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# Consumer-Producer Relationships for Trace Metals in *Chorthippus brunneus* (Thunberg.)

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The behavior of trace metals in terrestrial food chains is a subject of ecological interest, particularly in polluted environments where the potential exists for bioconcentration of metals known to be essential in trace amounts for normal plant and animal metabolism, as well as those with no known metabolic function but recognised toxicological properties. Food chain transport of a range of essential trace metals has been described together with biomagnification of certain non-essential elements as a result of their mobility in food chains and concentration by consumer populations (Hughes et al. 1980).

Laboratory studies of food chain relationships, whilst they can be criticised for their isolation from many phenomena that influence ecological behaviour of contaminants in the field, afford a means by which direct comparisons can be made between trace metals as a basis for interpretation of data collected from wild plant and animal populations. This study compares the behavior of three trace elements, copper, zinc and cadmium, in terms of their assimilation under experimental conditions by the herbivorous common field grasshopper, Chorthippus brunneus (Thunberg.). This voracious orthopteran is widely distributed in Britain and is particularly prominent in the restricted invertebrate community of some metal smelter-affected grasslands where it forms important seasonal prey for insectivorous small mammals.

## MATERIALS AND METHODS

Adult specimens of C. brunneus were raised under laboratory conditions at constant temperature (27°C) and with controlled illumination (14 hr. photoperiod). Until the final ecdysis the population was maintained in a series of experimental cages, at a non-limiting feeding density, on cut shoots of perennial ryegrass, Lolium perenne (L.) grown on a fertile peat-loam compost containing normal concentrations of copper (20 mg/kg), zinc (60 mg/kg) and cadmium (0.7 mg/kg). Young adults were then relocated in an equal sex ratio to feeding cages where they were either maintained on a control diet or transferred to a 40 mg/kg diet of copper, zinc or cadmium supplied via cut shoots of L. perenne. The feeding trial was conducted over 21 days with daily renewal of the food supply in order to optimise feeding behavior and to minimise competition for a depleting resource.

On termination of the experiment, animals were killed in chloroform, surface-washed with deionised water, weighed and individually digested in a 4:1 $^{v}/v$ mixture of concentrated $HNO_3$: $HClO_4$ at 120°C. Digests were assayed for copper, zinc and cadmium by flame atomic absorption spectrophotometry with background correction from a hydrogen continuum source. Samples with low concentrations of metals were analysed by a flameless technique using a carbon furnace. Sub-samples of L. perenne were assayed directly at regular intervals in order to monitor variation in the trace metal concentrations of the diet. This enabled the dietary exposure of all three metals to be maintained at ±5% of the optimum 40 mg/kg.

## RESULTS AND DISCUSSION

The total body concentrations of copper, zinc and cadmium for both sexes of C. brunneus are summarised in Table 1. From these data it is evident that the cadmium treatment not only resulted in a very marked increase in the total body cadmium concentration ($P < 0.001$) but also in significantly reduced zinc ($P < 0.01$) and copper ($P < 0.05$) values compared to the control group. The copper and zinc treatments also resulted in significantly elevated body concentrations of these elements compared to the control population ($P < 0.001$); but there was no apparent reciprocal effect on absorption, nor did either treatment affect body cadmium concentrations.

Table 1. Total body concentrations of trace metals in Chorthippus brunneus (Mean ± SE)*

| Diet treatment | Analyte element: Cd | Cu | Zn |
|---|---|---|---|
| Control | 0.041 ± 0.01 | 18.3 ± 1.0 | 48.6 ± 1.6 |
| Zn | 0.045 ± 0.01 | 20.4 ± 1.1 | 70.0 ± 1.7 |
| Cu | 0.044 ± 0.01 | 46.3 ± 2.5 | 49.2 ± 1.5 |
| Cd | 19.2 ± 1.7 | 14.6 ± 1.2 | 38.6 ± 2.1 |

*Data in mg/kg fresh body weight; n = 16

Sub-division of the total body concentration data (Table 2) shows no apparent sex difference in body concentrations for any of the major trace element treatments; but the significant reduction in copper values induced by the cadmium treatment relates only to the males of the population ($P < 0.05$). In the absence of diet supplements there was no difference between sexes for any of the three metals.

