Survival of juvenile inanga and koaro in the lower Tarawera River (summer 1998/99)

DOC SCIENCE INTERNAL SERIES 49

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Published by
Department of Conservation
P.O. Box 10-420
Wellington, New Zealand

DOC Science Internal Series is a published record of scientific research carried out, or advice given, by Department of Conservation staff, or external contractors funded by DOC. It comprises progress reports and short communications that are generally peer-reviewed within DOC, but not always externally refereed. Fully refereed contract reports funded from the Conservation Services Levy (CSL) are also included.

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ISSN 1175-6519

ISBN 0-478-22248-3

This report was prepared for publication by DOC Science Publishing, Science & Research Unit; editing and layout by Lynette Clelland. Publication was approved by the Manager, Science & Research Unit, Science Technology and Information Services, Department of Conservation, Wellington.

CONTENTS

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ABSTRACT

The lower Tarawera River in the Bay of Plenty receives industrial discharges from two pulp and paper mills. Effluent comprises approximately 10% of the river flow and in-river dissolved oxygen (DO) concentrations are decreased by as much as 60% during summer. The effects of effluent on DO, colour, temperature and suspended solids are well described; however, the effect of extended periods of low DO concentrations combined with effluent contaminants on the habitat of native freshwater fish is poorly understood.

In 1997, discharge consents renewals drove a need to fill this information gap to set an appropriate DO regime for the lower river. In response, this study provides a gross insight into the effect of low DO combined with discharge contaminants on the ability of juvenile native fish to survive in the lower Tarawera River.

During summer 1998/99, juvenile inanga (*Galaxias maculatus*) and koaro (*Galaxias brevipinnis*) were caged in the river for one month at reference and exposed sites. During the inanga study month, DO concentrations generally remained above 5 mg/L, with survival rate between reference and exposed sites similar, and no relationship between inanga mortality and changes in DO found. By contrast, during the koaro study month, DO concentrations at exposed sites remained below 5 mg/L for a considerable proportion of the time, and a relationship between koaro mortality and lowered DO concentrations was found. No koaro died at DO concentrations above 5 mg/L. Therefore, to avoid koaro mortality, DO concentrations must remain above 5 mg/L, which is above the absolute minimum of 4 mg/L in current consents for the lower river.

Keywords: Dissolved oxygen, combined effects, inanga (*Galaxias maculatus*), koaro (*Galaxias brevipinnis*), pulp and paper mill discharges, industrial effluent, caging, Tarawera River.

Young, K. 2002: Survival of juvenile inanga and koaro in the lower Tarawera River (summer 1998/99). *DOC Science Internal Series 49*. Department of Conservation, Wellington. 20 p.

1. Introduction

1.1 SCOPE

This report presents the findings of a study designed to determine the survival of two native freshwater fish species in the lower Tarawera River downstream from pulp and paper mill and municipal effluent discharges. Objectives of the study included:

- To investigate the survival of juvenile inanga (*Galaxias maculatus*) and juvenile koaro (*Galaxias brevipinnis*) in the lower Tarawera River.
- To compare the survival rate of fish at reference sites upstream and exposed sites downstream of pulp and paper mill discharge outfalls.
- To examine the potential for reduced dissolved oxygen (DO) in the lower river to impact on fish survival.

1.2 BACKGROUND

The lower Tarawera river is located in the Eastern Bay of Plenty and receives a continuous loading of pulp and paper mill effluent discharged from two mills situated in Kawerau (Fig. 1).

