Impacts of forest harvesting on giant kokupu, Ngakaroa Stream, Omataroa Forest, Bay of Plenty

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ABSTRACT

The aim of this study was to determine the effects of logging a pine forest catchment upon a population of giant kokopu (*Galaxias argenteus*) in a small third-order stream. Spotlighting was used to estimate fish abundance in the Ngakaroa Stream, Omataroa Forest, Bay of Plenty, New Zealand, on 15 occasions from February 1995 to July 2000. Between July 1997 and March 1998, the forest compartment enclosing the study area was clearfelled, using a combination of skyline hauling and skidding, and the compartments were replanted over winter 1998 and 1999. Abundance of giant kokopu varied greatly over the study period, ranging from two to 22 fish over the 600 m study reach. Although there was no statistically significant difference in the abundance of giant kokopu in the Ngakaroa Stream before or after logging, the study suggested that deliberate planting of riparian zones with pine trees can encourage regeneration of shade-tolerant, native scrub-hardwood species, thereby providing acceptable conditions for a range of native fish, including giant kokopu. This contrasts with reserving unplanted riparian 'buffer strips' which led to invasion by light-demanding exotic weed species. This pragmatic approach could lead to cost-effective and comparatively rapid restoration of habitat for native forest-dwelling fish such as giant kokopu. Appropriate planting and harvesting regimes are described.

Keywords: giant kokopu, *Galaxias argenteus*, forest catchment, riparian strips, habitat maintenance, exotic forest, Bay of Plenty, New Zealand.

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1. Introduction

1.1 BACKGROUND INFORMATION

In 1994, a preliminary study of streams in Omataroa Forest (eastern Bay of Plenty, New Zealand) to examine the impacts of plantation forestry practices on freshwater fishes and invertebrates (Mitchell 1994) showed that a number of native fish species were present within the forest. The most exciting find was a population of giant kokopu (*Galaxias argenteus*) in the Ngakaroa Stream. This large lowland native fish is now rare in many parts of New Zealand, including the Bay of Plenty. The decline is possibly due to one or more of: loss of instream cover, decreased stability of flows and other conditions resulting from intensive pastoral development, or competitive displacement by brown trout (*Salmo trutta*). Expert opinion is that it is likely this decline will continue (McDowall 1990). Giant kokopu have been classified as Threatened – Gradual Decline (Hitchmough 2002) by the Department of Conservation (DOC).

Despite pines having been planted to the stream margins (or perhaps because of it) and even a past channelisation of the stream for roading, the habitat requirements for giant kokopu were apparently met in the Ngakaroa Stream, within a 25-year exotic forest rotation. In contrast, abundance of giant kokopu declined markedly downstream, where a 10 m wide unplanted riparian margin had been imposed by the Regional Council as a planting precondition. Mitchell et al. (1995) concluded that the dense riparian understorey of native scrub-hardwoods that will develop beneath low-density exotic forest may simulate the native forest habitat of some native fish. They suggested that managed tree planting on riparian margins could be used as a practical, self-funding, large-scale method to rapidly restore selected small streams towards their original 'native forest' condition.

However, every 20–40 years, exotic forest plantations will be harvested. Logging may have a significant impact on the aquatic and fisheries values of streams flowing through recently harvested compartments (Mitchell et al. 1995). The purpose of this study was to determine the effects of logging on the resident giant kokopu population in the Ngakaroa Stream.

Most environmental monitoring studies are focused almost entirely on benthic macroinvertebrate communities (Stark 1994). However, the potential for decline in aquatic invertebrate diversity and abundance as an exotic forest matures and shades out instream production (Mitchell et al. 1995) may lead to the simple conclusion that exotic forestry has a negative impact upon stream ecosystems. Monitoring the native fish community may be a useful additional approach. Fish are widely used as biological indicators of ecosystem health. They are high on the food chain and require invertebrate populations to sustain them. Finally, fish tend to be both easily recognised and more appreciated by the general public than benthic macroinvertebrates.

1.2 STUDY AREA

The Ngakaroa Stream is a very minor tributary of the Rangitaiki River, the largest river system in the Bay of Plenty. It rises in Compartment 14, Omataroa Forest. This 7700 ha forest lies to the east of Te Teko township, and is bounded to the north by Awakeri and to the south by Matahina districts. The study area was located in Compartment 14, from NZMS V15 487 447 to V15 487 440, commencing approximately 2 km from the head of the Ngakaroa Stream.

