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**Journal
canadien des
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halieutiques et
aquatiques**

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Volume 49 • Number 9 • 1992

Pages 1673-1882

Canada



Fisheries
and Oceans

Pêches
et Océans

Linkage between Islands and Benthos in the Ohio River, with Implications for Riverine Management

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Thorp, J. H. 1992. Linkage between islands and benthos in the Ohio River, with implications for riverine management. *Can. J. Fish. Aquat. Sci.* 49: 1873–1882.

Anthropogenic reductions in braiding, meandering, and snag abundance have diminished habitat heterogeneity of regulated rivers, factors directly influencing island formation, retentive capacity of the ecosystem, and community diversity. Habitat heterogeneity associated with riverine islands should, therefore, be of paramount importance to the ecosystem and may require special management protection. To understand the influence of these alluvial formations on riverine benthos, macroinvertebrate assemblages were sampled near three islands in the Ohio River above Louisville, Kentucky, USA. Benthos was collected along six bank-to-bank transects located 1 km above and below islands and near the head, middle, and foot of islands. Islands have significant positive effects on invertebrate density and diversity that appear related to changes in physical habitat characteristics. Current velocity and substrate particle size are diminished in narrow channels between islands and shore, and areal extent of the littoral zone is enhanced within an otherwise deepwater region. Shallow water and slower currents promote growth of submerged vascular plants and macrophytic algae. Because of a relatively low exploitation by humans, islands probably enhance snag formation and input of organic matter, both factors having positive effects on macrofauna. Creation of selected riverine preserves near islands as a management tactic is recommended.

Les réductions d'origine anthropique de la réticulation, de la formation de méandres et de la fréquence des croches ont diminué l'hétérogénéité de l'habitat dans les cours d'eau aménagés, facteurs qui ont une influence directe sur la formation des îles, la capacité de rétention de l'écosystème et la diversité de la communauté. L'hétérogénéité de l'habitat associée aux îles fluviales devrait donc avoir une importance primordiale pour l'écosystème et peut exiger un régime spécial de protection. Pour comprendre l'influence de ces formations alluviales sur le benthos de la zone proche des berges, on a échantillonné des assemblages de macroinvertébrés près de trois îles se trouvant dans le fleuve Ohio en amont de Louisville (Kentucky), aux États-Unis. Le benthos a été recueilli le long de six transects de rive à rive situés à un 1 km au-dessus et au-dessous des îles et près de la tête, du milieu et de la queue des îles. Les îles ont des effets positifs notables sur la densité et la diversité des invertébrés, effets qui semblent liés à des modifications dans les caractéristiques physiques de l'habitat. La vitesse du courant et la granulométrie du substrat diminuent dans les chenaux étroits entre les îles et la berge, et la superficie de la zone littorale augmente dans une région d'eau profonde par ailleurs. La faible profondeur de l'eau et le ralentissement des courants favorisent la croissance des plantes vasculaires immergées et des algues macrophytes. Du fait qu'elles sont soumises à une exploitation relativement faible par les humains, les îles favorisent probablement la formation de croches et l'apport de matières organiques, deux facteurs qui ont des effets positifs sur la macrofaune. Il est recommandé comme méthode de gestion de créer des réserves protégeant des zones littorales choisies près des îles.

Received August 12, 1991

Accepted March 26, 1992

(JB178)

Reçu le 12 août 1991

Accepté le 26 mars 1992

Long, relatively pristine, and unregulated reaches of very large rivers have nearly vanished from developed nations (exceptions in North America include some rivers in Canada and Alaska) and are rapidly disappearing from the less-developed countries of our biosphere as a result of intentional and extensive alterations of natural rivers over the last 100 yr (Benke 1990). Prior to anthropogenic efforts to manage rivers by channelization and impoundment, medium to large rivers (orders 6–9) were highly braided with complex, anastomosing channels that significantly expanded opportunities for direct riparian influence (Cummins et al. 1984). In some ways, the rivers of 100 yr ago were more akin to modern, midorder streams than to today's large regulated rivers. Managed rivers are less shaded, deeper, less turbid, and more homogeneous in habitat than unregulated rivers; they also contain fewer debris dams and have a different mixture of allochthonous and autochthonous carbon sources (cf. Cummins et al. 1984; Ward and

Stanford 1989). A reduction in river meandering and channel complexity (including fewer islands) probably had dramatic effects on ecosystem properties that, in combination with anthropogenic pollution, depressed the density and diversity of riverine communities.

The very large rivers of the world will probably remain regulated for the foreseeable future because population pressures and the need for hydroelectric power and commercial navigation are unlikely to abate. Unfortunately, most of the world's large rivers have scarcely been examined from an ecological perspective (Statzner and Higler 1985; Williams 1988; Haag and Thorp 1991). Lotic research has focused on either headwater streams or a few unregulated tropical rivers, and, indeed, only 4% of the publications on running waters have dealt with large rivers (Hynes 1989). In recent years, it has become clear that ecological predictions made by extrapolating knowledge from midorder and headwater streams have failed to explain

adequately ecosystem behavior of very large rivers, especially those with extensive floodplains (Sedell et al. 1989).

Attempts to protect and partially restore large rivers must be based on sound ecological knowledge. One promising approach is to designate critical areas of a river for special protection while attempts are made to ameliorate conditions throughout the ecosystem. Habitats that seem to fit within this goal are riverine islands. Although few attempts have been made to study islands, the sparse data suggest that they enhance the biotic community (Gosse 1963).

The purposes of the present study were to investigate the influence of three islands in the Ohio River on the density, diversity, and species composition of the benthic macroinvertebrate assemblage, an important food web component of the river, and to examine these data in light of the potential need to establish critical habitat preserves. This research was part of an ongoing, collaborative study of the importance of temporally fluctuating combinations of physical, chemical, and biological factors in regulating riverine communities. I examined the effects of an island's location within the Ohio River (distance from a downstream dam), the direct influence of islands on benthos, and the relationships between benthic community characteristics and the interrelated physical parameters of water velocity, depth, and substrate type. As described later, these data can be applied to models for the restoration and management of rivers. This study was also meant to contribute to our general knowledge of ecosystem behavior of very large rivers.

Methods and Habitat Description

Study Sites

Based on average yearly discharge, the Ohio River is the second largest river in the United States (8127 m³/s) surpassed only by the Mississippi below its confluence with the Ohio (U.S. Geological Survey Water-Data Report for 1989, based on 61 yr of data). The average annual discharge of the Ohio at Louisville is 3273 m³/s (115 500 ft³/s), with a historical range of 60 to 31 455 m³/s. Peak current velocities during the sample period in late summer 1989 were approximately 0.7 m/s at the water surface in midchannel and 0.10 ± 0.05 m/s near the bank. The Ohio has a constricted channel upstream from Louisville but becomes a floodplain river downstream; however, small floodplains are common within portions of the constricted region. The river bottom is generally muddy or sandy nearshore but becomes sandy and gravelly in deeper water, as is usually the case in large rivers (Hynes 1970, p. 25); large patches of limestone cobbles and boulders occur frequently on either bank.