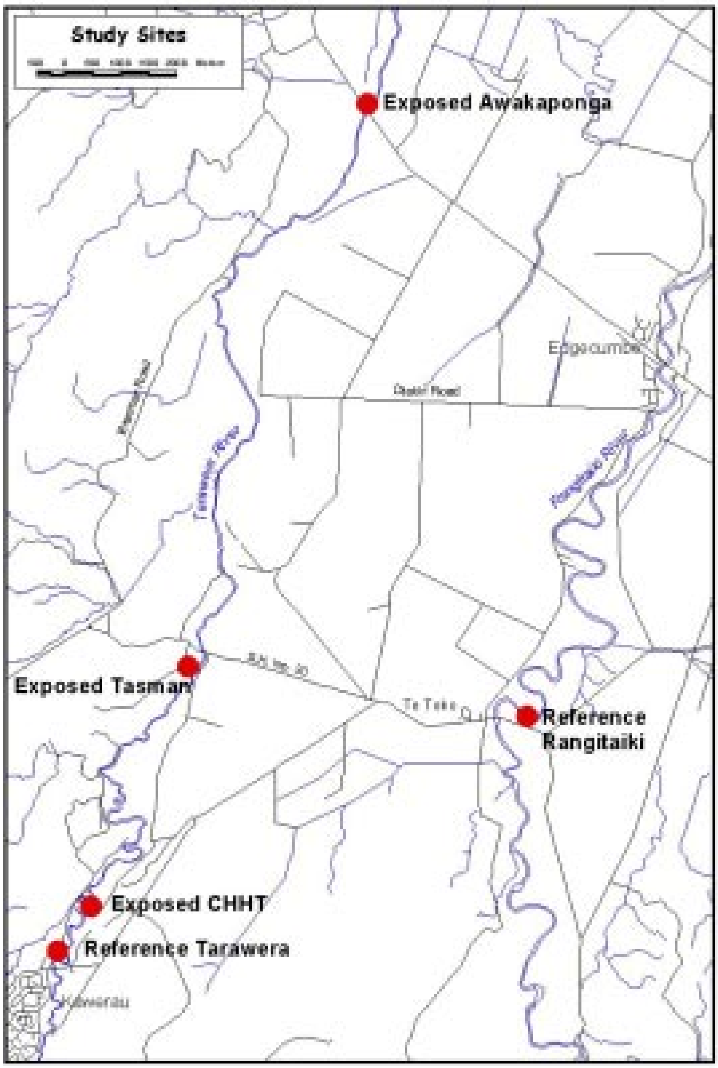
The effects of these discharges on water quality parameters such as DO, colour, temperature and suspended solids have been well described (Davies Colley et al. 1994; Environment Bay of Plenty 1994; Rutherford 1997). However, concern has been expressed over the limited information available on the combined effects of these discharges on the habitat of freshwater fish and, in particular, the effect of low DO concentrations combined with the effects of contaminants in the effluent discharges.

Many of New Zealand's native freshwater fish species are diadromous and therefore require both freshwater and the sea to complete their lifecycle (McDowall 1990). As a result, most species require access to the sea through the lower reaches of rivers and streams during their larval and juvenile lifestages. The lower Tarawera River is, therefore, a migratory pathway for all diadromous freshwater fish recruiting to the Tarawera River system.

The diversity of the freshwater fish species in the upper tributaries of the Tarawera River system is limited in comparison with other river systems in the Bay of Plenty (Young & Griffiths 1999). Of particular interest is the absence of koaro, a member of the galaxiid family, which is well distributed throughout the tributaries of river systems in New Zealand.

Each spring juvenile koaro migrate in mixed species shoals of the galaxiid family from the sea through the mouths of freshwater rivers and streams in pursuit of suitable upstream habitat. These shoals are commonly known as whitebait, and are harvested by whitebait fishers near the river and stream mouths. Koaro are known for their ability to penetrate inland and negotiate waterfalls and other barriers in their pursuit of upstream habitat (McDowall 1996).

Figure 1. Study area and study sites



The lack of species diversity in the upstream tributaries and, in particular, the absence of koaro in the Tarawera River system is puzzling. Several explanations have been proposed, including:

- the lack of suitable habitat provided by upstream tributaries,
- velocity barriers provided by the swiftly flowing tributaries,
- active avoidance or lethal response of juvenile fish to effluent loadings received by the river.

A recent survey of Tarawera River tributaries revealed that neither insufficient habitat nor velocity barriers were an impediment to successful recruitment to these tributaries (Young & Griffiths 1999). However, decreased DO concentrations can raise the toxicity of contaminants. For example, Lloyd (1961), Maguad et al. (1997) and, in particular, Hicks & De Witt (1971) observed an increase in the toxicity of pulp mill wastes to juvenile sockeye and coho salmon in the presence of low DO concentrations.

Therefore, the response of juvenile fish to the combined effects of the effluent and low DO warrants investigation.

'Combined effects' represents a wide range of both behavioural and physiological responses to the combination of a suite of contaminants. Unfortunately, such effects are typically difficult and expensive to study.

Rigorous investigation requires a high level of laboratory facilities and adequate equipment to set up an artificial environment which simulates desired conditions under a controlled regime. In this regime one variable, such as DO concentration, can be altered at a time.

Given the restraint of costs, laboratory equipment and time, the scope of this study was limited to providing a gross insight into the combined effects of the effluent discharges on the habitat of native fish in the lower Tarawera River.

