

27 Urban Playas of the Southern High Plains

The Influence of Water Quality on Macroinvertebrate Diversity and Community Structure

CRAIG F. WOLF, DARYL L. MOORHEAD, and
MICHAEL R. WILLIG

The urban playas of Lubbock, Texas, are hydrologically isolated and yet exist within a small geographical area, thus minimizing differences among impoundments due to differences in soils, climate, species pools, and evolutionary history that normally occur over larger distances. We hypothesized that differences in macroinvertebrate abundances, diversity, and community composition could be attributed to differences in surrounding landscape and water quality characteristics, but found little evidence to support this notion. In contrast, some differences in macroinvertebrate diversity among playas may be related to general habitat features. For example, macroinvertebrate abundances and diversity were greater in playas with extensive macrophyte communities. Conversely, a basin with no littoral vegetation had the highest numbers of zooplankton but the lowest number of insect taxa and lowest overall diversity of macroinvertebrates. Few relationships were found to exist between water quality characteristics and composition of aquatic macroinvertebrate communities, but ammonia concentrations were highest in the playa that was dominated by zooplankton, perhaps indicating a more eutrophic status than for the other playas. Analyses of community structure revealed few consistent relationships among playas, and similarities that did emerge appeared to be determined by abundances of relatively few taxa (e.g., palaemonids, chironomids,

notonectids, baetids, and gerrids). Thus, macroinvertebrate community composition and species dominance differed among urban playas even though species diversity was comparable.

URBAN PLAYAS

The Southern High Plains of West Texas contain between 25,000 and 30,000 playas that dominate the wetland and wildlife habitats of the region (Haukos and Smith 1992). Playas are shallow, ephemeral pools in largely isolated watersheds that capture approximately 88 percent of the local precipitation, which subsequently is lost through groundwater seepage and evaporation (Bolen et al. 1989). Playas provide critical habitat for more than 115 species of birds (including 20 species of waterfowl), 10 species of mammals, 14 species of amphibians, and 60 taxa of macroinvertebrates (Sublette and Sublette 1967, Haukos and Smith 1992, Neck and Schramm 1992, Smith 1993). The importance of playas as centers of biodiversity extends beyond the local level because they provide nesting and wintering habitats for more than 2 million waterfowl that use the central migratory flyway (U.S. Fish and Wildlife Service 1988).

Urban areas of the Southern High Plains incorporate modified playas in management plans for stormwater and urban runoff. Modifications usually consist of deepening playas to retain greater volumes of water, often resulting in permanent inundation. Thus, the hydrological regimes of rural and urban playas differ in duration; rural playas fill with spring rains and dry during the summer, while urban playas usually remain inundated throughout the year. Urban and rural playas also differ with respect to surrounding land use patterns and characteristics of entering runoff water. Areas immediately surrounding playas within the City of Lubbock, Texas, often are dedicated to city parks and open areas that host a wide range of recreational activities, embedded within a matrix of commercial, residential, and industrial lands. In contrast, most rural playas are surrounded by agricultural lands dedicated to row-crop agriculture, livestock grazing, and conservation grasslands. These landscape features undoubtedly affect physical attributes of the playas, such as water chemistry (see below), as well as biological communities, although comparative studies have not yet been performed.

Some differences between the biological communities of rural and urban playas are obvious. For example, most urban playas are stocked with fish, which can greatly alter the structure of invertebrate communities. In contrast, few rural playas have fish because they usually retain water for only a few months of each year. Large differences in vegetation also exist among urban and rural playas. Urban playas tend to have little vegetation, although scat-

tered stands of submerged and emergent macrophytes sometimes occur. Conversely, rural playas usually have stands of terrestrial plants that grow when basins are dry and are inundated when basins fill. For these reasons, the invertebrate communities of urban and rural playas might be expected to differ.

Although playas in Lubbock serve as centers of biodiversity in an urban setting, the diversity of macroinvertebrates in these playas has not been examined until now. Moreover, relationships among macroinvertebrates, land use patterns, and water quality have not been evaluated, despite ongoing investigations of the quality of stormwater runoff entering playas (Ennis 1994). The primary objective of this chapter is to evaluate the diversity and composition of aquatic macroinvertebrate communities of urban playas as they relate to water quality characteristics and surrounding land use patterns.

INVERTEBRATE BACKGROUND

Although research has focused on species diversity and community composition of aquatic macroinvertebrates in rural playas on the Southern High Plains of the United States (Sublette and Sublette 1967, Merickel and Wangberg 1981, Smith 1993), little attention has been given to macroinvertebrates in urban playas. Because of physical and morphological differences between rural and urban playas (see Hall et al., this volume), invertebrate community composition may differ between these habitats, especially with regard to species that require alternating wet and dry periods or cannot survive predation by fish that are present in most urban playas. Other factors that may differentially affect macroinvertebrate communities in rural and urban playas include habitat complexity (i.e., presence and absence of littoral vegetation), trophic status (i.e., oligotrophy versus eutrophy), and surface water quality. Water quality can be a particularly important factor affecting aquatic organisms in urban impoundments.

Urban Water Quality

Urban runoff typically contains high levels of suspended solids and organic matter that enhance oxygen demand of recipient waters, often increasing mortality rates of sensitive aquatic organisms (Mason 1991). Moreover, stormwater runoff accounts for the bulk of many inputs. For example, stormwater runoff provided 85 percent of metals, 90 percent of oxygen demand material, over 50 percent of nutrients, and 99 percent of suspended solids entering waterbodies in Tallahassee, Florida (Livingston and Cox 1989). Similar findings have been reported for Lubbock, Texas, where chemical oxygen demand, as well as total and suspended solids in surface water runoff entering playas, have exceeded standards for raw sewage (Thompson et al. 1974, Wells et al. 1975).

Chemical inputs to surface water impoundments differ as functions of surrounding land use (i.e., residential, commercial, or agricultural) and the area of adjacent, impervious surfaces, such as parking lots and streets (Porcella and Sorensen 1980, Jones and Clark 1987). Rimer and Nissen (1978) found that chemical oxygen demand, suspended solids, and total phosphorus concentrations in urban impoundments were correlated positively with the extent of impervious surfaces. Other factors that influence the type and quantity of materials entering surface water impoundments include the time of year in which the runoff occurs, elapsed time between inputs, and conditions prior to runoff, including human activities within the watershed (Wells et al. 1975).

Macroinvertebrate Communities and Water Quality

The influence of physicochemical conditions on the structure of invertebrate communities is a central focus of aquatic ecology (Macan 1963, Hynes 1970, Rosenberg and Resh 1993). Although much research has focused on the influences of productivity and trophic status (Macan 1949, Kullberg 1992, France 1995, Hanson and Butler 1994), other studies have demonstrated significant impacts of water quality on aquatic invertebrates (Hershey 1985, Hammer et al. 1990, Rasmussen 1993, Wollheim and Lovvorn 1995). Physicochemical conditions and habitat attributes may play even more dominant roles in structuring macroinvertebrate communities when human activities alter habitat quality (Ward 1992). Indeed, diversity and community composition of macroinvertebrates have been used to evaluate environmental stress resulting from urbanization and industrialization (Cairns and Pratt 1993). Playas located within urban areas are subject to many human activities, including direct modification of habitat, hydrological regime, and characteristics of drainage basins. Because macroinvertebrate communities in lentic ecosystems often are influenced by physicochemical characteristics of water, and because physicochemical characteristics of runoff entering urban impoundments are related to land use patterns and human activities, macroinvertebrate communities of urban playas should show some response to land use characteristics.