Benthic samples were collected near Six, Twelve, and Eighteen Mile Islands within the McAlpine Pool (Fig. 1) just upstream of Louisville (38°16'N, 85°47'W). These three islands are roughly similar in size (30–50 ha) and shape but differ in distance from both the mainland shore (which influences bottom characteristics of the channels) and the downstream dam at Louisville (which affects current velocity and, thereby, the size of suspended particles). Each island was apparently named for its approximate distance upstream from McAlpine Dam, the low head, navigation dam at Louisville. Six Mile Island is situated about 75 m from the Indiana shore; Twelve Mile Island is in the middle of the river (~300 and 500 m from Indiana and Kentucky shores, respectively); and the "chute" (a narrow channel between an island and the mainland) is less than 50 m wide between Eighteen Mile Island and the Kentucky bank (Fig. 1).

These three islands have similar origins and extant riparian and submerged vegetation. Silver maple (*Acer saccharinum*) and cottonwood (*Populus deltoides*) are the most abundant riparian trees, but sycamore (*Platanus occidentalis*), box elder (*Acer negundo*), black willow (*Salix nigra*), and various other species are also present. Shoal areas near islands and river banks support seasonal growth of benthic filamentous algae, pondweed (*Potamogeton* spp.), and eel or ribbon grass (*Vallisneria americana*). Each island is entirely of alluvial origin and contains silt loam and fine sandy loam soils (Kentucky State Nature Preserves Commission, unpubl. rep.). These islands can only be reached by boat, with most human activity occurring during summer weekends; however, tow barges regularly pass near all three islands.

Sampling Design and Biological Measurements

I collected benthic grab samples from the following six cross-river transects around each island (Fig. 1): "A," 1 km above the head of the island (presumably upstream from island effects); "B" and "E," across the head and foot of the island, respectively, at a minimum depth of 1 m; "C" and "D," one third and two thirds of the distance downstream from the head, respectively; and "F," 1 km below the island. Six grab samples were retrieved along each transect (Fig. 1) for a total of 108 samples in the study (3 islands × 6 transects/island × 6 samples/transect).

Benthic samples were collected with a Ponar grab from substrates composed primarily of either mud, sand, or gravel (small to large). Shoreline areas composed of either wood snags or cobbles and boulders were avoided, as these bottom types could not be sampled effectively. Although this eliminated substrates with distinctive invertebrate assemblages (cf. Thorp et al. 1985), systematic error was reduced among sites by maintaining sampling consistency. (Species composition and secondary production of fauna on these substrates are being determined in a separate study (M. D. DeLong and J. H. Thorp, unpubl. data).) Invertebrates were collected from all transects over a 3-wk span in late September and early October of 1989 when water temperatures were near 22°C from surface to bottom (usually ≤1°C difference between channel and bank).

Grab samples were sieved in the field through a 0.5-mm-mesh (U.S. Geological Series No. 35) and preserved in 70% EtOH + Phloxine B vital stain. Invertebrates were sorted in the laboratory and identified using keys in Merritt and Cummins (1984) and Thorp and Covich (1991). Body lengths (anterior–posterior) of Asiatic clams (*Corbicula fluminea*) were measured to provide information on size distribution of a numerically dominant species.

Habitat Characterization

Differences in water velocities among sample sites were measured 1 m below the water surface with a Marsh–McBirney velocity meter (model 201-D). Although very accurate for most of the water column, this meter cannot gauge velocities at the substrate surface where most riverine benthos reside. Therefore, current velocity data were used for macrocomparisons among shallow and deepwater sample locations rather than as a measure of microhabitat differences.

Predominant substrate types were estimated by wet sieving and qualitative field observations. Five of the seven substrate categories employed generally corresponded to those listed in Hynes (1970, p. 24): SI (silt and clay), FS (fine and very fine sand with some silt), CS (coarse sand), GR (gravel), and PB

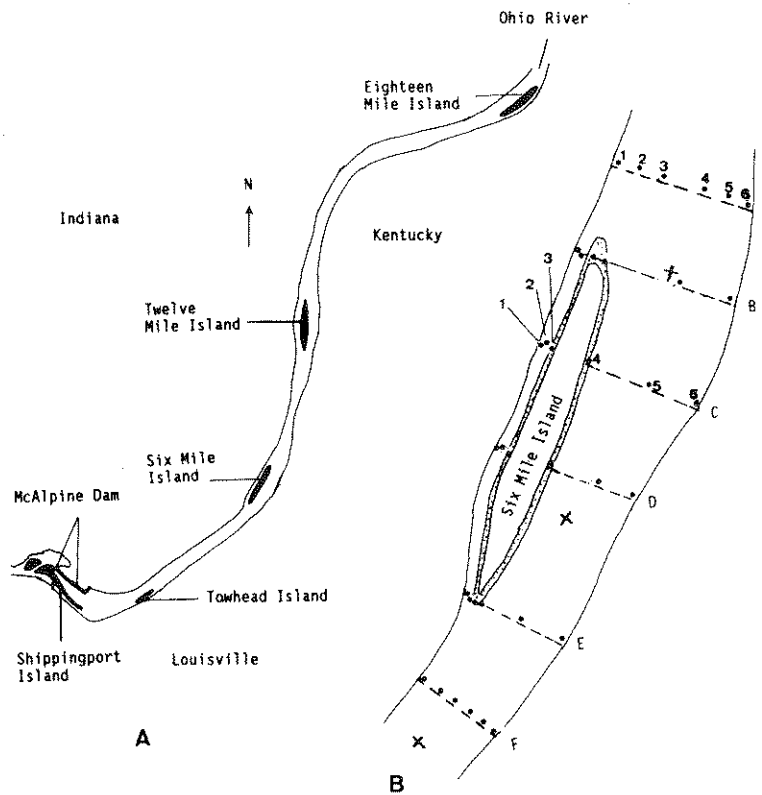


FIG. 1. (A) Stretch of the Ohio River as it flows southwesterly past Eighteen Mile Island through a navigation lock (between Shippingport Island and the Kentucky shore) or over and through the McAlpine Dam (an elongated z-shaped dam between Shippingport Island and the Falls of the Ohio near the Indiana shore); relative positions of the three islands studied here are shown. (B) Enlargement of the area around Six Mile Island showing the approximate positions of the six bank-to-bank transects (A-F), each with six sample sites (1-6); the crosses mark the midchannel area and are separated by 1.6 km (1 river mile); the narrow channel between the island and mainland is known as a chute.

(pebbles). Categories MG (muddy gravel) and SG (sandy gravel) were added because some habitats had markedly heterogeneous substrates during the sample period. Presence of vascular plants (mostly *Vallisneria*) or filamentous algae was recorded.

