Conservation, management and research directions for giant kokopu (*Galaxias argenteus*) in Otago

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ABSTRACT

In research on the threatened giant kokopu (*Galaxias argenteus*) in the Otago region between 1998 and 2002, significant populations of the species were found within small streams draining into the Taieri Floodplain but were rarely located from lentic waterbodies. Giant kokopu were regularly found with brown trout (*Salmo trutta*) within the same stream but co-existence at finer spatial scales was less common. Within streams, giant kokopu used specific habitat types and maintained restricted home-ranges during base flow conditions. During winter, giant kokopu were always concealed amongst cover during the day and located in open, low-velocity (0–0.05 m/s) habitats at night (i.e. strictly nocturnal). During summer, they were frequently active both during light and dark periods, with fish showing a marked increase in the use of shallower and higher-velocity (0.05–0.15 m/s) habitats, particularly at night. During summer and winter, aquatic and terrestrial items were both important components in the diet. During high-discharge events, fish displayed a range of behaviours, with some fish exhibiting homing capabilities. In many instances individual giant kokopu exhibited adaptive behaviours in response to high flows. Strategies are suggested for the future conservation and management of giant kokopu in Otago.

Keywords: threatened fish, native fish, giant kokopu, *Galaxias argenteus*, stream habitats, diet, stream velocity, Taieri Floodplain, Otago, New Zealand.

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1. Introduction

Many of New Zealand's native fishes are small, nocturnal and highly secretive (McDowall 2000). As a consequence the life histories and behaviour of many of these species are not well known. The family Galaxiidae is well represented in New Zealand, with at least five species known to have diadromous life histories (koaro, *G. brevipinnis*; inanga, *G. maculatus*; banded kokopu, *G. fasciatus*; shortjawed kokopu, *G. postvectis*; giant kokopu, *G. argenteus*). Of these, the giant kokopu is the largest, having been reported to grow to 58 cm and 2.7 kg in weight (McDowall 1990a).

The giant kokopu was once quite common, being regularly encountered and used as a food source by early settlers (Anderson 1916) and the Maori people (Ligar 1845). Today, however, it is less common and is currently classed as a Category B (second priority) threatened species (Williams & Given 1981; Hitchmough 2003). Although uncommon, the species is widely distributed throughout New Zealand due to its diadromous life history. Distributions are uneven, however, with most of the records for giant kokopu (87%) originating from Westland, Southland, Wellington, and Waikato (New Zealand Freshwater Fish Database (NZFFD), Fig. 1). Interestingly, few giant kokopu have been recorded from the east coast of New Zealand.

A growing number of studies indicate that the decline in abundance and fragmented distribution structure of many of New Zealand's native species (including the giant kokopu) is/has been the result of two main factors: habitat loss/degradation (e.g. Main 1988; Hanchet 1990; McDowall 1990a; Minns 1990; Swales & West 1991; Bonnett 2000; Chadderton & Allibone 2000), and predation/competition by introduced salmonids (e.g. Townsend & Crowl 1991; Crowl et al. 1992; McIntosh et al. 1992). For diadromous species such as the giant kokopu, the harvesting of migrating whitebait by recreational anglers may be having an additional, though perhaps less significant, impact (McDowall 1992; Bonnett 2000). The relative importance of each of the factors having contributed to the decline of giant kokopu is likely to be site-specific, although a combination of factors is likely to be involved. Thus an improved understanding of the habitat requirements and other aspects of giant kokopu ecology is required to ensure their future protection.

1.1 OBJECTIVES

The general objective of this research was to examine the ecology of giant kokopu at a variety of spatial and temporal scales in Otago and to provide information that could be used for future management of this species. More specifically, the spatial distribution; seasonal micro habitat use, home range and activity patterns; and flood behaviour of giant kokopu are discussed. The specific objectives were:

Spatial distribution

(1) To determine the distribution of giant kokopu and other fish within lentic and lotic habitats in the Taieri Floodplain.

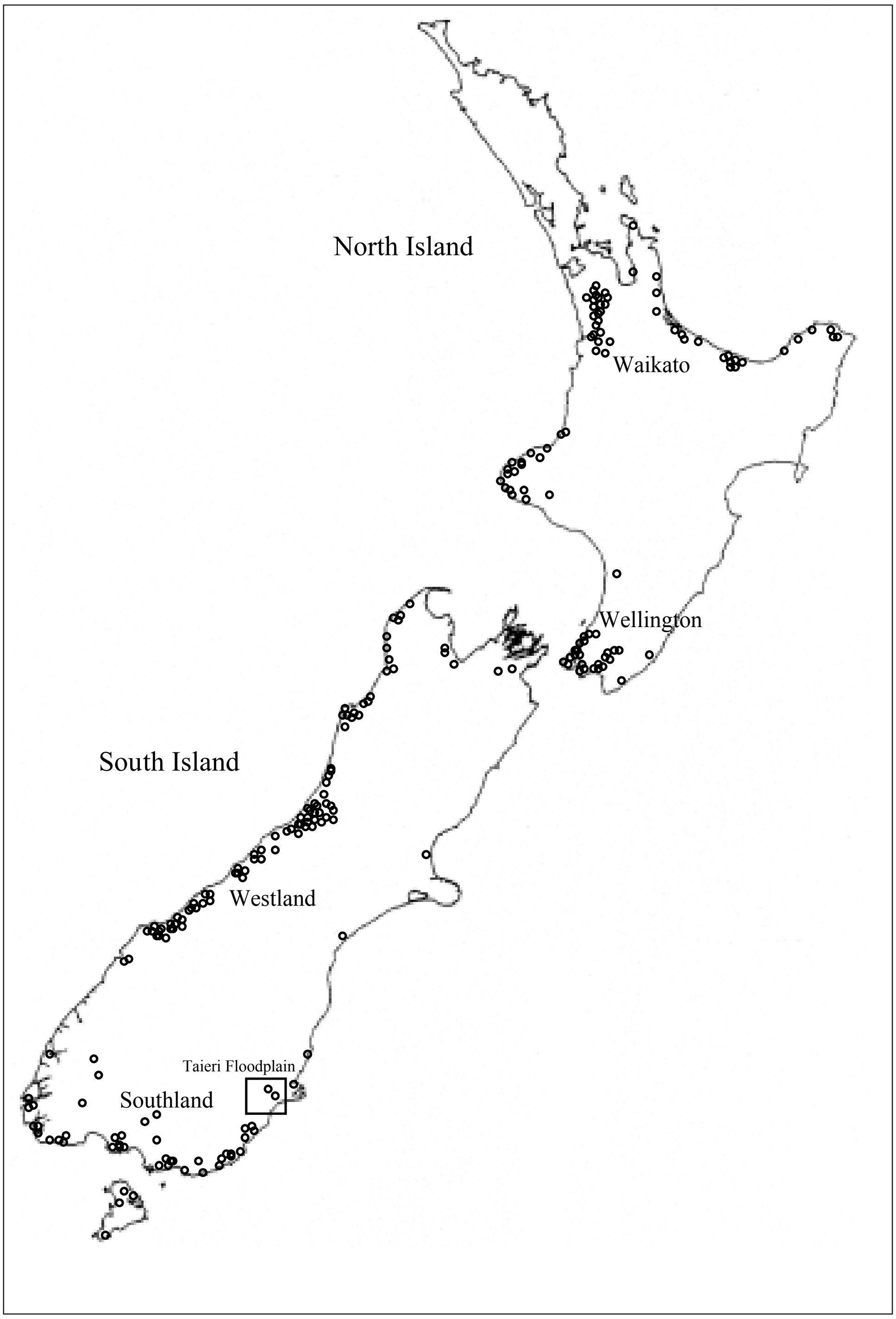


Figure 1. Distribution of giant kokupu (*Galaxias argenteus*) throughout New Zealand. Data obtained from the New Zealand Freshwater Fish Database. The boxed area, shown in detail in Fig. 2, indicates records within the Taieri Floodplain prior to the present research.

