was milky, indicating that relatively high levels of suspended solids had affected the river for several years after the slip occurred.

Sublethal levels of suspended solids in the lower reaches of rivers may therefore affect upstream migrations of native fish, and reduce native fish densities, biodiversity, ecosystem integrity and ecosystem functioning in the first and second order tributaries of rivers. The concentrations of suspended solids that affect migratory native fish, and the species affected, need to be determined if criteria for the protection of fish migrations in rivers are to be developed.

Both settleable solids and suspended solids can affect fish populations in a number of ways at different stages in their life cycle (Fig. 1). Two of these processes are currently being investigated by NIWA with funding provided by the Foundation for Reasearch Science and Technology (FRST). The avoidance responses of five migratory species to sublethal concentrations of suspended solids have been investigated (Boubee et. al 1995). Now, the effects of elevated SS on fish feeding ability are being studied. In this report, we summarize results obtained to date on the effects of sublethal suspended solids concentrations on the feeding ability of five native fish species. Our aim was to use laboratory studies to determine the species whose feeding ability was most affected by increased concentrations of suspended solids. As salmonids are often more sensitive to environmental changes than other fish species, it is important to determine whether migrant native fish are more or less sensitive than trout. Accordingly, we also present data obtained from a different study on the feeding ability of juvenile rainbow trout.

In the wild, factors such as seasonal and daily changes in water flow, water quality, light levels, predation pressure, and in prey abundance can all affect the responses of fish to increased levels of suspended solids. Thus, laboratory derived results obtained under controlled conditions are not always directly applicable to field situations. A field test is therefore needed to determine the implications of the laboratory results for natural populations. This latter study was funded by Carter Holt Harvey Forests Ltd. in support of the FRST funded studies of fish feeding ability.

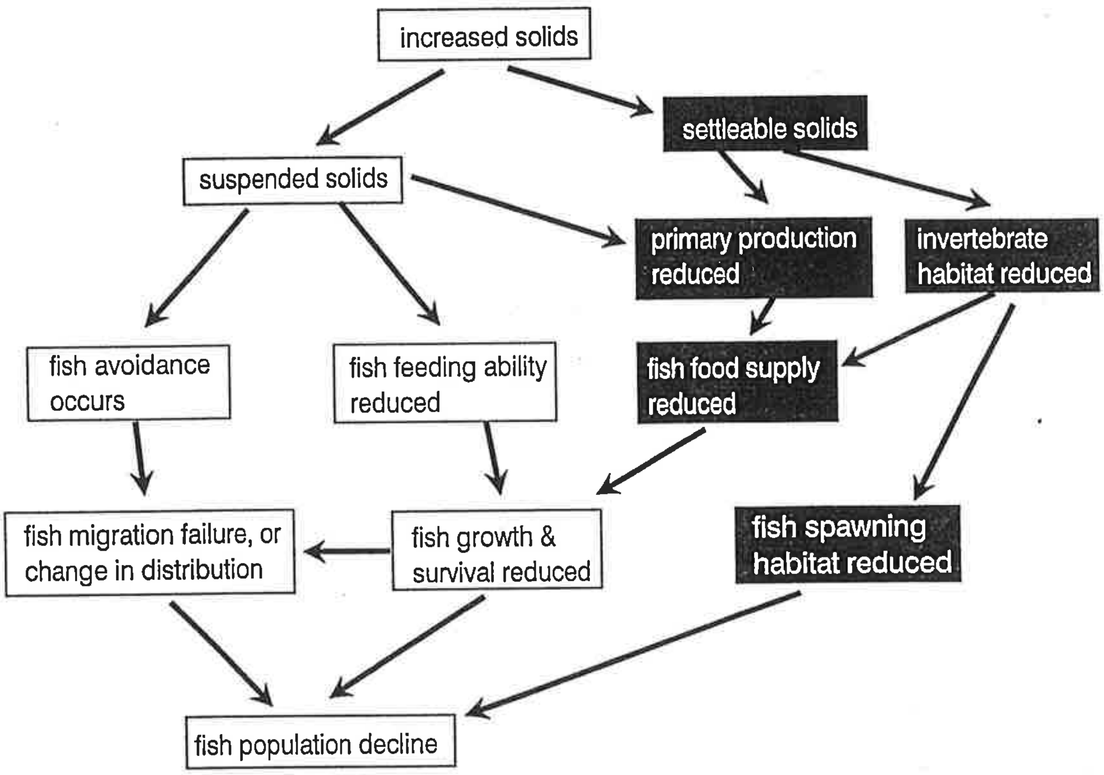

Fig. 1 Ecosystem model for effects of solid pollution on fish

2. Effects of SS concentrations on fish feeding ability

2.1 Introduction

Most fish are assumed to be visual feeders so that any reduction in water clarity due to elevated SS levels can be expected to reduce their ability to detect and capture prey. Many studies have measured the reduction in "reactive distance" between a fish and its prey caused by the reduced light levels associated with elevated SS (Vinyard & O'Brien 1976, Berg & Northcote 1985, Barrett 1992, Hecht & van der Lingen 1992, Gregory & Northcote 1993). However, in the wild, a reduction in reactive distance may be compensated for by a change in feeding behaviour or by longer feeding times to ensure that the daily food intake required to sustain growth is maintained. If so, there would be little measurable effect on the fish populations.

The effects of increased SS levels on fish feeding will only be biologically significant when the energetic cost of obtaining food is so high that growth is reduced. However, there are comparatively few studies on the effects of elevated SS levels on fish growth. This is because such studies are logistically difficult, require many replicates, involve extensive hatchery or pond facilities, and long periods of time to complete.

A compromise between "reactive distance" and "growth" studies is required and is provided by studies which measure the effects of increased suspended solids concentrations on the feeding rates of fish under controlled laboratory conditions. A significant reduction in feeding rate can be reasonably expected to reduce growth rate. We therefore used feeding rate experiments to measure the effect of various SS concentrations on fish feeding ability, and hence to determine the species that were most susceptible to increases in SS.