EXPERIMENTAL APPROACH

Details of experimental approaches are described elsewhere (Wolf 1996). Consequently, only a brief outline of methods and materials is included herein. Macroinvertebrate communities, water quality characteristics, and surrounding landscape features were examined for 8 of the 32 playas occurring within the City of Lubbock, Texas, USA (101°52'N, 33°35'W). Physical attributes and surrounding landscape characteristics for playas are given in Table 27.1. Macroinvertebrates were collected via net and dredge sampling in March, April, June, July, August, and November–December 1993 from the benthic, pleustonic, nektonic, and emergent vegetation regions of the littoral

TABLE 27.1. Total Watershed Area, Allocation among Land Use Categories, and Aquatic Vegetation of Selected Urban Playas in Lubbock, Texas

Playa	Watershed (ha) ^a	Single Family Residence (%)	Multiple Family Residence (%)	Commercial (%)	Parks (%)	Vegetation
Rushland	105	76.3	3.6	2.3	17.8	Seasonal ^b
Higinbotham	128	87.9	0.0	0.0	12.1	Seasonal
Wendover	139	68.9	3.8	9.3	18.1	Seasonal
Maxey	262	46.3	5.5	35.1	13.0	None
Leroy Elmore	196	76.3	6.2	2.2	15.4	None
Buster Long	162	14.0	23.4	53.3	9.3	None
Jack Stevens	148	78.7	3.8	6.2	11.3	Perennial ^c
Quaker & Brownfield	114	62.3	14.4	23.3	0.0	Perennial

^aTotal watershed area that provided direct surface water runoff to playas.

^bMostly summer annuals, e.g., smartweed (*Persicaria pennsylvanica*) and dockweed (*Rumex crispus*).

^cExtensive stands of cattails (*Typha* sp.) and persistent pondweed (*Potamogeton* sp.).

zone in each playa. Not all individuals could be identified to the specific level, although distinct morphotypes could be identified and were used in subsequent taxonomic analyses. To avoid confusion, herein we use the term *taxon-level* analysis to refer to analyses based on distinct morphotypes.

The suite of water quality characteristics determined for each playa was alkalinity, biological oxygen demand (BOD), chemical oxygen demand (COD), conductivity, dissolved oxygen, hardness, pH, temperature, total Kjeldahl nitrogen (TKN), ammonia, nitrate-nitrite nitrogen, total phosphorus, ortho-phosphorus, total carbon, total organic carbon (TOC), and total inorganic carbon (Table 27.2). Analyses were conducted at monthly intervals from February 1993 through March 1994. Temperature and pH were measured *in situ*, but for other assays grab-samples were taken from each playa, placed on ice, and transported to the laboratory for analyses. Chemical analyses were performed according to U.S. Environmental Protection Agency (1974) and American Public Health Association (1992) standards.

Urban land use surrounding each playa was classified as single-family housing, multiple-family housing, commercial, or parks and vacant lots. Total surface area of each land use category that drained directly into each lake was estimated from a topographical map of the U.S. Geological Survey. Only

TABLE 27.2. Water Quality Attributes of Urban Playas in Lubbock, Texas

Water Quality Parameter ^(a, b)	Units	Mean	Standard Deviation
Temperature ^{*. ns}	°C	15.39	7.51
pH ^{*. *}		8.80	0.57
Dissolved oxygen ^{*. ns}	mg O ₂ /L	8.58	2.76
Conductivity ^{*. ns}	mmhos	2.48	20.49
Alkalinity ^{*. *}	mg CaCO ₃ /L	103.27	30.42
Hardness ^{*. *}	mg CaCO ₃ /L	131.87	58.58
Chemical oxygen Demand ^{*. *}	mg O ₂ /L	67.05	24.32
Biological oxygen Demand ^{*. *}	mg O ₂ /L	8.30	5.50
Total Kjeldahl nitrogen ^{*. *}	mg N/L	2.92	2.47
Total phosphorus ^{*. ns}	mg P/L	0.73	2.55
Nitrate-nitrogen ^{*. *}	mg N/L	0.22	0.16
Ortho-phosphorus ^{*. ns}	mg P/L	0.29	0.16
Ammonia-nitrogen ^{*. *}	mg N/L	0.70	1.11
Total carbon ^{*. *}	mg C/L	27.94	7.81
Inorganic carbon ^{*. ns}	mg C/L	9.36	6.47
Total organic carbon ^{*. *}	mg C/L	18.58	5.63

Source: Wolf 1996.

^asignificant differences among dates indicated by an asterisk (*).

^bsignificant differences among playas indicated by an asterisk (*).

areas producing direct runoff of surface water into each lake were estimated. We did not include possible, but infrequent and unpredictable, inputs from storm sewers, or surface overflow drainage between playas.

PHYSICOCHEMICAL ATTRIBUTES OF URBAN PLAYAS

Ten of the 16 characteristics of water quality showed significant differences among playas (Table 27.2). Pairwise tests detected differences between playas in eight of the parameters, with some playas showing consistent differences from others (Wolf 1996). For example, BOD ranged from ca 3.7 mg O₂/L in Leroy Elmore and Jack Stevens playas to over 11 mg O₂/L in Rushland and Higinbotham playas; total organic carbon also was higher in Higinbotham (23.3 ± 5.3 mg C/L) than in Leroy Elmore and Jack Stevens playas (14.2 ± 1.9 and 15.6 ± 4.1 mg C/L, respectively). Ammonia concentrations were highest in Buster Long playa (1.9 ± 2.3 mg N/L), and TKN was significantly higher in Higinbotham than in Quaker & Brownfield playas (4.6 ± 2.7 versus 2.1 ± 2.1 mg N/L, respectively). Higinbotham was one of the most eutrophic playas, whereas Jack Stevens and Leroy Elmore were among the least eutrophic. Alkalinity, hardness, pH, and COD also showed significant differences between playas, although temporal patterns in alkalinity and hardness were similar among playas. Concentrations of nitrate-nitrogen and phosphorus showed few differences between playas and remained near detection limits throughout most of the study.

In general, urban playas in Lubbock are turbid, well mixed, and somewhat alkaline. Flat topography, continual winds, and alkaline soils probably contribute to these characteristics. Temperatures change in a roughly seasonal pattern, and infrequent stormwater runoff cause short-term fluctuations in concentrations of organic matter and nutrients. Although significant differences in a number of water quality characteristics existed among playas, temporal patterns were similar for all playas in this study. Detailed comparisons of water chemistry between urban and rural playas have not been made, but rural playas tend to be lower in hardness, chemical oxygen demand, total Kjeldahl nitrogen, and ammonia and higher with respect to ortho-phosphate concentrations (Hall et al., this volume). Urban and rural playas have similar levels of biological oxygen demand, nitrate-nitrogen, total carbon, total inorganic carbon, and total phosphorus content.

The areal extent of watersheds providing runoff to playas ranged from 105 ha (Rushland playa) to 262 ha (Leroy Elmore playa), averaging about 157 ha (Table 27.1). Patterns of land use also differed among watersheds, although single-family housing was the dominant land use category surrounding most playas (averaging 64 percent). Only the watershed of Buster Long playa was dominated by another land use, with 53 percent of the land surface associated with commercial operations. Open areas and parks represented about 12 per-

cent, on average, of the landscapes around these playas, whereas multiple family dwellings (apartment complexes) accounted for about 8 percent of the land surface.