Inanga and koaro were chosen for the study; Koaro because of its absence from the Tarawera River system and inanga (also a member of the galaxiid family) for the following reasons:

- The biology of inanga is well described (e.g. McDowall & Eldon 1980; McDowall 1990).
- Inanga provide a useful comparison to koaro. Inanga are closely related to koaro, both being members of the galaxiid family. The life cycle of inanga is similar to that of koaro.
- Juvenile inanga were readily available, easy to source at the time of year required for the study, and easy to handle.

Juvenile inanga and koaro were caged at four sites in the Tarawera River, and at one site in the adjacent Rangitaiki River, in a series of replicated flumes. The study took place in December 1998 and from mid January to mid February 1999. Each species was caged for a period of one month.

2. Methods

2.1 STUDY AREA

The study area is shown in Fig. 1. The Tarawera and Rangitaiki Rivers are situated in close proximity to one another in the Eastern Bay of Plenty. In the past, the two rivers were joined and jointly discharged to the coast via Matata lagoon. In the 1950s, individual channels were dredged for each river, and they now flow independently to the sea.

2.1.1 Tarawera River

The Tarawera River is fed from a catchment of approximately 984 km^2 (Environment Bay of Plenty 1994). The headwaters of the Tarawera River comprise eight volcanically formed lakes in the Tarawera Lakes region. The Tarawera Lakes are situated at approximately 300 m a.s.l. in the Rotorua Ecological District. Lake Tarawera is the largest of the lakes and the lowest lying. It is generally considered to be fed by five other lakes within the catchment of the complex (Environment Bay of Plenty 1994) and discharges through the Tarawera falls to form the start of the Tarawera River. Below the Tarawera falls the river enters a steep-sided valley which quickly broadens out into undulating country 150–300 m a.s.l.

Several fast-flowing, steeply graded tributaries feed the Tarawera River along its length. These tributaries are spring-fed and provide stable flows of clear, highly oxygenated water to the mainstem of the river throughout the year. Being predominantly lake- and spring-fed, the flow of the Tarawera River is relatively stable in comparison with the neighbouring Rangitaiki and Whakatane rivers. The substrate of the greater length of the river and its tributaries is pumice. The river meanders in its upper sections but tends to flow directly northwards in its lower reaches prior to discharging to the coast. The lower reaches of the river have been highly modified by swamp drainage schemes.

The lower section of the river, from Kawerau to the coast, receives treated industrial effluent discharged from two pulp and paper mills situated along the river. Together, the effluent discharges comprise approximately 10% of the total river flow. The nature of the effluent is such that it causes discoloration and reduced instream DO concentrations in this section of the river.

Study sites were situated along the length of the river, and were chosen to characterise different habitat quality for freshwater fish with respect to DO, colour and contaminant concentration.

2.1.2 Rangitaiki River

The Rangitaiki River is a large river fed by a catchment of approximately 3005 km^2 (Peter Blackwood, pers. comm.). The headwaters of the Rangitaiki River are in the Kaingaroa Ecological District in the southern Bay of Plenty. Several major tributaries, including the Wheao, Whirinaki and Horomanga Rivers, join the Rangitaiki River along its length.

The Rangitaiki River has been hydrologically modified to a significant extent. Two hydro-electricity dams—Matahina and Aniwhenua—are located on its mid section, and another hydro-electricity dam on the Wheao River diverts water from the Wheao directly to the Rangitaiki. As with the Tarawera River, drainage of the formerly vast Rangitaiki floodplain wetland complex has led to major modification of the lower reaches of the Rangitaiki and an independent river mouth has been cut directly to sea.

The study site was located 14 km from the coast on the Rangitaiki River. This site was chosen to correspond directly to the control site on the Tarawera River in terms of distance inland from the sea.

2.1.3 Study sites

Flumes were placed at five sites (Fig. 1, Table 1); four on the Tarawera River and one on the Rangitaiki River (Fig. 1). The Tarawera River sites were chosen in relation to the major discharge outfalls along the length of the lower river (Fig. 1, Table 1) and represent 'reference' (Tarawera control—above any industrial discharge)) and 'exposed' (CHHT, Tasman and Awakaponga—below industrial discharges) sections of the river. The study site on the Rangitaiki River was chosen to provide an additional reference site for the study and to identify any between-river variations.

TABLE 1. STUDY SITES ON THE TARAWERA AND RANGITAIKI RIVERS.

SITE NAME	GRID REFERENCE	LOCATION AND DESCRIPTION
Awakaponga	V15 414 557	200 m downstream from Awakaponga bridge on the true left bank
Tasman	V15 383 457	Downstream from TPP mill main discharge at Onepu. Situated adjacent to Onepu springs road on the true right bank
CHHT	V15 359 409	Downstream from CHHT mill discharge. Situated on the true left bank 20 m downstream of CHHT and TPP pipe bridge across the river
Tarawera reference	V15 357 406	Located above all pulp and paper mill discharges. Situated on true left bank 100 m downstream from Kawerau road bridge
Rangitaiki reference	V15 442 446	Located on the Rangitaiki river on the true right bank 200 m downstream from Te Teko road bridge.