2.2 Methods

2.2.1 Test fish and acclimation procedure

Juvenile migrant fish were obtained from the mouths of several North Island rivers during the spring/summer migration season. *Galaxias maculatus* and *Galaxias fasciatus* were collected from the Waitetuna River (Raglan Harbour) between October and December, *G. brevipinnis* were obtained from the Waipehi Stream mouth (Lake Taupo) in November, *Gobiomorphus cotidianus* were obtained from the Waikato River in December, and *Gobiomorphus huttoni* from the Tairua River (Coromandel) in February. Fish were transported to the laboratory and acclimatized for 3-5 days in a constant temperature room where temperatures were maintained at 15° C and the diel light regime was 12L:12D. We added 10% seawater to the tank water to overcome problems due to physiological stress and to suppress disease. The fish were fed on *Daphnia* once to twice a day, with one of these diurnal feeding opportunities being provided close to midday.

Juvenile rainbow trout *Oncorhynchus mykiss* (FL 40-70 mm) were obtained from the Ngongotaha Stream near Rotorua and acclimated in the same way as native fish.

2.2.2 *Test apparatus*

Feeding trials were carried out in an array of 8 polypropylene test tanks in the constant temperature room used to acclimatise the fish. Each test tank was 32 cm wide, by 42 cm long, by 21 cm deep, with a 21 l capacity. The sides were an opaque white colour, and we provided a brown coloured bottom designed to mimick the appearance of the sand/gravel substrate common in the lower regions of rivers. Light was provided by a bank of overhead fluorescent lights providing 10.2-14.9 $\mu E\ m^{-2}\ s^{-1}$ at the water surface. Water depth in the tanks was close to 14 cm and light levels 5 cm from the bottom ranged from 2.1-4.1 $\mu E\ m^{-2}\ s^{-1}$. (This range is lower than fish would experience below water on bright sunlit days in rivers, but above levels encountered on a heavily clouded, overcast day).

2.2.3 *Protocol*

Ten fish were placed in each of the eight test tanks 24 hours prior to testing, and were not fed during this period. A measured volume of stock solution, containing a high concentration of suspended solids (approximately 1000 NTU), was added to all but one experimental tank. This tank acted as a control. The volume of stock solution added to each tank was calculated to create turbidity levels of 10, 20, 40, 80, 160, 320, 640 NTU respectively. A corresponding volume of water was removed from each tank to maintain the same water depth in each. The concentration of SS in each tank was maintained by airstone bubblers which kept the suspended solids in solution and provided aeration for the fish. Airflow to each tank was regulated to ensure a low level of near uniform bubbling. NTU levels in all tanks were measured after addition and mixing of the SS stock solution, as well as approximately 3 hours later, after completion of the feeding test. There was little change with time at the low concentrations (i.e. 10-80 NTU), but concentrations at higher levels (160-640 NTU) were generally lower after 3 hours. Differences were minimal (less than 5%) except at the 640 NTU level where the decline was often as great as 10%. The test fish were acclimated to the respective turbidity levels for 2 hours before the feeding test was started.

Although *Daphnia* is not a natural prey for the test fish, it was considered the most appropriate and practicable test species. Migrant fish are likely to feed on zooplankton while at sea and the limited data available on their diet in rivers indicate that they feed throughout the water column, on whatever invertebrate foods are present (McDowall & Eldon 1980). We found that within 1-2 days of capture, all fish readily fed on *Daphnia* in the acclimation tanks found that within 1-2 days of capture, all fish readily fed on *Daphnia* in the acclimation tanks and it proved to be a good species for determining feeding rates. Other potential test prey, such as meal worms, were too macerated to be individually identified in the guts after ingestion. The mouth gape of the test fish was close to 4 mm, and they could feed on the largest *Daphnia* (2 mm diameter) available. However, we selected *Daphnia* for the feeding tests with a maximum body dimension of 0.25-0.5 mm as these were more readily available and, being harder to see than larger specimens, would provide a better test of the effects of turbidity on feeding ability. Close to 300 *Daphnia* were counted into fine meshed holding containers which were placed in the respective test tanks. These *Daphnia* were allowed to acclimatise to the SS levels in the test tanks for approximately 1 hour, after which the test was started by releasing the *Daphnia* into the test tank. They were mixed into the water column to achieve uniform distribution and hence equal exposure to predation by all fish. The fish were allowed to feed undisturbed on the *Daphnia* for 30 minutes after which the fish were netted out of each tank and humanely killed by freezing. Feeding at the end of 30 minutes stopped when staff entered the test room. The presence of staff in the test room disturbed the fish, resulting in a change from feeding behaviour to hiding and escape behaviour. All fish were netted out of the tanks within 2 minutes.

The length of each fish was measured, the alimentary canal dissected out, and the gut contents carefully examined under a binocular microscope. *Daphnia* were present mainly in the stomach, however, some were found in the oesophagus and buccal cavity in some fish. The number of *Daphnia* consumed was therefore determined by counting all the *Daphnia* in the alimentary tract, including the buccal cavity and oesophagus, but excluding the hind gut. The mean number of *Daphnia* consumed was calculated for each SS concentration to provide a measure of feeding rate.

The feeding ability of rainbow trout in different suspended solids concentrations was also tested. Benthic prey species (chironomid larvae and *Deleatidium*), were used as these species are their main prey in streams.

2.2.4 Tests of assumptions

The measurement of feeding rates as described above makes several assumptions. Firstly, elevated SS levels may cause physiological stress in fish (Redding et al. 1987, Servizi & Martens 1992) which could reduce appetite and hence feeding rate. Therefore, to determine whether the highest concentration of SS could suppress fish appetite, we exposed a group of 10 hungry fish, of each species, to the highest SS concentration used (i.e. 640 NTU) for four hours. These fish were then placed in a clear-water tank containing 300 *Daphnia* and allowed to feed for 30 minutes. After this, the fish were sacrificed and their gut contents examined. These fish all contained abundant *Daphnia* (20-50 per fish), so we concluded that the highest level of SS was not influencing fish feeding through SS induced changes in either health (e.g. gill damage), or other physiological stress effects, either of which could reduce appetite.

