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INVERTEBRATE FOOD SUPPLIES AND DIET OF BLUE DUCK ON RIVERS IN TWO REGIONS OF THE NORTH ISLAND, NEW ZEALAND

Summary: Benthic invertebrates and samples of blue duck faeces were collected in September 1988 from sites along Manganuiateao River, central North Island, and in November 1988 from seven rivers and streams on the East Cape. The occurrence of invertebrate taxa in the faeces varied within and between rivers, and within pairs of birds and family groups on the East Cape. In both regions, most blue duck had been consuming large proportions of cased caddisfly larvae. These are thought to have been mainly species of *Helicopsyche* and *Pycnocentrodes* at the East Cape sites and *Beraeoptera roria* at the Manganuiateao sites. Plecoptera larvae were also relatively abundant in blue duck faeces from most Manganuiateao sites in September. Overall, blue duck consumed proportionately more cased caddisfly larvae than occurred in the benthos (especially at the East Cape sites), but fewer Chironomidae, *Coloburiscus humeralis* and leptophlebiid mayfly (mainly *Deleatidium* spp.) larvae. Factors that affect the type of invertebrate foods available to blue duck at a particular site could include habitat heterogeneity, chance encounter, frequency and magnitude of floods, and geographic differences in the pool of invertebrate colonists. Apparent selectivity or avoidance of some benthic invertebrate groups by blue duck may partly reflect predator evasion by fast-moving invertebrate species, and differences in activity and distribution on upper stone surfaces where invertebrates should be more susceptible to predation by blue duck.

Keywords: blue duck; *Hymenolaimus malacorhynchos;* aquatic invertebrates; predation; faecal analysis; North Island; New Zealand.

Introduction

The endemic blue duck *(Hymenolaimus malacorhynchos* (Gmelin, 1789» is believed to have been widespread on rivers in New Zealand in pre-human times (Robertson, 1985), but populations are now largely restricted to forested, upland catchments in the central North Island and west coast of the South Island (Fordyce, 1976). Reasons for this decline are thought to include changes in land use, modifications to river flow regimes, and predation by introduced mammals (Fordyce and Tunnicliffe, 1973; Williams, *in press).* Kear (1972) suggested that changes in food resources through the feeding activities of introduced insectivorous birds and salmonids may also have detrimentally affected blue duck.

Aquatic invertebrates are the main foods of blue duck (Kear and Burton, 1971), and these are gleaned primarily from rocks in shallow water with moderate to fast current velocities (Veltman and Williams, 1990). Invertebrates are removed from stones with a bill that tapers towards the end and has a pair of soft, black flaps on each mandible (Kear and Burton, 1971). Blue duck can also feed on invertebrates by diving in deeper water and by grazing from emergent boulders, and they occasionally take adult insects from the water surface and drifting larvae from the water column (Craig, 1974; Fordyce and Tunnicliffe, 1973; Eldridge, 1986; Veltman and Williams, 1990). Work on the Manganuiateao River, central North Island, has shown that most diurnal feeding occurs close to the edges of riffles in the early morning and late afternoon in late summer and autumn, and throughout the day during winter, spring and early summer (Eldridge, 1986; Veltman and Williams, 1990).

Kear and Burton (1971) described the content of several blue duck faecal deposits, but no quantitative data have yet been published on diet and food supplies. I investigated the composition of aquatic invertebrate communities and blue duck diet on rivers in two regions of the North Island. My aim was to obtain quantitative data on diet at a variety of sites and to evaluate selectivity of benthic invertebrate prey in each region. I also collected some invertebrate samples from sites that did not support blue duck to see if the composition of benthic invertebrate faunas there differed from those sites with blue duck.