Statistical Analyses

Because macroinvertebrate abundances were low and spatial distributions of individual species were highly variable, the data were not normally distributed. Failure of traditional transformation techniques to normalize the data necessitated use of nonparametric techniques, principally Kruskal-Wallis ranked tests and Pearson's product moment correlations. Results were analyzed using subroutines of the Statistical Analysis System (SAS Institute, Inc. 1985); significance levels of 0.05 or lower were employed. Although invertebrates were usually identified to genus (Table 1), a priori statistical analyses were performed (unless otherwise noted) on 16 group variables: total invertebrate density, taxonomic richness, size of *Corbicula fluminea*, and densities of *Hydra*, Turbellaria, Oligochaeta, Hirudinea, Gastropoda, Bivalvia, Amphipoda, Ephemeroptera, Trichoptera, Chironomidae (larvae of all true midges), *Coelotanypus* (a predatory and overwhelmingly abundant midge), total "predatory" chironomids, and total "gatherer" midges.

Results and Discussion

The present study was restricted to analyses of responses of benthic macroinvertebrates to physical features associated with islands in one portion of a very large river. Ongoing research at the University of Louisville has been designed to evaluate the importance of competition, predation, and different sources of organic matter in shaping benthic and planktonic assemblages within the Ohio River.

Pool Effects

The construction of low head dams in the lower Ohio River over the last century altered this ecosystem into a series of flowing pools, averaging slightly over 100 river km in length. Differences in water velocity, river width, and substrate particle size are commonly observed from the shallower upstream section to the deeper downstream portion of a pool (J. H. Thorp, unpubl. data). Consequently, one might expect progressive changes in benthic and planktonic assemblages along the upper pool - lower pool gradient (cf. Delong and Payne 1985).

Contrary to our expectations, the relationship between longitudinal position within the lower McAlpine Pool and characteristics of the benthic fauna did not change in a consistent manner. Only five of the 16 independent, biotic variables tested were significantly affected by site within the pool, and their

TABLE 1. Mean abundance (no./m²) of benthic taxa collected near three Ohio River islands in 1989.

	Six Mile Island	Twelve Mile Island	Eighteen Mile Island
Total invertebrate density	1076.1	633.2	859.4
Phylum Cnidaria (class Hydrozoa)			
<i>Hydra vulgaris</i>	22.4	8.0	3.7
Phylum Platyhelminthes			
Class Turbellaria	10.0	18.1	12.2
Phylum Nematoda	— ^a	— ^a	— ^a
Phylum Entoprocta			
<i>Urnatella gracilis</i>	— ^a	— ^a	— ^a
Phylum Bryozoa (Ectoprocta)	— ^a	— ^a	— ^a
Phylum Annelida			
Class Oligochaeta	731.5	279.6	312.6
Class Hirudinea	4.8	1.6	2.1
(<i>Placobdella montifera</i> , <i>Placobdella</i> sp., and Glössiphoniidae)			
Phylum Mollusca			
Class Gastropoda			
<i>Ammicola</i> spp.	1.1	0.5	3.2
<i>Ferrissia</i> spp.	2.1	1.1	2.1
<i>Leptoxis praerosa</i>	0	0	0.5
<i>Lithasia obovata</i>	0.5	0	1.1
<i>Lithasia verrucosa</i>	0	0.5	1.1
<i>Pleurocera canaliculatum</i>	5.4	2.1	2.7
Class Bivalvia			
<i>Corbicula fluminea</i>	175.9	169.6	216.4
Phylum Arthropoda			
Subphylum Crustacea (order Amphipoda)			
<i>Gammarus fasciatus</i>	22.8	12.6	21.3
Subphylum Chelicerata (class Arachnida)			
Class Arachnida (Acari)	0.5	0.5	1.1
Subphylum Uniramia (class Insecta)			
Order Ephemeroptera			
<i>Caenis</i>	10.7	3.7	3.7
<i>Ephemeralla</i>	0	0	0.5
<i>Hexagenia</i>	6.9	22.9	26.8
<i>Stenacron</i>	2.1	4.2	4.2
<i>Stenonema</i>	0	0	0.5
Order Odonata (Anisoptera)	0	0	1.1
(<i>Neurocordulia</i> and <i>Somatochlora</i>)			
Order Coleoptera			
<i>Stenelmis</i>	0.5	0	0
Order Trichoptera			
<i>Cheumatopsyche</i>	0	0	0.5
<i>Hydropsyche</i>	1.6	1.6	12.2
<i>Hydroptila</i>	95.7	0	0
<i>Nectopsyche</i>	0.5	0	0.5
<i>Oecetis</i>	1.6	2.7	8.5
<i>Polycentropus</i>	0	0.5	0
Order Diptera			
Family Ceratopogonidae			
<i>Probezzia</i>	0	0.5	1.6
Family Chaoboridae			
<i>Chaoborus</i>	1.1	0	0
Family Chironomidae			
Subfamily Tanypodinae			
<i>Ablabesmyia</i> ^b	0	0	1.6
<i>Clinotanypus</i> ^b	0	0	3.7
<i>Coelotanypus</i> ^b	64.9	72.3	117.5
<i>Procladius</i> ^b	2.7	1.6	0.5
<i>Thienemannimyia</i> ^b	2.7	1.1	1.6

TABLE 1. (Concluded)

	Six Mile Island	Twelve Mile Island	Eighteen Mile Island
Subfamily Chironominae			
<i>Axarus</i>	22.3	0	0
<i>Cricotopus</i>	22.8	1.6	6.4
<i>Cryptochironomus</i> ^b	6.4	9.0	17.0
<i>Dicrotendipes</i>	2.7	0.5	0
<i>Nanocladius</i>	0.5	0	4.2
<i>Parachironomus</i> ^b	0	0	0.7
<i>Paracladopelma</i>	0.5	0.5	0
<i>Paratendipes</i>	0.5	0.5	10.6
<i>Phaenopsectra</i>	0	2.7	0
<i>Polypedilum</i>	20.3	7.4	59.0
<i>Rheotanytarsus</i>	5.3	0	0.5
<i>Stenochironomus</i>	0.5	1.1	0
<i>Tanytarsus</i>	1.1	0	0

^aTaxon present but not enumerated.

^bTrue midge that is principally a predator; all other midges primarily obtain food in some other fashion, most as "gatherers."

mean values did not vary in a progressive fashion along the downstream gradient (comparisons among islands with data pooled across transects and samples). Average taxonomic richness and total invertebrate densities were significantly different among islands ($\chi^2 = 5.91$ and 6.86 , respectively, $P < 0.05$), with the greatest means at the lower island and smallest values at the intermediate island. Total chironomids and the gatherer functional group of midges were most numerous near the upstream island and least dense at the middle island ($\chi^2 = 8.33$ and 10.74 , $P < 0.05$ and 0.01 , respectively); similarly, Asiatic clams were largest near Eighteen Mile Island and smallest near Twelve Mile Island ($\chi^2 = 9.09$, $P < 0.01$). In general, the intermediate island contained fewer invertebrate species and numbers than either the upstream or downstream island. A likely explanation for the poor fit of these data to a longitudinal gradient model within the McAlpine Pool is that all islands in the McAlpine Pool are in the lower portion of the pool; as a result, the "pool effect" was hidden within a more important, site-specific "island effect."

