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Water Quality of Selected Effluent-Dependent Stream Reaches in Southern Arizona as Indicated by Concentrations of Periphytic Chlorophyll *a* and Aquatic-Invertebrate Communities

By Joseph B. Gebler

Water-Resources Investigations Report 98—4199

National Water-Quality Assessment Program
Central Arizona Basins Study Unit

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FIRST PAGE TITLE-BLOCK PHOTOGRAPH:
Treated sewage effluent is discharged from the wastewater-treatment plant into the Salt River at 91st Avenue near Phoenix.

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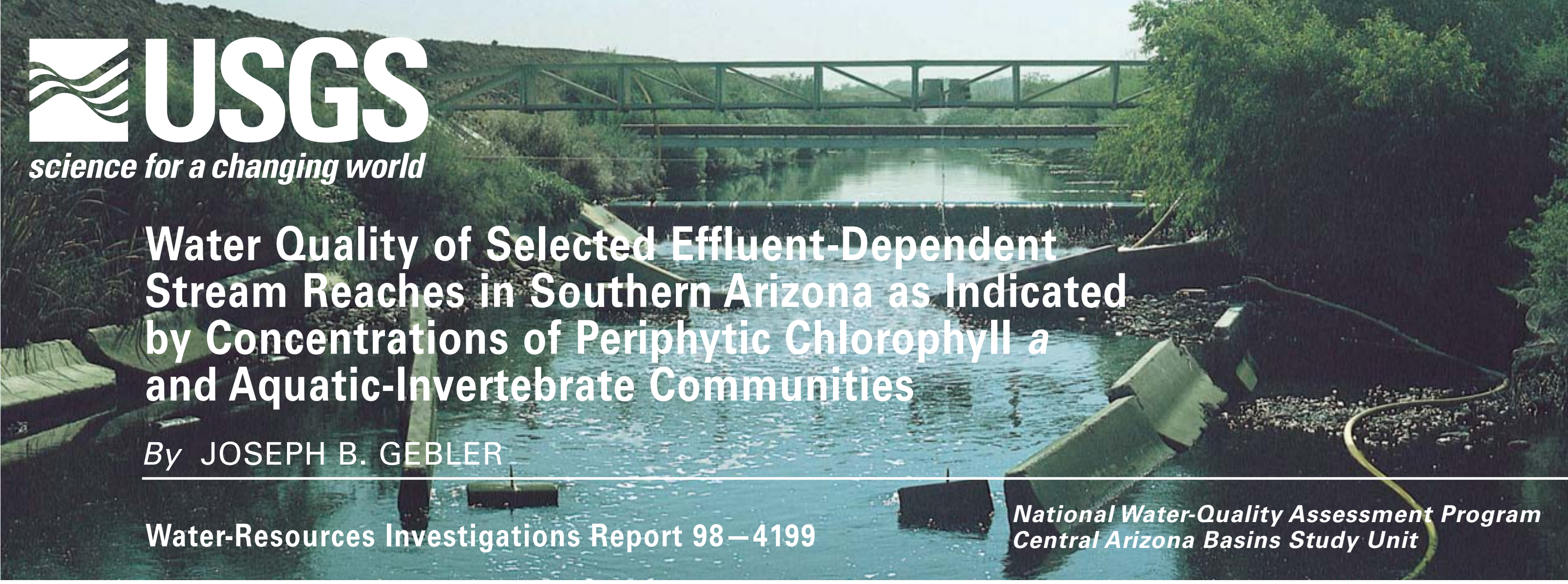

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Abstract

Concentrations of chlorophyll *a* and indices computed for aquatic-invertebrate communities in two effluent-dependent stream reaches on the Santa Cruz River and one on the Salt River were compared to those in noneffluent-dependent streams to examine potential differences in water quality. Periphytic chlorophyll *a* from riffle habitats and aquatic-invertebrate communities from riffle and multiple habitats were used for the comparison. Concentrations of chlorophyll *a* from effluent-dependent streams were elevated compared with concentrations in noneffluent-dependent streams. Aquatic-invertebrate communities from effluent-dependent streams were characterized by an abundant, yet taxonomically depauperate fauna of tolerant organisms; whereas, noneffluent-dependent streams supported a diverse assemblage of aquatic invertebrates including taxa considered sensitive to water-quality degradation. These results indicate that water quality of effluent-dependent streams is poor compared with water quality of noneffluent-dependent streams. Patterns of taxonomic composition of aquatic-invertebrate communities and abundances of aquatic invertebrates from effluent-dependent streams are the same as patterns discussed in the scientific literature.