Methods

Study area

Samples were collected from the middle section of Manganuiateao River and its tributary Mangaturuturu River, central North Island, and from seven rivers and streams on the East Cape (Fig. 1). Both regions have similar mean annual precipitation (2000-2500 mm) and soils (predominantly steepland yellow-brown earths and yellow-brown pumice soils) underlain by sedimentary rocks (McLintock, 1960; Gibbs, 1980; Molloy, 1988). Manganuiateao River (Fig. 1) originates on the western flank of Mt Ruapehu and flows for 80 km in a south-westerly direction into Whanganui River. Most samples at this site were taken from a 25 km-long stretch of river that started 27 km below the mountain source. In its upper reaches, Manganuiateao River and its tributaries drain an extensive area of indigenous forest of beech *(Nothofagus solandri* var. *cliffortoides* (Hook. f.) Poole and N. *menziesii* (Hook. f.) Oerst) and podocarps (including *Phyllocladus alpinus* Hook. f. and *Libocedrus bidwillii* Hook. f.). Around the study area the land was mostly in pasture and scrub, but a thin, semi-continuous strip of trees (consisting mostly of the exotic silver wattle *Acacia dealbata* Link., *N. fusca* (Hook. f.) Oerst and angiosperms such as *Beilschmiedia tawa* (A. Cunn.) Kirk, *Knightia excelsa* R. Br. and *Melicytus ramiflorus* J.R. & G. Forst.) grew along much of the river section studied.

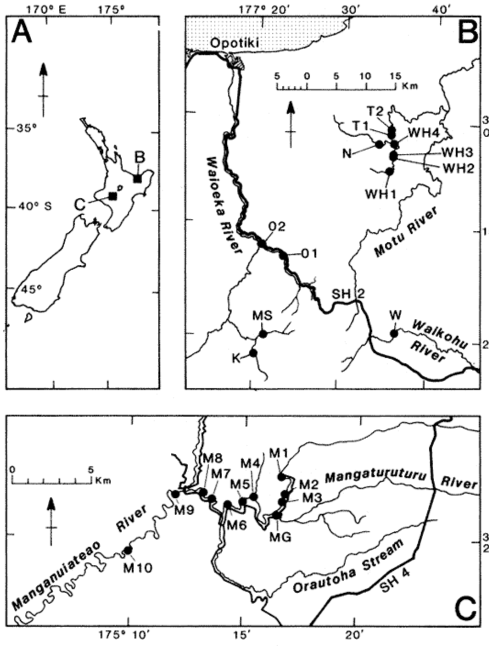

Figure 1: *Location of sampling sites (A) in the North Island of New Zealand;* (8) *East Cape and (C) Manganuiateao River. See text for site names*

The Manganuiateao River flows through a series of stable pools and riffles and the substrate is predominantly large (>26cm diameter), rounded boulders of andesite. Of the 11 Manganuiateao sampling sites (Fig. 1), one (MG) was on Mangaturuturu River just before its confluence with Manganuiateao River, and eight (M1-M8) were on the main channel above Ruatiti Domain (adjacent to M9; see Fig. 1), which represents the approximate downstream limit of blue duck distribution on Manganuiateao River (Williams, *in press).*

The 12 East Cape sites (Fig. 1) were on seven rivers and streams that drained steeplands and foothills of Raukumara Range. Flow at most sites was in a northerly direction, and large areas of pasture were present in some catchments, although scrub or indigenous forest was present alongside most sampling sites. The substrate at Waikohu River (W), Opato River (0) and Moanui Stream (MS) was predominantly boulders, whereas Koranga (K), Nga Upoko Tangata (N) and Whitikau (WH) Rivers had boulders and bedrock interspersed with cobbles (6-26cm diameter) and gravels (0.2-6cm diameter). In contrast, substrate at the Takaputahi (T) sites was mainly well sorted cobbles and gravels.

Faecal and/or benthic invertebrate samples were taken from the Manganuiateao sites in the spring (4-6 September) and from the East Cape sites in the early summer (21- 25 November) of 1988. Four sites (M9, MIO, K, W; see Fig. 1) did not support blue duck at the time of sampling, so only benthic samples were taken from those sites. Similarly, benthic samples only were collected from MG and M7 (both within blue duck territories) because faecal deposits could not be located. Most faecal samples were collected as they were encountered while searching for birds down rivers. As a result, samples were taken from most blue duck territories on a section of river, and analyses should, therefore, be representative of blue duck populations on the sections of river visited.

Invertebrate sampling

Where possible, benthic invertebrate samples were taken from shallow (0.1-0.5 m) riffles (the main feeding areas of blue duck) near where faeces were found. The two benthic samples collected from site O were pooled for analysis because they were collected upstream and downstream of the site where faecal deposits were obtained.

