DIET AND FEEDING OF KOARO (*GALAXIAS BREVIPINNIS*) IN FORESTED, SOUTH WESTLAND STREAMS

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ABSTRACT

The diet of koaro (*Galaxias brevipinnis* Günther) from 11 streams in South Westland was investigated. The most abundant prey in guts of summer-feeding fish were larvae of Trichoptera (34.6%), aquatic Diptera (24.6%) and Ephemeroptera (13.8%), whereas in winter, fish consumed ephemeropteran (24.2%) and trichopteran (23.1%) larvae. Prey were taken approximately in proportion to their abundance in the drift and benthos. Terrestrial prey items were present in low numbers in koaro guts, but they dominated gut contents gravimetrically, because of their greater individual weights. Stable carbon isotope analyses of fish tissue ($\delta^{13}C$ -25.0 to -25.5‰) confirmed that terrestrial prey were a major source of dietary carbon utilised by koaro in forested streams. In laboratory experiments, koaro selected aquatic prey when in still water, but they fed almost equally on terrestrial and aquatic prey when in running water. This suggests that terrestrial prey may be taken primarily when drift feeding in riffles.

KEYWORDS: Galaxiidae, South Westland, fish feeding, stable carbon isotope analyses.

INTRODUCTION

The koaro (*Galaxias brevipinnis* Günther) is one of the most widespread species of the Southern Hemisphere family Galaxiidae. It occurs in south-eastern Australia, Tasmania, mainland New Zealand, and on the Chatham, Campbell and Auckland Islands (McDowall, 1978). In New Zealand, its juveniles are second only to inanga (*Galaxias maculatus* (Jenyns)) in abundance in the economically important whitebait catch (McDowall, 1965). Despite this, little is known of the ecology or life history of the species, although McDowall & Eldon (1980) investigated factors influencing migration of the whitebait stage, Moffat (1984) considered interactions between koaro and trout in the Ryton River, Moffat & Davison (1986) examined koaro swimming performance, and Main *et al.* (1985), Taylor & Main (1987) and Taylor (in press) all considered koaro habitat requirements. In Lake Alexandrina, South Canterbury, Naylor (1983) found that koaro fed mainly on plankton, especially Cladocera, whereas Sagar & Eldon (1983) and Rounick & Hicks (1985), found only benthic invertebrates in the stomachs of seven and six fish respectively, taken from rivers.

In the present study, diets of koaro from 11 South Westland streams were investigated by a combination of gut contents examination and stable carbon isotope analysis. Simple laboratory experiments were carried out to investigate preferences for aquatic and terrestrial prey.

STUDY SITES

Collection sites were on 11 streams in the catchments of the Whakapohai River, Ship Creek, Waita River and Ohinetamatea River, South Westland, New Zealand. Most streams were small, with circum-neutral pH (6.8-7.4), and cool, summer water temperatures (between 8 & 14^{o}C at the time of sampling). Riparian vegetation at all sites was indigenous forest, dominated either by southern rata (*Metrosideros umbellata*), rimu (*Dacridium cupressinum*) and kahikatea (*Dacrycarpus dacrydioides*), or by silver beech (*Nothofagus menziesii*). The principal subcanopy species at most sites were kamahi (*Weinmannia racemosa*), pigeonwood (*Hedycarya arborea*) and whiteywood (*Melicytus ramiflorus*) (Table 1).

METHODS

COLLECTION METHODS AND STOMACH ANALYSES

Twenty-eight fish were collected between November, 1984 and February, 1985 (summer) from streams in the Whakapohai River, Waita River and Ship Creek catchments, using miniature fyke (hoop) nets (unbaited), Gee minnow traps (baited with salmon feed pellets), and a small stopnet (1 m long, 2 mm mesh). Minifyke nets were scaled-down versions of the eel-fishing fyke net, made from 12 mm mesh with a one metre long trap and leader, and a single non-return valve. Gee minnow traps were 40 cm long, conical, double-ended, wire-mesh basket traps with 8 mm mesh (Bloom, 1976). In winter (August, 1986), 15 fish were collected at night from a tributary of the Ohinetamatea River, using a torch and hand net. Total lengths of koaro after preservation ranged from 68 to 190 mm (summer), and 107 to 185 mm (winter).