INTRODUCTION

Effluent-dependent streams in Arizona consist primarily of discharge of treated wastewater. Although the effects of sewage effluent on aquatic biota have been studied for about 100 years (Cairns and Pratt, 1993), interest in the biota of effluent-dependent streams in the western United States has been renewed recently as regulators and managers consider modifying existing water-quality criteria or developing new criteria that may be more appropriate for arid and semiarid areas (Baumgartner and Smith, 1993). Few studies, however, have been done on aquatic biota in effluent-dependent streams in arid and semiarid areas.

From 1995 to 1997, as part of the National WAter-Quality Assessment (NAWQA) program of the U.S. Geological Survey (USGS), aquatic biota were sampled from selected effluent-dependent and noneffluent-dependent (natural) stream reaches (hereafter referred to as comparison sites) in the Central Arizona Basins (CAZB) study area (fig. 1). The purpose of the NAWQA program is to describe the status of and trends in the Nation’s ground-water and surface-water resources and to identify human and natural factors that affect water quality (Gilliom and others, 1995). Surveys of aquatic biota are an integral part of the NAWQA program as the only direct measure of biological integrity (Gurtz, 1994) and thus an indication of water quality.

Figure 1. Location of Central Arizona Basins study area.

This report describes concentrations of periphytic chlorophyll *a* and aquatic-invertebrate communities of two effluent-dependent stream reaches on the Santa Cruz River and one on the Salt River (fig. 2). These biological characteristics are compared with biological characteristics of the comparison sites on the San Pedro and Salt Rivers and are used as indicators of water quality. In addition, patterns of biological characteristics of effluent-dependent streams are compared to patterns described in scientific literature on organic loading.

Most previous studies on biological effects of sewage effluent have been in wet climates, particularly eastern North America, the United Kingdom, and northern Europe, where receiving streams generally have sufficient surface water to dilute effluent and lessen harmful effects. In these studies, algal growth generally was enhanced downstream from sewage discharges because of the addition of plant nutrients, primarily nitrogen and phosphorus (Hynes, 1960; Hellawell, 1986). In addition, sensitive taxa, such as aquatic worms (the order Oligochaeta) and midges (the insect family Chironomidae), dominate aquatic-invertebrate communities in the presence of low concentrations of dissolved oxygen, toxicants (such as ammonia), and sedimentation by suspended solids (Hynes, 1960; Hellawell, 1986). Streams receiving effluent in arid areas differ from receiving streams in wetter areas because they typically have little or no natural flow, and the flow often ends before reaching other streams because of infiltration and evaporation. Information is limited on how biological communities that develop in these systems after effluent is discharged into the channels compare with biological communities in other areas.

Study Sites

As part of the CAZB NAWQA study, aquatic biota were sampled from two effluent-dependent stream reaches on the Santa Cruz River (Santa Cruz River at Tubac and Santa Cruz River at Cortaro), and one on the Salt River at the wastewater-treatment plant (WWTP) at 91st Avenue near Phoenix (**fig. 2**). Surface water in the channel of all three reaches is almost exclusively sewage effluent except during floodflows, which are typically of short duration. Results from effluent-dependent reaches were compared to those form the comparison sites that were selected on the basis of their similarity to the effluent reaches (**table 1**).
The comparison sites are not necessarily classified as regional sites (Hughes and others, 1986) but serve a similar function in that they are not affected to any great extent by treated-sewage effluent.

The NAWQA sampling reach at Tubac is about 24 km downstream from the Nogales International Wastewater-Treatment Plant (NIWWTP), which supplies most of the water for this stream segment. Ground water, however, probably contributes some flow in the segment (Lawson, 1995). Wennmacher (1996) studied algal communities of the segment created by the NIWWTP and reported low species diversity and high ratios of pollution-tolerant species to natural-water species, which she concluded indicated poor water quality. Lawson(1995) studied macroinvertebrate communities from the same segment and concluded that the community was severely impaired immediately downstream from the NIWWTP. Lawson (1995) also observed that the communities recovered partially near the end of the segment, about 26 km from the NIWWTP, but did not recover to control-site conditions.