This area was originally covered in tawa/rimu-dominant forest. Owing to the easily erodable and low-fertility soils, pastoral farming was unsustainable. Control of regenerating manuka and bracken fern became uneconomic and the area was converted to plantation forestry in the 1970s (N. Geerkins pers. comm.). The site is favourable for silviculture and has a high growth index. *Pinus radiata, Eucalyptus nitens,* and *Eucalyptus fastigata* are grown on short rotations for pulp and sawn timber. The forest is intensively and efficiently managed. Considerable areas of native forest also remain within the forest, particularly where the land was too steep for clearing.

Soil structure in the forest is typical of the eastern Bay of Plenty. A thick mantle of airfall pumice overlies a basement of ignimbrite and shattered argillite rock. Pumice subsoils act as buffers, releasing rainfall at a steady rate. Supplied by this filtered groundwater, streams tend to be clear and stable. However, there may be a significant bedload of pumice sand, especially when steep unconsolidated stream banks are disturbed by logging or roading. Coarse substrates (boulders and cobbles) are usually absent. The upper reaches of the Ngakaroa Stream flow into a large wetland. Here inflows of deoxygenated groundwater resulted in heavy deposits of organic iron floc throughout the wetland and extending down through the study reach.

1.3 OBJECTIVES

The objectives of this study were to:

- Determine the effects of logging on the giant kokopu population in the Ngakaroa Stream.
- Monitor the abundance, size-structure, and species composition of fish populations in the Ngakaroa Stream.

2. Methods

2.1 SITE SELECTION

The study area was located from the Ngakaroa Stream culvert under Waiowhero Road, extending 600 m to the swamp area upstream. It was the only site in Omataroa Forest where giant kokopu were recorded, although over the duration of the study, a few fish were spotlighted downstream of the culvert. The 600 m study reach was bordered by Waiowhero Road and so was relatively accessible. Compartment 14, which surrounded the monitoring section and the entire upper catchment, was planted in *Pinus radiata* right to the stream margins in 1973 and was originally scheduled for logging in 1995. Trees bordering the lower 200 m of the section were eventually harvested in December 1995. Some windthrow across the stream onto the road then occurred and these trees were also extracted. In September 1997, all the trees bordering the upper 400 m of the section were felled in the process of completing the harvest of Compartment 14. Owing to the steep terrain surrounding the stream, many trees had to be felled downslope and dragged across the stream, but as far as was practicable, felling, limbing and skidding were done in a manner that minimised damage to the riparian native scrub-hardwood vegetation. Standard blanket herbicide applications were then made (again kept away from the stream margins) and the compartment was replanted with a mixture of *P. radiata* and *E. fastigata* over the winters of 1998 and 1999.

2.2 SPOTLIGHTING

Cryptic fish such as eels may become active at night. Other species are passive at night and remain near where they can be seen feeding during the day. In shallow clear water, it is possible to approach many fish at night, and identify and count them by using a powerful light. Because it is relatively non-disruptive, spotlighting was a technique particularly suitable for repeat monitoring of fish within this small stream (largely < 1 m wide).

At approximately 3-month intervals, between 21 February 1995 and 5 July 2000, the stream was spotlighted using hand-held 55 000 candlepower spotlights powered by 12 volt sealed lead-acid batteries. Observers walked upstream through the study reach, either along the stream banks or through the water where this was not possible. Surveys were carried out seven times from September 1995 to November 1997 (pre-logging) and eight times until July 2000 (post-logging/reestablishment) (see Tables in Appendix 1). All fish seen were counted, identified to species and their size estimated as large, medium, or small (juvenile). All sightings were immediately recorded on plastic field slates for later transcription.

Timing of monitoring depended upon water clarity. Spotlight counts were only undertaken if prior low rainfall indicated that good observations could be made.

2.3 HABITAT QUALITY

Additional notes were made during the study of other potentially relevant stream habitat characteristics such as riparian vegetation, substrate changes and iron-floc deposits, algae growth, and aquatic macrophytes and macro-invertebrates. Photographs were taken using a Canon EOS 500 camera with Fuji 100 ASA colour film.