Secondly, it is assumed that the increase in SS concentration does not affect prey behaviour in such a way that they are more or less susceptible to capture. To determine the effects of high SS on *Daphnia* distribution and mortality in the test tanks we placed 300 *Daphnia* in a clear tank and another 300 in a tank where SS concentrations produced a turbidity level of 640 NTU. After 15 minutes, the live *Daphnia* in the top 10 cm and bottom 10 cm of the water column in each tank were netted out with fine meshed nets. The depth distribution of *Daphnia* in each tank was then compared to determine whether elevated SS could influence their vertical distribution and so affect the availability of the *Daphnia* to the test fish. In addition, the number of dead *Daphnia* was determined in each tank to determine whether exposure to the highest SS level increased the mortality rates of the *Daphnia.* There was no difference in the depth distribution or mortality rate of *Daphnia* between the turbid and clear tanks.

Thirdly, the assumption that fish rely on vision for feeding, such that a reduction in feeding rate at high SS levels is due to the effects of turbidity on fish vision was tested. We determined whether the migrant juveniles of each species could feed in complete darkness. This test was designed to determine whether they could use non-visual senses, such as lateral line, proprioceptive, olfactory or gustatory sensory systems to locate and capture prey. Fish which had been acclimated to feed on *Daphnia,* and starved for the previous 24 hours, were placed in two tanks in complete darkness. About 300 *Daphnia* were then added to one of these tanks and none to the control tank. After 20 minutes the fish were removed from both tanks and their gut contents examined. The number of *Daphnia* in each fish was determined and the percentage of fish that were feeding plotted against the mean feeding rate. The controls for this experiment were 10 starved fish in a tank without food, and 10 fish in a tank with light and 300 *Daphnia.*

2.3 Results

Migrant inanga were not able to feed in the absence of light (Fig. 2) and therefore, during this stage in their development, require vision for feeding. A few koaro (30%) could feed in the absence of light, but the mean feeding rate was low (4.5 prey/fish) compared with that for control fish (31 prey/fish). This is consistent with a few koaro encountering prey at random and being able to capture them using proprioceptive sensory systems. Alternatively, a few fish may have developed a rudimentary lateral-line capability at this stage of their development.

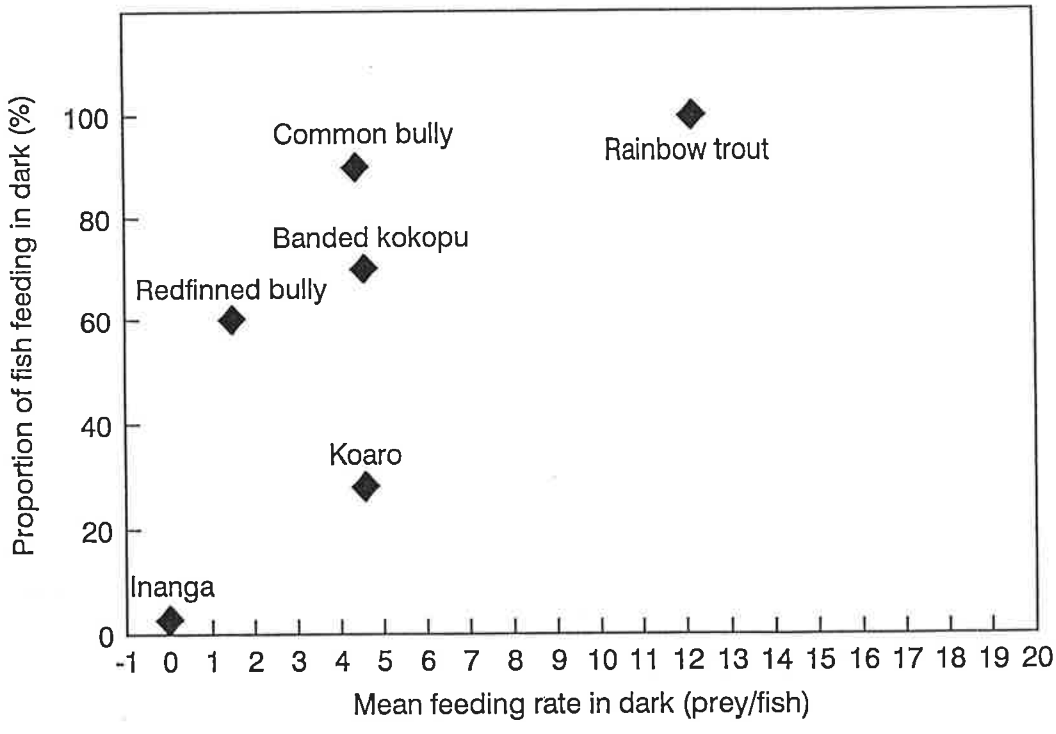

Fig. 2 Differences in the ability of juvenile fish to feed in the dark.

Most (>60%) of the two bully species and of the banded kokopu were able to feed in the absence of light indicating that they can use lateral line or proprioceptive sensory systems to locate and capture prey. However, the mean number of prey consumed was low, being less than 25% of that for control fish feeding in light. This indicates that while these fish have a rudimentary capability to feed in the absence of light (i.e. using non-visual sensory systems) vision is required if these fish are to feed efficiently.

All juvenile rainbow trout were able to feed on chironomid larvae in the absence of light and their mean feeding rate in the dark (12 prey/fish) was as high as in the light (11prey/fish). They therefore have a well developed ability to use non-visual systems to locate such prey. As they do not require vision for prey detection their feeding ability is unlikely to be greatly affected by turbidity.

Mean feeding rates and standard errors for each species at each NTU level are shown in Fig.3.

