Relationships Between Levels of Radiocaesium in Components of Terrestrial and Aquatic Food Webs of a Contaminated Streambed and Floodplain Community

I. L. Brisbin, Jr.; D. D. Breshears; K. L. Brown; M. Ladd; M. H. Smith; M. W. Smith; A. L. Towns

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RELATIONSHIPS BETWEEN LEVELS OF RADIOCAESIUM IN COMPONENTS OF TERRESTRIAL AND AQUATIC FOOD WEBS OF A CONTAMINATED STREAMBED AND FLOODPLAIN COMMUNITY

By I. L. BRISBIN, Jr, D. D. BRESHEARS,* K. L. BROWN,† M. LADD, M. H. SMITH, M. W. SMITH‡ and A. L. TOWNS*

Savannah River Ecology Laboratory, P.O. Drawer E, Aiken,
South Carolina 29801, U.S.A.

SUMMARY

(1) Radiocaesium concentrations of plants and animals from the watershed of a former reactor effluent stream declined 50–98% from 1971 to 1981.

(2) Radiocaesium concentrations of animals did not differ significantly between samples from locations along the stream channel, reflecting a previously demonstrated uniform distribution of radiocaesium in the sediments, and did not differ between animals from terrestrial vs. aquatic food webs.

(3) Significant correlations between radiocaesium contents of food-web components were about twice as frequent as would be expected by chance, but only seven of the twenty-three significantly correlated pairs contained components that were likely to have a direct trophic association.

(4) Caution should be used in arguing causation on the basis of simple correlations of contaminant levels of biotic compartments alone.

(5) The best 'indicator species' for radiocaesium contamination in aquatic food webs were the plants *Typha* and *Polygonum* and, even better, the animals *Palaemonetes* and *Etheostoma*. In terrestrial food webs, the best indicators were the plants *Alnus* and *Salix* and the animal groups of Araneae, Odonata (damsel flies) and Orthoptera.

INTRODUCTION

The continued release of radioactive contaminants into the environment as a result of human activity requires a better understanding of how such substances are distributed within biotic communities and food webs. The recent Chernobyl reactor accident and the consequent release of long-lived fission products throughout many environments in eastern Europe and Scandinavia is a particularly salient case in point (Hohenemser *et al.* 1986; Medvedev 1986). Gamma-emitting radionuclides such as radiocaesium, the principle long-lived isotope in the Chernobyl fallout (Devell *et al.* 1986), are particularly important from the point of view of human health. Moreover, they are particularly useful contaminants to study because of the ease with which they may be quantified without extensive sample preparation. The concept of trophic level concentration of radiocaesium (e.g. Pendleton *et al.* 1964; Jenkins & Fendley 1968; Reichle & Crossley 1969) has been used to prove some general principles for predicting the distribution of contaminants into

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* Present address: Department of Radiology and Radiation Biology, Colorado State University, Fort Collins, Colorado 80523, U.S.A.

† Present address: Department of Biological Sciences, Wichita State University, Wichita, Kansas 67208, U.S.A.

‡ Present address: Department of Biology, Johns Hopkins University, Baltimore, Maryland 21218, U.S.A.

food-web compartments. Anderson, Gentry & Smith (1973) showed that, although radiocaesium concentrations in dominant plants and arthropods of a contaminated streambed community in South Carolina were positively correlated with one another, the slopes of the linear relationships between various plant and arthropod groups were not constant. Moreover, no consistent trends were observed across trophic levels.

This paper reports results of studies in 1981 of the streambed community studied in 1971 by Anderson, Gentry & Smith (1973) and others, and attempts to document any changes which may have occurred in the distribution of radiocaesium in the various ecosystem components. Such information on the long-term declines and/or changes in the distribution of long-lived radionuclides in the biota from contaminated habitats can help to improve our ability to predict the long-term environmental consequences of future radionuclide releases which may occur as the result of accidents in operating nuclear facilities.