Note: TPP = Tasman Pulp and Paper Ltd, CHHT = Carter Holt Harvey Tissue Ltd.

2.2 GENERAL APPROACH

In order to expose fish to ambient river conditions for the entire length of the study period, fish were caged in the river in a series of flumes at each site (Figs 2 and 3). The use of flumes allowed the fish to be subjected to actual river conditions throughout the entire length of the study, and the level of maintenance required was low.

Each species was studied independently with inanga being caged for one month in December 1998 followed by koaro caged from mid January to mid February 1999.

Fish were not fed during the study period. Any dead fish were removed daily and recorded.

2.3 FLUMES

Three replicate flumes were set into the river margin in series at all monitoring sites (Figs 2 and 3). They were positioned so that they floated to a depth corresponding to approximately 3/4 full. Each flume was secured by rope to stakes driven into the river bank.

All flumes were in position approximately 1 week prior to stocking with fish and were maintained every alternate day to remove weed and algae growth from the front and back screens. The floor of each flume was left unattended during the study period and built up a considerable silt substrate at each site.

Figure 2. Replicate flumes at the Awakaponga site.

Figure 3. Replicate flumes at the Tarawera control site.

2.4 MONITORING

During the inanga study month, DO concentrations were obtained for the Awakaponga site only. The DO levels were recorded by Fletcher Challenge Paper Limited using a oxygen meter connected to a datalogger. During the koaro study month, dissolved oxygen concentrations were recorded at each site every day or every second day using a YSI model 57 oxygen meter to the nearest mg/L.

2.5 FISH

Each flume was stocked with approximately 30 fish. There was some variability in size class, which was unavoidable at the time of the year the fish were sourced. Inanga were gathered in the first week of December 1998, from the Tarawera River mouth, Matata lagoon and Awakaponga canal using a bag set and kick net routine (Charles Mitchell, pers. comm.). Fish were stored in plastic buckets while awaiting transfer to flume sites.

Koaro were gathered during the second week in January 1999 from the lower reaches of the Waipehi Stream using an electric fishing machine and stop net. The Waipehi Stream is a tributary of Lake Taupo, situated on the central North Island volcanic plateau. During the study handling of fish was minimised and fish were not fed.

At the conclusion of each study period, flumes were removed from the water and fish were recovered by hand. Silt which had built up during the study was sorted systematically with a sieve and water for remaining fish.

3. Results

3.1 INANGA

3.1.1 Overall survival

The flumes worked well in caging and retaining inanga; however, tampering invalidated the results of flume 1 at the CHHT site and these have been omitted from the final analysis. Table 2 presents the number of dead fish removed from each flume during the study and the number retrieved alive at the end of the study. Figure 4 shows the proportion of fish surviving at the end of the study.

100% survival was found at the Tarawera control and the CHHT sites. Survival rate was only slightly reduced at the Rangitaiki, Tasman and Awakaponga sites. This reduction was found to be not significant using an analysis of variance (ANOVA).

3.1.2 Changes in dissolved oxygen (DO)

At the end of the inanga study period our DO meter was found to be unreliable. Therefore, DO concentration records were obtained for the Awakaponga site only (recorded by Fletcher Challenge Paper Limited). Low levels of DO were recorded after day 16 of the monitoring period when concentrations fell to below 5 mg/L. However, no relationship between low DO levels and inanga mortality was found at the Awakaponga site (Fig. 5).

TABLE 2. INANGA—SUMMARY OF SURVIVAL.

SITE	FLUME	NUMBER OF DEAD FISH REMOVED DURING STUDY	NUMBER OF FISH REMOVED ALIVE AT COMPLETION OF STUDY	TOTAL NUMBER OF FISH PER FLUME
Upstream reference sites				
Tarawera	1	0	28	28
	2	0	24	24
	3	0	26	26
Rangitaiki	1	0	30	31
	2	0	29	29
	3	1	28	29
Downstream exposed sites				
Awakaponga	1	2	27	29
	2	0	28	28
	3	1	21	22
Tasman	1	1	28	29
	2	1	28	29
	3	2	28	30
CHHT	1	4	6	10
	2	0	26	26
	3	0	30	30