Island Effects

Islands interrupt the deepwater regions of this ecosystem by providing shallow-water habitats and access to different forms of food. Like areas along mainland banks, these littoral areas foster autochthonous production and furnish an alternative source of organic matter to the seston transported from floodplains and tributary streams. Macrophytes growing near island and mainland shores also afford greater habitat heterogeneity for benthic species. By adding a riparian zone in the "middle" of a river, islands serve as an additional source of allochthonous, partially labile, organic matter from recently fallen leaves (cf. Cummins and Klug 1979; Cummins et al. 1989). Terrestrial animals falling into the water from riparian plants and aquatic organisms growing on fallen trees are also considered a major source of high-quality food in rivers (Benke et al. 1984). Furthermore, shade from these trees and slower currents around islands alter light penetration and water temperatures.

The littoral zone benthos around islands appears similar to that present in shallow-water areas of the mainland bank (based on analyses of samples 1 and 6 versus 3 and 4 for transects B-E). In fact, none of the 16 independent variables tested showed significant variability between island and mainland lit-

toral habitats (Kruskal-Wallis ranked test: $P > 0.05$ in all cases). When analyzed by individual island, only oligochaete density and total invertebrate density were significantly greater near the mainland shore (for Six Mile Island only), and the latter variable probably reflects to a major degree changes in the abundance of worms ($\chi^2 = 6.89$ and 7.46 , respectively, $P < 0.01$). Estimated mean oligochaete densities were 475.3 and 803.1 worms/m² for island and mainland littoral areas, respectively; total invertebrate densities averaged 908.4 and 1199.4 individuals/m² for island and mainland shore habitats, respectively. Therefore, for the three islands studied here, the littoral benthos of island banks are generally equivalent to those on or in particulate sediments of mainland banks. An important caveat, however, is that these islands are entirely depositional in nature (composed principally of sand and finer particles) whereas the mainland shores contain some habitats with extensive beds of cobbles and boulders. Concurrent studies indicate that these latter habitats have an invertebrate fauna distinct from, and sometimes richer than, those found on particulate substrates near the three islands studied here (K. Greenwood and J. H. Thorp, unpubl. data on snail fauna on cobbles; M. D. Delong and J. H. Thorp, unpubl. data on secondary production on cobbles and snags).

To determine whether biotic effects of an island extend downstream below bordering, shallow-water regions, I compared benthos in transect A with that in transect F (~1 km above or below islands, respectively). Among the 16 group variables, only the gatherer functional feeding group of midges (hereafter called gatherer midges) was significantly different for pooled island data ($\bar{X} = 11.7$ versus 189.3 midges/m² for sites above and below islands, respectively; $\chi^2 = 3.99$, $P < 0.05$). When analyzed by island, results differed in only minor and inconsistent ways. *Corbicula* density ($\bar{X} = 226.4$ versus 32.0 clams/m²) and size ($\bar{X} = 16.38$ versus 5.21 mm) were elevated upstream of Twelve Mile Island ($\chi^2 = 4.43$, and 4.35, respectively, $P < 0.05$). In contrast, at Eighteen Mile Island the three variables which were significantly different had greater mean values downstream of the island (total invertebrate density: $\bar{X} = 520.6$ versus 1253.7/m², $\chi^2 = 3.69$, $P < 0.05$; total chironomids: $\bar{X} = 80.4$ versus 444.0/m², $\chi^2 = 4.41$, $P < 0.05$; and gatherer midges: $\bar{X} = 19.1$ versus 386.6/m², $\chi^2 = 3.97$, $P < 0.05$). Hence, results suggest that

the potential influence of islands on benthos does not extend much beyond the immediate shallow borders in a downstream direction, at least for the parameters I measured.

Finally, I compared diversity and density of benthos in the narrower and more shallow chute (sample 2 or 5, depending on the island, for transects B–E) with that in the wider and deeper midchannel region (the opposing sample 5 or 2; Fig. 1) to determine whether islands influence riverine benthos located lateral to islands. For this measure, islands had a strong influence on benthos. In general, densities were greater and assemblages were more diverse within island chutes (Fig. 2). Of the statistically significant comparisons, all followed this pattern ($P < 0.05$ for total Chironomidae and Turbellaria and $P < 0.01$ for *Hydra*, total Oligochaeta, *Coelotanypus*, and total predatory midges). *Corbicula*, total caddisflies, and gatherer midges were the only groups somewhat more dense in mid-channel regions, but all such comparisons were nonsignificant.

A definitive explanation for why the chute environment is more favorable to benthic invertebrates than the midchannel region is not possible at this point in our knowledge of rivers. However, current velocity and wave action tend to be lower in chutes, and the water is shallower (unpubl. data), factors which appear to promote greater densities and diversity within the community, as discussed below. Furthermore, the substrate particle size is typically smaller, and the sediment contains more organic matter (personal observations); based on previous studies of riverine benthos (e.g. Haag and Thorp 1991), these substrate differences may have the greatest direct impact on the nature of the benthos.

Influence of Water Depth, Current Velocity, and Substrate Type

Because water depth, current velocity, and substrate type have some causal linkage in rivers, it is not always possible to distinguish clearly the response of benthos to a single factor. Bearing that in mind, results of this study indicate that abun-

dances of most benthic species in the Ohio River were negatively correlated with both water depth and current velocity and were strongly influenced by substrate particle size and presence or absence of macrophytes, as documented below.

Eleven of 16 groups examined showed a negative correlation with water depth (for pooled samples, transects, and islands), but only five were significant (i.e. total invertebrate density and abundance of Oligochaeta: $P < 0.0001$; and size of Asiatic clams, density of *Coelotanypus*, and total abundance of predatory midges: $P < 0.05$ for Pearson's product moment correlations). None of the dependent variables had significant positive relationships with water depth. These results for the Ohio River initially seem to contrast with those reported for the Tennessee River below Kentucky Lake lock and dam (Haag and Thorp 1991), where most species showed a positive relationship with water depth. However, nearshore habitats (and all depths < 3.1 m) were not sampled in the Tennessee because of extensive fluctuations in water level. Such shallow habitats supported most of the species in the present study.

Twelve invertebrate groups were more abundant in slower water (based on Pearson's product moment correlations), and five of these were significantly so (i.e. total density, Oligochaeta, *Coelotanypus*, and total predatory midges: $P < 0.01$; and total chironomids: $P < 0.05$). The bivalve *Corbicula* also tended to be larger in slower water ($P < 0.05$); however, these Asiatic clams were the only invertebrates significantly more abundant in faster water ($P < 0.05$), possibly reflecting the fact that they depend more directly and heavily on suspended organic matter than do other invertebrate groups examined here. A direct influence of currents on benthos is probably less widespread and influential in general within large rivers than indirect effects of water movement on substrate particle size and plant abundance (see following discussion). However, water velocity by itself can bring about a shift in the composition of riverine benthos, as demonstrated by Beckett and Miller (1982) for Ohio River macroinvertebrates colonizing multiplate samplers.