MACROINVERTEBRATE COMMUNITIES IN URBAN PLAYAS

Macroinvertebrate Richness and Abundance

Over 10,500 individuals representing at least 94 taxa and 45 families of aquatic invertebrates were collected from playas during this study (Table 27.3). Taxa and individuals were not distributed evenly among playas, with 29–43 percent of the total taxa present in Rushland (33 percent), Higinbotham (32 percent), Wendover (38 percent), Quaker & Brownfield (43 percent), and Maxey (29 percent) playas. Jack Stevens playa contained 63 percent of the taxa, whereas Leroy Elmore and Buster Long playas were species-poor, containing 16 percent and 19 percent of the taxa, respectively. Although taxonomic richness was similar in five of the eight playas, abundances of invertebrates were highest in three playas, with over 70 percent of the total number of individuals collected from Rushland (19 percent), Wendover (21 percent), and Jack Stevens (30 percent) playas. Far fewer individuals were obtained from Higinbotham (6 percent), Quaker & Brownfield (9 percent), Maxey (7 percent), Buster Long (7 percent) and Leroy Elmore (<1 percent) playas.

Rank abundance plots illustrated similar patterns in the distributions of taxa in Rushland, Wendover, Quaker & Brownfield, Jack Stevens, and Higinbotham playas (Fig. 27.1), each of which contained > 30 taxa. However, numerically dominant taxa differed among playas. Crustaceans were numerically most abundant in three playas, with *Palaemonetes kadiakensis* (a freshwater shrimp) representing 33 percent and 61 percent of the invertebrates from Quaker & Brownfield and Maxey playas, respectively, and cladocerans accounting for 62 percent of individuals from Buster Long playa. In contrast, the Notonectidae (back-swimmers) and Corixidae (water boatmen) accounted for 38 percent and 44 percent of the individuals from Rushland and Wendover playas, respectively. The Coenagrionidae (damselfly) accounted for 26 percent of the individuals from Jack Stevens playa, whereas the Chironomidae (midges) accounted for 71 percent and 28 percent of the individuals from Leroy Elmore and Higinbotham playas, respectively. Thus, playas can be separated into two groups according to the numerical dominance of crustaceans or insects.

Macroinvertebrate Diversity

Fisher's log series α was used to estimate macroinvertebrate diversity in each playa (Taylor et al. 1976). This metric is robust with respect to deviations

TABLE 27.3. Systematic List of Aquatic Invertebrate Taxa Collected from Selected Urban Playas in Lubbock, Texas

<i>Annelida</i>	ODONATA
HIRUDINEA	Aeshnidae
Gnathobdellida	<i>Anax</i> sp.
Hirudinidae ^a	<i>Gynacantha</i> sp.
sp. 1	Libellulidae
sp. 2	<i>Belonia</i> sp.
Pharyngobdellida	<i>Erythrodiplax</i> sp.
Erpobdellidae ^a	<i>Orthemis</i> sp.
sp. 1	<i>Pachydiplax</i> sp.
<i>Mollusca</i>	<i>Perithemis</i> sp.
GASTROPODA	<i>Plathemis</i> sp.
Basommatophora	<i>Tramea</i> sp.
Lymnaeidae ^c	Coenagrionidae
sp. 1	<i>Enallagma</i> sp.
Physidae ^c	HEMIPTERA
sp. 1	Hydrometridae ^f
sp. 2	<i>Hydrometra martini</i>
sp. 3	Macroveliidae ^f
sp. 4	<i>Macrovelia</i> sp.
Planorbidae ^c	Gerridae
sp. 1	<i>Gerris marginatus</i>
sp. 2	<i>Rhematobates</i> sp.
<i>Arthropoda</i>	Belostomatidae
CRUSTACEA	<i>Belostoma flumineum</i>
Cladocera ^b	Nepidae ^f
sp. 1	<i>Ranatra nigra</i>
Eucopepoda ^b	Corixidae
Calanoid sp.	<i>Corisella edulis</i>
Cyclopoid sp.	<i>Corisella tarsalis</i>
Ostracoda ^b	<i>Ramphocorixa</i> sp.
sp. 1	<i>Sigara alternata</i>
sp. 2	Notonectidae
Decopoda	<i>Buenoa</i> sp. 1
Palaemonidae	<i>Buenoa</i> sp. 2
<i>Palaemonetes kadiakensis</i>	<i>Notonecta undulata</i>
INSECTA	Mesoveliidae
Collembola	<i>Mesovelia mulsanti</i>
Isotomidae	Hebridae ^f
sp. 1	<i>Hebrus</i> sp.
Ephemeroptera	Saldidae
Baetidae	sp. 1
<i>Callibaetis</i> sp.	<i>Saldula pallipes</i>
Caenidae	<i>Saldula</i> sp. 2
<i>Caenis punctatus</i>	

(continued)

TABLE 27.3. (Continued)

Coleoptera	<i>Stenus</i> sp. 1
Gyrinidae ^d	<i>Stenus</i> sp. 2
<i>Dineutus</i> sp.	Salpingidae ^d
Haliplidae	<i>Limnebius</i> sp.
<i>Haliphus</i> sp. 1	Georyssidae ^{d§}
<i>Haliphus</i> sp. 2	<i>Georyssus</i> sp.
<i>Peltodytes</i> sp.	Chrysomelidae
Dytiscidae	<i>Disonycha</i> sp.
<i>Brachyvatus</i> sp.	<i>Donacia</i> sp.
<i>Copelatus</i> sp.	sp. 1
<i>Laccophilus fasciatus</i>	Diptera
<i>Laccophilus proximus</i>	Tipulidae ^e
<i>Liodessus</i> sp.	sp. 1
<i>Neobidessus</i> sp.	Culicidae ^e
<i>Thermonectus</i> sp.	<i>Culex</i> sp.
<i>Uvarus</i> sp.	Chaoboridae ^e
Sphaeridae ^d	<i>Chaoborus</i> sp.
<i>Sphaerius</i> sp.	Psychodidae ^e
Hydrophilidae	<i>Pericoma</i> sp.
<i>Berosus</i> sp. 1	Ceratopogonidae ^e
<i>Berosus</i> sp. 2	sp. 1
<i>Berosus</i> sp. 3	Chironomidae
<i>Berosus</i> sp. 4	adult sp. 1
<i>Berosus</i> sp. 5	adult sp. 2
<i>Enochrus</i> sp.	adult sp. 3
<i>Helophorus</i> sp.	larvae spp.
<i>Hydrochous</i> sp.	Stratiomyidae
<i>Hydrophilus triangularis</i>	<i>Ondontomyia</i> sp.
<i>Laccobius</i> sp.	Tabanidae ^e
<i>Paracymus</i> sp.	<i>Tabanus</i> sp.
<i>Tropisternus lateralis</i>	Ephydriidae ^e
Staphylinidae ^d	sp. 1
<i>Micaralymma</i> sp.	Muscidae ^e
	sp. 1

^aFamilies were combined to form the Annelida group for familial data analyses.

^bTaxa in these orders were combined to form the Crustacea group for familial data analyses.

^cFamilies were combined to form the Gastropoda group for familial data analyses.

^dFamilies were combined to form the Coleoptera (other) group for familial data analyses.