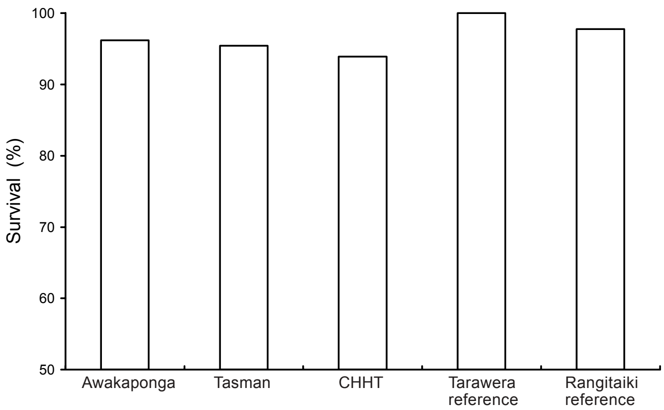


Figure 4. Survival rate of inanga at each site.

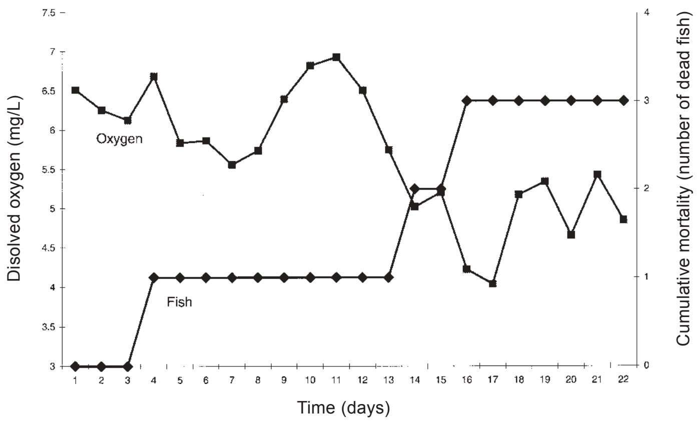


Figure 5. Cumulative mortality of inanga in relation to changes in dissolved oxygen over time at Awakaponga site.

3.2 KOARO

3.2.1 Overall survival

In contrast to inanga, the flumes did a poor job of retaining koaro and therefore overall survival rate could not be determined for this species. At the end of the study period most flumes had a substantial number of fish missing (Table 3), most likely because koaro were able to climb out of them.

TABLE 3. KOARO—SUMMARY OF SURVIVAL.

SITE	FLUME	NUMBER OF DEAD FISH REMOVED DURING STUDY	NUMBER OF FISH REMOVED ALIVE AT COMPLETION OF STUDY	TOTAL NUMBER OF FISH PER FLUME
Upstream reference sites				
Tarawera	1	1	14	15
	2	2	15	13
	3	0	-	30
Rangitaiki	1	0	7	23
	2	2	-	28
	3	2	25	3
Downstream exposed sites				
Awakaponga	1	11	17	2
	2	0	2	28
	3	11	-	19
Tasman	1	1	21	8
	2	1	9	20
	3	12	5	13
CHHT	1	0	8	22
	2	0	6	24
	3	0	5	25

3.2.2 Changes in dissolved oxygen (DO)

Figure 6 shows that DO concentrations fluctuated during the study period at all sites. At the Awakaponga site, concentrations were markedly lower than at all other sites. The highest mortality was recorded at this site with 22 fish found dead during the study period. This contrasts with 4 found dead at the Rangitaiki site, 3 at the Tarawera control site, 0 at the CHHT site and 14 at the Tasman site.

Figure 7 shows that sharp rises in mortality at the Awakaponga site occurred when DO concentrations fell below 5 mg/L. This is particularly apparent in reference to the second increase in mortality that occurred between days 13 and 18 of the study. When DO concentrations remained above 5 mg/L, koaro mortality was zero. A significant relationship was found between lowered DO concentrations and increased mortality (Fig. 8) ($p < 0.0001$) where mortality was the dependent variable, as summarised in Table 4.