Because the occurrence of some aquatic invertebrates on upper surfaces of stones (i.e., those surfaces probably most accessible to blue duck) can vary depending on time of day and several environmental variables (Elliott, 1968; Pierce, 1986;

Death, 1988), invertebrates were collected from all substrate surfaces. This was achieved by turning over and brushing stones upstream of a triangular net (0.5 mm mesh) in a similar manner and with similar efficiency at all sites in each region to provide comparable information on the relative abundance of invertebrate taxa. Samples were preserved immediately in 70% isopropyl alcohol, and in the laboratory were passed through 1 mm and 0.43 mm mesh sieves. Invertebrates retained by the 1 mm sieve were picked out on a white tray, and material caught by the finer mesh sieve was sorted at 10x magnification. All invertebrates were identified under a binocular microscope using the key of Winterbourn and Gregson (1981).

Faecal analyses

Where possible, fresh (moist) faeces were collected from emergent rocks and logs on rivers, or, for most East Cape samples, from bags in which birds were held before banding. Developmental stages (i.e., adult or juvenile) and sexes of birds that defecated in bags were recorded, enabling the diet of different birds that had presumably fed in the same stretch of river to be compared. Where several faecal deposits (up to three) from unknown birds were collected, samples from each site (i.e., those from M1-M6, M8, MS or O) were pooled for analysis. Faeces were frozen or preserved in 70% isopropyl alcohol following collection.

In the laboratory, faeces were dispersed with a magnetic stirrer and bulked samples or large single deposits from known birds were split into convenient fractions (1/2 -1/16) using a Folsom-type splitter. Subsamples obtained in this way contained fragments representing 46-592 invertebrates of different species, whereas analyses of whole (small) faecal deposits yielded 7-86 individuals. Fragments that were resistant to digestion and diagnostic of invertebrate taxa (whole heads, mandibles, clypera, terminal segments) were identified and counted at 8-64x magnification. Identifications were made from preserved material and photos of prepared slides, and numbers of individuals in the total sample were calculated using appropriate equations. Use of diagnostic fragments enabled the analyst to focus on specific search images during sorting, and reduced the possibility of misclassifying or overlooking fragments (I. Henderson and C. Veltman, Massey University, *pers. comm.).*

The Leptophlebiidae group was made up predominantly of *Deleatidium* spp., and also probably included *Austroclima* spp., *Mauiulus luma* Towns & Peters and *Zephlebia* spp. The *Hydropsychidae* contained mostly larvae of *Aoteapsyche colonica* (McLachlan). Cased caddisflies could be separated into (the "BCP" group) comprised of *Beraeoptera roria* Mosely/*Confluens hamiltoni (Tillyard)*/*Pycnocentria* spp., and *Olingaferedayi* (McLachlan), *Pycnocentrodes* spp., or *Helicopsyche* spp. on the basis of whole heads or clypera. However, unlike the other groups, this high taxonomic resolution was not possible on the basis of mandibles alone (I. Henderson and C. Veltman, Massey *University,pers. comm.).* Thus, information obtained from heads and clypera was used when comparing sites based on the presence or absence of invertebrate taxa in faeces for *O.feredayi*. *Pycnocentrodes* spp., *Helicopsyche* spp. and the BCP group, but these groups were combined into cased caddisflies when relative abundance was being considered.

Key fragments that could not be assigned to any of the taxonomic groups in Table I were designated as "Other" and were not included in subsequent data analysis. "Other" taxa recorded in faeces were unidentified Coleoptera (0.7 and 4% of total invertebrates at sites M3 and M2, respectively), and adult Tipulidae (0.2% at site M5). Some faeces from blue duck on Manganuiateao River also contained clumps of filamentous algae (particulary faeces from M3 and M6) which were still green, but these were not quantified.

Results

Composition of faeces and benthos

Of the 15 sites from which faeces were collected (combining faecal data from all birds), fragments of *Pycnocentrodes* spp. and Leptophlebiidae were found at 13 sites, *Helicopsyche* spp. and Hydrobiosidae at 12 sites, and the BCP group at 11 sites. These taxa were also found in all benthic samples from the same 15 sites and comprised 0.3-50% of the total invertebrate fauna in them. Leptophlebiidae and Hydrobiosidae comprised up to 36% and 7%, respectively, of invertebrates in faeces, whereas cased caddisflies comprised up to 100% of the faeces, and were relatively abundant in most samples (Table 1). Based on information provided by whole heads and clypera in the faeces or relative abundances of invertebrates in the benthos, *Helicopsyche* and *Pycnocentrodes* species probably made up most of the cased caddisflies in faeces from the East Cape sites in November, whereas larvae of *B. roria* were probably the dominant cased caddisfly in faeces from the Manganuiateao sites in September.