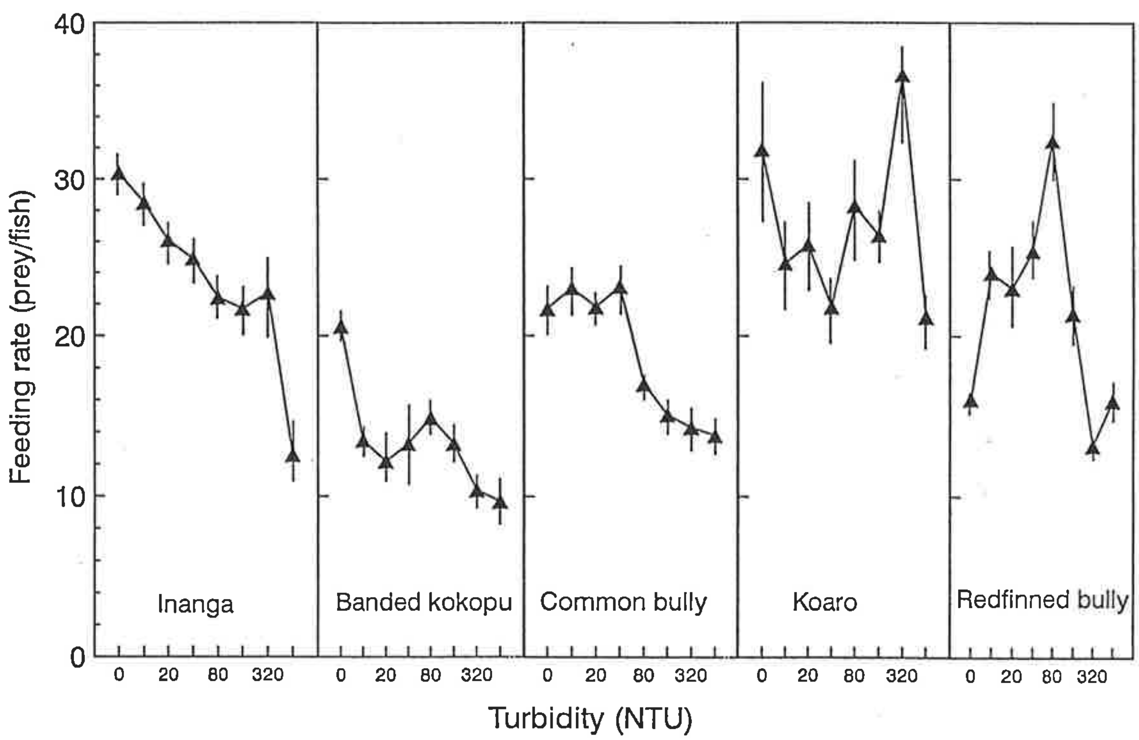

Fig 3. Effect of turbidity levels on feeding rates of five migratory fish species.

Although the differences in mean feeding rate between given NTU levels maybe statistically significant, we do not regard such differences in values as important as the overall trend in feeding rate with increasing NTU levels. The reason for this is that the number of prey consumed by an individual fish can be expected to be influenced by a number of factors.

These include fish size, its previous feeding history, parasite loading, the effects of disease, and stress. All of these can influence fish appetite and hence the number of prey consumed in a feeding bout. In addition, the presence of size-related or behaviourally mediated dominance hierarchies can result in changes in both individual fish appetite as well as in access to food. Consequently, we have taken the trends in feeding rate with increasing NTU levels, rather than the changes in values for mean feeding rate between NTU levels, as an indication of the effects of turbidity on fish feeding ability.

In general, the mean feeding rate for banded kokopu and inanga declined as NTU levels increased (Fig. 3). In contrast, the feeding rate for the common bully was not affected by turbidities up to 40 NTU, but then declined steadily as turbidity levels increased above 40 NTU. Feeding rate for the koaro varied greatly between the various NTU levels and no clear trend was apparent, however, the feeding rate at 320 NTU was as high as that at 0 NTU. The feeding rate for the redfinned bully initially increased as NTU levels rose to 80 NTU, then declined as NTU levels increased to 640 NTU.

Not unexpectedly, the feeding rate of juvenile trout was not reduced as turbidity levels increased (Fig. 4).

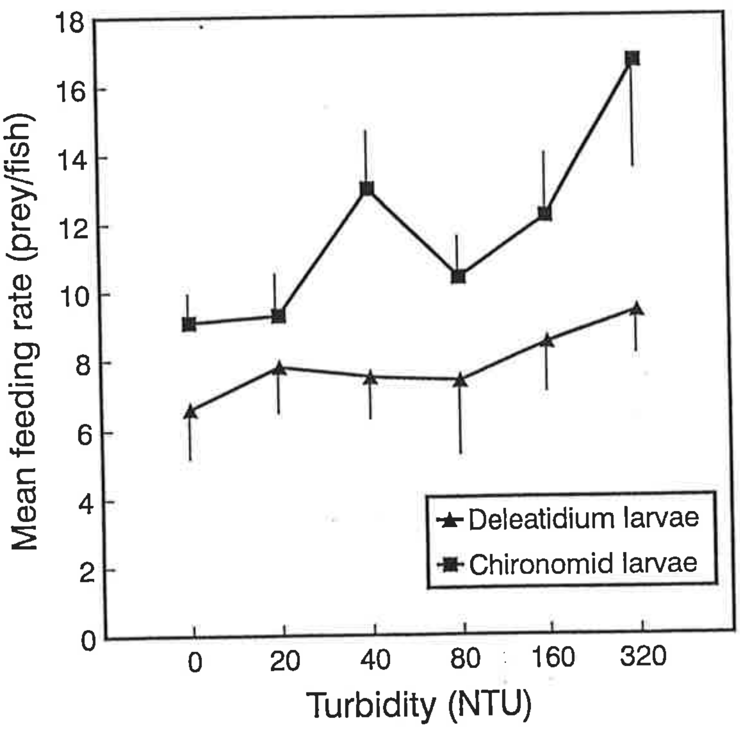

Fig 4 Effect of turbidity on the feeding rate of juvenile trout

However, whereas the ability of trout to locate prey was not affected by increased concentrations of SS, the ability to select large-sized prey was. In clear water (0 NTU) juvenile trout exhibited positive selection for the largest prey and negative selection for the smallest prey (Fig. 5a & 5b).