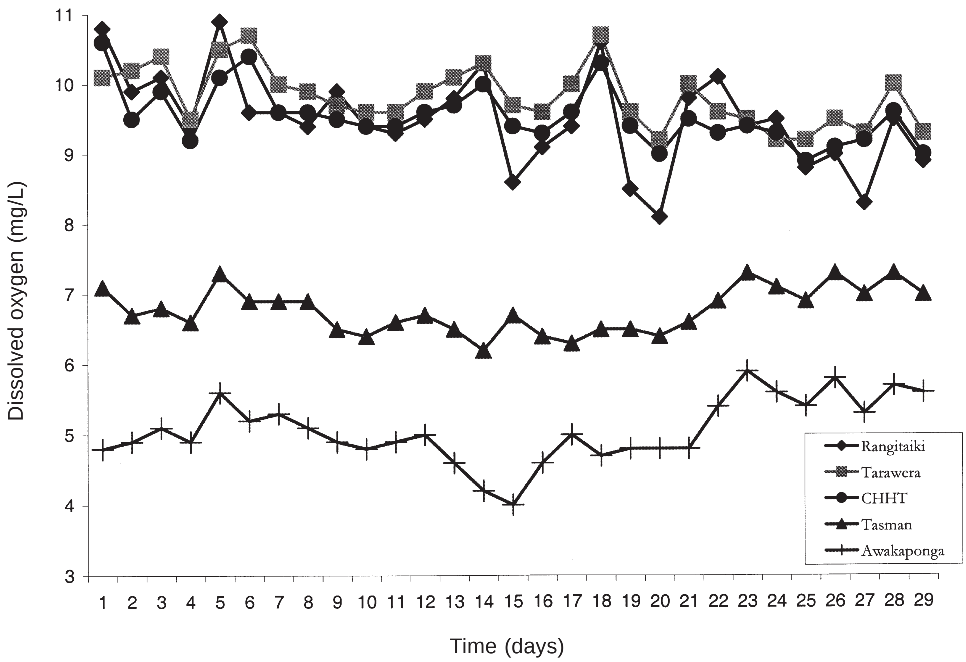


Figure 6. Changes in dissolved oxygen over time at each site during koaro study month.

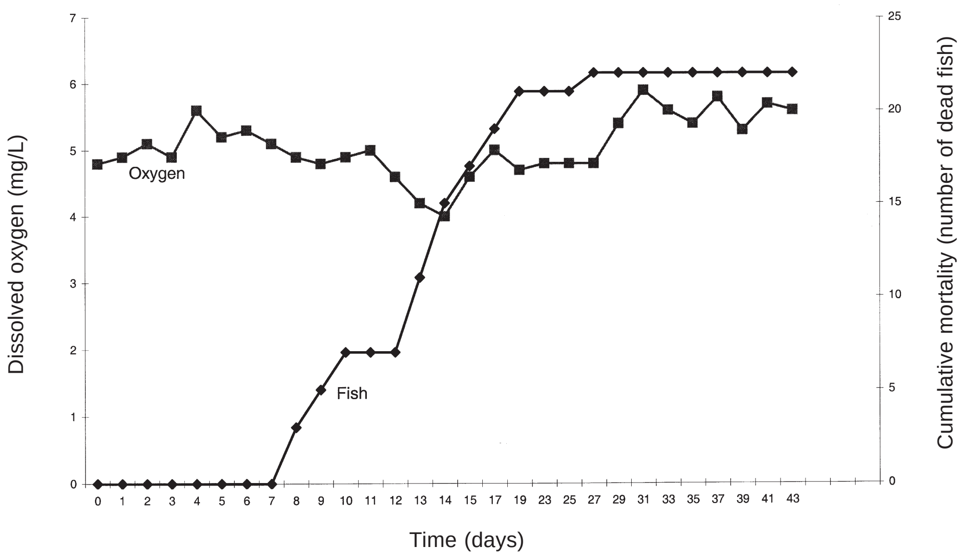


Figure 7. Cumulative mortality of koaro in relation to changes in dissolved oxygen over time at Awakaponga site.

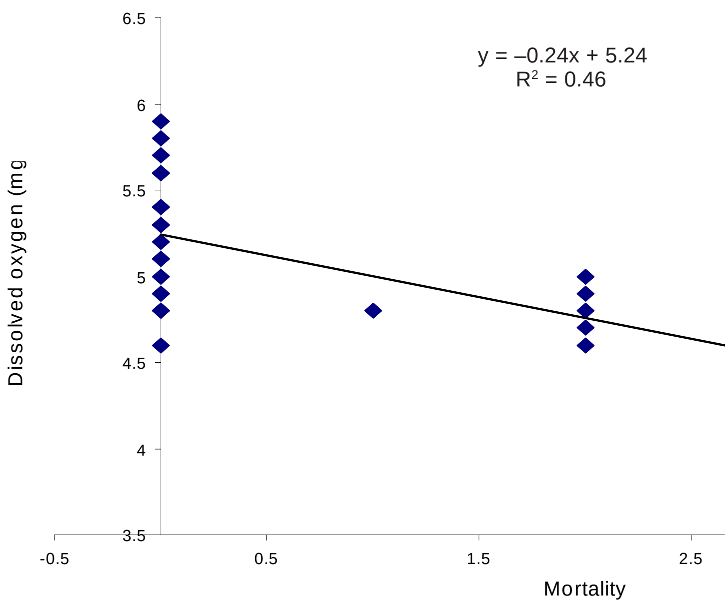


Figure 8. Relationship between dissolved oxygen and mortality.