^eFamilies were combined to form the Diptera (other) group for familial data analyses.

^fFamilies were combined to form the Hemiptera (other) group for familial data analyses.

from log series distributions, as well as to variation in the total number of individuals sampled (Magurran 1988). In particular, the index (α) is given by:

$$\alpha = N(1 - x)/x$$

where N is the total number of individuals and x is the ratio of taxon richness

(S) to total number of individuals (N). More specifically, x can be estimated by iteration (Taylor et al. 1976):

$$S/N = [(1 - x)^{-1}][-\ln(1 - x)]$$

Chi-square goodness-of-fit tests were used to compare observed versus expected species distributions for each playa and to evaluate whether the observed distribution was significantly different from the expected log series model (Fig. 27.1; Sokal and Rohlf 1995). For all playas except Buster Long ($P = 0.029$), distributions of macroinvertebrate taxa collected from all dates adhered to the log series model, suggesting that one or few factors dominate the composition of the community (Magurran 1988). Alternatively, Magurran (1988) suggests that a log-series distribution can result from sequential arrival of species that occupy a random proportion of the unoccupied niche space.

To compare diversity between playas, Fisher's log series α for particular playas was considered to be significantly different if their 95 percent confidence limits did not overlap (Table 27.4). Although this method inflates experiment-wise error rate, results can be useful in a heuristic context. Based on all invertebrates collected from March through December, α was significantly greater for Jack Stevens than Buster Long and Rushland playas; α for Buster Long playa was significantly lower than that of Jack Stevens and Quaker & Brownfield playas (final column, Table 27.4).

Fisher's log series α also was calculated for each playa in each sampling season, based on macroinvertebrate collections made in spring (March and April), summer (June, July, and August), and fall (November–December). Jack Stevens playa consistently had the highest α throughout all seasons (Table 27.4). During the spring diversity of Jack Stevens playa was significantly higher than of all other playas except Quaker & Brownfield playa. Fisher's log series α was not calculated for Higinbotham and Leroy Elmore playas during the spring, because species abundances were evenly distributed among the few collected species. For the summer, diversity of Buster Long playa was significantly lower than Quaker & Brownfield and Jack Stevens playas. For the fall, diversity of Leroy Elmore and Buster Long playas was each significantly lower than Rushland, Higinbotham, Quaker & Brownfield, or Jack Stevens playas.

Macroinvertebrate Community Composition

Two communities could exhibit the same richness and diversity, but their composition could be completely different. In contrast, community composition reflects species richness and relative abundances, but retains a taxonomic component. Invertebrate community composition was evaluated at two levels of taxonomic resolution: the taxon level (defined previously) and the familial level (Table 27.3). Invertebrates were grouped according to familial or higher taxonomic level (i.e., order, class) so that each group contained at

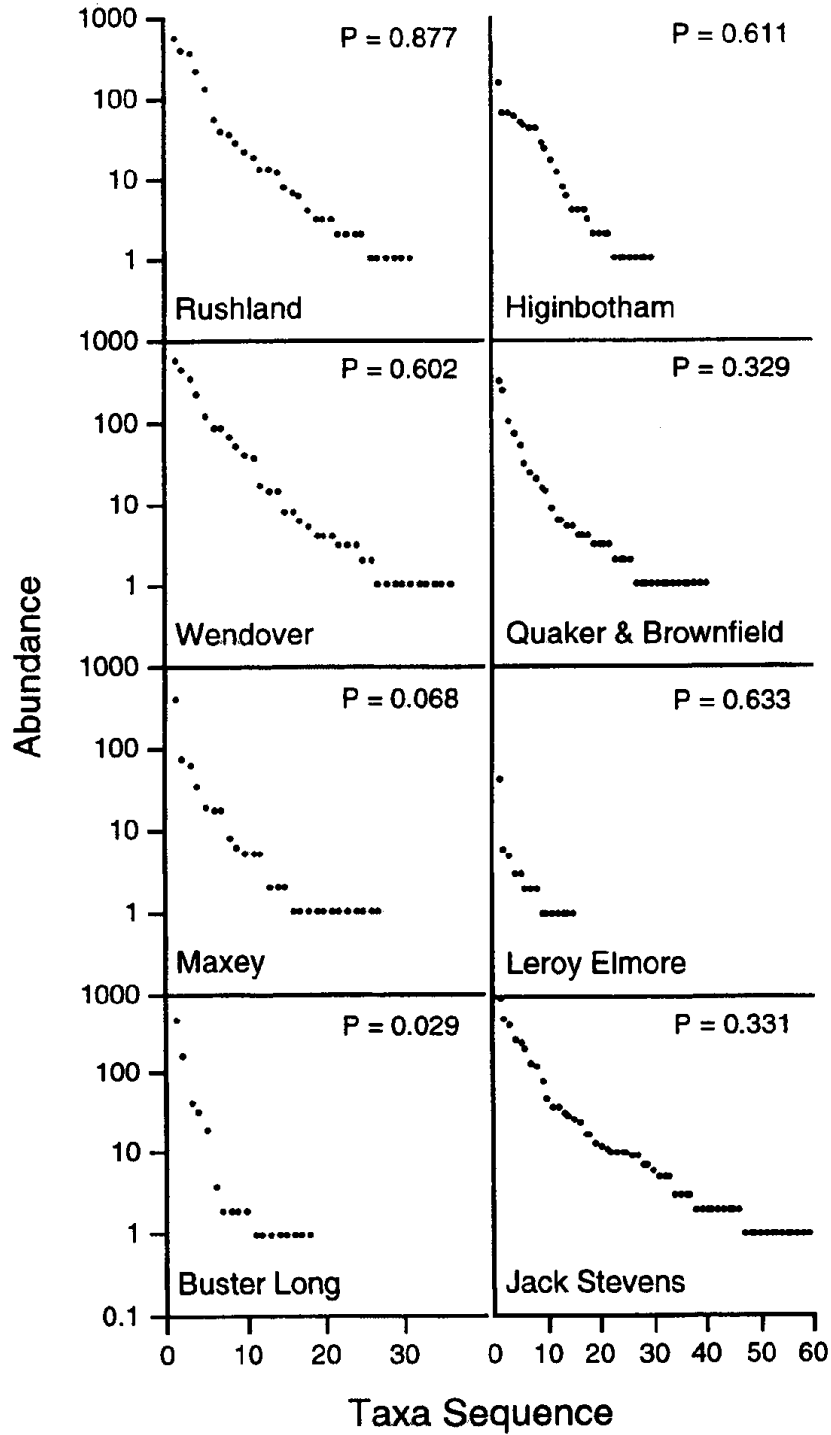


Fig. 27.1. Rank abundance of aquatic invertebrates in urban playas of Lubbock, Texas. Probability values for chi-square goodness-of-fit tests compare observed to expected log series distributions.