(2) To compare the longitudinal distribution of giant kokopu relative to brown trout in streams.

Habitat use, home range and activity

(1) To record the activity of individual adult giant kokopu over 24 h periods during winter and summer.

(2) To record point-in-time microhabitat use data for giant kokopu during the day and night throughout winter and summer.

(3) To use these data to determine the home range of giant kokopu.

Flood behaviour

(1) To examine the movements of giant kokopu before, during, and after high-discharge events.

2. Spatial distribution

2.1 BACKGROUND

The Taieri Floodplain lies approximately 45 km south-west of Dunedin and is characterised by a variety of lentic and lotic habitats. Despite substantial sampling by numerous researchers prior to this study, only two individual giant kokopu had been recorded from the Taieri Floodplain in the last 40 years, one from Mill Stream (1994) and one from Silver Stream (1964) (Fig. 2, NZFFD). An additional four giant kokopu (three from Titri Channel and one from the Sinclair Wetlands) were captured in August 1998 just before the present research began (P. Ravenscroft pers. comm, B. David unpubl. data, Fig. 2) indicating that perhaps this species was more common than previous records indicated.

In order to determine the extent of the distribution of giant kokopu across the floodplain, two landscape-scale surveys were conducted. The first was within lentic (pond, lake) habitats from November to December 1998 and the other within lotic (stream, creek) habitats from January to April 1999.

2.2 METHODS

The lentic survey was conducted throughout the Waihola/Waipori Wetland Complex in 1998, with many waterbodies within the Sinclair Wetlands sampled. In total, 27 waterbodies were surveyed, using a variety of techniques including fyke, gill, and seine nets, minnow traps and spotlighting (for more information see David 2002).

Lotic habitats were sampled using a continuous longitudinal spotlight sampling approach in the summer of 1999. This approach enabled any longitudinal changes in fish distributions to be detected. Stream selection was based on the following characteristics: size (2^{nd} to 3^{rd} order), depth (max. < 2 m), width (max. < 4 m), clarity (visibility to the stream bed), length (less than 10 km), distance to sea (< 40 km), year-round flow (permanent) and accessibility for diadromous species (no artificial structures blocking passage to or from the sea). Of the streams present within the floodplain, eight met these criteria: Lee, Cullen's, Alex, and Boundary Creeks, which entered the Waipori River system, and Owhiro, Mill, Flagstaff and Picnic Gully Creeks, which entered the Taieri River system (Fig. 2).

To describe the longitudinal distributions of giant kokopu and brown trout, a Global Positioning System (GPS) point was taken c. every 80–100 m while spotlighting. Each GPS point provided a reference location that was later used

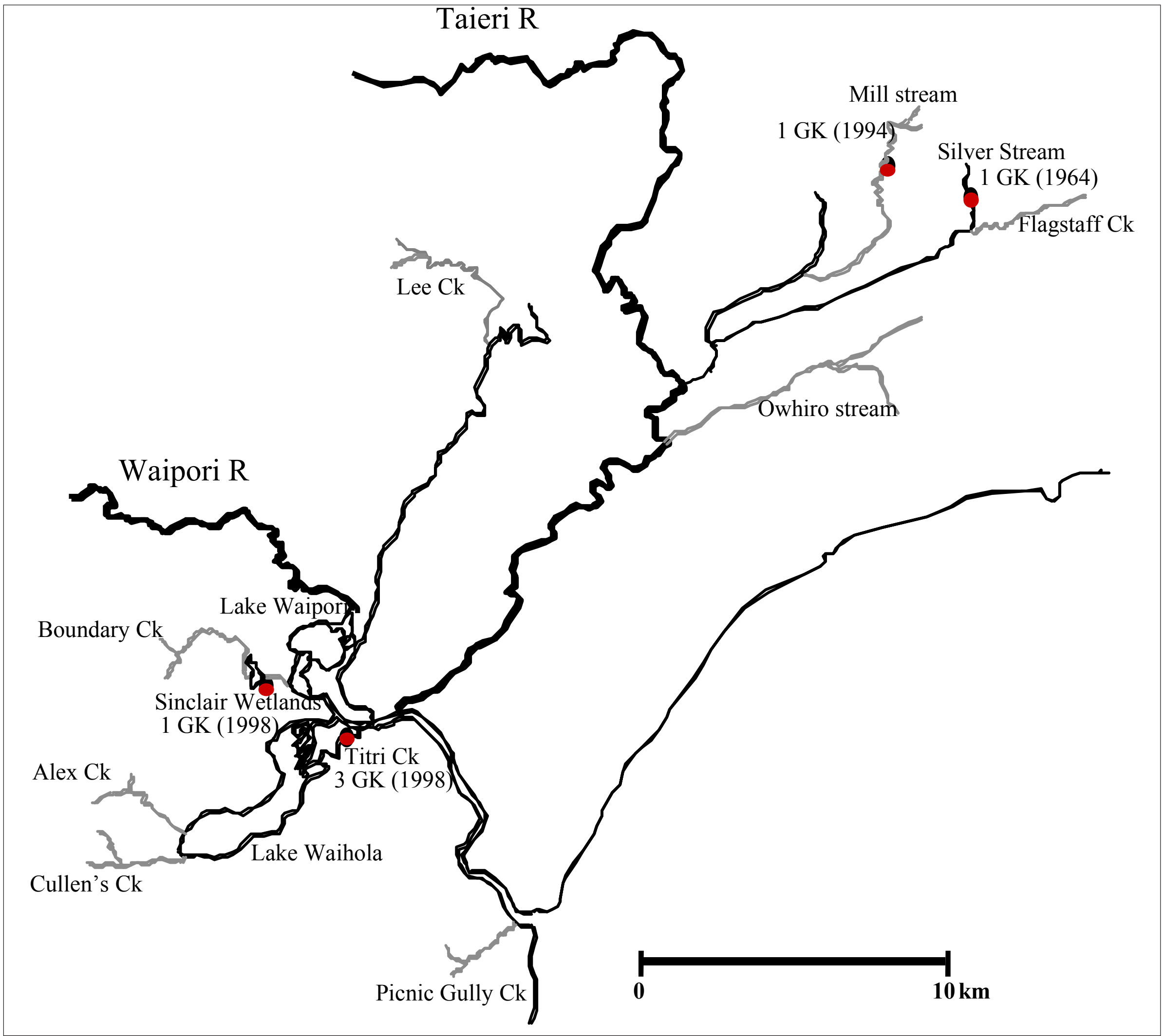


Figure 2. The Taieri Floodplain. Location and number of giant kokupu recorded prior to the present study are indicated by GK.