Table 2. Sex differences in total body concentrations of trace metals in *Chorthippus brunneus* (Mean ± SE)*

| Diet treatment | Cd | | Cu | | Zn | |
|---|---|---|---|---|---|---|
| | M | F | M | F | M | F |
| Control | 0.039 ± 0.01 | 0.043 ± 0.007 | 20.5 ± 1.2 | 16.2 ± 1.1 | 46.5 ± 1.9 | 50.7 ± 2.2 |
| Zn | 0.042 ± 0.005 | 0.047 ± 0.004 | 22 ± 3 | 18.7 ± 3.3 | 67.6 ± 2.6*** | 72.4 ± 1.9*** |
| Cu | 0.043 ± 0.004 | 0.045 ± 0.001 | 46.9 ± 3.1*** | 45.7 ± 4.4*** | 50.3 ± 1.1 | 48.1 ± 2.9 |
| Cd | 21.3 ± 3.1*** | 17 ± 0.9*** | 14.9 ± 1.2** | 14.3 ± 5.3 | 39.6 ± 2.7 | 37.6 ± 5.5 |

(Analyte element: Cd, Cu, Zn)

* Data in mg/kg fresh weight; n = 8

** Significantly lower than control male mean ($P < 0.05$)

*** Significantly greater than control mean ($P < 0.001$)

Table 3. Body concentration ratios (treatment : control) for trace metals in Chorthippus brunneus

| | Analyte element | | |
|---|---|---|---|
| Diet treatment | Cd | Cu | Zn |
| Zn | 1.1 | 1.01 | 1.44 |
| Cu | 1.07 | 2.53 | 1.11 |
| Cd | 470 | 0.8 | 0.79 |

Table 4. Total body : diet concentration ratios for trace metals in Chorthippus brunneus

| | Control | Treated diet* | % change |
|---|---|---|---|
| Zn | 4.05 | 1.66 | - 59.0 |
| Cu | 5.54 | 1.10 | - 80.1 |
| Cd | 0.41 | 0.46 | + 12.2 |

*Supplemented to a regulated 40 mg/kg of Zn, Cu or Cd

The ratios for total body concentrations (treatment : control) and for total body : diet concentrations are summarised in Tables 3 and 4 respectively. Table 3, which takes no account of the relative changes in dietary trace element concentrations between the supplementary metal and control treatments, suggests that a comparatively homeostatic position is maintained for body zinc and copper, with treatment : control ratios of 1.44 and 2.53 respectively, as against 470 for cadmium. When account is taken of changes between the background metal concentrations of L. perenne (Zn: 12 mg/kg; Cu: 3.3 mg/kg; Cd: 0.1 mg/kg) and the elevated treatment levels of 40 $\pm$ 2 mg/kg, the difference in behavior of the copper, zinc and cadmium based on body retention by C. brunneus is more readily apparent (Table 4). Moreover, the short duration of the trial probably minimised the differences between cadmium, for which there is evidence of age-dependent accumulation (Hughes et al. 1980), and copper and zinc for which regulatory mechanisms are thought to exist, at least in mammals (Hunter and Johnson 1981).

Food chain transport of cumulative toxins by which primary consumers act as carriers to higher trophic levels where the toxicological effects on target species are more prominent is a recognised phenomenon for a range of synthetic chemicals. Particularly prominent examples are the organomercurials and halogenated hydrocarbons, both of which have been the cause for ecological concern regarding exposure hazards to wildlife, and in particular to predatory carnivores (Moriarty 1975).

Certain trace elements which, unlike synthetic pesticides, occur in the natural environment at low concentrations, may also acquire ecological significance through the increased environmental burdens derived from man's activities. Field experimental evidence from a range of contaminated environments suggests, however, that increased trace metal concentrations in soil and vegetation by no means automatically result in biomagnification in taxa of higher trophic levels (Roberts et al. 1979). In the present study of a single-step transfer between primary producer and consumer, a clear distinction has emerged in the regulatory behavior of two essential trace metals, copper and zinc, as compared to cadmium, a trace metal with no known biological function. Field and laboratory investigations of small mammals have also provided evidence of generally low food chain transfer potentials for copper (Hunter and Johnson 1981) and zinc (Roberts and Johnson 1978), a situation in marked contrast to that for cadmium (Roberts and Johnson 1979).

There have been few equivalent studies of macroinvertebrates and those that have been undertaken, for example with molluscs and zinc (Martin and Coughtrey 1976) and isopods and copper (Wieser et al. 1977), suggest that homeostasis, a common feature in mammalian physiology, may not always be evident in lower organisms. In contrast, C. brunneus provides evidence that some terrestrial invertebrates can largely buffer increased dietary concentrations of zinc and copper, and certainly to a much greater extent than is achieved for cadmium, though the underlying control mechanisms remain unknown. If these regulatory differences for trace metals in lower organisms apply also to field conditions they suggest, particularly when allied to mammalian responses to cadmium, that biomagnification of this metal in food chains is a factor of ecological importance in stressed environments.

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