3. Results

3.1 HABITAT DESCRIPTIONS

3.1.1 Riparian vegetation

The riparian vegetation varied greatly over the sampling period. Prior to harvesting, the riparian margins in the study section of the Ngakaroa Stream were well shaded by a canopy of mature pines growing on the steep banks along the true right-bank. Sandwiched between this bank and the road embankment, the study section effectively flowed in a narrow gully lit only by dappled overhead light. Shading appeared to suppress the light-demanding exotic plants otherwise common in Omataroa Forest such as buddleia (*Buddleia davidii*) and pampas grass (*Cortaderia selloana*). Shading by *Pinus radiata* over 22 years had resulted in an understorey dominated by shade-tolerant native plants: black mamaku (*Cyathea medullaris*), ponga (*Dicksonia squarrosa*), tutu (*Coriaria arborea*), whiteywood (*Melicytus ramiflorus*), hangehange (*Geniostoma ligustrifolium*), and karamu (*Coprosma robusta*). Nevertheless, patches of blackberry (*Rubus fruticosus*) also persisted within this riparian margin.

Figure 1. Ngakaroa Stream six months after logging.

The most notable effect following logging was the exposure of the stream to direct sunlight (Fig. 1). Even 'careful' felling and extraction of the tree crop resulted in whole-scale flattening and extensive damage to the riparian scrub hardwoods. However, rapid and vigorous regrowth, even from bent-over, snapped and partially buried plants, was a feature of the post-harvest phase. In addition, seedlings of light-demanding weed species such as blackberry and pampas grass germinated profusely, wherever the ground had been bared and disturbed.

By July 2000 at the conclusion of this study, the stream was again almost completely overgrown with riparian vegetation (Fig. 2). This vegetation now comprised a relatively low-stature mix of shade-tolerant survivors: hangehange, karamu, tutu, tree ferns and smaller ferns, together with light demanding species such as blackberry, buddleia, pampas grass, toetoe (*Cortaderia toetoe)* plus the sedges *Carex geminata* and *Carex secta*. Pruning shears and a slasher had to be used to maintain access through the blanket of blackberry over portions of the stream.

Figure 2.
Ngakaroa Stream 2 years after logging.

3.1.2 Stream morphology

Prior to logging, the study reach was basically a straight and narrow artificial channel. In 1981 the stream had been diverted and confined along one side of the valley, in order to prepare the logging road. Substrates were mainly silt/sand, with artificial additions of rocks that had entered the stream during the roading works. The stream bed, together with branches, etc. in the stream, was coated with a light brown film of iron-floc, originating from the swamp further upstream.

Logging caused significant disturbance. In addition to the removal of the large overshadowing trees, considerable lengths of the riparian margin vegetation had been broken down or swept away altogether by trees being dragged across the stream. As an unavoidable part of this process and following a prolonged period of high rainfall, a substantial volume of pumice fines and silt covered the stream bed. Although the stream was largely cleared of slash, some large woody debris had been left behind (at our request). Together with twigs, leafy branches and needles, this material formed a series of clumps and debris dams that trapped sediments and eventually became largely buried. Owing to the depth of fines in the pools and low-gradient sections that resulted from these dams, walking up the stream became more difficult in some areas than previously. It was noticed that considerable volumes of gas bubbles were released by walking on these buried accumulations of vegetation. Stream clarity also improved, the iron-floc deposits characteristic of the streambed prior to logging disappearing over the following winter. Possibly, enhanced flows following logging up-slope of the swamp area had reduced the contribution/importance of deoxygenated groundwater to overall stream flows.

One year after logging, the stream had begun to stabilise, and denser and coarser substrates such as road metal, pumice gravel, and stones gradually appeared along the narrower and faster-flowing sections as repeated floods winnowed fines away. Pools remained characterised by thick layers of silt. Ferric oxide deposits were again present. Anaerobic gas bubbles from mats of decaying vegetation largely disappeared. Overall, the most noticeable differences were an increase in stream discharge and the persistence of a number of small plunge pools formed by buried logs and branches.

Table 1 summarises the main features of habitat changes observed during the study period.

TABLE 1. RIPARIAN VEGETATION, STREAM MORPHOLOGY, AND STREAMBED SUBSTRATES IN THE NGAKAROA STREAM STUDY SECTION PRE- AND POST-HARVESTING.