TABLE 4. SUMMARY OF ANOVA RESULTS—RELATIONSHIP BETWEEN DISSOLVED OXYGEN AND MORTALITY.

	Df	*Sum of squares*	*Mean square*	*F*	*Significance F*
Regression	1	2.67	2.67	23.18	< 0.001
Residual	27	3.10	0.11		
Total	28	5.77			

4. Discussion

In recent years concern has been expressed regarding the effects of pulp and paper mill effluent discharges on the ability of juvenile fish (whitebait) to survive and migrate through the lower Tarawera River. One of the more quantifiable effects on freshwater fish habitat in the lower river is low DO concentrations during summer low flow conditions, which may compound the effect of toxicants discharged in the effluent streams.

Studies such as that of Lloyd (1961) and Maguad et al. (1997) have shown that contaminants such as heavy metals, monohydric phenols and ammonia become more toxic when DO is at low levels. In particular, an increase in the toxicity of pulp mill wastes to juvenile sockeye and coho salmon was observed in the presence of low oxygen (Hicks & De Witt 1972); and Marier (1973) found that kraft mill effluent was 3 times more toxic when DO concentrations were reduced from 6.5 mg/L to 4 mg/L.

Dissolved oxygen criteria have been set by the United States Environmental Protection Agency (USEPA) with different concentrations set for different fish species present according to acceptable levels of impairment. Studies targeted at identifying the tolerances of New Zealand native fish to different DO regimes have yet to be done. However, a study by Dean & Richardson (1999) of the responses of seven species of native freshwater fish and a shrimp to low levels of DO found that the levels set by the USEPA (1986) for waters inhabited by salmonids provided adequate protection for native fish. These could provide an interim standard (Tables 5 and 6).

Of the four sites on the Tarawera River, DO concentrations were lowest at the Awakaponga site during both the inanga and koaro study periods. Environment Bay of Plenty records show that DO concentrations have been known to fall as low as 3.7 mg/L at this site during summer low flows in the river (Environment Bay of Plenty, 1994). These low levels are directly attributable to the effluent discharges containing high loads of biological-oxygen-demanding substances (BOD) (Environment Bay of Plenty 1994).

The highest mortality of koaro occurred at the Awakaponga site and a relationship was found between decreasing concentrations of DO and increased mortality of koaro. In contrast, however, no relationship was found between mortality and DO for inanga, and no significant difference in survival was found between the ‘reference’ Tarawera and Rangitaiki sites and the ‘exposed’ CHHT, Tasman and Awakaponga sites.

TABLE 5. DISSOLVED OXYGEN (DO) CONCENTRATIONS (mg/L) RECOMMENDED BY THE USEPA (1986) TO CONFER LEVELS OF PROTECTION FOR WATERS CONTAINING SALMONIDS.

DEGREE OF IMPAIRMENT ACCEPTABLE	EARLY LIFE STAGES mg/L	OTHER LIFE STAGES mg/L
None	11.0 (8.0)	8.0
Slight	9.0 (6.0)	6.0
Moderate	8.0 (5.0)	5.0
Severe	7.0 (4.0)	4.0
Acute limit	6.0 (3.0)	3.0

TABLE 6. DEGREE OF IMPAIRMENT IN RELATION TO GROWTH IMPAIRMENT.

DEGREE OF IMPAIRMENT	GROWTH IMPAIRMENT (%)
Slight	10
Moderate	20
Severe	40
Acute	50

Note: growth impairment of 50% or greater is often accompanied by mortality.

The difference between the response of inanga and the response of koaro to changes in DO is most likely due to the difference in DO concentrations over their respective study periods. During the inanga study period DO concentrations remained above 5 mg/L at the Awakaponga site for most of the time except for 3 occasions on days 16, 17, and 21. At these concentrations mortality was not expected. Dean & Richardson (1999) found that at concentrations of 5 mg/L there was 100% survival for of all 7 native species studied.

In contrast, DO concentrations during the koaro study period fell below 5 mg/L at the Awakaponga site for a continuous period of time from day 9 to day 22 of the study period, and during this time fell to as low as 4.2 mg/L on day 14 and 4.0 mg/L on day 15. According to the USEPA criteria, concentrations below 5 mg/L render 'severe' impairment to the fishery.