The NAWQA sampling reach at Cortaro is about 1.6 and 11.3 km downstream from two wastewater-treatment plants near Tucson. Minimal contributions of ground water are possible within the segment (Ken Galyean, hydrologist, USGS, oral commun., 1997). Two studies by Harding Lawson Associates (1986, 1997) included sampling of aquatic-invertebrate communities from six locations in the segment.
A maximum abundance of 17 individuals per square meter in six families was reported (Harding Lawson Associates, 1986). Harding Lawson Associates (1997) reported similar low taxonomic richness but did not report abundance data.

Figure 2. Central Arizona Basins study area and effluent-dependent stream and comparison-stream reaches.

Table 1. Selected characteristics for effluent-dependent stream and comparison-stream reaches

[Downstream distance is approximate. Dominant substrate is sand. NA, not applicable; WWTP, wastewater-treatment plant; km, kilometer; m, meter; m/s, meters per second; υS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius]

Stream name	Date of sample	Downstream distance from effluent source (km)	Width at time of sampling (m)			Depth at time of sampling (m)			Velocity at time of sampling (m/s)			Specific conductance (uS.cm at 25°C)
			Number of samples	Mean	Range	Number of samples	Mean	Range	Number of samples	Mean	Range	
San Pedro at Charleston	Dec. 6–8, 1995	NA	6	8.6	2.7–15.6	17	0.20	0.07–.54	17	0.34	0.05–.67	490
Santa Cruz at Tubac	Jan. 17–19, 1996	24	6	12.6	7.2–18.8	19	.23	.08–.30	19	.62	.07–1.13	660
Santa Cruz at Cortaro	Jan. 22–24, 1996	1.6 and 1.3	6	13.8	8.3–23.1	18	.33	.16–.69	18	.87	.47–1.28	990
Salt River near Roosevelt	Dec. 12–14, 1995	NA	6	47.2	22.2–66.7	20	.70	.10–1.15	20	.54	.03–1.82	3,680
WWTP at 91st Avenue	Nov. 28–30, 1995	.2	5	20.1	16.4–27.1	15	.62	.20–1.30	15	.88	0–1.35	1,510

Each effluent-dependent reach of the Santa Cruz River was compared to a reach on the San Pedro River at Charleston. The water quality of the Sand Pedro River at Charleston has been affected occasionally by sewage effluent (Arizona Department of Environmental Quality, 1996) and mine-tailings spills from Mexico (King and others, 1992). Flow in perennial sections of the river, however, is sustained by groundwater inflow from the regional aquifer (Jackson and others, 1987) rather than treated-sewage effluent. Recover of aquatic life following mine spills appears to occur quickly; recovery of aquatic organisms was recorded 4 months after a major spill in 1979 (Jackson and others, 1987). Although the San Pedro River is not pristine, the reach at Charleston is the best available site for comparison with sites on the Santa Cruz River because it is similar in channel size and has noneffluent perennial flow.

The sampling reach on the Salt River is about 0.2 km downstream from the WWTP at 91st Avenue near Phoenix, which creates this effluent-dependent stream segment. Effluent from the WWTP at 23rd Avenue may contribute subsurface flow to the sampling reach at 91st Avenue. CH2MHill and others (1997) reported 12 taxa of macroinvertebrates collected from six sites within the segment. Only two taxa (chironomids and oligochaetes, totaling 247 individuals per square meter) were reported from their sampling site immediately downstream from the outfall. CH2MHill and others (1997) noted that these taxa were representative of high organic loads and variable oxygen content.

A sampling reach on the Salt River near Roosevelt was selected for comparison with the sampling reach at the WWTP at 91st Avenue because of similarities in channel size and particularly specific conductance of the water. Potential sources of water-quality impairment of the Salt River near Roosevelt include grazing and forestry practices within the basin and inflow from Pinal Creek, which contains manganese (Brown and Eychaner, 1996). Pinal Creek is immediately upstream from the sampling reach on the Salt River; however, the volume of flow from Pinal Creek is minimal in relation to the volume of flow from the Salt River (Brown and Eychaner, 1996). In addition, manganese toxicity is low compared with toxicity of other metals and metalloids (Kaiser, 1980). Alteration of benthic habitat by precipitation of metallic oxides could affect algal and aquatic-invertebrate communities (Lewis and Burraychak, 1979).