Fish were preserved in 40% isopropanol. Later, stomachs were removed, their contents were examined microscopically and analysed using an abundance and a gravimetric method. To obtain gravimetric values, the abundance of each item of interest was multiplied by the mean dry weight of an equivalent undigested item.

To obtain an estimate of the abundance of drifting invertebrates (potential prey), collections were made at the winter sampling site (Ohinetamatea River tributary) with three surface-sampling drift nets (mouth openings 20 x 8 cm), each with a 1 m long bag of 0.2 mm mesh. Drift was sampled continuously for 24 hours, after which five benthic samples were collected from the middle of riffles, using a 0.1 m^2 Surber sampler (mesh size 0.5 mm).

STABLE CARBON ISOTOPE ANALYSES

Stable carbon isotope (SCI) analyses were made to provide an additional assessment of the relative importance of terrestrial and aquatic food items in the diets of koaro.

Table 1. Physical and riparian characteristics of study sites. Water temperature and pH were measured when fish were collected.

Site	Width (m)	pH	Summer water Temperature °C	Substrate	Flow regime	Riparian Vegetation
Robinson Ck	3	7.4	10.5	Gravel, cobbles, small boulders	Runs, torrents, cascades	Weinmannia
Waita R.	2 & 5	6.8	14.0	Gravel, cobbles	Riffles, torrents	podocarp-hardwood forest
Waterfall Ck	1.5	7.0	13.0	Gravel, cobbles, boulders, bedrock	Pools, runs, falls	Weinmannia
Upper Ship Ck	2	7.2	12.75	Cobbles, boulders, bedrock	Pools, cascades	Dacrydium, Dacrycarpus, Metrosideros, Weinmannia
Cement Ck	2	7.3	12.25	Cobbles, boulders	Pools, runs, cascades	Dacrycarpus, Dacrydium, Nothofagus, Weinmannia
Cement Ck Trib.	5?	7.0	12.75	Gravel, cobbles, boulders	Pools, cascades	Dacrycarpus, Dacrydium, Nothofagus, Weinmannia
Upper Ship Ck	1.5	7.0	12.75	Cobbles, boulders	Pools, riffles, cascades	Dacrydium, Weinmannia
Upper Whakapohai R.	1.5	7.1	8.0	Cobbles, boulders	Pools, runs	Nothofagus
Stuart Gully	1.5	6.8	?	Gravel, small boulders	Pools, runs, cascades	Nothofagus
Mathias Ck	1	7.0	12.25	Gravel cobbles	Runs	Nothofagus
Ohinetamatea Trib.	1	?	?	Gravel, cobbles, small boulders	Pools, runs, cascades	Metrosideros, Weinmannia

The SCI technique uses differences in the natural abundances of the stable carbon isotopes ^{13}C and ^{12}C as tracers, which move with little alteration through food chains (Rounick & Winterbourn, 1986). It is possible to distinguish between aquatic and terrestrial food sources, because they often have different $^{13}C/^{12}C$ ratios. The ratio of ^{13}C to ^{12}C in a consumer's tissue provides a summary of an animal's recent feeding history (Fry & Arnold, 1982), and reflects only materials actually converted into tissue (Rounick & Winterbourn, 1986).

Terrestrial invertebrates for SCI analysis were collected from riparian podocarp-hardwood forest within the study area (Main & Lyon, in press). Aquatic invertebrates and four fish were collected from the Ohinetamatea River tributary in winter, 1986. All SCI samples were preserved by freezing.

Depending on their size, 2-20 head capsules of arthropod prey taxa were pooled for analysis, and samples of muscle (1-5 g) were taken from the left caudal peduncles of fish. Muscle samples had low carbon: nitrogen ratios (3.4 to 3.6; G.L. Lyon, unpublished data) indicating that they contained little fat which could have resulted in localised ^{13}C-depletion.

All samples were freeze-dried, and subsequently, 3-5 mg subsamples were oxidised in quartz "vycor" tubing, using the breakseal method of Buchanan & Corcoran (1959). The resulting CO_2 was purified and analysed in a Nuclide 6-60 ratio mass spectrometer. Results are expressed as $\delta^{13}C$ values, which are the relative difference per mille (‰), between the isotope ratio of the sample and that of the international PDB (Pee Dee belemnite) standard (Craig, 1957). Analytical precision was greater than 0.2 ‰.