together with fish distribution data to plot the longitudinal distribution of giant kokopu relative to brown trout in each stream. An aerial photograph of each stream was scanned into a Geographic Information System (GIS) program onto which the GPS points and fish distributions were plotted. The sum of the distance between each of the GPS points (determined using the GIS program) represented the total stream distance surveyed, from which a coarse estimate of fish abundance (number of fish/km) was calculated (for more detailed information see David et al. 2002)

To assess and compare the habitat used by giant kokopu and brown trout we classified stream morphology into five coarse habitat types: agricultural channel (modified stream channel with uniform depth and width), backwater (distinct areas connected to main channel but lacking flow), pool (smooth, deep, slow flow), riffle (fast, shallow, broken water), and run (moderately fast water deeper than riffle, unbroken surface). Each time a fish was located, its length and the stream morphology category in which it was present were recorded. Fish length was measured either directly (by capture with a dip net) or visually estimated (accuracy ± 3 cm, $n = 43$). Giant kokopu and brown trout < 10 cm were classified as small young-of-the-year fish (Jellyman 1979; Elliott 1994). Individuals of both species > 10 cm were classified as large. Habitats used by all individuals of a species and within each size category were pooled for all eight streams surveyed. Habitat use was expressed as the frequency of occasions that each species was detected in each of the five habitat types.

To examine whether recent recruitment (within the last 2 years) of giant kokopu had occurred within each stream, the size distribution was examined. Individual fish were categorised into one of eight size classes (0–5 cm, then in 5 cm increments to > 35 cm).

2.3 RESULTS SUMMARY

Despite intensive sampling within more than 25 lakes, no giant kokopu were captured in the lentic survey. In contrast, they were detected in each of the eight lotic habitats that were surveyed.

A total of eight native and two introduced species were recorded during the lotic survey. Eels (*Anguilla* sp.) and giant kokopu were the most widely distributed species, being located in all streams surveyed. Common bullies (*Gobiomorphus cotidianus*) and brown trout (*Salmo trutta*) were also widely distributed, being detected in seven and six of the streams, respectively (Table 1).

The size structure of giant kokopu located in each stream indicated that substantial recruitment only occurred in Cullen's and Alex Creeks. Recruitment in all other streams was limited or non-existent (only larger size classes present) indicating that these populations may be vulnerable to extirpation in the future (Table 2).

Three streams of potential conservation significance were identified: Picnic Gully Creek, which contained a significant population of banded kokopu, *Galaxias fasciatus* (a 3rd priority threatened species), and Cullen's and Alex Creeks, which contained significant populations of giant kokopu (Table 1).

Distributions of brown trout and giant kokopu rarely overlapped at a local scale (see David et al. 2002). Coarse habitat use data indicated that brown trout

TABLE 1. TOTAL DISTANCE (DIST) IN METRES OF EACH STREAM SURVEYED BY SPOTLIGHT AND THE ESTIMATED ABUNDANCE OF *Galaxias argenteus* (GK), *Salmo trutta* (BT), *Anguilla australis* AND *A. dieffenbachii* (Eel), *Gobiomorphus cotidianus* (CB), *Perca fluviatilis* (EP), *Galaxias maculatus* (IN), *Galaxias brevipinnis* (KO), *Gobiomorphus huttoni* (RFB) AND *Galaxias fasciatus* (BK) PER KM OF STREAM.

STREAM	DIST (m)	GK /km	BT /km	Eel /km	CB /km	EP /km	IN /km	KO /km	RFB /km	BK /km	TOTAL FISH/km
Owhiro	3586	3.6	0.0	2.5	32.3	0.0	1.1	0.0	0.0	0.0	39.6
Alex	2684	65.6	0.4	16.4	12.7	0.0	20.1	0.0	0.7	0.0	115.9
Cullen's	1208	38.1	3.3	9.1	24.8	0.8	145.7	0.8	0.8	0.0	223.5
Lee	3925	3.8	144.7	11.7	65.5	0.0	0.8	1.5	0.3	0.0	228.3
Mill	3479	8.9	135.1	10.6	0.3	0.0	0.0	0.0	0.0	0.0	154.9
Boundary	2712	5.5	39.8	6.6	6.3	6.6	4.8	0.0	0.0	0.0	69.7
Flagstaff	1731	2.9	47.9	4.0	0.6	0.0	0.0	3.5	0.0	0.0	58.9
Picnic Gully	1152	0.9	0.0	0.9	0.0	0.0	0.0	2.6	5.2	218.8	228.3

TABLE 2. NUMBER AND PERCENTAGE OF GIANT KOKUPU RECORDED WITHIN EACH SIZE CATEGORY (TOTAL LENGTH, cm) FOR EIGHT STREAMS SURVEYED.

STREAM	0-5	6-10	11-15	16-20	21-25	26-30	31-35	> 35	TOTAL
Cullen's	1	9	6	16	2	3	5	1	43
Mill	0	2	5	12	5	6	1	0	31
Flagstaff	0	1	1	2	1	0	0	0	5
Alex	3	54	42	36	23	10	9	0	177
Boundary	0	1	6	6	2	0	1	0	16
Lee	0	3	8	3	0	0	1	0	15
Owhiro	1	0	3	3	5	1	0	0	13
Picnic Gully	0	1	0	0	0	0	0	0	1
Total	5	71	71	78	38	20	17	1	301
Percentage	1.7	23.6	23.6	25.9	12.6	6.6	5.6	0.3	100

regularly occupied a variety of habitat types, including modified agricultural channels. In contrast, giant kokopu rarely used agricultural channels, being predominantly located in pool habitats (Fig. 3).

2.4 CONCLUSIONS AND RECOMMENDATIONS

Cullen's and Alex Creeks should be given high conservation priority, since the population of giant kokopu in them represents the largest known on the east coast of New Zealand (excluding Southland). Recruitment to both streams is substantial, with good numbers of juvenile (5–10 cm) to medium (10.1–15 cm) size classes present on a yearly basis. The main issues for these creeks revolves around habitat degradation. Livestock are frequently granted access directly to

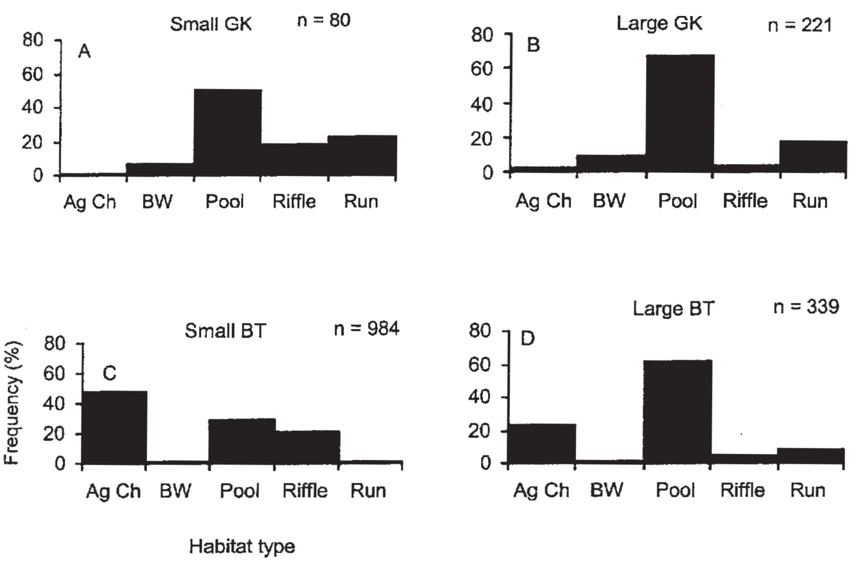


Figure 3. Proportional use of habitat by (A) small and (B) large giant kokopu (GK) and (C) small and (D) large brown trout (BT) recorded from eight streams, using spotlighting.
Small < 10 cm, large > 10 cm. Ag Ch agricultural channel, BW backwater.

both streams, and this has caused an increase in sediment transport due to stream bank collapse (making parts of the stream shallower) and decreased the water quality (increase in turbidity and nutrients). Faecal inputs into both streams from livestock may also be having adverse effects on stream biota and be a contributing factor to the algal blooms recently experienced in Lake Waihola into which both these streams drain. More research is needed here.