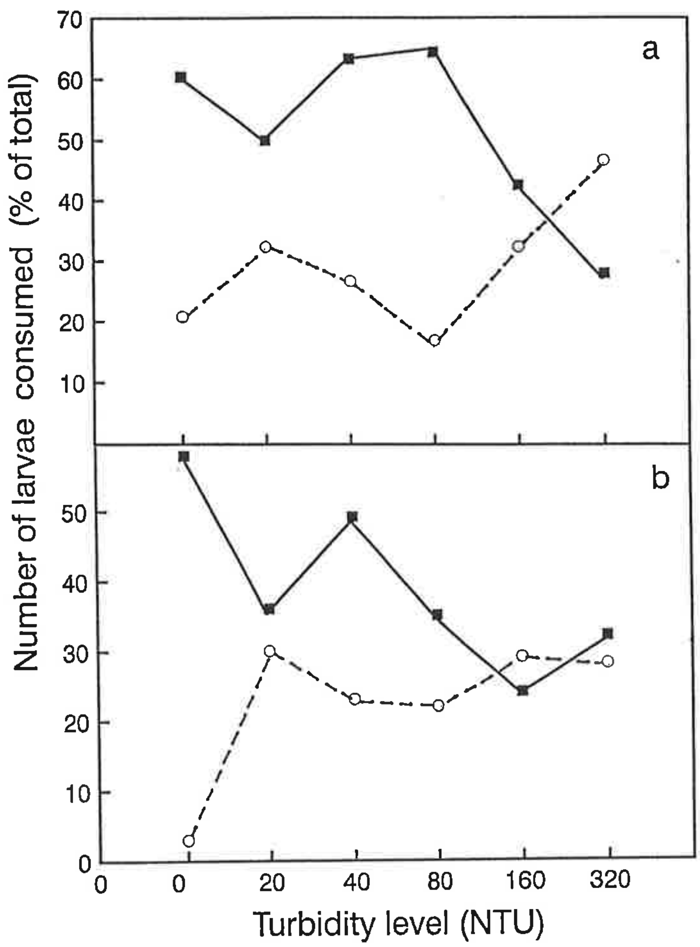

Fig. 5 Effects of turbidity on size selectivity by trout on (a) *Deleatidum* larvae and (b) *Chironomid* larvae (solid line-large larvae, dashed line-small larvae).

Such size selectivity was apparent at SS levels up to 80 NTU, but there was no selectivity when SS levels exceeded 160 NTU (Fig. 5a & 5b). Thus, while high levels of SS did not affect prey detection and location, the ability of trout to discriminate between different sizes of prey was clearly affected by SS levels of 160 NTU or more.

2.4 Discussion

The downward trend in feeding rate with increasing NTU levels for both inanga and banded kokopu indicates that turbidity levels as low as 10-20 NTU may affect the feeding ability of these species. In comparison, the ability of the common bully to feed as well at 40 NTU as at 0 NTU indicates that it is less sensitive to the effects of turbidity than either inanga or banded kokopu juveniles. Similarly, optimal feeding at moderate levels of turbidity for the redfinned bully indicates that it is also less sensitive to turbidity than inanga and banded kokopu. Such optimal feeding at moderate NTU levels has been recorded for other fish species (Gregory & Northcote 1993) and interpreted as a predator avoidance effect.

The variability in mean feeding rates for koaro was much higher than for the other species and an examination of the raw data indicated that whereas some fish had fed heavily (between 55-130 prey/fish), others had fed minimally (0-5 prey/fish). Thus high individual variability is likely to have affected the results for this species and the tests will need to be repeated. Nonetheless, the high feeding rate at 320 NTU indicates that some koaro can feed efficiently at such high levels of turbidity.

Thus, of the species tested so far, inanga and particularly banded kokopu appear to be the most sensitive to the effects of turbidity on feeding and appear to be affected by turbidity levels as low as 20 NTU. More tests will be carried out to confirm this and to determine any differences between these two species. As the banded kokopu has been shown to avoid lower SS concentrations than the other species in choice chamber testing (Boubee et al. 1995), its avoidance response may be due to its inability to feed efficiently in turbid waters.

The results on trout indicate that juveniles can be expected to use visual as well as non-visual senses to detect and capture prey. Visual cues are probably used primarily in clear water, whereas pressure waves produced by prey movements can be expected to be detected by the lateral line system and used for prey location and capture at night, or in highly turbid waters. However, as the ability to discriminate between different sized prey was lost at high levels of suspended solids, it appears that visual cues are required for determining the relative size of prey. The effect of increased turbidity on size selectivity was not investigated for the migrant native fish, but the same principle could apply to fish species that exhibit size selective predation and rely on vision for this.

3. Field test of fish feeding results

3.1 Introduction

The laboratory results indicated that the feeding rate of banded kokopu and inanga declined with relatively small increases in SS levels. Thus these species are comparatively sensitive to SS and could be reduced in turbid rivers compared with clear ones. In contrast, the koaro, appeared to be the least affected. To test the implications of these laboratory based findings for fish in the wild we hypothesized that the species that are most sensitive to high SS levels would be less abundant in turbid rivers compared with clear ones. To provide a valid comparison we selected rivers that were either turbid or clear during the fish migration season as this is the time when migrant fish would be affected by elevated SS levels, and when upstream migrations to adult habitats could be reduced by high levels of SS in river water. Our hypothesis was that banded kokopu would be less common in turbid rivers compared with clear ones and that koaro would be comparatively unaffected.

3.2 Method

3.2.1 River selection

Laboratory tests indicated that banded kokopu would avoid SS levels over 20 NTU (Boubee et al. 1995) and that the feeding ability of both banded kokopu and inanga was reduced at SS levels exceeding 20 NTU. We therefore chose 20 NTU (approximately 120 mgl^{-1} SS) as the threshold level for effects of SS on migratory fish. However, as the severity of SS impacts on fish in the wild depends on the duration of unacceptable SS levels (Newcombe & McDonald 1991) we also needed to rank rivers in terms of the duration of time for which SS levels exceeded 120 mgl^{-1}.

To accomplish this the SS data available on New Zealand rivers in the NIWA Water Resources Archive was examined by Dr M. Hicks and J. Hill (NIWA Christchurch). Measurements of suspended solids concentrations collected from New Zealand rivers were collated and related to the corresponding flow data in a relational database. A "best fit" mathematical relationship between flow rate and SS level was then determined. For rivers where this relationship was reliable, the more extensive flow data was used to generate a temporal record of changes in SS levels. Frequency distributions for SS concentrations were then constructed for each river from the generated SS data and the percent of time when SS levels in the river exceeded 120 mgl^{-1} during the August-December period (main migration period) calculated. The rivers were then ranked on the basis of the percent of time for which SS levels during August-December exceeded 120 mgl^{-1}.