Field Methods

Quantitative samples of attache algae were collected from riffles at all sampling sites using nationally standardized NAWQA methods (Porter and others, 1993). Twenty-five samples of epilithic algae were collected from rocks that were selected from riffles within the sampling reach. These individual samples were composited to obtain a single sample for each reach that represented a total sampled area of 75 cm^2. A portion of known volume from each composite sample was submitted to the USGS National WAter-Quality Laboratory (NWQL) for analysis of chlorophyll *a*.

Aquatic invertebrates were sampled using nationally standardized NAWQA methods (Cuffney and others, 1993). Two types of samples were collected—a semiquantitative sample was collected from riffle habitats and a qualitative sample was collected from all habitat types in the reach.

Riffles, which generally support a taxonomically rich invertebrate fauna (Hynes, 1970), are targeted for sampling by the NAWQA program. Five benthic samples were collected from riffles distributed throughout each reach using a modified Surber[1] sampler with a 425-micrometer mesh net. Large rocks were scrubbed to remove organisms, and the bottom was disturbed to a depth of about 10 cm for 30 seconds. Individual samples were combined to yield a single composite sample for each reach; total area sampled was about 1.25 m^2. Samples were processed in the field to remove mineral material and were sent to the Biological Unit of the USGS NWQL for taxonomic determination.

A 210-micrometer mesh, D-frame sweep net was used for qualitative multihabitat sampling (Cuffney and others, 1993). The goal of this sampling was to obtain as complete a list as possible of invertebrate taxa from all habitat types, which included macrophytes, woody debris, depositional zones, and riffles within the reach. This qualitative technique results in a list of taxa in the sampled reach but is not intended to provide abundance data for specific organisms.

Geomorphological features were used to select sampling reaches. At least one habitat cycle was included in each reach. Habitat cycles included two riffles and all intervening habitat types, such as pools, runs, and (or) glides. Criteria for reach definition are detailed by Cuffney and others (1993) and Porter and others (1993).

[1]Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not constitute endorsement by the U.S. Government.

Data Analysis

Data in this report are presented in two separate sets. One set presents data for the two effluent-dependent reaches of the Santa Cruz River and the comparison site, San Pedro River at Charleston. The second set presents data for the effluent-dependent reach at 91st Avenue and the comparison site, Salt River at Charleston. The second set presents data for the effluent-dependent reach at 91st Avenue and the comparison site, Salt River near Roosevelt. After initial within-set comparisons, the effluent-dependent and comparison sites were examined to determine if there were similarities among the stream types and if the similarities corresponded with results of other studies.

Periphytic Chlorophyll *a*

Samples of algae submitted to the NWQL were analyzed for concentrations of chlorophyll *a*. The concentrations, in milligrams per square meter, are a measurement of algal standing crop. Concentrations of chlorophyll *a* from effluent-dependent reaches were compared with concentrations from their respective comparison sites.

Aquatic-Invertebrate Communities

Aquatic-invertebrate samples were submitted to the Biological Unit of the USGS NWQL for taxonomic determinations. Abundance data for aquatic invertebrates were normalized to number of individuals per square meter. In order to avoid overestimating measure of taxonomic richness and to maintain comparability among sites, the lowest taxonomic level common to all samples was used in data analyses. Family-level data resulted for the insecta orders Odonata, Ephemeroptera, Plecoptera, Trichoptera, Diptera, Megaloptera, Coleoptera, and Hemiptera. Lepidoptera was summed to order. Aquatic worms were resolved to class (Oligochaeta), and water mites were identified to subcohort (Hydrachnidia). Specimens that were identified to levels higher than these were not included in the analyses. The semiaquatic groups, Colembola and Staphylinidae (Merritt and Cummins, 1996), also were not included in analyses because they may not reflect water quality.

Four biological indices were used to evaluate semiquantitative aquatic-invertebrate data from riffles—total taxa richness (TTR); taxonomic richness of insects in the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT taxa richness); the percentage contribution of the two most dominant taxa (PDT-2); and the Family Biotic Index (FBI; Hilsenhoff, 1988). The first two indices are simply the number of taxa or taxonomic groups present; whereas, the latter two indices are used to indicate community balance (Barbour and others, 1992). The FBI also is a biotic index that uses empirically derived tolerance values of taxa to organic contamination. Total diversity within a sampling reach was determined by combining data from multihabitat samples with data from riffle samples. These data were evaluated using only TTR and EPT.