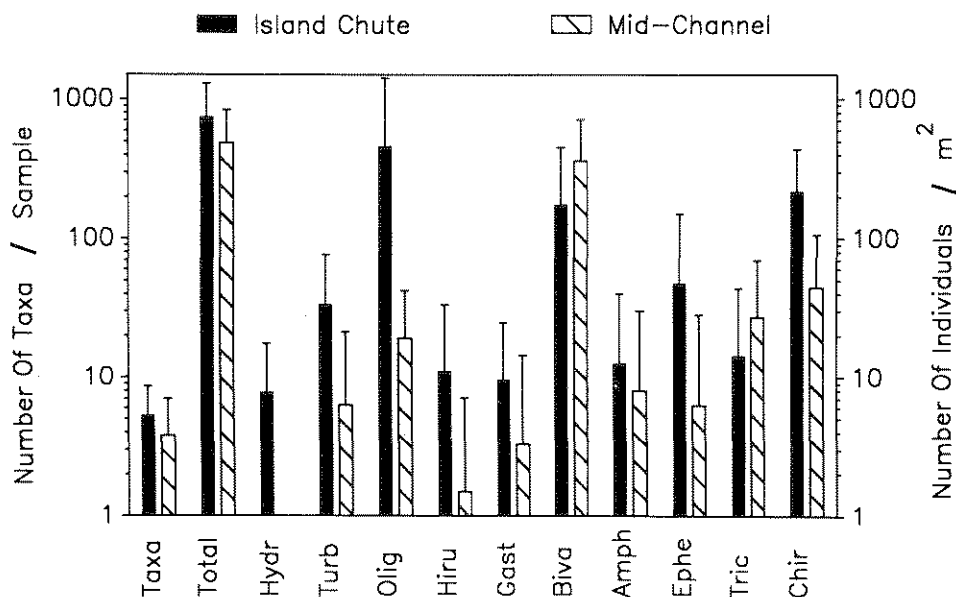


FIG. 2. Diversity and density of benthos in the narrower chute or wider midchannel region around three islands in the Ohio River. Values are means + 1 SD for taxonomic richness (Taxa, only dependent value on left ordinate scale), total invertebrate density, and densities of *Hydra* (Hydr), Turbellaria (Turb), Oligochaeta (Olig), Hirudinea (Hiru), Gastropoda (Gast), Bivalvia (Biva), Amphipoda (Amph), Ephemeroptera (Ephe), Trichoptera (Tric), and Chironomidae (Chir).

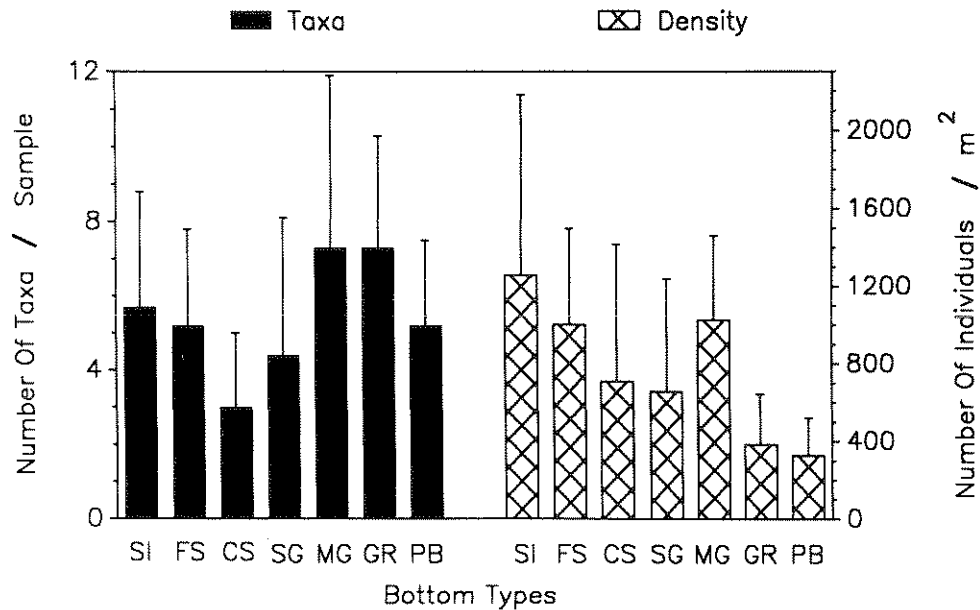


FIG. 3. Relationships between substrate size and both diversity (left ordinate scale) and total density (right ordinate scale) of benthos near three islands in the Ohio River. Values are means + 1 SD for benthos on silt and clay (SI), fine and very fine sand (FS), coarse sand (CS), sandy gravel (SG), muddy gravel (MG), gravel (GR), and pebbles (PB).

Nearly 70% of the benthic grabs taken in this study were from sediments with small particle sizes (silt-sand) because the sampling emphasized island and mainland shores. This does not reflect the proportion of these substrates in the entire river, however, as shallow areas with wood snags, cobbles, or boulders were completely avoided and the largest portion of the river, the deepwater regions with typical pebble, gravel, and coarse sand bottoms, represented a minority of the samples.

Taxonomic richness and total invertebrate density were significantly influenced by substrate particle size ($\chi^2 = 20.31$ and 28.14 , respectively, $P < 0.01$), a pattern previously shown for Tennessee River benthos (Haag and Thorp 1991). Diversity was greatest on gravel and muddy gravel and least on coarse sand in the Ohio River (Fig. 3). Total density was highest on silt-clay bottoms if the oligochaetes were included; otherwise, total abundance peaked on sandy gravel. Similar responses to particle size were evident for most invertebrate groups (Fig. 4). Coarse sand or pebbles supported the fewest individuals in 100% of the cases where density of a group was significantly related to sediment size (i.e. *Hydra*, Turbellaria, Oligochaeta, Amphipoda, Ephemeroptera, Trichoptera, total Chironomidae, *Coelotanypus*, and total predatory chironomids: $\chi^2 = 30.06$, 19.64 , 40.15 , 18.64 , 26.20 , 19.56 , 27.02 , 35.43 , and 30.36 , respectively, $P < 0.01$ in all cases). Coarse sand was the least colonized substrate for 60% of all groups tested, while midges and oligochaetes were seldom found on pebbles. The most favorable substrate was less consistent among groups, but 70% of those tested had highest densities on either muddy gravel or silt-clay bottoms. Other researchers have also confirmed the importance of substrate size to benthic assemblages (e.g. Thorp 1964; Resh and Lamberti 1979), with maximum densities often occurring on medium-sized particles (Rabeni and Minshall 1977; Williams and Mundie 1978).