STUDY AREA

The Steel Creek watershed is located almost wholly within Barnwell County, South Carolina, U.S.A., within the boundaries of the Savannah River Plant, a nuclear production and research facility of the United States Department of Energy (Fig. 1). Steel Creek is *c.* 20 km long and is paralleled by two stream channels draining a contiguous watershed of *c.* 290 km^2 (Langley & Marter 1973). In its lower reaches, the floodplains broaden and the creek enters an area of dammed levee deposits of the Savannah River, creating a swamp delta *c.* 16 km long and 2·5 km wide. For several years before 1961, Steel Creek received cooling water and disassembly basin effluents from two nuclear production reactors near the headwaters of the stream. Maximum stream flow was increased from a pre-discharge level of 1·0 m^3 s^{-1} to as high as 24 m^3 s^{-1} as a result of reactor effluent discharges (Ruby, Reinhart & Reel 1981). From 1961 to 1970, these effluents received *c.* 966 GBq of radiocaesium and smaller amounts of other gamma-emitting radionuclides which had leaked from defective experimental fuel assemblies (Marter 1970). Most of the radiocaesium in the Steel Creek watershed is currently found in the stream and floodplain soils and sediments. Low detectable amounts of radiocaesium occur in the stream water, in the suspended particulate load during periods of high storm flows or flooding (Brisbin *et al.* 1974; Smith, Sharitz & Gladden 1981, 1982).

An earlier description of the Steel Creek habitat is provided by Anderson, Gentry & Smith (1973). In the ensuing years, however, rapid succession replaced the predominantly old-field habitat with a hardwood–shrub community, covering most of the previously exposed streambed and mudflats (Martin, Christy & McLeod 1977). Dominant tree species now include alder (*Alnus serrulata* Aiton) and sweetgum (*Liquidambar styraciflua* L.) in the upper reaches of the watershed. Wax myrtle (*Myrica cerifera* L.) and willow (*Salix* spp.) dominate the downstream floodplain community. In the lower reaches of the watershed, the swamp delta is dominated by successional willow forests, shrub communities of buttonbush (*Cephalanthus occidentalis* L.) and herbaceous wetlands dominated by cutgrass (*Leersia* spp.) (Smith, Sharitz & Gladden 1981).

METHODS

Twelve study locations were established along Steel Creek, between the swamp/delta and the uppermost reactor from which contaminated effluents had been released (Fig. 1). At each location, the access point (i.e. the point of entry from the nearest road or bridge) was

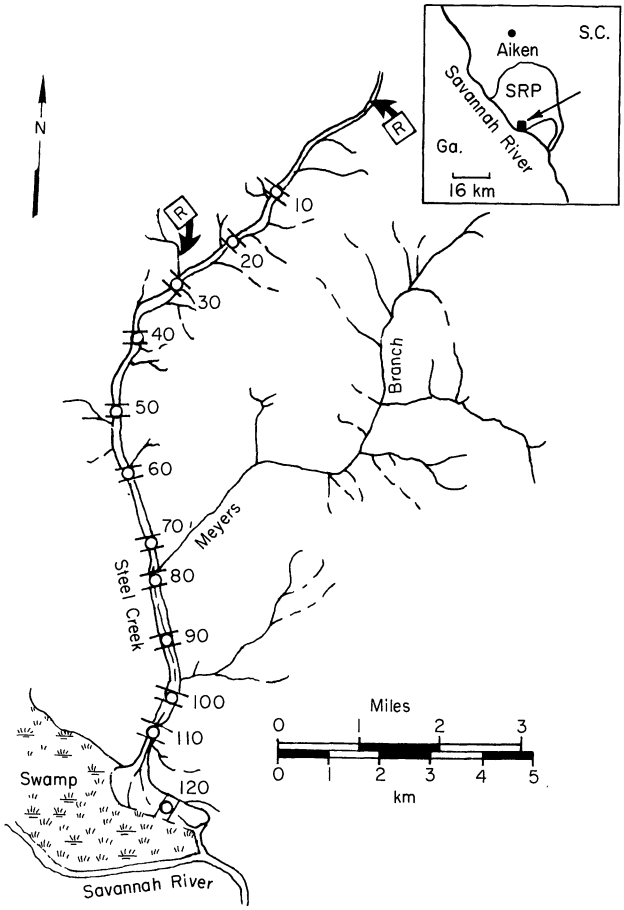

FIG. 1. Upstream and downstream sampling areas (short horizontal lines) at twelve study locations (○) in the Steel Creek watershed of the United States Department of Energy's Savannah River Plant (SRP) in South Carolina. Numbers indicate designations of sampling stations, and arrows indicate former points of entry of contaminated effluents from nuclear production reactors (R).

chosen as the centre, and two sampling areas were defined, each bounded laterally by the limits of the stream's floodplain. One of these sampling areas was within an arbitrarily set region of 30–130 m upstream and the other within 30–130 m downstream from the centre.