HABITAT FEATURE	PRE-HARVESTING	POST-HARVESTING
Riparian vegetation	Pine trees, scrub hardwoods, ferns	Blackberry, carex sedges, tutu, ferns
Stream morphology	Pools, riffles, runs	Pools, riffles, runs, debris-plunge pools
Streambed substrates	Sand, silt, boulders coated with iron floc	Gravel, pebble, sand, silt, boulders coated with iron floc

3.2 FISH ABUNDANCE AND DISTRIBUTION

Seven species of fish were observed in the sampling site over the study period. These were: giant kokopu (*Galaxias argentus*), banded kokopu *(G. fasciatus*), longfin eel (*Anguilla dieffenbachii*), brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), common smelt (*Retropinna retropinna*), and redfin bully (*Gobiomorphus huttoni*).

3.2.1 Giant kokopu

There was no significant difference in the abundance of giant kokopu in the Ngakaroa Stream following logging. A statistical analysis (Student *t*-test) before and after logging showed no difference for any size class ($p > 0.05$). The mean numbers of large giant kokopu recorded pre- and post-logging were remarkably similar (Table 2, see details in Appendix 1).

However, the abundance of giant kokopu did vary greatly over the study period, with no obvious seasonal patterns (see Appendix 1). The highest number of kokopu (22 fish per 600 m) was recorded in February 1999, approximately 18 months after harvesting. High numbers of giant kokopu were also counted in February 1995 (19

TABLE 2. MEAN NUMBER OF GIANT KOKOPU OBSERVED PER 600 m IN THE NGAKAROA STREAM, BEFORE AND AFTER HARVESTING.

	ALL SIZE CLASSES	SMALL (< 70 mm)	MEDIUM (70–120 mm)	LARGE (> 120mm)
Pre-harvest	12.5	2.5	4.67	5.3
Post-harvest	10.33	1.78	3.11	5.4
Probability	p = 0.578	p = 0.517	p = 0.454	p = 0.140

fish per 600 m), April 1997 (21 fish per 600 m) and November 1997 (20 fish per 600 m). The lowest counts were recorded in June 1996 (2 fish per 600 m), September 1999 (4 fish per 600 m) and December 1999 (3 fish per 600 m). Floods might have dispersed fish before these low counts were made.

The giant kokopu population in the Ngakaroa Stream was composed mainly of large-sized kokopu (> 120 mm). McDowall (1990) considered that records of giant kokopu larger than 300 mm are now uncommon. However, even the largest fish in this small stream were nowhere near this size, and the largest giant kokopu observed was approximately 200 mm in length while the smallest were about 60 mm in length.

In general, the abundance of large-sized fish closely mirrored the overall abundance of giant kokopu. Medium-sized fish (70–120 mm and probably 1–2 years old) made up most of the population on only two sampling occasions (November 1997 and September 1998), both after the harvesting impact.

Small-sized (< 70 mm) giant kokopu made up a relatively minor proportion of the Ngakaroa Stream population over the study period although they were the dominant size class in July 2000, at the final fish count.

3.2.2 Other fishes

In addition to giant kokopu, six other species of fish were recorded during the study period, as mentioned above. Longfin eel, brown trout and rainbow trout became more abundant after harvesting, whereas banded kokopu and common smelt were less abundant (see Appendix 1). However, the only statistically significant change in abundance was the marked increase in redfin bully numbers (Table 3).

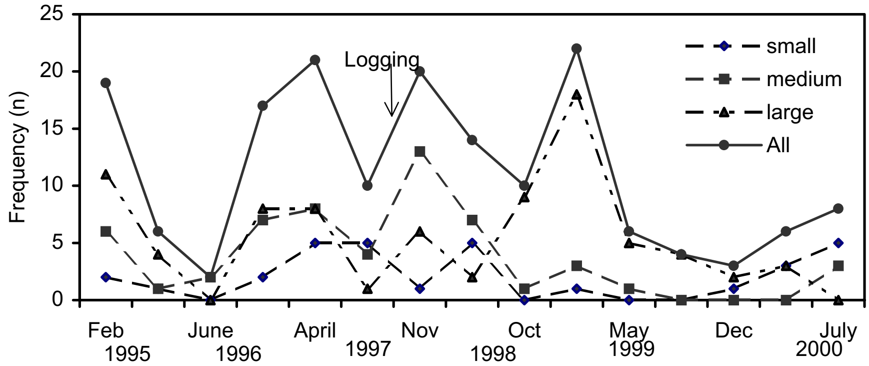

Figure 3.
Abundance of giant kokopu (small, medium, and large) in Ngakaroa Stream, Omataroa Forest.