Among all substrates, the dominant benthic groups within this portion of the Ohio River (Table 1) were oligochaetes (present in 90% of all samples), Asiatic clams (77% of samples),

and chironomids (71%). The estimated average density of worms was 440 animals/m^2 (their density was difficult to gauge precisely because of worm fragmentation during sieving); they were especially abundant in muddy, shallow-water habitats. *Corbicula fluminea* was the most common species within the river (mean density of $187/\text{m}^2$). Although biomass values were not recorded, this exotic species also appeared to dominate total invertebrate biomass, despite the fact that it was extremely rare to encounter individuals in the Ohio River which had reached even half their reported maximum body size (see Chap. 11 in Thorp and Covich 1991). Asiatic clams colonized all habitats but seemed to prefer, or survived best in, bottoms of coarse sand. Native unionid mussels are important in many areas of the Ohio River, but were not collected with a grab sampler in this study; however, while scuba diving, I have observed a few individuals just upstream of Eighteen Mile Island. Chironomids averaged $158 \text{ individuals/m}^2$ and occurred most frequently in substrates composed of a mixture of mud and either gravel or fine sand. In studies of the lower Mississippi River, midchannel sand habitats were dominated by chironomids (Beckett et al. 1983). *Coelotanypus* represented 54% of the midges collected in my study, and this predator was most dense on muddy gravel. Overall, 63.4% of the midges identified in this study are considered carnivorous, while 82% consume animals all or part of the time (Merritt and Cummins 1984).

Taxonomic richness and total invertebrate density were significantly higher when filamentous algae or vascular plants, such as *Vallisneria*, were present (Fig. 5) ($\chi^2 = 9.10$ and 10.28 , respectively, $P < 0.01$). Similar patterns were evident when densities of individual taxa were compared in the presence or absence of plants (significant for Oligochaeta, Amphipoda, total Chironomidae, and gatherer midges: $\chi^2 = 9.92$, 7.38 , 8.73 , and 16.02 , respectively, $P < 0.01$, and for Gastropoda, *Coelotanypus*, and total predatory midges: $\chi^2 = 3.87$, 4.73 , and 3.91 , respectively, $P < 0.05$). These results were expected for riverine benthos, based on studies in lentic eco-

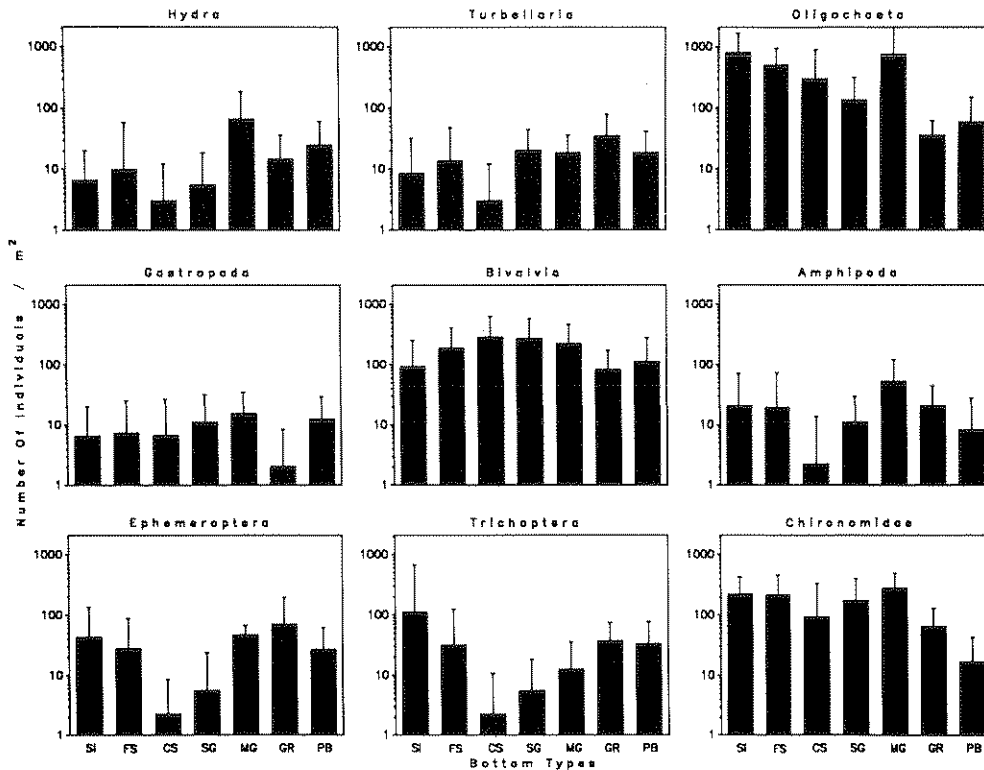


FIG. 4. Abundance of nine invertebrate groups on selected substrate types near three islands in the Ohio River. Values are means + 1 SD for benthos on silt and clay (SI), fine and very fine sand (FS), coarse sand (CS), sandy gravel (SG), muddy gravel (MG), gravel (GR), and pebbles (PB).

systems (e.g. Hershey 1985; Thorp 1988) where macrophytes provide partial refuges for some invertebrates and may serve as additional sources of food.

Importance of Local Habitats in the Ecosystem Continuum Concept

Large rivers have not been examined in an ecosystem context as well as headwater streams and essentially represent ecological "black boxes." Current depictions of large river ecosystems are based primarily on (1) the river continuum concept (RCC: Vanotte et al. 1980) and subsequent modifications (e.g. Minshall et al. 1983, 1985), (2) the serial discontinuity concept (Ward and Stanford 1983), which integrates effects of large dams and reservoirs on the RCC, and (3) the flood pulse concept in river-floodplain systems (Junk et al. 1989) and its relationship to the RCC (Sedell et al. 1989). Such notable theories are, unfortunately, primarily based on research conducted in medium-sized to small streams. By concentrating on demonstrably important downstream and lateral processes, these theories have, in my opinion, ignored important local phenomena which influence community structure and function.

An implicit assumption seems to exist (see fig. 1 in Vannote et al. 1980) that benthic communities of large rivers consist almost entirely of collectors (filterers and gatherers) and a few predators. In contrast, data from the present and concurrent studies (K. Greenwood and J. H. Thorp, unpubl. data; M. D. Delong and J. H. Thorp, unpubl. data) do not support this assumption. Although "collector" clams and mussels are important in some substrates of the Ohio River, different functional feeding groups, such as grazing snails and omnivorous amphipods, are prominent in other habitats (e.g. in patches of cobbles, wood snags, and macrophyte beds). The importance

of various trophic guilds to the ecosystem cannot be evaluated with confidence until we possess comprehensive data on relative densities, biomasses, and secondary productivities; such data are almost entirely lacking. Results of the present study and ongoing research suggest, however, that riverine food webs are habitat based and more complex than originally assumed. For these and other reasons, environmental managers should integrate habitat-specific concerns into their management strategies, as discussed below.

Management of Critical Riverine Habitats

Flood control, hydroelectric, and navigation projects have greatly modified the ecological nature of almost all major rivers of the world (e.g. Cummins et al. 1984; Sedell and Froggatt 1984; Dister et al. 1990). For example, 90% of the original floodplains for the lower Mississippi River have been lost through construction of levees, a process that began more than 150 yr ago (Fremling et al. 1989). This has influenced sediment and organic input and has diminished the amount of habitat available for fish nurseries and invertebrate production. Recent interest in restoring productivity within some of these rivers has resulted in proposals for comprehensive management practices. Among the tools suggested by Petts et al. (1989) are flow modification, water quality control, and habitat management. Included in the last category is the construction of islands, a technique which has been employed in several large rivers, such as the Mississippi (Fremling et al. 1989), with consistently satisfactory results (Petts et al. 1989).