Field collections were made between 8 June and 13 August 1981. Within each area, sampling started at the centre of the stream channel and moved laterally onto the floodplain, until appropriate habitat was encountered for the species sought. All species or groups were not present at every location. Collection methods varied and were often opportunistic. Individual animals collected from each area were pooled to form a single sample. Because of logistic limitations to the study, no animal samples were collected from stations 30, 60 or 90 (Fig. 1). In the case of vegetation, only leaves were collected and, after oven-drying to constant weight at 65 °C, these were pooled to provide single biomass samples of generally uniform size and counting geometry. Radiocaesium contents for vegetation at a given location represented the mean of composited leaves from six individual plants. Aquatic samples were briefly rinsed in the field to remove adhering debris and/or sediments, before being brought to the laboratory for analysis.

Ecosystem components selected for study were taxonomically defined, and ranged from single species to groups including representatives of entire orders, since it was not feasible to identify all individuals to species level, and often numbers of given species were not sufficient to provide enough biomass for adequate radionuclide analyses. Groups studied are listed in Table 1.

Samples were ground into fragments, which were packed into a uniform counting geometry, by filling a 2·7-cm diameter plastic vial to a depth of $\leqslant 5{\cdot}0$ cm, and oven-dried. Radiocaesium contents were determined by a method similar to that used by Anderson, Gentry & Smith (1973): samples were counted individually in a Beckman Gamma 8000 well-type thallium-activated sodium-iodide crystal (7·6 cm diameter × 7·6 cm deep with a well 2·8 cm diameter × 7·6 cm deep). Vegetation samples were counted for 10 min. Because of their smaller biomass, animal samples often showed counting rates below the minimum detection limits for 20-min counting times. All animal samples with biomasses smaller than that required to give detectable counts above background, assuming an average count rate for animals as a whole, were counted for longer.

Gamma spectrometry was performed using a 500–750 KeV counting window. Counts in this region were considered to represent ^{137}Cs emissions and were compared with same-day counts of 3700 Bq NBS calibrated Tracerlab phantoms to provide an estimate of radiocaesium content after correcting for daily background measurements. Although a few other isotopes (e.g. ^{134}Cs, ^{214}Bi and/or ^{228}Ac) also produce gamma emissions within this 500–750 KeV counting window, previous studies and the unique contamination history of our study area (Marter 1970) indicated that, with the exception of ^{134}Cs, no other isotopes either were or ever had been present in the study area in detectable quantities. Further confirmation of this fact was obtained by counting six randomly selected samples each, of sediments, vegetation and arthropods (grasshoppers) on a 43-mm diameter × 46 mm deep germanium (lithium-drifted) semiconductor crystal (GeLi) and a reverse germanium electrode detector (REGE) coupled with a Canberra Series 85 multichannel analyser. These analyses showed that even ^{214}Bi, which may occasionally be present as a natural daughter product of ^{226}Ra decay, was only present in biota from our study area at levels of from 1/120 (arthropods) to 1/600 (vegetation) of that of ^{137}Cs. The ^{134}Cs isotope has a much shorter half-life than ^{137}Cs and, being nearly two orders of magnitude less abundant than ^{137}Cs in the late 1960s (Marter 1970), is unlikely to have made any significant contribution to the counts recorded here as 'radiocaesium'.

Because radiocaesium concentrations commonly fail to show a normal frequency distribution in environmental samples (Pinder & Smith 1975), non-parametric statistical methods were used for all data analyses and median values were reported rather than means. Radiocaesium concentrations of the various groups were compared using a Kruskal–Wallis test (Sokal & Rohlf 1969). Because only leaves were used and not whole plants, no direct comparisons were made between radiocaesium values of plants and animals. In seeking correlations between the concentrations of pairs of components, data were paired according to the particular locations from which the samples were collected and a Spearman rank correlation analysis (Sokal & Rohlf 1969) was used to determine relationships within the watershed.