The population of giant kokopu in streams in which recruitment appears to be poor (e.g. Mill, Owhiro) should be monitored regularly by spotlight to assess whether there is a decline in abundance through time. Results may indicate whether the population is vulnerable to extirpation in the future.

Both habitat requirements and competition or predation (not necessarily by trout) appear to influence the distribution of giant kokopu and brown trout. At the coarsest scale of habitat use it is apparent that brown trout may occupy a variety of habitat types, including highly degraded agricultural channels. In contrast, giant kokopu tend to exhibit less flexibility in habitat use, with larger fish being located primarily in pool habitats within streams.

Direct visual observations of competition between giant kokopu and brown trout would be an informative and fruitful area for future research.

3. Habitat use, home range, and activity

3.1 BACKGROUND

Vast tracts of forest have disappeared from the New Zealand landscape in a short period of time. The area of indigenous forest prior to Polynesian arrival covered more than 21 million hectares (King 1984), and now it is less than six million hectares. For streams, the resultant effects of deforestation include increased light, temperature and nutrient inputs, and increased erosion and sedimentation (McDowall 1990a). In Otago and elsewhere around New Zealand, these effects have no doubt been exacerbated by the conversion of cleared forest to pasture, and intensified through the trampling of stream banks by stock and artificial channelisation of watercourses. Understanding how these practices can impact on giant kokopu is critical to their future management and protection, and requires an improved understanding of their ecology.

3.2 METHODS

Detailed habitat use, home range and activity of 16 giant kokopu were examined in Cullen's and Alex Creeks using radiotelemetry between 1999 and 2001. Habitats used by and available to individual giant kokopu were recorded to determine their habitat preferences. Measurements included, depth, flow and substrate type, and cover types used by fish were also recorded. Activity of individual fish over 24 h was recorded using a remote radiotelemetry system (David & Closs 2001). Diet of giant kokopu (excluding radio-tagged fish) was examined by non-destructive stomach pumping of anaesthetised fish during summer (n = 18 fish) and winter (n = 20 fish).

3.3 RESULTS SUMMARY

During winter, giant kokopu predominantly used streams with low velocities (max. 0.08 m/s), silt substrates and intermediate depths during both light and dark periods (Fig. 4). Activity recorded during 72 h periods (Figs 5, 6) indicated

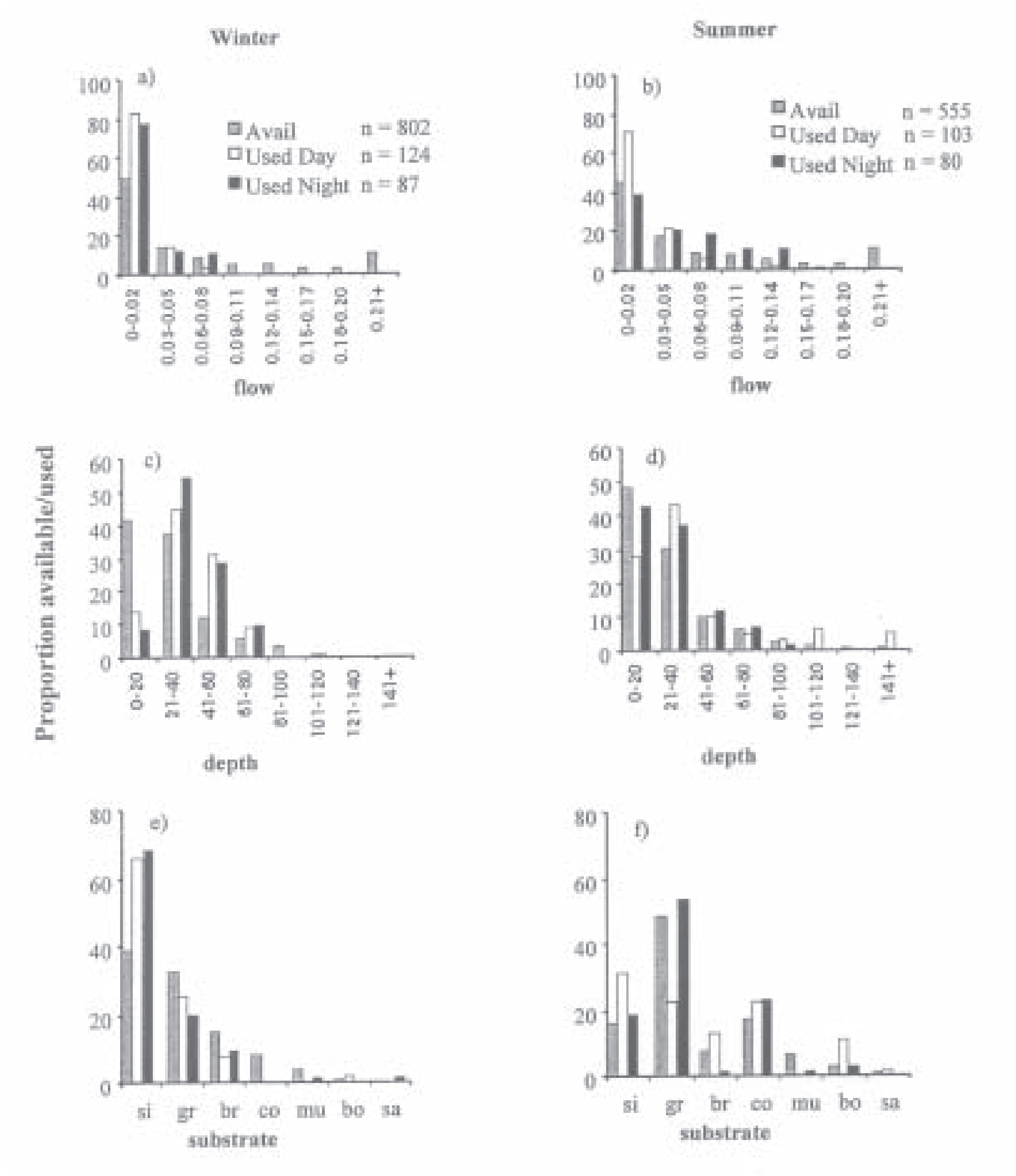


Figure 4. Proportion of habitats (flow, depth, substrate) used by, and available to, giant kokopu during the night and day throughout winter and summer.