Longfin eel

Longfin eel appeared more numerous after logging (Table 3), although the difference was not significant at the 5% level. Longfins ranged in length from 200 to 700 mm. The largest eels were probably resident, as they were seen repeatedly over the sampling period in the same sections of the stream. Large eels were most often found in pools and slow-flowing runs.

Redfin bully

There was a significant difference in redfinned bully abundance after logging ($p < 0.05$) (Table 3).

Trout

Brown and rainbow trout were only observed after logging (Table 3). A total of five fingerling-size trout were observed—three rainbow trout (September 1998) and two brown trout (July 2000). These juvenile trout were typically found in small pools in the lowest reach of the study area.

Banded kokopu and common smelt

Numbers of banded kokopu and common smelt were too few to derive any trends in abundance. Although the difference in the abundance of these species before and after logging was not significant, these fish did appear less numerous following logging.

TABLE 3. MEAN NUMBERS OF DIFFERENT FISH SPECIES OBSERVED PRE- AND POST- HARVEST, NGAKAROA STREAM, OMATAROA FOREST.

	BANDED KOKOPU	LONGFIN EEL	BROWN TROUT	RAINBOW TROUT	COMMON SMELT	REDFIN BULLY
Pre-harvest	1.3	4.7	0	0	3	8.5
Post-harvest	0.44	8.22	0.22	0.33	2.3	47.3
Probability	$p = 0.123$	$p = 0.061$	$p = 0.435$	$p = 0.435$	$p = 0.837$	$p = 0.030$

3.3 BENTHIC INVERTEBRATES

The benthic invertebrate fauna in the study site was composed mainly of freshwater snail (*Potamopyrgus* sp.) and freshwater shrimp (*Paratya curvirostris*). Freshwater shrimp were not observed within the study site before logging. Larval mayfly (*Ephemeoptera* sp.) and caddisfly (*Trichoptera* sp.) were present at low densities in the riffles. An earlier survey (Mitchell et al. 1995) found this stream had the lowest density and diversity of invertebrates out of seven streams sampled within the forest.

4. Discussion

4.1 SHORT-TERM IMPACTS OF LOGGING ON FISH ABUNDANCE AND SPECIES DIVERSITY

Despite logging of the surrounding pine forest, the Ngakaroa Stream continued to support an abundant population of giant kokopu. Moreover, it appeared that some fish species, such as redfin bully and longfin eel became more abundant in the stream after logging.

4.2 GIANT KOKOPU

The abundance of giant kokopu varied greatly over the study period, with no obvious seasonal patterns. Statistical comparison of surveys before and after logging showed no significant difference in abundance. The highest number of kokopu (22 fish per 600 m) was recorded in February 1999 approximately 18 months after harvesting. Therefore the short-term impacts associated with logging activities clearly did not cause a dramatic decline in the abundance of giant kokopu, and the Ngakaroa Stream continued to provide suitable conditions for them.

Mitchell et al. (1995) reported that banded and giant kokopu in Omataroa Forest streams were present at sites with overhanging riparian vegetation and often large organic debris (tree trunks and large branches). Although logging had a severe impact on the Ngakaroa Stream riparian vegetation, there was rapid regrowth of the native scrub hardwoods left along the stream banks (even from bent, snapped, and partially buried plants). In addition, considerable amounts of large woody debris entered the stream during logging and extraction, potentially providing long-term cover for giant kokopu.

Logging of pine forest could mimic natural windthrow events in native forest. A survey of streams in Omataroa Forest (Mitchell et al. 1995) included native forest catchments. It was found that steep, unconsolidated pumice soils resulted in regular bank collapse and toppling of mature native trees into these streams. Native fish remained present and seemed likely to be adapted to this type of disturbance.

In contrast, complete conversion of catchments from forest to pasture, with riparian vegetation dominated by grasses, no overhead cover, and loss of any woody debris supply, may help to explain the scarcity of giant kokopu over wide areas of New Zealand (McDowall 1990).

4.3 OTHER FISH SPECIES

More redfin bully, longfin eel, brown trout, and rainbow trout were found in Ngakaroa Stream after logging. Reason(s) for this apparent increase are unknown but possibilities are: increased instream photosynthesis, more accurate fish counts, and natural variation in fish numbers.