TTR is the number of taxa found within samples collected from a reach, regardless of abundances, and generally is high in streams with good water quality and low in streams with poor water quality. EPT taxa richness is the number of taxa from the orders Ephemeroptera, Plecoptera, and Trichoptera, which generally are regarded as intolerant to water-quality impairment (Lenat, 1988). Consequently, EPT values also are high in streams with good water quality and low in streams with poor water quality. Although EPT is a subset of TTR, by enumerating only clean water taxa, it extracts and highlights information within TTR.

Communities numerically dominated by few taxa often indicate environmental stress (Klemm and others, 1990). The percentage of the two most dominant taxa (PDT-2) from each sample was used for this assessment.

A modification of the FBI (Hilsenhoff, 1988) also was used to examine semiquantitative-invertebrate data. Hilsenhoff's (1988) index was developed specifically to evaluate organic loading from sewage. Following protocols by Plafkin and others (1989), tolerance values from Bode (1988) were used to supplement Hilsenhoff's (1988) tolerance values. Pollution-tolerance values of the U.S. Environmental Protection Agency (Donald J. Klemm and Philip A. Lewis, research aquatic biologists, U.S. Environmental Protection agency, oral commun., 1997) were used for Hydrachnidia (equivalent to Hydracarina), Nematoda, Nematea, and Culicidae. Average tolerance values were computed from Hilsenhoff (1988) for chironomids (mean = 7) and from Bode (1988) for oligochaetes (mean = 8). Bivalva, Naucoridae, Nepidae, and Corixidae were excluded from FBI computations as tolerance values were not available. These four groups were rare in samples. The FBI ranges from 0 to 10, and higher scores indicate poorer water quality.

WATER-QUALITY INDICATORS

Concentrations of Chlorophyll *a*

Concentrations of periphytic chlorophyll *a* at effluent-dependent sites were one to two orders of magnitude greater than at the respective comparison sites (**fig. 3**). Samples from effluent-dependent reaches of the Santa Cruz River contained concentrations of chlorophyll *a* that were an order of magnitude greater than concentrations in samples from the San pedro River at Charleston. The estimated concentration of chlorophyll *a* in the sample from the WWTP at 91st Avenue was two orders of magnitude greater than the sample from the Salt River near Roosevelt. These findings are consistent with those from other studies in which increased concentrations of plant nutrients, primarily nitrogen and phosphorus, resulted in increased algal standing crop below sewage-inflow points (Hynes, 1960; Hellawell, 1986), and indicate that water quality of the effluent-dependent sites is poor compared with water quality at the comparison sites.

Aquatic-Invertebrate Communities

Reduced values of TTR and EPT for all three effluent-dependent sampling reaches relative to their respective comparison sites (**fig. 4**) indicate that water quality of the effluent-dependent reaches is poor. Ten EPT taxa were collected from the San Pedro River; whereas, none were collected from the Santa Cruz River at Cortaro, and only two EPT taxa were collected from the Santa Cruz River at Tubac. Intermediate TTR values for the Tubac site could indicate some degree of improvement in the invertebrate community as water quality improves with increased distance from the outfall; however, the improvement is slight as shown by the low EPT values and high values of PDT-2 and FBI. Generally, a few moderately tolerant groups of dipterans, odonates, and coleopterans account for the increased TTR at the Tubac site compared with TTR at the Cortaro site. Field measurements of temperature and specific conductance within a 1,000-meter section of the Santa Cruz River, which included the site at Tubac, indicated a localized area of possible ground-water inflow. Consequently, the increase in TTR may be a result of localized streamflow dilution in the reach at Tubac. In this case, the increased TTR would indicate a reach-specific rather than general phenomenon.