PREY SELECTION EXPERIMENTS

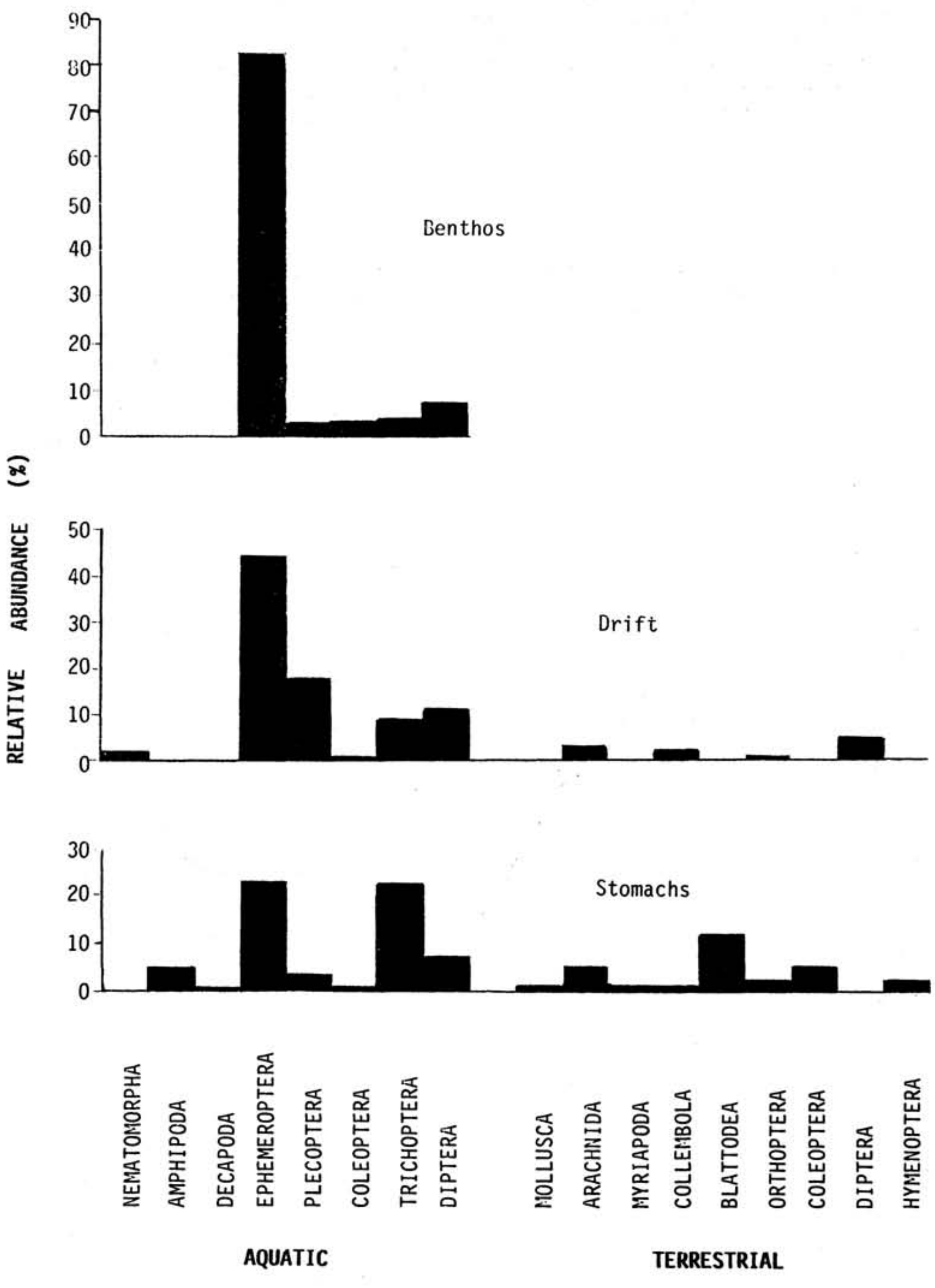
Fish were offered aquatic and terrestrial prey of equivalent size (8-10 mm) in choice experiments conducted in a small laboratory stream. The stream was 140 cm long, 14 cm wide, 12 cm deep, and was maintained at 11-14°C. Two series of trials were run, the first in still water and the second in constantly-flowing water (8 cm s^{-1}). In each series, 10 trials were conducted; five with each of two fish which had been kept without food for two days. In the still-water trials, the fish were allowed 30 minutes to consume up to 10 mayfly (*Deleatidium* spp.) nymphs (aquatic prey), and 10 locust (*Locusta migratoria*) or cockroach (*Periplaneta americana*) nymphs (terrestrial prey) of comparable size, which were placed on the streambed (aquatic prey) or water surface (terrestrial prey), at the start of the period. During drift feeding trials in flowing water, pairs of aquatic and terrestrial prey were released simultaneously into the current at one minute intervals for 10 minutes, and captures were recorded.