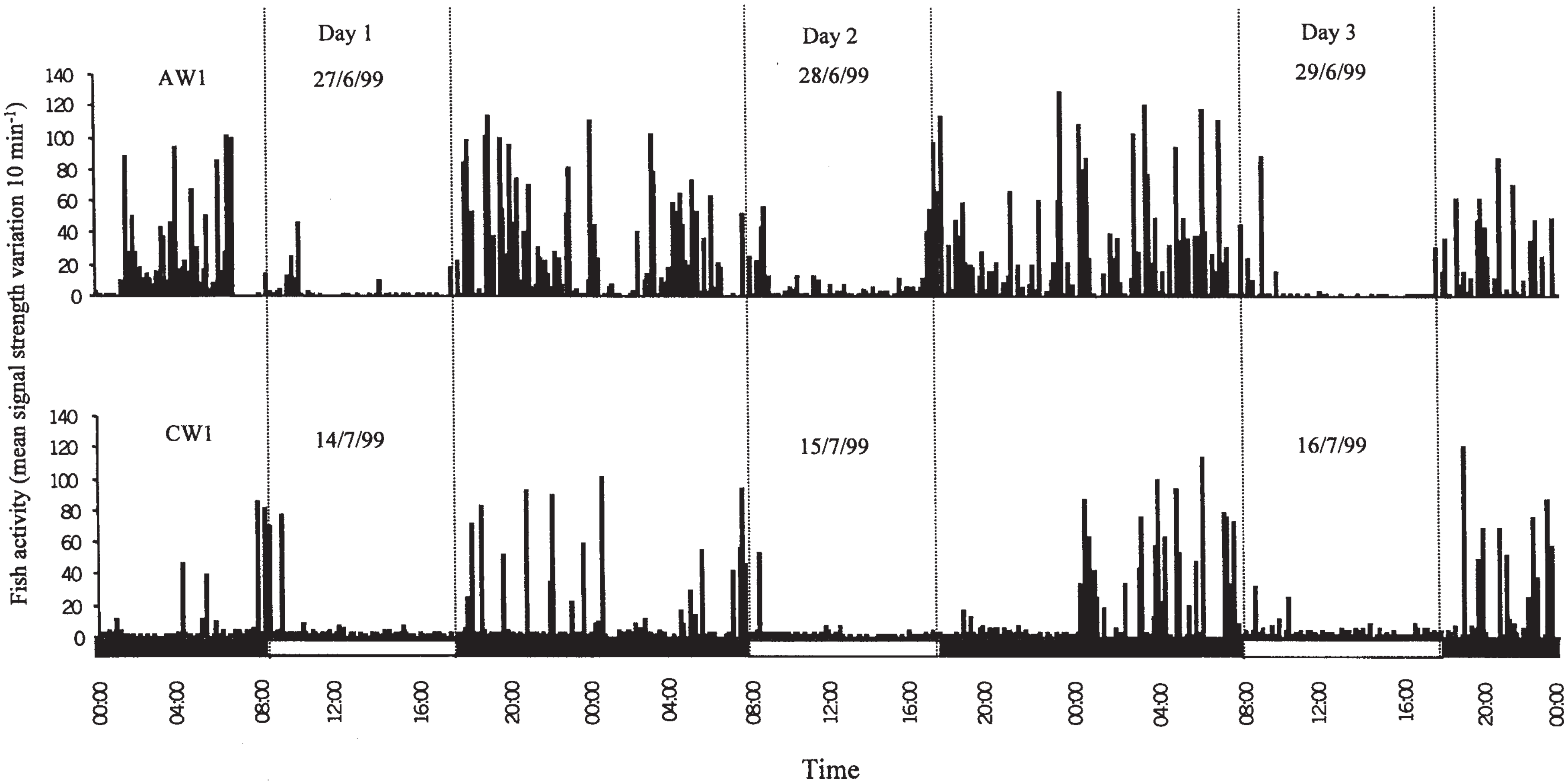


Figure 5. Activity of giant kokopu individuals AW1 and CW1 recorded over three consecutive days during winter. Each bar represents the mean variation in signal strength over three 10 sec intervals recorded every 10 min for 72 h. Bar at bottom indicates light and dark periods.

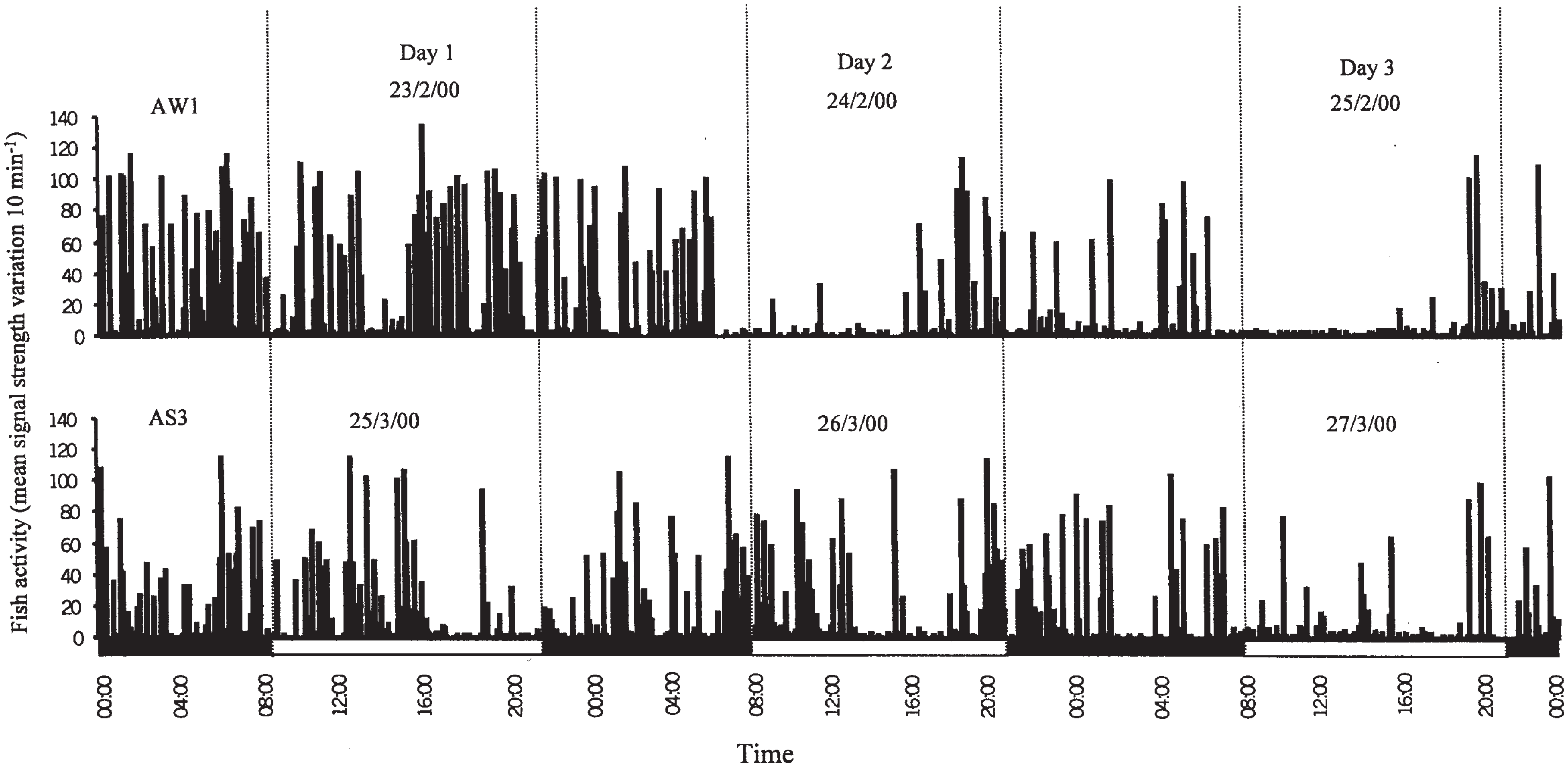


Figure 6. Activity of giant kokopu individuals AW1 and AS3 recorded over three consecutive days during summer. Each bar represents the mean variation in signal strength over three 10 sec intervals recorded every 10 min for 72 h. Bar at bottom indicates light and dark periods.