Increased photosynthesis

It is possible that removal of the overshadowing canopy of pine trees increased primary production and consequently the abundance of aquatic invertebrates. Fishes that feed upon aquatic invertebrates, such as redfin bullies, could be expected to increase in numbers. Small heavily shaded streams flowing through forest seldom support an abundance of aquatic plants or algae. As a result, the photosynthesis that drives the stream ecosystem largely occurs within the surrounding forest. Dissolved organic nutrients, leaf-litter, woody debris, and terrestrial insects that fall into forest streams play a pivotal role in supporting aquatic life (Hicks 1997). This was probably the natural state of small lowland streams in New Zealand.

Removing the forest and exposing the stream to sunlight alters energy pathways. Aquatic plants and algae then supply the food of aquatic invertebrates and ultimately fish (Hicks 1997). A survey of invertebrates and fish within Omataroa Forest streams found that the Waiwhero Stream, one year after logging and subsequent thorough removal of slash and debris, had the highest aquatic invertebrate abundance and one of the lowest fish densities (Mitchell et al. 1995). At that time, these results were in contrast to the similar-sized and adjacent Ngakaroa Stream. Studies have shown that eel growth in pastoral streams significantly exceeds that in forested catchments (Chisnall & Hayes 1991). With their tolerance of high silt loads and an ability to forage on a wide variety of foods, eels are the survivors in pastoral streams. However, the specialised native fish community adapted to live under forested conditions seems to largely disappear (Swales & West 1991).

More accurate fish counts

Up to one year after logging, the removal and flattening of riparian vegetation allowed relatively easy access and possibly enabled more accurate fish counts. Subsequently, blackberry and pampas grass reached a stage where access again became difficult. As counts of species such as redfin bully still remained high, it appeared that counting accuracy was reasonably consistent throughout.

Natural variations in fish numbers

Possibly the increase in numbers of 'other' fishes was simply due to normal natural variation.

5. Suggestions for forest management

Some native freshwater fishes, particularly the kokopu species, are widely considered to be specialised inhabitants of streams flowing beneath native forest (McDowall 1990). If the stream habitats required by these fishes could be provided within plantation forestry, perhaps some populations could be restored. This study suggested that narrow (10–20 m) riparian strips of native scrub-hardwoods within and beneath exotic forest could provide a reasonable simulation of native forest streams.

Discussions with the forest managers indicated the planting regime required for exotic trees to reliably and rapidly establish a diverse understorey of native scrub-hardwoods along riparian margins.

The first point made was that reserving compulsory unplanted riparian strips for stream 'protection' during forest establishment was of little value. It was widely observed through the forest that grasses and light-demanding weed species dominated these strips for at least two decades. From the perspective of the forest managers, riparian vegetation is incidental and could be anything except invasive weeds such as blackberry, pampas, and buddleia. Leaving strips of these problem plants in place during harvesting, in order to protect stream margins, simply provides a large-scale source of seed for rapid re-invasion during the forest establishment phase. These weeds provide significant competition for young trees and incur large control costs. Therefore forest managers tend to 'clean' reserved riparian margins in the process of preparing adjacent compartments for replanting. From their perspective, buffer strips of native vegetation would be more desirable because they could provide a permanent barrier to weed establishment, while protecting riparian values.

The second point was that deliberate establishment of riparian margins of native scrub-hardwoods would not be difficult. These species are largely bird-dispersed and they establish and regenerate naturally. No active management or expenses such as planting or releasing are necessary. This is a major advantage when kilometres of riparian margins may be present within an exotic forest. However, scrub-hardwoods grow naturally on the margins or within forest and so these conditions must first be provided. More tolerant 'pioneer' species such as *Coprosma robusta* and *Coriara aborea* will quickly colonise the early forest soils that develop from pine-needle litter. However, it is the 'dappled light' climate beneath the mature tree canopy that appears critical for rapid establishment of a diverse understorey of native scrub-hardwoods, paving the way for native forest succession.

Therefore the first tree-crop should be planted to the stream margins as a nurse crop, providing the light regime and leaf litter required for native plants to establish and out-compete invasive exotic weed species. Every sizeable exotic forest offers examples of different planting regimes and compartment ages, where the effects of different light regimes on the understory can easily be seen. Under the conditions of Omataroa Forest, the following planting and management strategy was suggested to develop the best native scrub-hardwood riparian strips:

1. Because the stream channel will naturally form a lightwell, only a minor tree-planting setback from stream margins should be made (of course there will be steep or swampy banks that cannot be planted).
2. Following a standard initial planting density of 800 stems/ha right to the edge of the stream, a riparian strip reaching back 10 m from each bank should then be managed separately. Along this strip, trees should be thinned to 200–300 stems/ha at 8 years. Active thinning should also be done on any wilding pine establishment. This density of pine trees was considered about optimum for native understorey species to establish in Omataroa Forest (N. Geerkins pers. comm.). In contrast, the remainder of a compartment under a pulpwood regime would probably only be thinned to 400 stems/ha. At this high density, only the hardiest ferns will establish, at infrequent intervals across the forest floor.