Chironomidae (1-35%) and Plecoptera (1-45%) were found in all faecal samples and corresponding benthic samples (9-40% and 2-19%, respectively) from Manganuiateao River. These taxa were recorded in faeces at only one or two of the East Cape sites (Table 1), even though they occurred in all benthic samples there. Hydropsychidae comprised a small proportion (0-3%) of the faeces at most Manganuiateao sites,

Table 1: *Abundance classes of invertebrate taxa found in faecal samples from the Manganuiateao and East Cape sites. For stage/sex abbreviations, A = Adult, J = Juvenile, m = male, f = female. For T2J, faeces from male and female juvenile birds were combined. Feacal samples represent single deposits (all N, T and WH samples) or up to* 3 *pooled deposits (all Manganuiateao sites, O, MS). For abundance classes: 6=>50% of individuals in faeces, 5=20-49.9%, 4=10-19.9%,* 3=5-9.9%, *2=2-4.9%, I =>0-1.9%,* Ñ *=not recorded.*

	Manganuiateao River							East Cape														
Site	M1	M2	M3	M4	M5	M6	M8	N	T2	T2	T2	WH1	WH1	WH2	WH3	WH3	WH3	WH3	WH4	WH4	O	MS
Stage/sex								Am	Am	Af	J	Am	Af	Am	Am	Af	Jm	Jf	Am	Af		
Leptophlebiidae	4	1	2	2	1	4	1	5	2	3	2	2	3	-	-	1	1	1	-	2	-	2
Coloburiscus humeralis	1	1	2	-	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Nesameletus sp.	2	-	2	2	1	1	1	4	1	1	-	1	-	-	-	1	1	1	-	-	-	-
Plecoptera	4	5	4	4	2	3	1	-	-	2	-	-	-	-	1	1	1	-	-	-	-	-
Hydrobiosidae	1	1	-	1	1	2	3	2	-	1	1	1	1	-	1	-	1	-	2	-	-	1
Hydropsychidae	1	2	-	-	-	2	5	-	-	2	-	-	1	-	-	-	-	-	-	-	-	-
Oxyethira albiceps	-	-	-	-	-	-	-	-	-	2	-	-	1	-	-	-	-	-	-	-	2	1
Cased caddisfly	6	2	5	6	6	6	1	6	6	6	6	6	6	6	6	6	6	6	6	6	6	2
Chironomidae	2	1	5	2	3	2	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
Aphrophila neozelandica	-	-	-	-	-	1	4	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1
Elmidae	1	5	1	-	-	2	1	-	-	-	-	2	-	-	2	2	-	1	-	-	-	-
Archichauliodes diversus	-	-	-	-	-	1	-	-	-	-	-	2	-	-	-	1	1	1	-	-	-	-
Hydrophilidae	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

although at M8 they made up 47% of total invertebrates in the faeces but only 2% of the benthic fauna. Similarly, Elmidae comprised <4% of the faeces at most Manganuiateao sites except for M2 where they made up 40% (and where almost all Elmidae were adults) of invertebrates in the faeces, but only 0.3% (all of which were larvae) of the benthos.

Classification of sites

Sites within each region were clustered according to the presence or absence of invertebrate taxa in the faeces or benthos using Ward's linkage method and relative Euclidean distance measure (Fig. 2). Dendrograms were interpreted at the arbitrary level of 3 or 4 clusters.

All Manganuiateao sites sampled in September occurred in Cluster A (Fig. 2A). Though possibly due to differences in sampling month, this dichotomy probably reflects geographic differences as many species of the New Zealand aquatic invertebrate fauna have non-seasonal life cycles and are likely to be present at all times of year (Towns, 1981; Winterbourn, Rounick and Cowie, 1981; Boothroyd, 1987). Cluster B included most East Cape sites that supported blue duck, but not T1 which had fewer taxa (21) than the other East Cape sites (24-33), and occurred in Cluster A. Cluster C included the two East Cape sites (Wand K) that did not support blue duck, but the Manganuiateao sites without blue duck (M9 and M 10) were not distinguished from the other Manganuiateao sites on the basis of presence or absence of benthic invertebrate taxa.