TABLE 27.4. Fisher's Log Series α (Mean \pm Standard Deviation) for Each Playa^a

Play	Spring	Summer	Autumn	Combined
Rushland	1.5 \pm 0.8a	4.7 \pm 0.9ab	3.7 \pm 1.0a	5.2 \pm 0.9ab
Higinbotham		5.5 \pm 1.1ab	3.2 \pm 1.1a	6.4 \pm 1.2abc
Wendover	1.5 \pm 0.8a	5.1 \pm 0.9ab	1.6 \pm 0.5ab	6.1 \pm 1.0abc
Quaker & Brownfield	2.4 \pm 0.8ab	7.3 \pm 1.3ab	3.3 \pm 0.9a	8.4 \pm 1.3ac
Maxey	1.5 \pm 0.6a	5.3 \pm 1.1ab	1.4 \pm 0.7ab	5.6 \pm 1.1abc
Leroy Elmore		4.9 \pm 1.4ab	0.3 \pm 0.3b	5.6 \pm 1.4abc
Buster Long	1.1 \pm 0.5a	3.0 \pm 0.8a	0.5 \pm 0.3b	3.3 \pm 0.8b
Jack Stevens	6.2 \pm 1.3b	8.7 \pm 1.2b	4.0 \pm 1.0a	10.3 \pm 1.3c

^aSame letters following means denote playas that are indistinguishable (within season) based on species diversity.

least 1 percent of the total number of collected organisms. This approach minimizes the influence exerted by a few individuals representing a single taxon on measures of community similarity, and permits an assessment of whether the taxonomic level of identification affects the conclusions of community analyses. The term familial is used throughout the remainder of this chapter in reference to composite groupings at which quantitative analyses were undertaken.

Four similarity measures (Euclidean distance, Cosine, Jaccard, Ochai) were used to evaluate the relationships among urban playas based on macroinvertebrate community composition (Ludwig and Reynolds 1988). Organisms collected at all dates were pooled for these analyses (separate analyses performed by date provided no additional insights and thus are not included herein).

Euclidean distance and Cosine similarity are based on species abundance data, but differ in the degree to which they are sensitive to abundance. Euclidean distance (E_{jk}) is defined as:

$$E_{jk} = \sqrt{\sum_{i=1}^s (x_{ij} - x_{ik})^2}$$

where x_{ij} and x_{ik} are the abundances of the i^{th} species (s) for playa j and k , respectively. This measure emphasizes differences in the abundances of taxa between playas. Conversely, the Cosine index (C_{jk}) is defined by:

$$(C_{jk}) = \frac{\sum_{i=1}^s (x_{ij}x_{ik})}{\sqrt{\left(\sum_{i=1}^s x_{ij}^2\right)\left(\sum_{i=1}^s x_{ik}^2\right)}}$$

and places greater importance on the relative abundances of taxa.

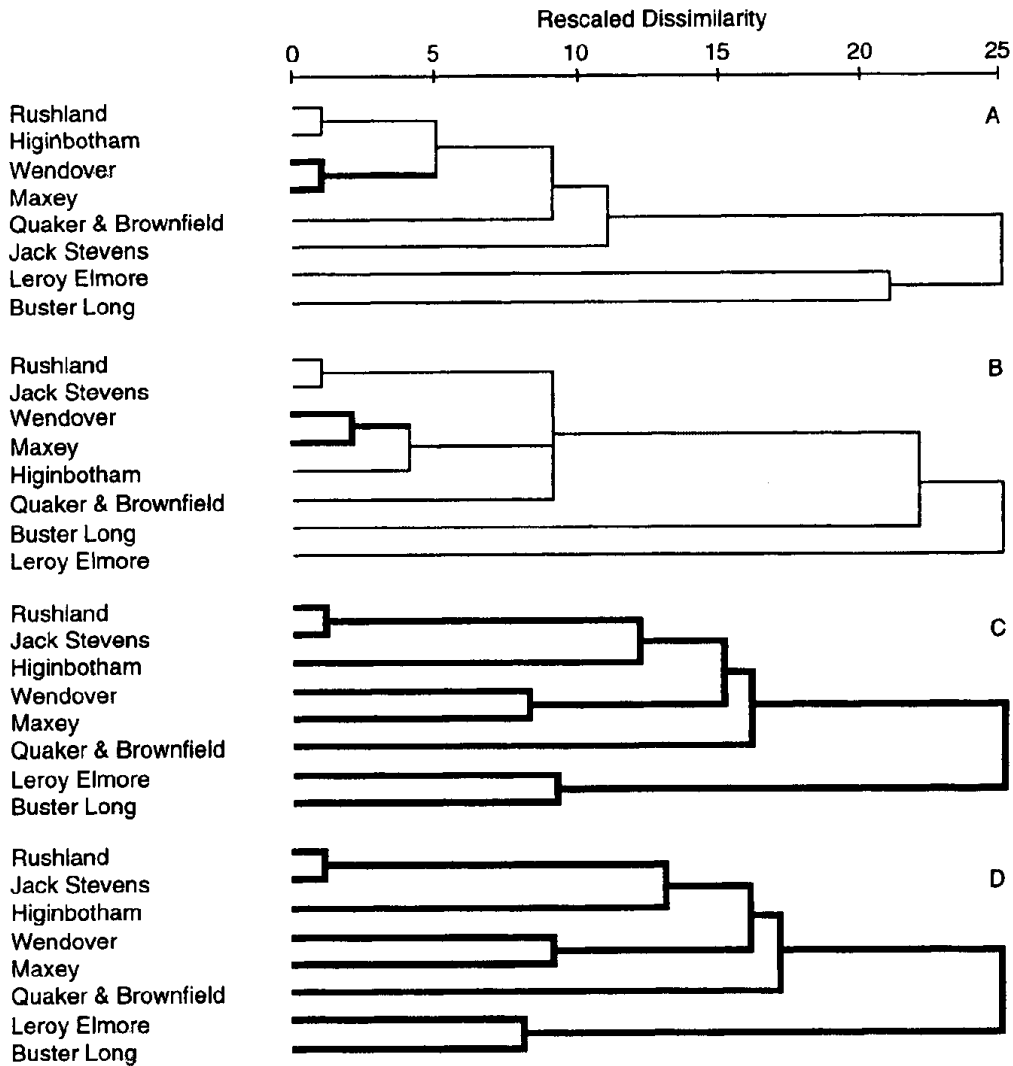


Fig. 27.2. Results of cluster analyses based on Jaccard and Ochai similarity indexes for macroinvertebrate communities in urban playas of Lubbock, Texas. Consensus between dendrograms represented by bold lines. (a) Jaccard's index based on taxon-level data. (b) Ochai's index based on taxon-level data. (c) Jaccard's index based on familial data. (d) Ochai's index based on familial data.

27.3a, b). Analyses based on familial-level data showed greater correspondence between indexes (Fig. 27.3c, d), consistently pairing Quaker & Brownfield and Maxey playas, Higinbotham and Leroy Elmore playas, and Jack Stevens and Rushland playas. Analyses at both taxon and familial levels clustered Leroy Elmore, Quaker & Brownfield and Maxey playas. However, taxon-level data indicated that Leroy Elmore playa was similar to Wendover playa and distant from Higinbotham playa, whereas familial-level data suggested that Leroy Elmore and Higinbotham playas were more similar.