RESULTS

Medians and ranges of the radiocaesium concentrations of the various components of the Steel Creek watershed are presented in Table 1. Using data from all animal species, a

TABLE 1. Component groups sampled from aquatic and terrestrial food webs of the Steel Creek watershed and their median radiocaesium concentrations^{-1} based on composite samples from twenty-four sampling locations

Component group	Number of samples*	Radiocaesium concentration ($\mathrm{Bq\ g^{-1}}$ dry wt) Median	Range
Aquatic food webs			
Vegetation†			
Sagittaria spp.	14	9·6	(26/3·3)
Typha spp.	6	0·37	(1·48/0·33)
Polygonum spp.	15	4·8	(20/0·37)
Invertebrates			
Mollusca: Pelecypoda			
(*Corbicula fluminea* Müller)‡	16	0·37	(2·2/0·11)
Crustacea: Cambaridae			
(*Procambarus* spp.)	17	1·9	(3·3/−5·9)§
Crustacea: Palaemonidae			
(*Palaemonetes paludosus* Gibbes)	15	1·9	(8·1/0·37)
Insecta: Odonata¶			
Burrowing larvae	17	1·1	(1·9/−0·15)§
Crawling larvae	17	2·2	(17/−9·3)§
Sprawling larvae	17	1·1	(26/0·74)
Insecta: Coleoptera			
Gyrinidae	13	0·74	(1·5/−0·74)§
Vertebrates (Pisces)			
Notropis spp.	18	1·1	(14/0·37)
Etheostoma spp.	13	1·1	(0)
Vertebrates (Amphibia—Caudata)			
Pseudotriton ruber Sonnini, and			
Eurycea bislineata (Green (larvae)	15	1·1	(3·3/−3·0)§
Terrestrial food webs			
Vegetation†			
Alnus spp.	13	4·4	(9·6/2·6)
Myrica spp.	15	2·2	(5·6/0·74)
Salix spp.	17	8·5	(21/1·9)
Rubus spp.	15	3·0	(6·3/1·5)
Invertebrates (Arthropoda)			
Araneae (all spiders)	16	1·1	(13/0·004)
Lepidoptera (butterflies)	16	0·37	(1·9/−0·74)§
Orthoptera (grasshoppers)	18	3·3	(8·9/1·5)
Hymenoptera (bees)	16	0·04	(9·3/−1·1)
Odonata (damsel flies)	16	0·74	(1·5/−23)§

* Number of transects from which the group was collected.

† Leaves only were sampled.

‡ Radiocaesium determinations were made on soft body parts only.

§ Negative values result from samples for which the gamma count-rate cannot be statistically distinguished from background (see text).

¶ Division of aquatic odonate larvae into climbing, sprawling and burrowing niches was made according to the descriptions of Smith & Pritchard (1956).

Kruskal–Wallis test indicated no significant effect of location of collection on radiocaesium contents of animals from either terrestrial or aquatic food webs ($H = 6{\cdot}39$, d.f. $= 8$, $P = 0{\cdot}60$ (terrestrial) and $H = 11{\cdot}93$, d.f. $= 8$, $P = 0{\cdot}15$ (aquatic)). Pooling data for animals from all locations, an additional Kruskal–Wallis test indicated no significant

TABLE 2. Ten-year changes in the mean ($\bar{x}$)* summer radiocaesium concentrations (Bq g^{-1} dry wt) of selected plants and insects from the Steel Creek watershed

	1971†				1981		
	Floodplain		Islands				
	n	$\bar{x}$(C.V.)‡	*n*	$\bar{x}$(C.V.)	*n*	$\bar{x}$(C.V.)	Physical decay alone§
Plant genera							
Alnus	10	14 (51·2)	8	37 (79·2)	13	4·4 (30·1)	20
Myrica	10	20 (164)	8	56 (147)	15	2·6 (44·3)	30
Salix	10	19 (174)	10	59 (117)	17	9·6 (63·4)	31
Arthropod orders							
Araneae	25	9·6 (135)	25	36 (87·6)	16	2·2 (13·3)	18
Coleoptera	25	16 (330)	24	37 (94·0)	13	0·74 (90·2)	21
Orthoptera	25	15 (100)	25	56 (93·3)	18	3·3 (47·1)	28

* Although data analyses in the present study were based on the medians, means were also calculated across all locations from the present study, to permit direct comparisons with the 1971 data.