Four faecal clusters were distinguished (Fig. 2B). Cluster D contained five of the seven Manganuiateao sites and, therefore, reflected to some degree the apparent geographic separation of the benthic samples. Unlike samples from these Manganuiateao sites, fragments of C. *humeralis* and Elmidae larvae were not recorded in faeces from M4 and M5. These sites were incorporated.into Cluster E, along with several East Cape sites (Fig. 2B). The ecological basis behind Clusters E, F and G is unclear, and did not seem to be related to family group, sex or developmental stage of birds. An adult male at WH2 had been feeding exclusively on cased caddisfly larvae (most appeared to be *Helicopsyche),* and was the main outlier in the faecal cluster analysis (Fig. 2B).

Prey selection

Relative abundances of taxa recorded in the faeces (all birds at any site combined) or corresponding benthic samples in each region were averaged and used to calculate Ivlev's Electivity Index (D) which ranges up to 1 for positive selection and down to -I for negative selection (Jacobs, 1974). Only those taxa that comprised 5% of the benthos or faeces at the East Cape or Manganuiateao sites were considered. Electivity indicies indicated that, overall, blue duck consumed Leptophlebiidae, C. *humeralis* and Chironomidae in lower proportions than they occurred in benthic samples in both regions (Fig. 3). In contrast, cased caddisflies were consumed in greater proportions than in benthic samples (particularly at the East Cape sites; Fig. 3), and overall comprised a major proportion numerically (>50% of individuals in faeces) of blue duck diet in both regions. Apparent preferences for

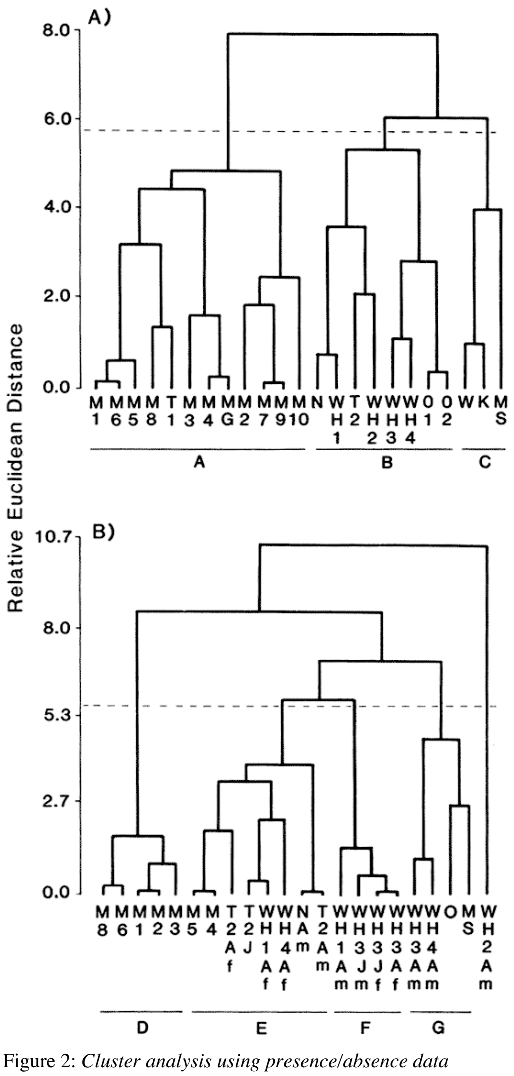

Figure 2: *Cluster analysis using presence/absence data of invertebrate taxa found in the benthos (A) and faeces of blue duck (B) at the East Cape and Manganuiateao sites. Abbreviations as for Table* 1.

Hydropsychidae and Elmidae larvae in Manganuiateao River mainly reflected high relative abundances of these taxa in faeces of blue duck from only one site (Table 1).

Discussion

Diet of blue duck

In addition to the 13 invertebrate taxa reported here, blue duck are also known to eat water mites, larvae of aquatic Muscidae and Blephariceridae (Diptera), possibly freshwater crayfish *(Paranephrops* spp.), Myriopoda and adults of several aquatic insect taxa (Craig, 1974; Kear and Burton, 1971; Williams, 1989). Most blue duck faeces collected in my study contained large proportions of cased caddisfly larvae, supporting observations on other rivers in September to December (Kear and Burton, 1971) that cased caddisflies can be a large component of blue duck diet. Harding (1990) found that blue duck in Arthur's Pass also consumed large numbers of berries from riparian shrubs in autumn, indicating that they are capable of exploiting other temporally abundant food resources.