By the time of replanting, the riparian margin will be obvious. Desiccants should not be applied along this zone unless pine replanting is necessary. Replanting will only be required where significant logging damage has occurred or where weed species have become dominant. By the middle of this second tree crop, some 30 to 40 years after conversion to forestry, the mature scrub-hardwoods should begin to provide the dappled light regime and forest soils required for the establishment of canopy and subcanopy native trees. At Omataroa, nearby native forest remnants act as a source for species such as pigeonwood (*Hedycarya arborea*), mangeao (*Litsea calicaris*), rewarewa (*Knightia excelsa*), and tawa (*Beilschmiedia tawa*).

By the third logging cycle, the regeneration of riparian margins should have reached a stage where final compartment boundaries can be delineated. Logging practice should be controlled to fell trees away from the riparian margins wherever possible, although some level of intrusion and windthrow of trees through the scrub-hardwood riparian corridors will be inevitable. Therefore standard ‘stream cleaning’ to remove debris dams and blankets of light slash material will continue to be required after logging to avert flash floods. However, at each harvesting, an effort should be made to limit damage to the riparian margins while leaving enough large stable timber in the stream after ‘cleaning’ to provide cover for fish, mimicking a native forest stream. The surrounding exotic forest will continue to supply this instream timber from windthrow and the logging cycle. Otherwise large woody debris would not be provided until the slow-to-establish, long-lived riparian native trees became senile, perhaps requiring centuries.

It is suggested that one long-term goal for forest managers could be to manage plantation forests in such a way as to restore within-forest streams towards their original condition.

6. Conclusions

Seasonal spotlighting surveys have proved to be an efficient means by which to examine the long-term impacts of tree harvesting practice upon a giant kokopu population in the Ngakaroa Stream.

Although the abundance of giant kokopu varied greatly over the 5-year study, there was no significant decline in the abundance of giant kokopu in the Ngakaroa Stream following logging of the catchment. Redfinned bully were more numerous after logging; the increase in longfinned eel, brown trout, and rainbow trout numbers was not significant in statistical terms.

After logging, regeneration of a native plant reserve along the riparian margins appeared to maintain suitable habitat conditions for giant kokopu.

The deliberate use of pine plantings to encourage regeneration of shade-tolerant native hardwood scrub species along riparian margins, in preference to invasive light-demanding weed species, is suggested as a practical and low-cost method for restoring native fish habitat, with long-term benefits for forest management.

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Appendix 1

Sampling dates and numbers of fish observed in the Ngakaroa Stream, Omataroa Forest

DATE	GIANT KOKOPU				BANDED	LONGFIN	BROWN	RAINBOW	COMMON	REDFIN
	SMALL	MEDIUM	LARGE	TOTAL	KOKOPU	EEL	TROUT	TROUT	SMELT	BULLY
21 Feb 95	2	6	11	19	4	3	0	0	0	1
21 Sep 95	1	1	4	6	1	4	0	0	0	3
03 Jun 96	0	2	0	2	1	3	0	0	2	5
09 Nov 96	2	7	8	17	0	9	0	0	0	21
01 Apr 97	5	8	8	21	1	6	0	0	8	7
29 May 97	5	4	1	10	1	3	0	0	8	14
Logging										
25 Nov 97	1	13	6	20	2	7	0	0	0	9
09 Sep98	5	7	2	14	1	14	0	3	0	50
11 Oct 98	0	1	9	10	1	13	0	0	0	28
27 Feb 99	1	3	18	22	0	4	0	0	21	126
08 May 99	0	1	5	6	0	6	0	0	0	38
06 Sep 99	0	0	4	4	0	6	0	0	0	19
11 Dec 99	1	0	2	3	0	12	0	0	0	25
28 Mar 00	3	0	3	6	0	5	0	0	0	38
05 Jul 00	5	3	0	8	0	7	2	0	0	93