† From Anderson, Gentry & Smith (1973).

‡ Coefficient of variation.

§ Radiocaesium concentrations that would be predicted for the average of the 1971 floodplain and island values, if only physical decay of the isotope occurred.

difference between the radiocaesium contents of animals from terrestrial and aquatic food webs ($H = 0·71$, d.f. $= 1$, $P = 0·40$).

Because field collections and counting procedures were undertaken in the same general manner as used by Anderson, Gentry & Smith (1973), comparisons could be made to reveal 10-year changes in radiocaesium concentrations of food-web components sampled in both studies (Table 2). The 1971 samples were confined to a small area of the Steel Creek watershed in the vicinity of our transect 100 (Fig. 1). However, the lack of a significant location effect upon radiocaesium concentrations in animals from aquatic or terrestrial food webs, as revealed in the present study, suggest that a valid comparison can be made between the 1971 data and our pooled data from all transects within the watershed in 1981. These comparisons indicated that, between 1971 and 1981, radiocaesium contents of these food-web components declined by at least 50% (*Salix*) and as much as 98% (Coleoptera) (Table 2). The variability of radiocaesium concentrations, as indicated by coefficients of variation, also declined during the 10 years (Table 2), despite the wider scale of sampling in 1981.

Twenty-three of the 231 possible pairings of food-web components showed statistically significant ($P \leqslant 0·05$) correlations between their radiocaesium concentrations (Table 3). The frequencies of occurrence of aquatic/aquatic vs. terrestrial/terrestrial vs. aquatic/terrestrial pairs in significant correlations (Table 3) did not differ significantly from the frequencies these pairings would be expected to show from chance alone ($\chi^2 < 0·001$, d.f. $= 2$, $P > 0·99$). Similarly, neither animals vs. plants nor aquatic vs. terrestrial groups appeared in the twenty-three significantly correlated pairs in frequencies that differed significantly from the proportions in which they appeared in all of the groups examined ($\chi^2 = 0·015$, d.f. $= 1$, $P > 0·80$ and $\chi^2 = 0·00$, d.f. $= 1$, $P > 0·95$, respectively).

Only seven of the twenty-three significantly correlated pairs contained components that could possibly be expected to have a direct trophic association (i.e. one member of the pair could conceivably be eaten by the other). The correlation coefficients of these seven trophic pairs were all positive, ranged from 0·82 to 0·51 and did not seem to be any more

Table 3. Paired food-web components showing significant correlations of radiocaesium concentrations within a contaminated watershed receiving nuclear production reactor effluents

Correlated pair	Correlation coefficient (r_s)	Level of significance
Aquatic food webs		
Typha/Caudata	−0·94	0·005
Etheostoma/*Typha*	0·89	0·019
Sagittaria/*Typha**	0·83	0·040
Palaemonetes/*Etheostoma*†	0·75	0·003
Coleoptera/*Etheostoma*†	0·64	0·024
Coleoptera/*Notropis*†	0·58	0·040
Corbicula/*Palaemonetes*	−0·56	0·046
Odonata (burrowing dragonfly larvae)/*Procambarus*†	0·51	0·045
Terrestrial food webs		
Rubus/Hymenoptera†	0·75	0·002
Salix/Araneae	0·74	0·002
Odonata (damsel flies)/Orthoptera	0·59	0·015
Orthoptera/Araneae†	0·53	0·036
Aquatic/terrestrial food webs		
Typha/*Alnus**	−0·94	0·005
Palaemonetes/Araneae	−0·85	<0·001
Sagittaria/Lepidoptera†	0·82	0·001
Palaemonetes/*Salix*	−0·75	0·002
Palaemonetes/*Rubus*	−0·73	0·007
Etheostoma/*Salix*	−0·72	0·007
Sagittaria/*Alnus**	−0·72	0·008
Caudata/Lepidoptera	0·71	0·007
Corbicula/*Salix*	0·58	0·020
Corbicula/Lepidoptera	−0·54	0·050
Corbicula/Orthoptera	0·52	0·037

* Pairs in which there is the possibility of a closely shared resource (e.g. two plant species which may grow in close association in the same substrate).