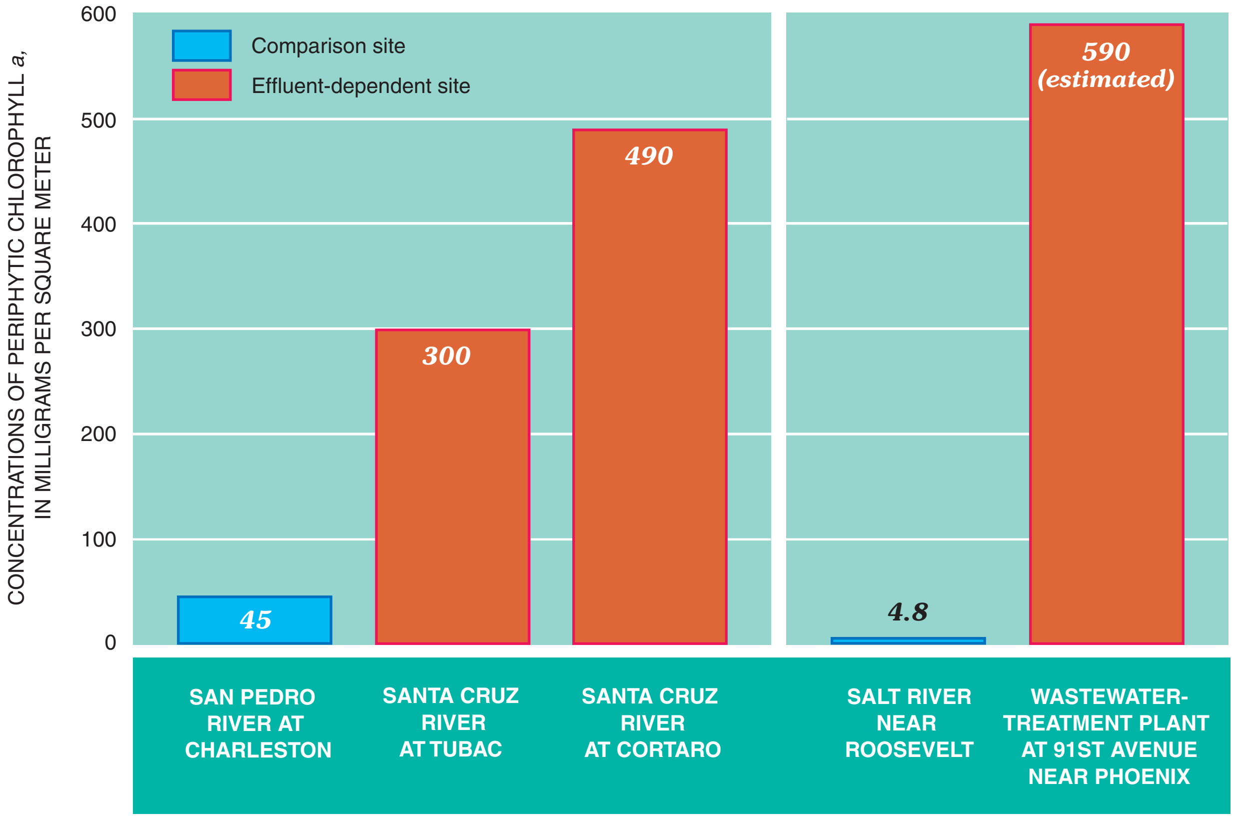

Figure 3. Concentrations of periphytic chlorophyll *a* for effluent-dependent stream and comparison-stream reaches. (Value for wastewater-treatment plant at 91st Avenue was estimated because of a spillage of 20–30 percent of the aliquot before analysis.)