Only rivers where SS levels were measured in the main stem close to the river mouth were selected for comparison. If SS concentrations were determined at a river site above one or more major tributary streams, we could not be sure that tributary water would not dilute the SS levels in the main stem and hence reduce SS concentrations at the river mouth. So, rivers where SS levels near the river mouth could have been lower than at the sampling site were not included in this analysis.

A frequency distribution was prepared showing the number of rivers in each 10 percent time band for which concentrations of SS exceeded 120 mgl^{-1} during the fish migration season.

3.2.2. Fisheries data analysis

Nine species of diadromous fish have been recorded from, or can be expected to occur, in the turbid and clear North Island rivers selected for comparison. The data on these native fish for each river were obtained from the New Zealand Freshwater Fish Database. This database contains records of fish catches at sites in New Zealand rivers and streams sampled over the past 30 years.

Because of the variability in sampling methods between sites, we restricted our analysis to presence/absence data only. However, even presence/absence data can be expected to contain some bias. For example, some records are now over 20 years old, and changes in fish faunas may have occurred in some rivers since that time. Bias may also occur because electric fishing, the main form of sampling, is often carried out at sites which are accessible by road or 4WD vehicle. As turbid rivers are generally associated with more developed catchments allowing road access to the upper reaches, more sites may have been accessed in the upper regions of some of the turbid rivers compared with the clear ones. If so, such sampling differences between rivers could bias results as fish species distributions vary with altitude (McDowall 1993).

Effects of river-specific sampling biases were minimised by ensuring that the sampling sites in each river were not concentrated in upper or lower reaches. Rivers where there were too few sampling sites or where coverage was inadequate were excluded from the analysis. To further minimise any river specific biases we compared the mean percent site occurrence for each of the nine diadromous fish species between as many turbid and clear rivers as possible.

3.3 Results

The frequency distribution for the percent of time in which SS concentrations exceeded 120 mgl^{-1}, during the fish migration season, was heavily skewed (Fig. 6).

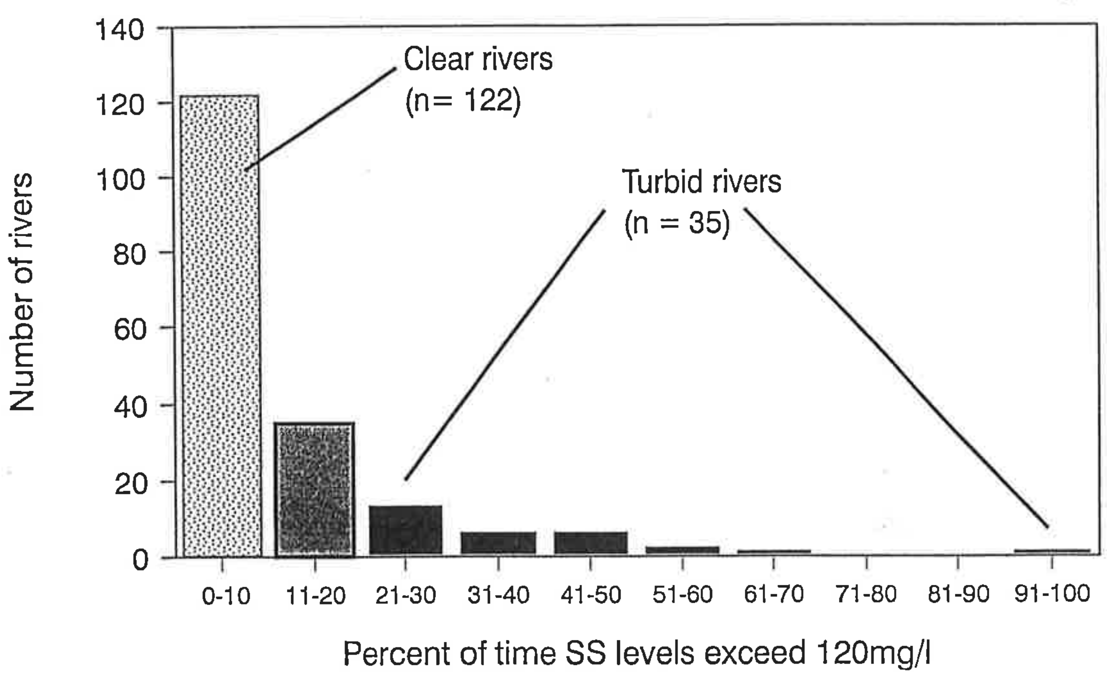

Fig. 6 Frequency distribution for percent of time, within the fish migration season (Aug-Dec), during which SS levels at 192 river sites exceed 120 mg/l.

Concentrations of SS exceeded 120 mgl^{-1} for less than 10% of the time in 122 sites and the rivers where such sites occurred near the mouth can be regarded as relatively clear rivers. An arbitrary cutoff point was required to determine relatively turbid sites. As only 5 sites had SS levels of 120 mgl^{-1} for more than 50% of the time, this point was set at 20%. Thus 35 sites were deemed to be relatively turbid as SS levels exceeded 120 mgl^{-1} for more than 20% of the time. More than 20% of these 35 sites were in inland tributaries of other SI rivers (e.g Hooker, Shotover, Arrow, Lindis, Kawarau Rivers, etc.) and these rivers were not suitable for determining the effects of elevated SS levels on migrant native fish. Other sites occurred upstream of lower ones in the same river catchment. However, 11 of the relatively turbid sites occurred near the mouths of North Island rivers. These rivers therefore formed a comparable group of rivers which all experienced relatively high turbidities near the river mouth during the fish migration season.

There was insufficient or inadequate fisheries data for 3 of these 11 relatively turbid rivers and for 6 of the 14 clearest, North Island rivers selected as a control group. Thus the comparison of fish occurrence in turbid and clear rivers was limited to 8 turbid rivers and 8 clear ones in the North Island.