The occurrence of invertebrate taxa in different faecal samples varied considerably between and within river systems, and this variability may partly reflect heterogenous distribution of the invertebrate prey. Factors that influence the distribution of benthic invertebrates include differences in substrate characteristics (size, depth and roughness), current velocity, and the availability of food resources (Hawkins and Sedell, 1981; Statzner, Gore and Resh, 1988; Jowett and Richardson, 1990).

Geographic location can also affect the composition of benthic invertebrate communities (Winterbourn, 1981), and this was reflected in my study by some apparent homogeneity within regions in the benthos and diet of blue duck. This suggests that the consumption of taxa by blue duck at a particular locality is partly influenced by the pool of available invertebrate colonisers. The occurrence of prey taxa in the diet of pairs of birds and their offspring at the East Cape sites was also variable even though they had presumably been feeding all together in the same territory. This implies a certain element of chance or individuality in which prey taxa are encountered and consumed. Nevertheless, in a stable carbon isotope study on Manganuiateao River, Collier and Lyon (1991) found that feathers of different birds living in the same territories generally had similar $^{13}C/^{12}C$ ratios indicating that they had assimilated carbon from isotopically similar sources.

Other work on Manganuiateao River has shown that the invertebrate diet of blue duck also changes with time (Newton, 1989). Thus, diet changed from predominantly cased caddisflies for one date in January, to mainly Chironomidae larvae for two dates in March and May. These changes reflected temporal variations in the composition of the benthic invertebrate community that were effected, to a large degree, by the frequency and magnitude of floods (Collier and Wakelin, 1990). Stochastic flood events and subsequent invertebrate recolonisation patterns are likely to be other important factors influencing the abundance and composition of invertebrate food supplies for blue duck.

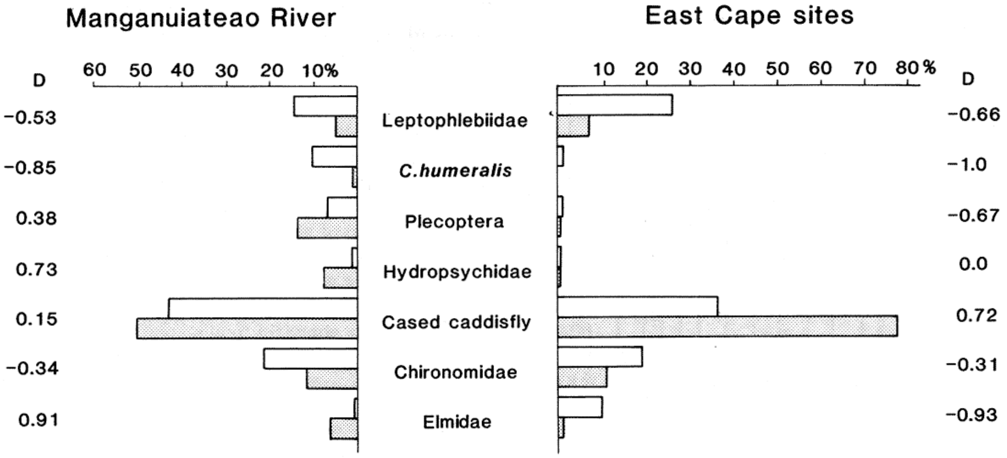

Figure 3: *Mean relative abundances of invertebrate taxa found in the faeces of blue duck (closed bars) and corresponding benthic samples (open bars) at the East Cape and Manganuiateao sites. Only those taxa that on average made up 5% of invertebrate numbers in the bethos or faeces in either region were considered. lvlev's Electivity Index (D) was calculated using the method of Jacobs (1974).*

Prey preferences

In my study, cased caddisflies appeared to be the strongly preferred prey at the East Cape sites in September, whereas larvae of the mayflies C. *humeralis* and Leptophlebiidae were commonly eaten but in much lower proportions overall than they were collected in the benthos in both regions (Fig. 3). Cased caddisflies form a taxonomically broad group composed of a variety of species whose microhabitat preferences vary. For example, *Helicopsyche* commonly occur on the undersides of rocks or in hollows and cracks on rock surfaces (Cowley, 1978), and therefore would seem to be largely unavailable to blue duck. *Helicopsyche* was relatively common in the benthos of both sets of sites, but appeared to be abundant in blue duck faeces only at the East Cape sites in November. This may partly reflect differences in the surface topography of substrates between regions that could have affected the availability of refugia for *Helicopsyche* larvae.