† Pairs in which there is the possibility of a direct trophic interaction within the food web. In these pairs, the component representing the lowest trophic level of the two is presented first.

highly correlated than the remaining seventeen pairs, whose correlation coefficients were positive or negative and ranged in absolute value from 0·94 to 0·52. Three additional pairings represented plant species that may grow in close association on a common substrate. Of the twenty-three significant correlations, nine were negative, and all but two of these nine pairs involved both aquatic and terrestrial food-web components (Table 3).

DISCUSSION

Comparisons of radiocaesium concentrations for plants and insects with corresponding values reported by Anderson, Gentry & Smith (1973), indicated a marked decline during the 10 years (Table 2). These decreases were much larger than would be expected on the basis of physical isotope decay alone (Table 2). As documented by other studies (Brisbin *et al.* 1974; Smith, Sharitz & Gladden 1981, 1982), some fraction of the radiocaesium has either: (i) left the Steel Creek watershed and moved downstream as a result of storms and/or flooding, (ii) become physically less available to the biota of the area, (iii) become chemically sequestered within the system, or (iv) a combination of these factors. Brisbin *et* *al.* (1974) used desorption procedures to show that radiocaesium was not tightly bound by sediments of the Steel Creek watershed in 1972, and at that time, over 68% of the total radiocaesium inventory was in the upper 20 cm of the sediments, where it would have been readily available to biota. More recent data (Smith, Sharitz & Gladden 1982; Gladden *et al.* 1985) suggest that the region of highest radiocaesium concentration has moved downward in the sediments, as compared with the 1974 study (Brisbin *et al.* 1974). This has probably resulted from the recent deposition of uncontaminated sediments over those showing higher concentrations of radiocaesium. This process would decrease the physical availability of the radiocaesium to resident biota over the 10 years. In addition, in 1981, *c.* 74% of the original radiocaesium release was estimated to have left the Steel Creek watershed as a result of downstream movement (Smith, Sharitz & Gladden 1982). Thus, physical forces and abiotic factors, particularly those related to the transport and redeposition of stream sediments, must play a dominant role in determining the patterns of radiocaesium distribution within the biota of this study area. These abiotic factors and their possible influences upon radiocaesium distribution in stream biota are discussed at greater length in other studies of this area (Brisbin *et al.* 1974; Pinder & Smith 1975; Ruby, Reinhart & Reel 1981; Smith, Sharitz & Gladden 1981, 1982; Gladden *et al.* 1985).

Both the frequency and magnitude of significant correlations between radiocaesium contents of plants and insects from Steel Creek were lower in this study than in results obtained by Anderson, Gentry & Smith (1973) (Table 3). The lower radiocaesium concentrations in the present study undoubtedly contributed to this reduction in correlations since, unlike the 1971 data, many 1981 samples had radiocaesium concentrations that were so low that the inability to distinguish them clearly from the background counts may have obscured many correlations.

The failure to demonstrate location differences in radiocaesium concentrations of Steel Creek animals in 1981 undoubtedly reflects the importance of physical forces and abiotic factors, particularly those related to the movement and redeposition of sediments along the stream channel. Brisbin *et al.* (1974) found no differences in sediment radiocaesium concentrations between upstream and swamp-delta locations in 1972 and this uniformity of distribution within the sediments has almost certainly influenced the distribution of radiocaesium within the biotic communities associated with them.