Therefore, while inanga whitebait were able to survive in the lower Tarawera River for a period of one month, and no difference in survival was found between reference and exposed sites when DO concentrations mostly exceeded 5 mg/L, no comment can be made regarding inanga response to long periods of low DO (between 4 and 5 mg/L) and whether survival rate would then differ between reference and exposed sites.

Unfortunately, the survival rate of koaro could not be determined because of the failure of the flumes to retain the fish. Koaro are extraordinarily capable climbers and have the ability to remain out of water for short periods of time. It is possible that koaro may have responded to the continual low DO levels by simply leaving the flumes. This response has been recorded for banded kokopu (*Galaxias fasciatus*) which left experimental tanks completely after exposure to very low levels of DO (1 mg/L, Dean & Richardson 1999).

Despite our inability to determine differences in survival rate for koaro between the reference and exposed sites, the relationship found between koaro mortality and decreased DO concentrations suggests that either low DO concentrations increase the toxicity of contaminants to koaro in the lower river, or that the presence of industrial effluent increases the sensitivity of koaro to low DO concentrations.

The USEPA criteria for a slightly impaired trout fishery have been applied to the Tarawera River for the pulp and paper mill and municipal sewage discharge consents. These criteria require that the 30-day moving average for DO falls no lower than 6 mg/L with a one-day absolute minimum of 4 mg/L. Dissolved oxygen concentrations of 4–5 mg/L severely impair the fishery, causing 40% reduction in growth. 3.0 mg/L, in the absence of contaminants, is set as the acute limit in the USEPA criteria.

During the entire koaro study month, DO concentrations remained above 4 mg/L; however, mortality still occurred when concentrations fell below 5 mg/L.

The mortality of koaro at DO levels above the acute concentration of 3 mg/L suggests that DO concentrations would need to remain above 5 mg/L in the presence of pulp mill contamination in the lower Tarawera River to avoid mortality of juvenile koaro during the summer low-flow period. This is above the absolute minimum DO of 4 mg/L set in the resource consents.

It is important to note that the relationship between low DO concentrations and koaro mortality found in this study provides little explanation for the absence of koaro from the Tarawera river system. Juvenile koaro migrate into eastern Bay of Plenty rivers and streams as part of the whitebait run in September–October (spring) each year (Young 2000). Based on documented swimming speeds of some whitebait species (Stancliff et al. 1988), their journey through the lower reaches of eastern Bay of Plenty rivers in pursuit of suitable upstream habitat is likely to take no more than a period of one month. This means that they are unlikely to be affected by the summer low-flow season when DO levels fall below 5 mg/L. Therefore, the relevance of the above findings to the absence of koaro should be considered with caution.

5. Conclusions

1. Dissolved oxygen (DO) concentrations during the inanga study month remained above 5 mg/L for the greater part of the study period. At these concentrations no significant difference in survival rate of inanga between reference and exposed sites was found, and no relationship between mortality and changes in DO was found.
2. Dissolved oxygen concentrations during the koaro study month remained below 5 mg/L for a considerable proportion of the time. At these concentrations, a relationship between koaro mortality and lowered DO concentrations was found. No koaro deaths occurred at concentrations above 5 mg/L.

3. In order to avoid mortality of koaro during summer low-flow conditions, DO concentrations would need to remain above 5 mg/L, which is also above the 4 mg/L absolute minimum specified in resource consents. However, given that it is unlikely that juvenile koaro would be using the lower river during the summer season, the relevance of this finding should be considered with caution.
4. Differences in the responses of inanga and koaro to changing concentrations of DO are most likely due to the differences in DO regimes throughout the respective study periods.
5. The survival rate of koaro could not be determined due to the failure of the flumes to retain the fish.

6. Acknowledgements

Funding was provided by Tasman Pulp and Paper Ltd (now Norske Skog Limited), Carter Holt Harvey Tissue Ltd and the Department of Conservation for the purchase of equipment and monitoring of the flumes.

Charles Mitchell (Charles Mitchell Associates Ltd) designed and constructed flumes used in the study and provided valuable comment on the study design.

Charles Mitchell and Ian Kusabs sourced all fish used in the study.

Valuable comment on the study proposal was provided by Robert Donald, Jody Richardson (NIWA) Ian Jowett (NIWA) and Dr Wayne Donnovan (Bioresearchers).

Statistical advice provided by Dr Cindy Baker (NIWA Ecosystems) is greatly appreciated.

I am very grateful to Dr Mike Van den Heuvel (Forest Research) who reviewed the draft of this report and provided valuable comment to improve its content.

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