Alternatively, other cased caddisfly taxa (e.g., *B. roria)* could have been more accessible to blue duck in Manganuiateao River in September. *B. roria* larvae often can be found on the upper surfaces of rocks with thin coverings of epilithon in Manganuiateao River (Collier and Lyon, 1991), and often congregate in areas of moderate current velocity (Cowley, 1978) such as those in habitats preferred by blue duck for feeding (Veltman and Williams, 1990). Similarly, although Pierce (1986) found *P. aureola* larvae mainly on undersides of stones in Cass River, South Island, other observations indicate that *Pycnocentrodes* commonly occur on surfaces of stones where they feed on epilithon, often in areas of rapid current velocity (Cowley, 1978). Thus, high consumption of some cased caddisflies can be partly explained by differences in activity and distribution on upper stone surfaces where larvae would be more susceptible to predation by blue duck.

The mayflies C. *humeralis* and *Deleatidium* spp. are found most often on the undersides of stones (Wisley, 1962; Pierce, 1986), and thus would not be expected to be favoured food items if prey availablity were substantially influenced by microhabitat use of upper stone surfaces. However, Pierce (1986) found that *Deleatidium* spp. larvae were active on upper surfaces of stones in the Cass River, South Island, in the early morning and evening. These periods correspond to peak diurnal feeding times for blue duck on Manganuiateao River during the non-breeding season (Eldridge, 1986), but, in the present study, faecal samples were collected during the breeding season when feeding periodicity is less pronounced (Veltman and Williams, 1990). Stable carbon isotope analyses of invertebrates and blue duck feathers on Manganuiateao River suggested that taxa like C. *humeralis* and *Deleatidium* contributed less to blue duck nutrition than other (more isotopically enriched) taxa (Collier and Lyon, 1991). Compared with cased caddisflies, these mayfly taxa are fast-moving and this may enable many to evade predation by blue duck.

The present study suggests that the diet of blue duck is largely influenced by the availability of invertebrate food resources at a particular site. Some of the apparent prey selectivity appears likely to reflect patterns of benthic invertebrate activity and distribution on stone surfaces. The resulting diet of blue duck on the dates sampled included large proportions of stony-cased caddisfly larvae whose total dry weight can comprise 83% inorganic material (Pierce, 1979). Cased caddisfly larvae are therefore likely to be of relatively low energy value (per unit dry weight) compared with mayflies such as *Deleatidium* which were generally eaten in lower proportions than they occurred in the benthos in my study. This observation is in contrast to that noted for some other endemic birds that feed on the benthos of New Zealand rivers. Wrybill *(Anarhynchus frontalis* Quoy & Gaimard, 1830) and black stilt *(Himantopus novaezealandiae* Gould, 1764) feed primarily on larvae of *Deleatidium* spp. even though other aquatic invertebrate prey, including many taxa eaten by blue duck, were also available (Pierce, 1979, 1986). Wrybills and black stilts glean benthic invertebrates with long, pointed bills, quite unlike the short, flat bill of blue duck. The bill morphology of blue duck seems more likely to result in non-specialised feeding that maximises prey intake on each foraging bout.

Acknowledgements

I am grateful to Sandy Bull, Keith Owen, Paul Jansen, Barry Ovenden, Rob MacCallum, John Heaphy and Sue Triggs, Department of Conservation, for assistance in the field. Thanks also to Lisa Newton and Martin Williams, Massey University, for doing the faecal analyses using the method developed by Ian Henderson and Clare Veltman. Mike Wakelin, DoC, assisted with sorting invertebrate samples, and Zoology Department, University of Canterbury, provided use of computer facilities. Murray Williams, DoC, gave encouragement throughout the study, and along with Clare Veltman, Ian Henderson, Graeme Lyon, Martin Cawthorn, Mary Creswell, Mick Clout, Richard Sadleir, Jill Rapson and an anonymous referee, provided helpful comments on draft manuscripts. Leigh Moore, Shaun Hutton and Chris Edkins drafted the figures.

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