The three islands studied here had a significant positive influence on an important food-web component of the ecosystem, the benthic macroinvertebrate assemblage. Although density of species within McAlpine Pool was low on average and species

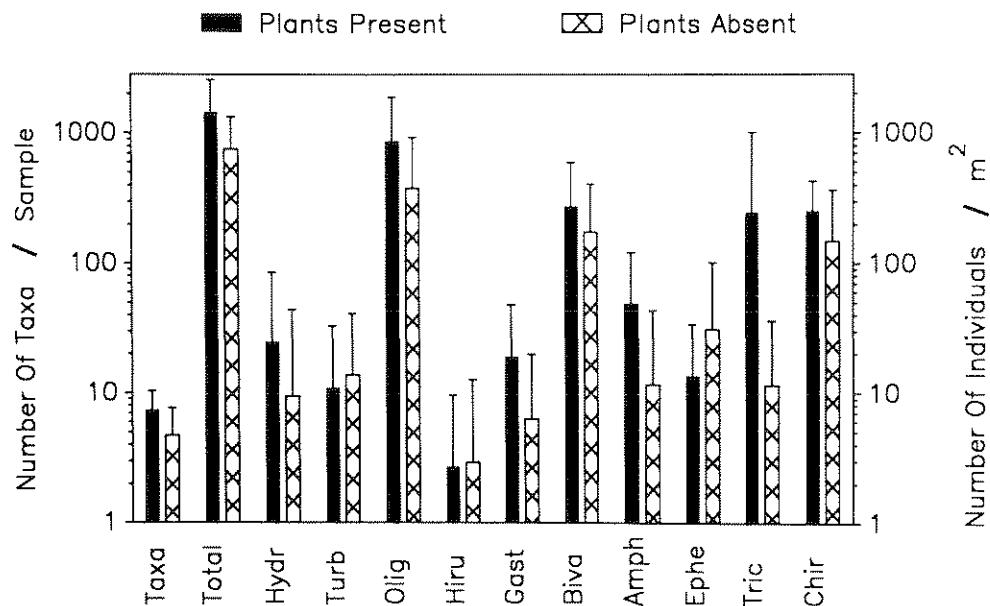


FIG. 5. Diversity and density of macroinvertebrates in the presence or absence of macrophytic algae and vascular plants around three islands in the Ohio River. Values are means + 1 SD for taxonomic richness (Taxa, only dependent value on left ordinate scale), total invertebrate density, and densities of *Hydra* (Hydr), Turbellaria (Turb), Oligochaeta (Olig), Hirudinea (Hiru), Gastropoda (Gast), Bivalvia (Biva), Amphipoda (Amph), Ephemeroptera (Ephe), Trichoptera (Tric), and Chironomidae (Chir).

distributions were often patchy (making it more difficult to detect statistically significant island effects), the presence of islands operated in several ways to enhance density and diversity of macrofauna. Littoral areas were present in otherwise deep water zones, and these shallow-water habitats supported more species than deepwater habitats. This was due in part to submerged macrophytes, whose presence in the littoral zone was consistently associated with a higher density and diversity of macrofauna. The riparian zones of islands near populated regions appear to produce more snags and leaf litter than comparable areas on nearby mainland banks because these ephemeral islands are usually less developed by humans. Studies have clearly shown that snag habitats are associated with higher secondary productivity in rivers (Benke et al. 1984; Sedell and Froggatt 1984), and more readily available, labile organic matter from abundant riparian vegetation should also boost production. Islands can decrease current velocity and substrate particle size in adjacent areas; within the narrow chute of the islands I examined, macroinvertebrates were significantly more abundant than in the broader, deeper, and faster flowing main channel.

Evidence from the present project strongly supports, therefore, the management hypothesis that islands are good for riverine invertebrates. From such data, one can infer that these alluvial islands also benefit fish populations, a conclusion strengthened by results of research on fish productivity near islands in the middle Zaire River (Gosse 1963, cited in Ward and Stanford 1989).

The lower Ohio River contains fewer than 40 islands over a stretch of 876 river km, which makes their importance to the river as a whole somewhat questionable at first glance. However, riverine islands and other slackwater areas may be even more valuable to the ecosystem because of their rarity. This makes protection of the few islands surviving navigation and flood control management practices a vital goal if we are to protect and restore river ecosystems. In conjunction with a

comprehensive and much larger management plan suggested by others (e.g. Petts et al. 1989), I believe that protected zones should be established around carefully chosen islands in major rivers of the United States. These zones should be designed to safeguard not only the island itself (as is being done for many islands in the upper Ohio River in response to federal legislation and for Six Mile Island in the McAlpine Pool by the Kentucky State Nature Preserves Commission) but also some adjacent waters. Such preserves should limit human access to the islands, boat traffic in adjacent chutes, commercial harvesting of mussels, and gravel/sand removal operations immediately upstream of an island. Restoration measures could then be undertaken to foster habitat heterogeneity in these wildlife preserves. Furthermore, the U.S. Army Corps of Engineers in the United States and similar agencies in other countries should be encouraged to build islands and other habitat enhancements, where economically feasible, as part of river dredging operations.

Acknowledgements

I greatly appreciate the field and laboratory support of several people, especially Kim Greenwood, Dr. Kim Haag, and Dr. Nina Hemphill. Suggestions from Dr. Jan Stevenson and other members of our "ecological lunch bunch" aided in the original design of this study. I am grateful to Drs. Kim Haag, Nina Hemphill, and Bernhard Statzner as well as an anonymous reviewer for constructive criticisms of an earlier draft of this manuscript.

References

- BECKETT, D. C., C. R. BINGHAM, AND L. G. SANDERS. 1983. Benthic macroinvertebrates of selected habitats of the lower Mississippi River. *J. Freshwater Ecol.* 2: 247-261.
- BECKETT, D. C., AND M. C. MILLER. 1982. Macroinvertebrate colonization of multiplate samplers in the Ohio River: the effect of dams. *Can. J. Fish. Aquat. Sci.* 39: 1622-1627.
- BENKE, A. C. 1990. A perspective on American's vanishing streams. *J. N. Am. Benthol. Soc.* 9: 77-88.