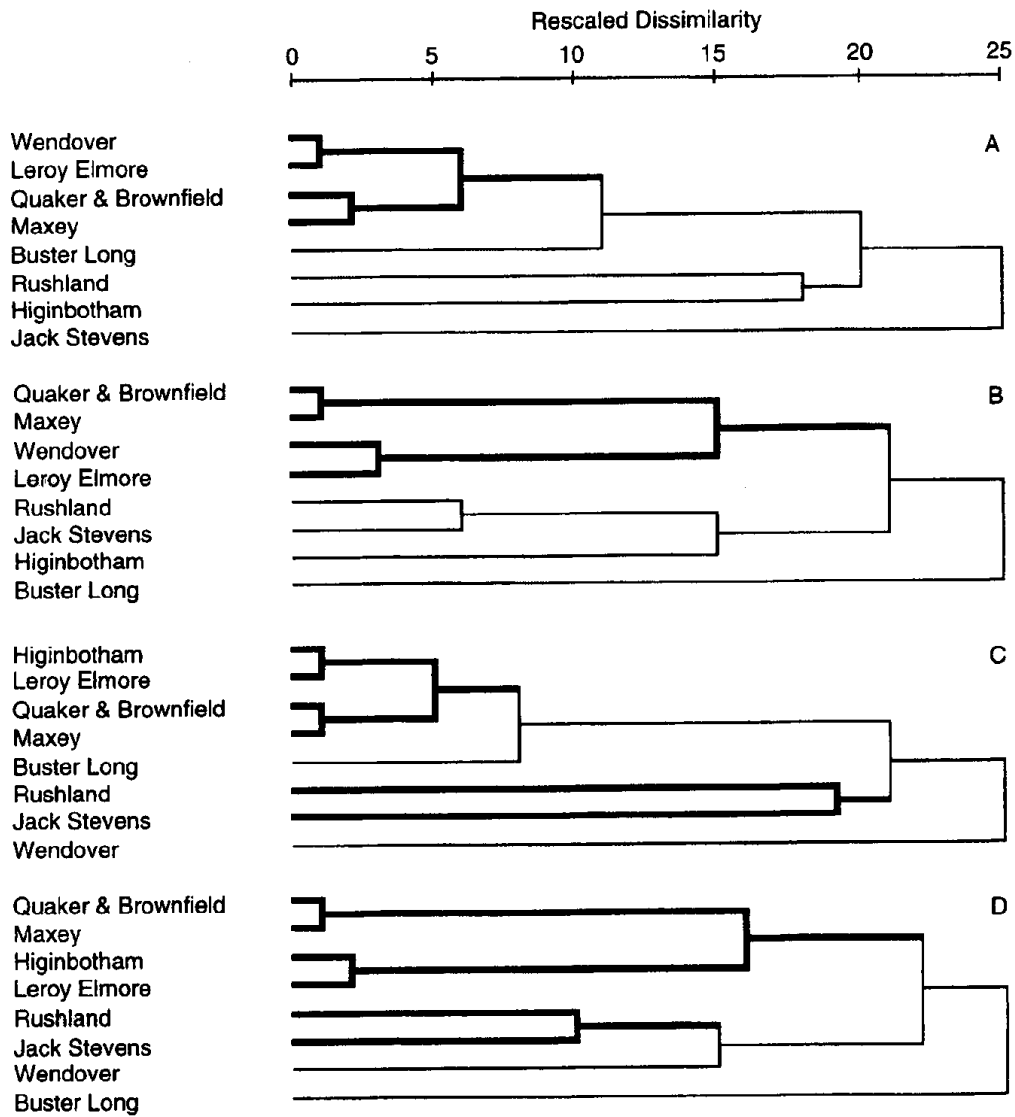


Fig. 27.3. Results of cluster analyses based on Jaccard and Ochai similarity indexes for macroinvertebrate communities in urban playas of Lubbock, Texas. Consensus between dendrograms represented by bold lines. (a) Euclidian distance based on taxon-level data. (b) Cosine index based on taxon-level data. (c) Euclidian distance index based on familial data, (d) Cosine index based on familial data.

Comparisons between approaches based on presence-absence of taxa (Jaccard and Ochai indexes) and those based on abundances of taxa (Euclidean distance and Cosine indexes) revealed that Wendover and Maxey playas consistently were placed within a cluster of two to four playas, based on taxon-level analyses. Buster Long playa was consistently outside this cluster of two to four playas, based on taxon-level data. At the familial level all indexes paired Rushland and Jack Stevens playas, whereas Quaker & Brownfield, Higinbotham, and Maxey playas were grouped within clusters that variously

consisted of five to six playas. The only consistent relationship between playas identified by all indexes at both levels of taxonomic resolution was that Quaker & Brownfield and Maxey playas always occurred within a cluster composed of the six most similar playas.

A principal components analysis (PCA) was conducted to identify macroinvertebrate families that contributed the greatest variation among urban playas (SPSS 1990). The first three PC scores accounted for 75 percent of the variation in abundances of familial groups. The first PC accounted for 44 percent of the variation among urban playas in macroinvertebrate familial abundances and was loaded positively with densities of gastropods, baetid mayflies, annelids, and aeshnid dragonflies. This PC separated Jack Stevens playa from the other playas. The second PC accounted for 16 percent of the variation, was loaded positively with densities of chrysomelid beetles and gerrids (water striders), and distinguished Quaker & Brownfield playa. The third PC accounted for 15 percent of the variation, was loaded positively with notonectids (back-swimmers) and corixids (water boatmen), and separated Wendover playa from all the others. These results were most consistent with cluster analysis based on the Cosine index and familial-level data (Fig. 27.3*d*). A cluster consisted of Rushland, Jack Stevens, and Wendover playas, which contained relatively greater numbers of notonectids, baetid mayflies, caenid mayflies, coenagrionids (damselflies), and chironomids (midges). A second cluster consisted of Quaker & Brownfield, Maxey, Leroy Elmore, and Hig-inbotham playas, which contained greater numbers of palaemonids (fresh-water shrimp), corixids, and gerrids.

Macroinvertebrate-Environment Relationships

Mantel's nonparametric test (Manly 1985, 1986) evaluated whether differences in water chemistry among playas were correlated with differences in community composition among playas (Smouse et al. 1986). Because macroinvertebrates were collected on six dates (March, April, June, July, August, and November–December), only physicochemical data for these dates were used in the analysis. Thus, two similarity matrices were constructed for each sampling date, one characterizing pair-wise differences in macroinvertebrate composition (based on abundances of individual taxa) and the other representing pair-wise differences in water chemistry. Because water chemistry attributes have different units (i.e., mg/L, mmho, °C), data were transformed to Z scores for analysis. A significant positive relationship existed between interplaya differences in physicochemical attributes and invertebrate community composition during November ($P = 0.048$), but no significant relationships occurred at other dates ($P > 0.2$ in all cases). Thus, little evidence supports the hypothesis that differences in macroinvertebrate communities are related to differences in water quality characteristics among urban playas.

Spearman rank correlations between particular physicochemical parameters and land use categories revealed few significant relationships, despite interplaya variation in water quality parameters and surrounding land use patterns

(Wolf 1996). Conductivity and ammonia concentration were correlated positively to area of multiple-family housing and commercial land use; total organic carbon also was correlated positively to multiple-family housing. Nevertheless, the general lack of correlation between land use patterns and water quality characteristics does not preclude the possible importance of water quality parameters as a factor influencing macroinvertebrate communities.

IMPLICATIONS

The urban playas of Lubbock provide an uncommon context in which to study aquatic macroinvertebrate communities. Playas are isolated hydrologically but remain comparable in many respects. A number of communities can be examined within a small geographical area, minimizing differences among impoundments due to differences in soils, climate, surrounding landscape, drainage relationships, species pools, and evolutionary history that normally occur over larger distances. Although some significant differences in physicochemical and biological characteristics exist among playas, little indicates that these characteristics are correlated.