that fish were active at night and inactive during the day in winter (Fig. 5). Activity data corresponded to point-in-time habitat use data, which indicated that fish were concealed amongst cover during the day and used open water habitats at night.

During summer, giant kokopu used streams with higher flows (max. 0.17 m/s), shallower depths and coarser substrates, particularly at night and also occasionally during the day (Fig. 4). Activity data indicated that they were active during both light and dark periods (Fig. 6), although periods of activity were less defined and less predictable than during winter, when giant kokopu were strictly nocturnal (Fig. 5).

Point-in-time and 24 h activity data indicated that adult giant kokopu used predictable home reaches during stable flow conditions, with most individuals exhibiting an affinity for one or two cover locations within the home reach that they used repeatedly (Table 3). Cover type (composition) used by fish did not appear to be important (Fig. 7). Reaches used by individuals rarely exceeded 26 m in length during summer or winter and always included a pool–riffle sequence (Table 4).

Diet of giant kokopu indicated that both terrestrial and aquatic items were consumed in winter and summer (Table 5).

TABLE 3. NUMBER OF COVER LOCATIONS USED BY INDIVIDUAL GIANT KOKOPU IN CULLEN'S AND ALEX CREEKS DURING WINTER AND SUMMER.

Numbers in parentheses represent the number of day locations on which cover use in each reach was based (CL R1 = Cover Location(s) used in Reach 1). * indicates those fish for which more than 25 day/night locations were obtained in a single reach.

	WINTER				SUMMER			
STREAM	FISH	CL R1	CL R2	CL R3	FISH	CL R1	CL R2	CL R3
Cullen's	CW1 *	1 (20) *	-	-	CW1 *	1 (13) *	-	-
	CW2	2 (7)	1 (5)	-	CS2	3 (7)	-	-
	CW3	2 (4)	2 (9)	3 (4)	CS3	3 (7)	1 (6)	-
	CW4	2 (9)	2 (4)	-	CS4	1 (3)	-	-
Alex	AW1 *	2 (4)	3 (16) *	-	AW1 *	1 (15) *	-	-
	AW2	2 (5)	1 (7)	-	AS2	1 (14) *	-	-
	AW3	1 (15) *	1 (2)	-	AS3	4 (15) *	-	-
	AW4	2 (4)	1 (9)	-	AS4	2 (8)	1 (8)	-

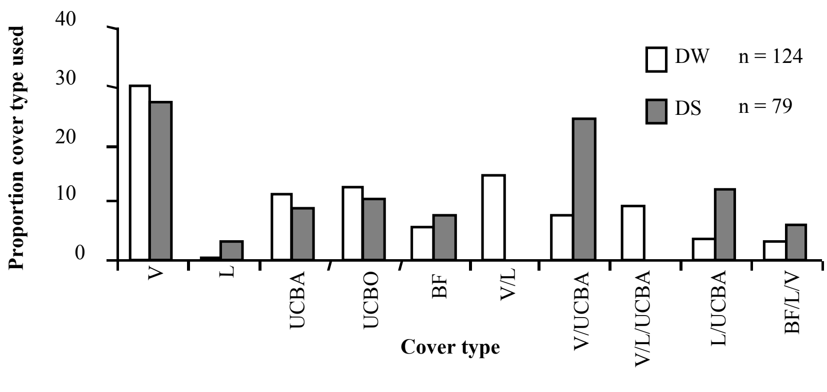


Figure 7. Proportion of cover types used by giant kokopu during the day in winter (DW) and summer (DS). V vegetation; L logs; UCBA undercut bank; UCBO undercut boulder; BF bankfall; remaining cover types are combinations, e.g. V/L vegetation and logs.

TABLE 4. HOME RANGES (m) AND POOL LENGTH (m) USED BY INDIVIDUAL GIANT KOKOPU IN CULLEN'S AND ALEX CREEKS DURING WINTER AND SUMMER.

Numbers in parentheses represent the total day and night locations on which the home range in each reach was estimated (HR R1 = Home Range Reach 1, PL R1 = Pool Length Reach 1). * indicates fish for which more than 25 day and night locations were recorded in a single reach.

	WINTER							SUMMER						
STREAM	FISH	HR R1	PL R1	HR R2	PL R2	HR R3	PL R3	FISH	HR R1	PL R1	HR R2	PL R2	HR R3	PL R3
Cullen's	CW1	18 (35) *	20	-	-	-	-	CW1	14 (25) *	20	-	-	-	-
	CW2	20 (14)	20	14 (8)	22	-	-	CS2	68 (13)	52	-	-	-	-
	CW3	16 (8)	18	10 (15)	10	12 (6)	13	CS3	22 (14)	20	22 (11)	35	-	-
	CW4	16 (14)	19	8 (8)	11	-	-	CS4	14 (6)	14	-	-	-	-
Alex	AW1	8 (8)	9	18 (25) *	18	-	-	AW1	16 (25) *	18	-	-	-	-
	AW2	12 (9)	12	12 (10)	12	-	-	AS2	24 (25) *	22	-	-	-	-
	AW3	14 (25) *	15	18 (4)	23	-	-	AS3	12 (25) *	12	-	-	-	-
	AW4	10 (8)	10	14 (15)	14	-	-	AS4	82 (15)	55	12 (13)	14	-	-

TABLE 5. PROPORTION OF VARIOUS AQUATIC AND TERRESTRIAL PREY ITEMS IDENTIFIED FROM THE GUTS OF 20 GIANT KOKOPU IN WINTER 1999 AND 18 IN SUMMER 2000. Total no. ID TOTAL NUMBER OF ITEMS IDENTIFIED.

PREY ORIGIN	PREY TYPE	WINTER	SUMMER
Aquatic	caddisflies	68.7%	44.3%
	mayflies	2.3%	40.7%
	other	29%	15%
Total no. ID	-	245	325
Terrestrial	beetles	17.7%	36.8%
	millipedes	55.3%	4.6%
	leafhoppers	0	21%
	spiders	4.3%	13.8%
	other	22.7%	24.1%
Total no. ID	-	141	325

3.4 CONCLUSIONS AND RECOMMENDATIONS

Knowledge of the habitat requirements and distributions of giant kokopu in unmodified streams (e.g. Chadderton & Allibone 1996, 2000; Bonnett 2000) or slightly modified streams (Bonnett 2000; Whitehead 2001; David 2002) can indicate how loss of suitable habitat can be detrimental to this species.