Torrentfish, smelt, inanga, shortfinned eels, banded kokopu and redfinned bullies were all less prevalent in turbid rivers compared with clear ones (Fig. 7).

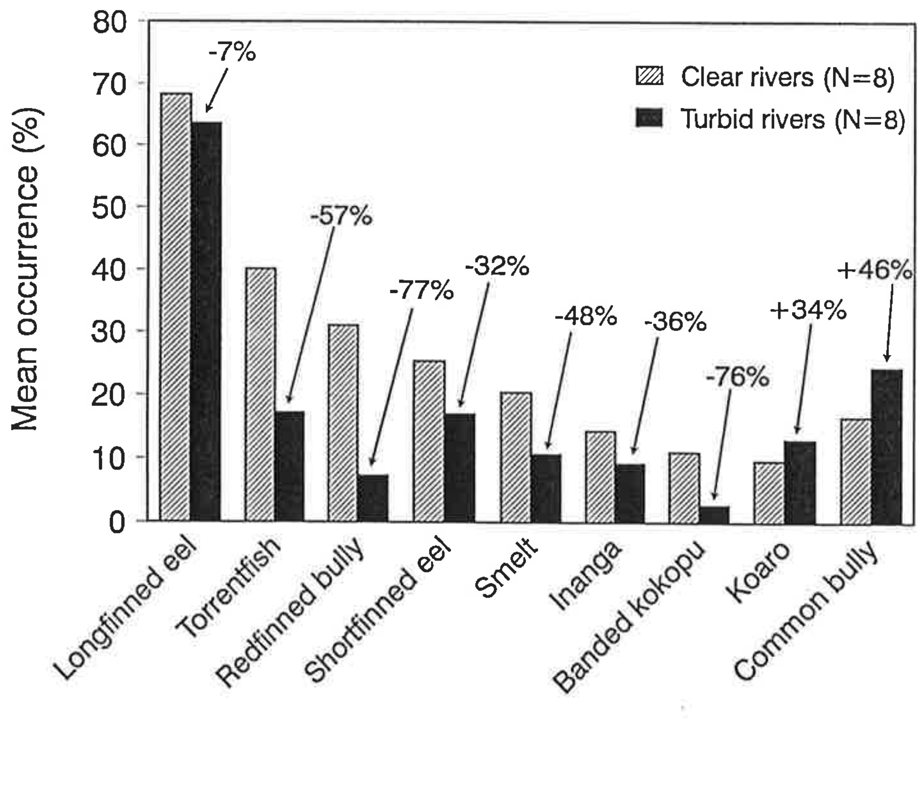

Fig 7. Percent change in the occurrence of nine diadromous fish species between clear and turbid rivers.

In particular, the occurrence of banded kokopu and redfinned bullies was more than 75% lower in turbid rivers than in clear ones. There was little difference in the mean occurrence of longfinned eels between the turbid and clear rivers, and the koaro and common bully were both more common in turbid than in clear rivers.

3.4 Discussion

These differences in species occurrence between turbid and clear rivers are in general agreement with the results of other field studies that have examined the factors affecting native fish in rivers. For example, Minns (1990) determined associations between the presence/absence of native fish species in New Zealand rivers and a range of environmental factors, including different types of land use. He found that both banded kokopu and redfinned bullies were negatively associated with catchments containing high production pasture. Similarly, Hanchet (1990) and Rowe et al. (In prep) found that densities of banded kokopu and redfinned bullies were generally lower in pasture streams than in forested ones. Pasture streams are often characterised by high levels of turbidity (Quinn et al. 1994).

In contrast to banded kokopu and redfinned bullies, koaro and common bullies were more common in turbid rivers than in clear ones. McDowall & Eldon (1980) indicated that koaro were more abundant than other whitebait species in the snow fed rivers of the West Coast, where glacial flour colours the water during snowmelt in spring. Koaro were also abundant in the Motu River in the North Island (Rowe et al. 1981) which is prone to slips from heavy rainfall and which is characterised by a relatively high level of SS (Adams 1979). Similarly, the common bully thrives in waters which are relatively turbid (Hayes et al. 1992). Thus, these two species are comparatively insensitive to increased levels of SS.

The results from these field studies support the results of our analysis of fish occurrence in clear and turbid rivers and indicate that whereas banded kokopu is reduced in turbid rivers, the koaro is not. Thus the field data corroborate the laboratory findings, and indicate that increased levels of turbidity may well affect native fish in rivers through effects on juvenile migrant fish. The field data also indicated that other native fish species, whose feeding rates were affected at higher SS levels than for banded kokopu, were reduced in turbid rivers. Thus concentrations of SS as low as 120 mgl^{-1}, occurring for as little as 20% of the time during the fish migration season, may impact on native fish other than banded kokopu.

Comparisons between the field and laboratory results also show that native fish species reactions to SS are not straightforward and due simply to avoidance or reduced feeding. Whereas the laboratory and field results are in accordance and indicate that this may be so for banded kokopu, the feeding rate of migrant redfinned bullies was not reduced by elevated SS levels in laboratory tests. Nevertheless, adult redfinned bullies were less common in turbid rivers. Thus processes other than the effects of SS on feeding (e.g. effects of settled solids on spawning success) could influence this species occurrence in rivers.

4. Summary and implications for fish conservation

We have presented laboratory data showing that the feeding rate of migrant juveniles of some native fish species can be reduced by increased levels of SS. In particular, the feeding rate of banded kokopu and inanga declined at SS levels as low as 10-20 NTU, and these species are more affected by SS than others, including trout.

The field data on fish occurrence indicated that most of the native fish species whose feeding rates were reduced by elevated SS levels were less common in rivers where turbidity levels over 20 NTU occurred for more than 20% of the time during the fish migration season. Thus, the field data are in accordance with the main laboratory findings and show that relatively low levels of SS in rivers could be expected to influence the distribution and abundance of native fish, through effects on migrants entering rivers from the sea.