RESULTS

STOMACH ANALYSES

Koaro consumed most prey items approximately in proportion to their abundance in the drift and benthos (Fig. 1). However, small dipterans which were common in surface drift were not found in stomachs, whereas Blattodea and Coleoptera were overrepresented in stomachs. Cockroaches and beetles were relatively large animals, so fish may have been feeding on them selectively, even though they were present in low numbers. Such a feeding strategy would be consistent with that recorded for banded kokopu (*Galaxias fasciatus* Gray) which feed size-selectively on drifting terrestrial prey (Main & Lyon, in press).

Koaro collected in summer had been feeding mainly on larval Trichoptera (34.6% of prey items by abundance), Diptera (24.6%) and Ephemeroptera (13.8%). In winter, ephemeropteran and trichopteran larvae were the most abundant prey (24.2% and 23.1%, respectively), while aquatic Diptera made up 7.7% of total prey items (Table 2). Fish were taken from different streams in summer and winter, however, so differences in fish diets are likely to reflect site-specific, as well as seasonal factors. For example,



1. Relative abundance of invertebrates in stomachs of koaro (n= 15), drift samples and benthic samples taken from the Ohinetamatea River tributary, August 1986.

Blephariceridae were abundant at the higher altitude sites sampled in summer, and were common in fish stomachs. A fish (koaro) had been eaten by one 157 mm long individual. Terrestrial prey formed a relatively small percentage of the number of prey items present in koaro stomachs (15.7% in summer and 30.8% in winter), but, in gravimetric terms, terrestrial organisms were more important than aquatic prey (63.1% of weight in summer and 87.4% in winter), because of their greater individual biomass (Table 2).

Table 2. Relative abundance and biomass of prey items present in stomachs of koaro collected from South Westland streams in winter (n=15 fish) and summer (n=28 fish).

	Winter		Summer	
	Abundance (%)	Weight (%)	Abundance (%)	Weight (%)
Aquatic prey				
Mollusca	-	-	1.3	0.4
Nematomorpha	1.1	0.9	1.9	1.5
Amphipoda	5.5	0.2	-	-
Decapoda	1.1	1.5	0.6	9.5
Insecta				
Ephemeroptera	24.2	2.1	13.8	1.8
Plecoptera	4.4	2.5	4.4	3.8
Coleoptera	1.1	<0.1	2.5	0.1
Trichoptera	23.1	4.5	34.6	10.4
Diptera	7.7	0.8	24.6	0.2
Fish	-	-	0.6	9.1
	68.2	12.6	84.3	36.8
Terrestrial prey				
Mollusca	2.2	<0.1	-	-
Myriapoda	1.1	2.2	1.9	5.9
Arachnida	5.5	3.7	3.1	3.3
Insecta				
Collembola	1.1	<0.1	-	-
Blattodea	12.1	30.1	2.5	9.5
Orthoptera	2.2	27.5	-	-
Coleoptera	5.5	22.7	6.9	43.5
Diptera	-	-	1.3	0.9
Hymenoptera	2.2	1.1	-	-
	31.9	87.3	15.7	63.1

STABLE CARBON ISOTOPE ANALYSES

Stable carbon isotope values (Table 3) also indicated that terrestrial prey were important in the diet. Thus, $\delta^{13}C$ values of koaro ($\bar{x}$ -25.3 ± 1SD 0.21 ‰; n=4) were more similar to those of terrestrial arthropods (-28.6 to -20.6 ‰; Main & Lyon, in press), than aquatic invertebrates (-30.4 to -24.7‰; Table 3). In particular, the $\delta^{13}C$ values of the aquatic prey which were most abundant in stomach contents (Ephemeroptera and Trichoptera), were substantially more depleted in ^{13}C than those of the fish. It is interesting to note also, that the value of -24.7 ‰ obtained for aquatic, non-feeding, gordian worms (Nematomorpha) corresponds closely to that of the terrestrial orthopterans (-25.5 ‰), which are the hosts of their parasitic larvae.