The highest median radiocaesium concentrations (all those $> 3{\cdot}33$ Bq g^{-1} dry wt) were shown by plants (Table 1), a trend also shown in 1971 (Anderson, Gentry & Smith 1973). Our 1981 data, however, showed no clear trends for either increasing or decreasing radiocaesium concentrations across trophic levels (Table 1). One reason may be the ways in which food chain components were designated. Insect groups such as the Coleoptera, for example, may show a diversity of feeding habits. In our study, the genera studied were generally omnivorous or carnivorous, while the coleopterans studied by Anderson, Gentry & Smith were probably herbivorous and possibly carnivorous. Moreoever, caution should be applied in making direct comparisons between our data for Coleoptera, all of which were of aquatic taxa (Gyrinidae) and those of Anderson, Gentry & Smith (1973), whose coleopterans were all terrestrial.

There are also potential inaccuracies in assuming a trophic level for taxonomic groups whose members may actually feed in more than one trophic position in the community. Moreover, many of these organisms may have acquired radiocaesium from non-food sources (e.g. ingestion of contaminated sediments clinging to food items). Considering these broad groupings of many food-web components, the demonstration of twenty-three significant correlations (Table 3) indicates some degree of correlative (although not necessarily causative) relationship within the matrices of components studied. Ten of the twenty-three significant correlations represented pairings of components for which there was a possibility of either direct trophic interaction or a shared substrate resource (Table 3). Thus, thirteen of the twenty-three pairs showed correlations that could not be explained on the basis of simple causal mechanisms. This number was quite close to the number of pairs (11·6) that would be expected to show significance of correlation by chance alone at a level of $P \leqslant 0{\cdot}05$. One significantly correlated pair for which the components seemed to have a direct trophic relationship was Araneae vs. Orthoptera ($r_s = 0{\cdot}53$). This pair showed the highest degree of correlation ($r = 0{\cdot}98$) reported by Anderson, Gentry & Smith (1973) and, at least when contamination is high, would seem to be a particularly useful one for further studies of trophic relationships of radiocaesium and perhaps other contaminants, in this and similar ecosystems. Nevertheless, the data reported here would argue strongly for caution in reasoning directly to causality simply on the basis of correlation of radiocaesium contents alone. Despite the strong correlation between the radiocaesium contents of Araneae and Orthoptera, for example, other high correlations between components that were not trophically related (e.g. *Palaemonetes*/Araneae) would not indicate that radiocaesium contents in the higher trophic levels resulted from or were controlled by contamination at the lower trophic levels.

Evaluations of the cycling of contaminants in the environment have often used the concept of the 'indicator species'. Implicit in this concept is the assumption that the concentrations of some contaminant in a certain species/group, may be related, precisely and predictably, to the concentrations of the same contaminant in other components of the food web and/or ecosystem. Seldom, however, has this assumption been examined critically. Our data provide an opportunity to explore the value of the 'indicator species' concept for radiocaesium contamination in aquatic and terrestrial food webs of the Steel Creek watershed. As explained above, however, the numbers of negatively correlated pairs and correlated pairs for which no obvious causal or trophic relationships could be demonstrated, would argue for great caution in basing any general conclusions on the 'indicator species' concept alone. Nevertheless, if it were necessary to select some 'indicator species' for this study area, the usefulness of a given food-web component as an indicator of contaminant concentration in other components could be quantified by the procedure of Brisbin & Smith (1975), which provides a weighted ranking of each component with respect to: (i) the frequency with which the contaminant concentrations in that component showed significant correlations with those in other components and (ii) the magnitude of the correlation coefficients of all of the relationships in which that component was involved.

When applied to the data from this study, these rankings suggested that radiocaesium concentrations in aquatic food webs in Steel Creek would be best indicated by the plant genus *Typha*, and to a lesser degree *Polygonum* but, even better, by the animal genera *Palaemonetes* and *Etheostoma*. Radiocaesium concentrations in terrestrial food webs, on the other hand, would be best indicated by the plant genera *Alnus* and *Salix* and by the animal groups of Araneae, Odonata (damsel flies) and Orthoptera. It must be remembered, however, that other criteria related to abundance, phenology, ease of collection, seasonal availability or direct importance to man as a food item (e.g. sport fish and game) must also be considered in selecting appropriate indicator species or groups.

Over the next decade, studies of wetland habitats contaminated with radiocaesium as a result of the Chernobyl accident should provide numerous opportunities to apply and test the relationships described here. The results of such comparisons should help to determine how such relationships are controlled within natural ecosystems.

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