In the present study, giant kokopu used a predictable and generally small (< 20 m) home reach that contained both riffle and pool habitats; specific cover positions which provided a zero-low flow environment (though its composition was not important); low flows and fine substrates during the day and night in winter; and higher flows, coarser substrates and shallower depths in summer particularly at night.

This information highlights the facts that giant kokopu living in streams require heterogeneous rather than homogeneous habitats, and that they require a dynamic rather than a uniform flow regime. Thus, the absence of giant kokopu from degraded (particularly channelised) reaches of streams may be due to the lack of habitat heterogeneity and the often uniform flow conditions associated with these areas. Furthermore, such areas probably provide little or no refuge during high-discharge periods and thus fish would be unable to move into low-flow areas to avoid being displaced (see Section 4).

The habitat and activity information recorded also indicates that giant kokopu exhibit distinct seasonal and diel (day/night) differences in behaviour—behaviours which are important to consider when making management decisions. For example, a study conducted only during winter might suggest that giant kokopu are strictly nocturnal and always use low flows, but information collected during summer would suggest otherwise.

Overhead riparian cover does not appear to be an essential requirement for giant kokopu since they are commonly found in streams (or stream reaches) with or without it (Bonnett 2000; David et al. 2002). Nevertheless the presence of riparian vegetation is likely to be beneficial in that the quantity of terrestrial prey items available to giant kokopu would probably increase (Edwards & Huryn 1995). Terrestrial prey often constitute a substantial proportion of the foods consumed by giant kokopu (see Bonnett 2000; David 2002). An additional benefit of riparian vegetation is long-term stability of stream banks, as banks lacking vegetation are more prone to erosion, which may lead to increased sediment inputs and ultimately the in-filling of stream pools (and eventually decreased habitat heterogeneity).

Perhaps the greatest value of knowing the habitat requirements of stream-dwelling giant kokopu is that this information can be used to implement effective management strategies, for example to re-create or restore suitable giant kokopu habitat in degraded stream reaches (see Section 5.2).

4. Flood behaviour

4.1 BACKGROUND

High-discharge events occur in most stream systems. Their regularity, duration and magnitude may differ widely within and between streams, and how fish behave during such disturbances has important management implications. Opportunities to assess the influence of floods on fish behaviour are infrequent, however, probably because of the unpredictability of such events and the logistic problems associated with fieldwork (Matthews 1998). Understanding of flood effects on fish behaviour is limited and based primarily on comparisons of fish community structure before and after floods (e.g. Matthews 1986; Jowett & Richardson 1989; Matthews et al. 1994). Although such comparisons can provide information on what happened to the fish community as a result of an event, little is known of fish behaviour during an event.

The small coastal streams in which giant kokopu often reside can be subjected to regular 'flashy' spates due to New Zealand's highly variable maritime climate (Mosely & Pearson 1997). It is not known how giant kokopu are affected by these spates, although their persistence in such small streams suggests that they may have well-adapted responses.

4.2 METHODS

Sixteen giant kokopu were monitored during seven different floods using radiotelemetry. During each flood the movements made by each radio-tagged fish were tracked over consecutive days until flows subsided to pre-flood levels. Fish movements were categorised into three types: stay, move, and move and return. The distance travelled by each individual on each day was recorded.

4.3 RESULTS SUMMARY

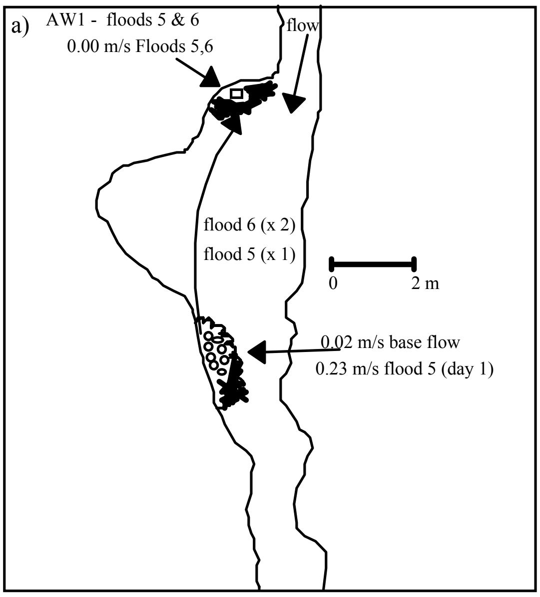
Giant kokopu remained within defined stream reaches during base flow conditions. During high-discharge events, individuals either stayed within their home reach, moved and settled elsewhere, or moved and returned to their home reach as flows subsided (Table 6).

In many instances, giant kokopu appeared to exhibit adaptive behaviours in response to high discharges. Behaviours supporting this view included fish that did not move during the highest floods, fish that moved upstream during the peak discharge period, and fish that made purposeful 'micro-movements' (movements < 1 m) into low-velocity habitats (e.g. Fig. 8, see also David & Closs 2002).

TABLE 6. NUMBER OF GIANT KOKOPU THAT STAYED (STAY), MOVED AND SETTLED ELSEWHERE (GO), AND MOVED AND RETURNED (RETURN) DURING EACH OF SEVEN FLOODS.

FLOOD	STAY	GO	RETURN
1	1	3	1
2	1	5	2
3	1	1	1
4	1	3	2
5	3	2	1
6	2	1	2
7	0	1	1
Total	9	16	10

Figure 8. Giant kokopu individual AW1 made micro-movements from its regular cover position (circles) to the same refuge location (open square) during floods 5 and 6, thereby escaping the high base flow they caused.



4.4 CONCLUSIONS AND RECOMMENDATIONS

The variable behaviour exhibited by individual giant kokopu suggested that reasons for moving during floods were complex, but might have included reproduction and mate searching, and or lack of adequate refugia.

High-discharge events may play an important role in re-distributing and re-organising populations of fish in small streams by providing opportunities for individuals restricted during base flow conditions to move to other stream locations.

·Giant kokopu did not appear to be passively displaced by floods in many instances, with some individuals remaining within their home reach during the most severe events, although others moved considerable distances during these periods. Consequently, habitat alteration and construction of barriers preventing longitudinal movement require careful consideration in streams containing giant kokopu, and it is important to recognise that barriers may not only impede movement of migrating whitebait from the sea but may also impede movement of the general resident population during high-flow events.

5. Future research directions

5.1 EFFECT OF INTRODUCED SALMONIDS

Introduced salmonids have been shown to negatively impact on native galaxiid species in both New Zealand (Townsend & Crowl 1991; Crowl et al. 1992; McIntosh et al. 1992) and Australia (Fletcher 1979; Ault & White 1994; Closs & Lake 1996). Most galaxiids rarely grow larger than 15 cm in total length (McDowall 2000), and their small size is likely to render them susceptible to predation or exclusion by larger salmonids. The importance of trout size relative to the impacts imposed on galaxiids has been demonstrated by McIntosh et al. (1994). In their study, densities of a small New Zealand galaxiid *Galaxias vulgaris*, declined in the presence of large brown trout, but did not differ when small trout or no trout were present. Trout size, as one might expect, was concluded to be the most important factor determining galaxiid density.