Few consistent differences among playas characterize macroinvertebrate diversity, but Jack Stevens playa usually showed significantly higher diversity than did Buster Long and Leroy Elmore playas (Table 27.4). This was evident in overall diversity (combined data from all seasons) as well as diversity for each season. Fisher's log series α was highest for Jack Stevens playa at all times, whereas α for Buster Long playa was usually the lowest. Some of these differences may be related to general habitat characteristics; Jack Stevens playa is shallow and supports an extensive emergent and submerged macrophyte community, whereas Buster Long playa is a steep-sloping basin with no littoral vegetation and high phytoplankton populations (Brownlow 1994). Indeed, Wollheim and Lovvorn (1995) report a direct relationship between biomass of aquatic invertebrates and extent of macrophyte habitat in shallow lakes of the Wyoming High Plains. Moreover, an inverse relationship existed between biomass of zooplankton and that of other aquatic invertebrates. Characteristics of urban playas of Lubbock are consistent with these observations; the highest numbers of zooplankton and lowest number of insect taxa occurred in Buster Long playa, which lacks macrophytes and has high phytoplankton populations (Brownlow 1994). Wollheim and Lovvorn (1995) also found that littoral macrophyte habitats supported a greater diversity and abundance of aquatic invertebrates. This greater abundance of invertebrates probably occurs because macrophytes increase structural and resource dimensions of niche space (Rosine 1955, Rooke 1984) by enhancing food quality (Carpenter and Lodge 1986) and cover from predators (Crowder and Cooper 1982). The higher diversity and abundance of invertebrates in Jack Stevens and Quaker & Brownfield playas may result from the greater extent of macrophyte habitat in these playas (Table 27.1).

Analyses of community structure also revealed few consistent relationships among playas. Only Quaker & Brownfield and Maxey playas were always among the six most similar playas—possibly because only these two playas had relatively high abundances of palaemonids and chironomids. However, the PCA and cluster analysis based on the Cosine similarity measure (familial-level data) shared some common features. The Cosine index produced two main clusters of playas with one (including Jack Stevens and Wendover playas) having relatively greater numbers of notonectids and baetid mayflies and a second group (including Quaker & Brownfield playa) having relatively greater numbers of gerrids. In comparison, the PC-1 separated Jack Stevens playa from the others, partly based on densities of baetid mayflies; the PC-2 separated Quaker & Brownfield playa from the rest, in part due to densities of gerrids; the PC-3 separated Wendover playa from the others, partly based on abundances of notonectids.

Species-Environment Relationships

Urban playas were variable with respect to some water quality measures, but Mantel analyses demonstrated little overall relationship between water quality and composition of aquatic macroinvertebrate communities, although many water quality attributes that differed among playas have been shown to influence community composition of aquatic invertebrates elsewhere (Effler et al. 1990, Hammer et al. 1990, Gower et al. 1994, Malmqvist and Eriksson 1995, Wollheim and Lovvorn 1995). For example, many invertebrates are sensitive to levels of dissolved oxygen (Wetzel 1983). Dissolved oxygen ranged between 14.35 and 1.87 mg/L in Lubbock playas, with the latter value approaching a stressful level for some organisms (e.g., mayflies, dragonflies, and damselflies; Merritt and Cummins 1984). Also, invertebrate communities in prairie lakes can be affected by salinity (Wollheim and Lovvorn 1995, Hammer et al. 1990). Salinity was not measured directly for urban playas of Lubbock, but relatively high conductivity and alkalinity illustrate high ionic concentrations.

The level of eutrophication or trophic status in lakes long has been used as a predictor of species distributions and abundances (Macan 1963, Saether 1979). In fact, Scheffer (1990) proposed two types of shallow freshwater lakes: those with clear water (oligotrophic) dominated by macrophytes and those with turbid waters (eutrophic) dominated by phytoplankton. Nutrient enrichment can cause a shift from a macrophyte-dominated community to a phytoplankton-dominated community, with attendant changes in invertebrate communities (Saether 1979, Growns et al. 1992). In the present study total organic carbon, ammonia, TKN and nitrate concentrations differed significantly between playas (Wolf 1996) and may be responsible for some differences in macroinvertebrate communities. For example, ammonia can have significant impacts on aquatic invertebrates (Effler et al. 1990, Richards et al. 1993). In the present study ammonia concentrations were highest in Buster Long playa (1.9 ± 2.3 mg N/L; Wolf 1996), which also differed from other

playas in that its macroinvertebrate community was dominated by cladocerans and copepods. This is consistent with large phytoplankton populations reported for this playa (Brownlow 1994). A relationship between ammonia and abundances of cladocerans may be mediated by phytoplankton in this playa.

In conclusion, urban playas exhibited similar macroinvertebrate species diversity, although invertebrate community composition and dominance differed greatly. Differences in community composition were not related differences in water quality characteristics, although some taxa are affected by particular physicochemical characteristics. Macroinvertebrate communities of urban playas in the Southern High Plains region of West Texas may be affected most strongly by vegetational characteristics, and secondarily by particular water quality parameters.

ACKNOWLEDGMENTS

Voucher specimens were identified by Dr. Robert Sites (University of Missouri). Financial support was provided by the Office of Research Services and Department of Biological Sciences, Texas Tech University.

LITERATURE CITED

- American Public Health Association (APHA). 1992. Standard Methods for the Examination of Water and Waste Water. (18th ed.). American Public Health Association, Washington, DC.
- Bolen, E. G., L. M. Smith, and H. L. Schramm, Jr. 1989. Playa lakes: Prairie wetlands of the Southern High Plains. *Bioscience* 39:615–623.
- Brownlow, C. J. 1994. Trophic state assessment of an urban lake, Lubbock, Texas. Master's Thesis, Texas Tech University, Lubbock, TX.
- Cairns, J., Jr., and J. R. Pratt. 1993. A history of biological monitoring using benthic macroinvertebrates. Pages 10–27 in D. M. Rosenberg and V. H. Resh (eds.), *Freshwater Biomonitoring and Benthic Macroinvertebrates*. Chapman & Hall, New York.
- Carpenter, S. D., and D. M. Lodge. 1986. Effects of submersed macrophytes on ecosystem processes. *Aquatic Botany* 26:341–370.
- Crowder, L. B., and W. E. Cooper. 1982. Habitat structural complexity and the interaction between bluegills and their prey. *Ecology* 63:1802–1813.
- Effler, S. W., C. M. Brooks, M. T. Auer, and S. M. Doerr. 1990. Free ammonia and toxicity criteria in polluted urban lake. *Research Journal of Water Pollution Control Federation* 62:771–779.
- Ennis, T. E. 1994. City of Lubbock stormwater NPDES permit data analysis. Master's Thesis, Texas Tech University, Lubbock, TX.
- Environmental Protection Agency (EPA). 1974. *Methods for Chemical Analysis of Water and Wastes*. Environmental Protection Agency, Water Quality Office, Analytical Quality Control Laboratory, Cincinnati, OH.