- BENKE, A. C., T. C. VAN ARSDALL, JR., D. M. GILLESPIE, AND F. K. PARRISH. 1984. Invertebrate productivity in a subtropical blackwater river: the importance of habitat and life history. *Ecol. Monogr.* 54: 25-63.
- CUMMINS, K. W., AND M. J. KLUG. 1979. Feeding ecology of stream invertebrates. *Annu. Rev. Ecol. Syst.* 10: 147-172.
- CUMMINS, K. W., G. W. MINSHALL, J. R. SEDELL, C. E. CUSHING, AND R. C. PETERSEN. 1984. Stream ecosystem theory. *Verh. Int. Ver. Limnol.* 22: 1818-1827.
- CUMMINS, K. W., M. A. WILZBACH, D. M. GATES, J. B. PERRY, AND W. B. TALIAFERRO. 1989. Shredders and riparian vegetation. *BioScience* 39: 24-30.
- DELONG, M. D., AND J. F. PAYNE. 1985. Patterns of colonization by macroinvertebrates on artificial substrate samplers: the effects of depth. *Freshwater Invertebr. Biol.* 4: 194-200.
- DISTER, E., D. GOMER, P. OBRDLIK, P. PETERMANN, AND E. SCHNEIDER. 1990. Water management and ecological perspectives of the upper Rhine's floodplains. *Regul. Rivers: Res. Manage.* 5: 1-15.
- FREMLING, C. R., J. L. RASMUSSEN, R. E. SPARKS, S. P. COBB, C. F. BRYAN, AND T. O. CLAFLIN. 1989. Mississippi River fisheries: a case history, p. 309-351. *In* D. P. Dodge [ed.] *Proceedings of the International Large River Symposium (LARS)*. *Can. Spec. Publ. Fish. Aquat. Sci.* 106: 629 p.
- GOSSE, J.-P. 1963. Le milieu aquatique et l'ecologie des poissons dans la region de Yangambi. *Annu. Rev. Mus. R. Afr. Cent. Zool.* 116: 113-270.
- HAAG, K. H., AND J. H. THORP. 1991. Cross-channel distribution patterns of invertebrate benthos in a regulated reach of the Tennessee River. *Regul. Rivers: Res. Manage.* 6: 225-233.
- HERSHEY, A. E. 1985. Effects of predatory sculpin on the chironomid communities in an arctic lake. *Ecology* 66: 1131-1138.
- HYNES, H. B. N. 1970. *The ecology of running waters*. University of Toronto Press, Toronto, Ont. 555 p.
1989. Keynote address, p. 5-10. *In* D. P. Dodge [ed.] *Proceedings of the International Large River Symposium (LARS)*. *Can. Spec. Publ. Fish. Aquat. Sci.* 106: 629 p.
- JUNK, W. J., P. B. BAYLEY, AND R. E. SPARKS. 1989. The flood pulse concept in river-floodplain systems, p. 89-109. *In* D. P. Dodge [ed.] *Proceedings of the International Large River Symposium (LARS)*. *Can. Spec. Publ. Fish. Aquat. Sci.* 106: 629 p.
- MERRITT, R. W., AND K. W. CUMMINS [ED.]. 1984. *An introduction to the aquatic insects of North America*. 2nd ed. Kendall/Hunt, Dubuque, IA.
- MINSHALL, G. W., K. W. CUMMINS, R. C. PETERSON, C. E. CUSHING, D. A. BURNS, J. R. SEDELL, AND R. L. VANNOTE. 1985. Developments in stream ecosystem theory. *Can. J. Fish. Aquat. Sci.* 42: 1045-1055.
- MINSHALL, G. W., R. C. PETERSON, K. W. CUMMINS, T. L. BOTT, J. R. SEDELL, C. E. CUSHING, AND R. L. VANNOTE. 1983. Interbiome comparison of stream ecosystem dynamics. *Ecol. Monogr.* 53: 1-25.
- PETTS, G. E., J. G. IMHOF, B. A. MANNY, J. F. B. MAHER, AND S. B. WEISBERG. 1989. Management of fish populations in large rivers: a review of tools and approaches, p. 578-588. *In* D. P. Dodge [ed.] *Proceedings of the International Large River Symposium (LARS)*. *Can. Spec. Publ. Fish. Aquat. Sci.* 106: 629 p.
- RABENI, C. F., AND G. W. MINSHALL. 1977. Factors affecting microdistribution of stream benthic insects. *Oikos* 29: 33-43.
- RESH, V. H., AND G. A. LAMBERTI. 1979. Substrate relationships, spatial distribution patterns, and sampling variability in stream caddisfly population. *Environ. Entomol.* 8: 561-567.
- SAS INSTITUTE, INC.. 1985. *SAS user's guide: statistics*. SAS Institute, Inc., Cary, NC.
- SEDELL, J. R., AND J. L. FROGGATT. 1984. Importance of streamside forests to large rivers: the isolation of the Willamette River, Oregon, U.S.A., from its floodplain by snagging and streamside forest removal. *Verh. Int. Ver. Limnol.* 22: 1828-1834.
- SEDELL, J. R., J. E. RICHEY, AND F. J. SWANSON. 1989. The river continuum: a basis for the expected ecosystem behavior of very large rivers?, p. 49-55. *In* D. P. Dodge [ed.] *Proceedings of the International Large River Symposium (LARS)*. *Can. Spec. Publ. Fish. Aquat. Sci.* 106: 629 p.
- STATZNER, B., AND B. HIGLER. 1985. Questions and comments on the River Continuum Concept. *Can. J. Fish. Aquat. Sci.* 42: 1038-1044.
- THORP, J. H. 1988. Patches and the responses of lake benthos to sunfish nest-building. *Oecologia* 76: 168-174.
- THORP, J. H., E. M. MCEWAN, M. F. FLYNN, AND F. R. HAUER. 1985. Invertebrate colonization of submerged wood in a cypress-tupelo swamp and blackwater stream. *Am. Midl. Nat.* 113: 56-68.
- THORP, J. H., AND A. P. COVICH [ED.]. 1991. *Ecology and classification of North American freshwater invertebrates*. Academic Press, New York, NY. 911 p.
- THORP, J. 1964. Substrate type and its value as a basis for the delimitation of bottom fauna communities in running waters. *In* K. W. Cummins, C. A. Tryon, and R. T. Hartman [ed.] *Organisms substrate relationships in streams*. Edward Bros., Ann Arbor, MI.
- VANNOTE, R. L., G. W. MINSHALL, K. W. CUMMINS, J. R. SEDELL, AND C. E. CUSHING. 1980. The river continuum concept. *Can. J. Fish. Aquat. Sci.* 37: 130-137.
- WARD, J. V., AND J. A. STANFORD. 1983. The serial discontinuity concept of lotic ecosystems, p. 29-42. *In* T. D. Fontaine and S. M. Bartell [ed.] *Dynamics of lotic ecosystems*. Ann Arbor Science Publishers, Ann Arbor, MI. 494 p.
1989. Riverine ecosystems: the influence of man on catchment dynamics and fish ecology, p. 55-64. *In* D. P. Dodge [ed.] *Proceedings of the International Large River Symposium (LARS)*. *Can. Spec. Publ. Fish. Aquat. Sci.* 106: 629 p.
- WILLIAMS, D. D., AND J. H. MUNDIE. 1978. Substrate size selection by stream invertebrates and the influence of sand. *Limnol. Oceanogr.* 23: 1030-1033.
- WILLIAMS, W. D. 1988. Limnological imbalances: an antipodean viewpoint. *Freshwater Biol.* 20: 407-420.