Table 3. Stable carbon isotope values ($\delta^{13}C$‰) for koaro (mean and range, n = 4) and representative prey from South Westland streams. Values for terrestrial prey from Main & Lyon (in press).

Fish and prey	$\delta^{13}C$(‰)
Galaxias brevipinnis (koaro)	-25.3 (-25.5 - -25.0)
Aquatic prey	
Nematomorpha	-24.7
Ephemeroptera	
Deleatidium sp.	-29.0
Nesameletus sp.	-28.9
Coloburiscus humeralis	-29.1
Trichoptera	
Pycnocentria sp.	-30.4
Diptera	
Blephariceridae	-26.5
Terrestrial prey	
Arachnida	
Araneae	-23.5
Opiliones	-28.6
Myriapoda	-22.1
Insecta	
Blattodea	-24.6
Orthoptera	
Rhaphidophoridae	-25.5
Coleoptera	
Circulionidae	-20.6
Staphylinidae	-24.3
Carabidae	-24.8
Hymenoptera	
Formicidae	-25.2

PREY SELECTION EXPERIMENTS

In laboratory feeding trials, koaro selected aquatic prey preferentially when in still water, but fed on terrestrial and aquatic prey in almost equal numbers when drift feeding in flowing water (Table 4). The manner of drift feeding was similar to that described by Kalleberg (1958) for fingerlings of brown trout (*Salmo trutta* L.), in that fish rose obliquely to the surface, where the prey was caught with a sudden turn, and then regained station on the bottom.

Table 4. The percentage of terrestrial and aquatic prey items offered that were eaten in laboratory experiments ($\bar{x} \pm 1SD$) (see text for details).

Flow regime	Aquatic prey (mayfly larvae)	Terrestrial prey (locusts, roaches)	χ^2	P
Still water	94 ± 2	20 ± 0	118	<0.001
Flowing water	79 ± 7	87 ± 5	2.82	0.09

DISCUSSION

The koaro is an elongated, negatively buoyant fish which rests on the streambed, and has an undershot jaw, similar to that of the torrentfish (*Cheimarrichthys fosteri* Haast). This morphological feature may allow it to remove invertebrates from cobbles as described for torrentfish (Sagar & Eldon, 1983), and indeed, we found that the stomachs of koaro were dominated numerically by benthic prey. Sagar & Eldon (1983), and Rounick & Hicks (1985), also found that aquatic invertebrates were the most abundant items in the stomachs of fish they examined. One koaro had been eaten by an individual dissected in the present study, and although a redfinned bully (*Gobiomorphus huttoni* Ogilby) was found in the diet of a large koaro from an Okarito River tributary (M.R. Main, unpublished), it seems that fish are only incidental dietary items.

In the Rakaia River, Sagar & Eldon (1983) found that koaro consumed mainly larvae of the mayfly *Deleatidium*, which was the dominant benthic invertebrate taxon, and for this reason they concluded that koaro were non-selective feeders. Similarly, our results suggest that koaro exhibit little prey selection when feeding on benthos and drifting organisms. In contrast, banded kokopu that sometimes coexist with koaro in South Westland streams, feed selectively on terrestrial prey (Main & Lyon, in press).

Koaro are usually described as fish of fast waters, and they occur commonly in riffles (McDowall, 1970). However, in South Westland they often occur in pools (Taylor, in press) especially if other fish are uncommon. When feeding in pools, koaro probably take benthic prey most frequently, as they did during still water feeding experiments, but in riffles they may feed more extensively on drift. Sagar & Eldon (1983) suggested that most of the drifting organisms taken by koaro originated in the benthos, and our results confirm that koaro can, and probably do, feed extensively on drift from this source. However, they also feed on terrestrial invertebrates that fall on to the surface film of South Westland streams, and a high proportion of the food converted into fish biomass can be traced to terrestrial prey, as indicated by SCI values. Nevertheless, koaro are less dependent on riparian vegetation to provide a source of food than are banded kokopu, and perhaps as a consequence their habitat requirements and distribution are more diverse.

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