- France, R. L. 1995. Macroinvertebrate standing crop in littoral regions of allochthonous detritus accumulation: Implications for forest management. *Biological Conservation* 75:35–39.
- Gower, A. M., G. Myers, M. Kent, and M. E. Foulkes. 1994. Relationships between macroinvertebrate communities and environmental variables in metal-contaminated streams in south-west England. *Freshwater Biology* 32:199–221.
- Growns, J. E., J. A. Davis, F. Cheal, L. G. Schmidt, R. S. Rosich, and S. J. Bradley. 1992. Multivariate pattern analysis of wetland invertebrate communities and environmental variables in Western Australia. *Australian Journal of Ecology* 17:275–288.
- Hall, D. L., R. W. Sites, E. B. Fish, T. R. Mollhagen, D. L. Moorhead, and M. R. Willig. Playas of the Southern High Plains: The macroinvertebrate fauna. This volume.
- Hammer, U. T., J. S. Sheard, and J. Kranabetter. 1990. Distribution and abundance of littoral benthic fauna in Canadian prairie saline lakes. *Hydrobiologia* 197:173–192.
- Hanson, M. A., and M. G. Butler. 1994. Responses of food web manipulation in a shallow waterfowl lake. *Hydrobiologia* 279/280:457–466.
- Haukos, D. A., and L. M. Smith. 1992. Ecology of Playa Lakes. Waterfowl management handbook leaflet 13.3.7, Office of Information Transfer, U.S. Fish and Wildlife Service, Fort Collins, CO.
- Hershey, A. E. 1985. Littoral chironomid communities in an arctic Alaskan lake. *Holarctic Ecology* 8:39–48.
- Hynes, H. B. N. 1970. *The ecology of Running Waters*. University of Toronto, Toronto, ON.
- Jones, R., and C. C. Clark. 1987. Impact of watershed urbanization on stream insect communities. *Water Resources Bulletin* 23:1047–1055.
- Kullberg, A. 1992. Benthic macroinvertebrate community structure in 20 streams of varying pH and humic content. *Environmental Pollution* 78:103–106.
- Livingston, E., and J. Cox. 1989. *Florida Development Manual*. Vol. 1., Florida Department of Environmental Regulation, Tallahassee, FL.
- Ludwig, J. A., and J. F. Reynolds. 1988. *Statistical ecology: A Primer on Methods and Computing*. John Wiley & Sons, New York.
- Macan, T. T. 1949. Corixidae (Hemiptera) of an evolved lake in the English Lake District. *Hydrobiologia* 2:1–23.
- Macan, T. T. 1963. *Freshwater ecology*. John Wiley & Sons, New York.
- Magurran, A. E. 1988. *Ecological Diversity and Its Measurement*. Princeton University Press, Princeton, NJ.
- Malmqvist, B., and A. Eriksson. 1995. Benthic insects in Swedish lake-outlet streams: Patterns in species richness and assemblage structure. *Freshwater Biology* 34:285–296.
- Manly, B. F. 1985. *The Statistics of Natural Selection on Animal Populations*. Chapman & Hall, New York.
- Manly, B. F. 1986. *Multivariate Statistical Methods: A Primer*. Chapman & Hall, New York.
- Mason, C. F. 1991. *Biology of freshwater pollution* (2nd ed.). Longman Scientific & Technical, Harlow, Essex, UK.

- Merickel, F. W., and J. K. Wangberg. 1981. Species composition and diversity of macroinvertebrates in two playa lakes on the Southern High Plains, Texas. *Southwestern Naturalist* 26:153–158.
- Merritt, R. W., and K. W. Cummins. 1984. *An Introduction to the Aquatic Insects of North America* (2nd ed.). Kendall/Hunt, Dubuque, IA.
- Neck, R. W., and H. L. Schramm, Jr. 1992. Freshwater molluscs of selected playa lakes of the Southern High Plains of Texas. *Southwestern Naturalist* 37:205–209.
- Porcella, D. B., and D. L. Sorensen. 1980. Characteristics of nonpoint source urban runoff and its effects on stream ecosystems. Corvallis Environmental Research Laboratory, Office of Research and Development (U.S. EPA), Corvallis, OR.
- Rasmussen, J. B. 1993. Patterns in the size structure of littoral zone macroinvertebrate communities. *Canadian Journal of Aquatic Sciences* 50:2192–2207.
- Richards, C., G. E. Host, and J. W. Arthur. 1993. Identification of predominant environmental factors structuring stream macroinvertebrate communities within a large agricultural catchment. *Freshwater Biology* 29:285–294.
- Rimer, A. E., and J. A. Nissen. 1978. Characterization and impact of stormwater runoff from various land cover types. *Water Pollution Control Federation* 50:252–264.
- Rooke, B. J. 1984. The invertebrate fauna of four macrophytes in a lotic system. *Freshwater Biology* 14:507–513.
- Rosenberg, D. M., and V. H. Resh. 1993. *Freshwater Biomonitoring and Benthic Macroinvertebrates*. Chapman & Hall, New York.
- Rosine, W. N. 1955. The distribution of invertebrates on submerged aquatic plant surfaces in Muskee Lake, Colorado. *Ecology* 36:308–314.
- Saether, O. A. 1979. Chironomid communities as water quality indicators. *Holarctic Ecology* 2:65–74.
- Scheffer, M. 1990. Multiplicity of stable states in freshwater systems. *Hydrobiologia* 200/201:475–486.
- Smith, C. L. 1993. Water boatmen (Hemiptera: Corixidae) faunas in the playa lakes of the Southern High Plains. Master's Thesis, Texas Tech University, Lubbock, TX.
- Smouse, P. E., J. C. Long, and R. R. Sokal. 1986. Multiple regression and correlation extensions of the Mantel test of matrix correspondence. *Systematic Zoology* 35: 627–632.
- Sokal, R. R., and F. J. Rohlf. 1995. *Biometry: The Principles and Practice of Statistics in Biological Research* (3rd ed.). W. H. Freeman & Co., New York.
- SPSS. 1990. *Statistical Package for the Social Sciences*. SPSS, Chicago, IL.
- Sublette, J. E., and M. S. Sublette. 1967. The limnology of playa lakes on the Llano Estacado, New Mexico and Texas. *Southwestern Naturalist* 12:369–406.
- Taylor, L. R., R. A. Kempton, and I. P. Woivod. 1976. Diversity and the log series model. *Journal of Animal Ecology* 45:255–271.
- Thompson, G. B., D. M. Wells, R. M. Sweazy, and B. J. Claborn. 1974. Variation of Urban Runoff Quality and Quantity with Duration and Intensity of Storms. Interim Report, Water Resources Center, Texas Tech University, Lubbock, TX.
- U.S. Fish and Wildlife Service. 1988. Playa Lakes Region Waterfowl Habitat Concept Plan, Category 24 of the North American Waterfowl Management Plan. U.S. Fish and Wildlife Service, Albuquerque, NM.

- Ward, J. V. 1992. *Aquatic Insect Ecology: Biology and Habitat*. John Wiley & Sons, New York.
- Wells, D. M., R. M. Sweazy, B. J. Claborn, and R. H. Ramsey. 1975. Variation of Urban Runoff Quality and Quantity with Duration and Intensity of Storms: Phase III. Vol. 4, Project Summary. Final report of the office of Water Research and Technology, Water Resources Center, Texas Tech University, Lubbock, TX.
- Wetzel, R. G. 1983. *Limnology*. CBS College, New York.
- Wolf, C. F. 1996. Aquatic macroinvertebrate diversity and water quality of urban lakes. Master's Thesis, Texas Tech University, Lubbock, TX.
- Wollheim, W. M., and J. R. Lovvorn. 1995. Salinity effects on macroinvertebrate assemblages and waterbird food webs in shallow lakes of the Wyoming High Plains. *Hydrobiologia* 310:207–223.