The implications of these findings for fish conservation are important. River mouths are the gateways to river catchments and are critical choke-points for the annual re-colonisation of tributary streams by diadromous native fish. Fish are near the top of food chains in aquatic ecosystems so changes in their abundance and distribution in tributary streams can be expected to affect the integrity of the aquatic ecosystems in these streams. As increased levels of SS now characterize the lower reaches of many New Zealand rivers, fish migrations from the sea into such rivers may be reduced and the effects of land use changes on fish habitat may be compounded by reduced recruitment of juveniles to tributaries above the lower reaches of affected rivers. Thus increased loading of SS in rivers may affect aquatic ecosystems in river tributaries as well as fisheries.

This possibility emphasises the need to establish SS criteria to protect fish migrations. Further research, funded by both FRST and Carter Holt Harvey Forests Ltd. is now being undertaken to help establish and underpin such criteria.

Acknowledgments

We thank Murray Hicks and Jane Hill for the analysis of SS concentrations in New Zealand rivers which enabled the selection of turbid and clear rivers. We also thank Ian Johnstone of Electricorp, Gary Pyle from the Ministry of the Environment and Marcus Simmons from the Department of Conservation for their encouragement to prepare this report. Rhys Barrier, Dave West, David Spiers and Jacques Boubee all helped with various aspects of the practical work and Jody Richardson provided valuable comments on an earlier draft of this report.

References

Adams, J. 1979. Sediment loads of North Island rivers, New Zealand- a reconaissance. *New Zealand Journal of Hydrology 18*: 36-48.

Alabaster, J.S.; Lloyd, R. 1980. Finely divided solids. pp 1-20. *In* Alabaster, J.S. & Lloyd, R. *ed.* Water Quality Criteria for Freshwater Fish. Butterworth, London.

Barrett, J. C. 1992. Turbidity induced changes in reactive distance of rainbow trout. *Transactions of the American Fisheries Society 121*: 437-443.

Berg, L.; Northcote, T.G. 1985. Changes in territoriality, gill flaring and feeding behaviour in juvenile coho salmon (*Oncorhynchus kisutch*) following short term pulses of suspended sediment. *Canadian Journal of Fisheries and Aquatic Sciences 42*: 1410-1417.

Boubee, J.A.T.; Barrier, R.F.G.; West, D.W. 1995. Avoidance of suspended sediment by five migratory native freshwater fish species. *NIWA Report No. NRZ501.*

Gregory, R.S and Northcote, T.G. 1993. Surface, planktonic and benthic foraging by juvenile chinook salmon (*Oncorhynchus tshawytscha*) in turbid laboratory conditions. *Canadian Journal of Fisheries and Aquatic Sciences 50*: 233-240.

Hanchet, S.M. 1990. Effect of land use on the distribution and abundance of native fish in tributaries of the Waikato River in the Hakarimata Range, North Island. *New Zealand Journal of Marine and Freshwater Research 24*: 159-171.

Hayes, J.W.; Rutledge, M.J.; Chisnall, B.L. Ward, F.J. 1992. Effects of elevated turbidity on shallow lake fish communities. *Environmental Biology of Fishes 35*: 149-168.

Hecht, T.; van der Lingen, C.D. 1992. Turbidity induced changes in feeding strategies of fish in estuaries. *South African Journal of Zoology 27*: 95-107.

McDowall, R.M. 1993. Implications of diadromy for the structuring and modeling of riverine fish communities in New Zealand. *New Zealand Journal of Marine and Freshwater Research 27*: 453-462.

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

Minns, C.K. 1990: Patterns of distribution and association of freshwater fish in New Zealand. *New Zealand Journal of Marine and Freshwater Research 24*: 31-34.

Newcombe, C.P.; McDonald, D.D. 1991. Effects of suspended sediments on aquatic ecosystems. *North American Journal of Fisheries Management 11*:72-82.

Quinn, J.M.; Cooper, A.B.; Davies-Colley, R.J.; Rutherford, J.C.; Williams, R.B. 1994. Land-use effects on New Zealand hill country streams and implications for riparian management. *In* Link, G.L.; Naiman, R.J. *ed.* The ecology and management of aquatic-terrestrial ecotones. pp 19-27. University of Washington, Seattle.

Redding, J. M.; Schreck, C.B.; Everest, F.H. 1987. Physiological effects on coho salmon and steelhead of exposure to suspended solids. *Transactions of the American Fisheries Society 116*: 737-744.

Rowe, D.K. 1981. Fisheries investigations in the Motu River. New Zealand. New Zealand Ministry of Agriculture and Fisheries, *Fisheries Environmental Report No. 11.*

Rowe, D.K.; Chisnall, B.L. Boubee, J.A.T. 1989. Synoptic survey of native fish in selected catchments of the Wanganui River, August 1989. New Zealand Ministry of Agriculture and Fisheries, *Freshwater Fisheries Miscellaneous Report No. 16.*

Rowe, D.K.; Chisnall, B.L.; Dean, T. (In prep.). Effects of afforestation and land use changes on native fish communities in Bay of Plenty and Coromandel streams, New Zealand. *New Zealand Journal of Marine and Freshwater Research.*

Ryan, P. A. 1991. Environmental effects of sediment on New Zealand streams: a review. *New Zealand Journal of Marine and Freshwater Research 25:*207-221.

Saxton, B. A.; Rowe, D.K.; Stancliff, A.G. 1987. Species composition and relative importance of whitebait fisheries in the Bay of Plenty, New Zealand. New Zealand Ministry of Agriculture and Fisheries, *Fisheries Environmental Report No.* 79.

Schicker, K. P.; Boubee, J.A.T. 1990. Distribution of small migratory fish and shrimps in the Waikato River at Ngaruawahia. New Zealand Ministry of Agriculture and Fisheries, *Freshwater Fisheries Miscellaneous Report No. 63.*

Servizi, J.A. & Martens, D.W. 1992. Sublethal responses of coho salmon (*Oncorhynchus kisutsh*) to suspended sediments. *Canadian Journal of Fisheries and Aquatic Sciences 49*: 1389-1395.

Vinyard, G.L; O'Brien, W.J. 1976. Effects of light and turbidity on the reactive distance of bluegill (*Lepomis macrochirus*). *Journal of the Fisheries Research Board of Canada 33*: 2845-2849.