In contrast to most other galaxiids, giant kokopu may commonly attain 30–40 cm total length. In addition, they exhibit territoriality (David & Stoffels in press), and diet studies indicate that they will prey on other fish (Jellyman 1979; Rasmussen 1990; Bonnett 2000). Thus, while large trout may prey on or out-compete smaller giant kokopu, their influence over giant kokopu of similar or larger size may be quite different. Significant potential exists to examine (via direct visual observations) the importance of fish size in competitive interactions between these species. In challenging the dominant paradigm that galaxiids are inferior competitors to salmonids, it would be useful to measure at what size relative to brown trout do giant kokopu become the dominant fish. This would provide information on the susceptibility of a stream to invasion by salmonids, particularly if large giant kokopu are resident. It may also help to explain some of the distribution patterns within the Taieri Floodplain, in particular the distinct segregation of populations of brown trout and giant kokopu in Mill Stream and Lee Creek and to a lesser extent in Alex, Cullen's and Boundary Creeks (see David et al. 2002)

Several researchers (e.g. Moyle et al. 1983; Baltz & Moyle 1993) have suggested that native fish communities may be resistant to invasion by introduced fishes, despite the absence of obvious barriers to invasion and the presence of suitable habitat. Baltz & Moyle (1993) found that certain Californian stream systems resist invasion by exotic fish species providing they are relatively undisturbed by human activity. Although most waterways have been modified to some extent in New Zealand, there are a number of areas which are relatively undisturbed by human activity and in which introduced species are either absent or present only in low abundance, for example streams on Stewart Island (Chadderton & Allibone 2000), small streams on the west coast of the South Island (Jowett et al. 1998; B. David unpublished data), and a number of small streams on the east coast (Rowe et al. 1999) and west coast (Hayes et al. 1989) of the North Island. Despite the absence of barriers to invasion and the availability of suitable habitat, the low abundance of introduced fish in these streams suggests that, like certain Californian streams, they may also be resistant to invasion.

The potential for such streams to resist invasion, coupled with their unmodified habitats and intact fauna, highlights them as key areas for protection. In addition to providing a safe haven for native fish of varying size classes, these streams may also act as a seeding source for diadromous species, with the offspring produced contributing to other populations along the coast. Of the streams surveyed during this research, Picnic Gully Creek was the only one (of eight surveyed) that was unmodified by human activity and was one of only two that did not contain brown trout. Although Alex and Cullen's Creeks were slightly modified (channelised in lower reaches, grazed by stock in their mid reaches), these streams contained significant populations of giant kokopu and few trout. From a local perspective, serious consideration should be given to limiting or controlling the human activity that is currently occurring on these two streams. Recent (2001) channelisation of a section of Cullen's Creek and one of its tributaries has caused a significant decline in the populations of giant kokopu that previously existed in these areas, and a small number of brown trout and European perch appear to have moved in (B. David pers. obs.).

5.2 STREAM RESTORATION

There are numerous small streams flowing into the Taieri Floodplain, and elsewhere around New Zealand, that maintain viable populations of giant kokopu in their middle and/or upper reaches but where their lower reaches have been channelised and contain few if any fish. Based on distributions in unmodified streams, e.g. Stewart Island (Chadderton & Allibone 1996, 2000), it is likely that these sections once contained giant kokopu but in their current condition do not appear to provide suitable habitat. These streams would be ideal candidates for rehabilitation. Since juveniles (< 10 cm) appear to use habitats which are distinctly different from larger fish (Whitehead 2001), creating 'marginal' habitats for recruiting juveniles would be essential, in addition to creating suitable adult habitat. The movements of giant kokopu during flood events (see Section 4.3) indicate that giant kokopu may use these events to move and settle into new locations. Thus, providing that a suitable population occurs upstream, potential exists to test the effectiveness of stream restoration via natural re-population during floods and via natural recruitment of juveniles rather than managed re-introductions.

For restoration, a stream should provide habitat that:

- at a broad scale provides a pool/riffle configuration
- is suitable for all size classes of fish
- can be accessed by new recruits
- can be occupied irrespective of season (summer/winter) or diel period (day/night)
- provides natural or artificial refuge locations during a range of flow conditions, including floods
- contains predominantly low flows (0–0.05 m/s) but also areas of higher flow (0.05–0.2 m/s) during stable conditions
- provides areas in which fish may drift feed particularly during summer.
- provides refuge areas such as shallow (0–5 cm) edge habitats or riffles for small fish from potential predation by larger fish
- contains cover (of any composition) enabling fish to be completely concealed from view, and associated with areas of low water velocity.

Ideally stabilisation of banks and newly created habitat by planting riparian margins with native plant species would be desirable. Plant species would also provide additional food inputs in the long term, for example manuka trees are important in the life cycle of the manuka beetle, which is prevalent in the diet of giant kokopu during both summer and winter (David 2002).

5.3 LOCATION OF SPAWNING SITES AND ORIGINS OF RECRUITMENT

The spawning sites of giant kokopu are still to be found. Giant kokopu are thought to spawn between late autumn and early winter (McDowall & Kelly 1999) though in Cullen's and Alex Creeks some females and males were still ripe at the end of August (B. David unpubl. data). Anecdotal evidence suggests that a downstream movement of giant kokopu from June-September to an as yet unidentified spawning location probably occurs (McDowall 1990b; V. Thompson pers. comm.). In the radio-tagging study, one ripe individual moved downstream to within 100 m of lake Waihola during a flood before returning to its home pool two days later, seemingly spent. Specific knowledge of where giant kokopu spawn and the type of conditions required for developing eggs is important for the conservation of this species.

It may be equally important to determine whether giant kokopu are indeed primarily diadromous (McDowall 1990a). There are a number of native and supposedly diadromous fish species in New Zealand that are capable of forming landlocked populations (e.g. common bully *Gobiomorphus cotidianus*, koaro *Galaxias brevipinnis,* and the giant kokopu), indicating that diadromy is not obligatory for these species, and the pelagic phase, normally marine, occurs in freshwater lentic habitats. In streams with access to the coast it is presumed that populations are facilitated by diadromy. However, observations of giant kokopu larvae migrating into streams in the lower Taieri Floodplain several months after localised flooding and well outside the months during which peak whitebait runs occur suggest that these fish may have completed their lifecycle within the lower Taieri system, possibly within Lake Waihola. For giant kokopu, the most significant populations appear to be located in streams that drain into extensive coastal wetlands and lakes (e.g. Bonnett 2000; David 2002; NZFFD). Given that the marine phase is not obligatory, the situation for landlocked populations might also occur in coastal wetlands, with larvae using them to complete the pelagic phase rather than moving to the sea. Populations tend to be higher in streams that enter coastal wetlands, and current research (using otolith micro-chemistry) suggests that this may be occurring. A number of fish analysed from Cullen's and Alex Creeks indicates that, despite having direct access to the sea, the population in these streams is composed mainly of fish which have recruited locally rather than from the sea (B. David pers. obs.). Determining the origin of recruitment is likely to be of major conservation significance. Results from such a study may indicate the importance of wetland habitats to recruitment of giant kokopu populations and also the potential impacts imposed by recreational anglers harvesting whitebait. There are also issues regarding genetic drift within populations and re-stocking or re-introductions.

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