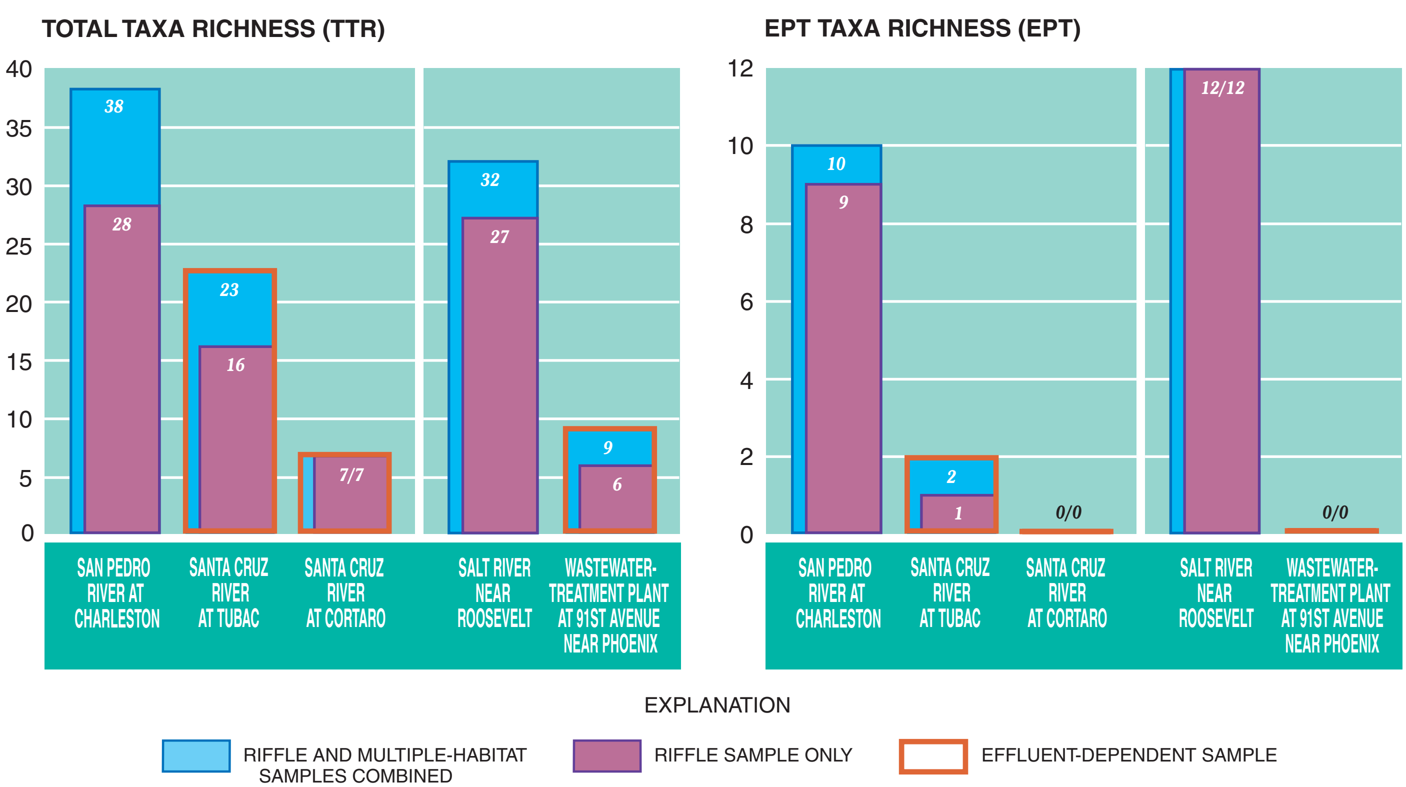

Figure 4. Results of total taxa-richness (TTR) and EPT taxa-richness computations for aquatic-invertebrate communities from riffle samples from effluent-dependent stream and comparison-stream reaches.

The two dominant taxa in the San Pedro River at Charleston were a capniid stonefly and a baetid mayfly (orders Plecoptera and Ephemeroptera, respectively), which accounted for about 40 percent of the sample (figs. 5 and 6). These taxa generally are considered to be intolerant of water-quality impairment. Oligochaetes and chironomids, which are tolerant to organic loading, were abundant and dominated both sites on the Santa Cruz River. These two groups accounted for nearly 100 and 93 percent of aquatic invertebrates at the Cortaro and Tubac sites, respectively. The finding that oligochaetes and chironomids were extremely abundant and dominated the community structure of these effluent-dependent reaches is identical to the pattern reported in the scientific literature for severely degraded zones of streams that are subjected to organic loading (Hynes, 1960; Hellawell, 1986). This finding indicates that poor water quality favors these tolerant types and precludes more sensitive taxa from inhabiting the effluent-dependent reaches of the Santa Cruz River. Additionally, FBI values were higher for the effluent-dependent sites than for comparison sites (fig. 5), which also indicates poor water quality.

Similar results were obtained from the comparison of aquatic-invertebrate communities at the WWTP at 91st Avenue and Salt River near Roosevelt. Thirty-two taxa, including 2 EPT taxa, were found at the Salt River near Roosevelt site, compared with only 9 total and 0 EPT taxa at the 91st Avenue site (fig. 4). Abundant tolerant taxa (chironomids and oligochaetes), which indicate severely degraded zones of effluent-affected streams in other areas accounted for nearly 99 percent of the community at 91st Avenue; whereas, the two dominant taxa at the site near Roosevelt were the intolerant baetid mayflies and hydropsychid caddisfles (orders Ephmeroptera and Trichoptera, respectively). These two taxa accounted for almost 50 percent of the community (figs. 5 and 6). High values of PDT-2 and the FBI at the 91st Avenue site compared to lower values at Salt River near Roosevelt (fig. 5) indicate poor water quality at the 91st Avenue site.

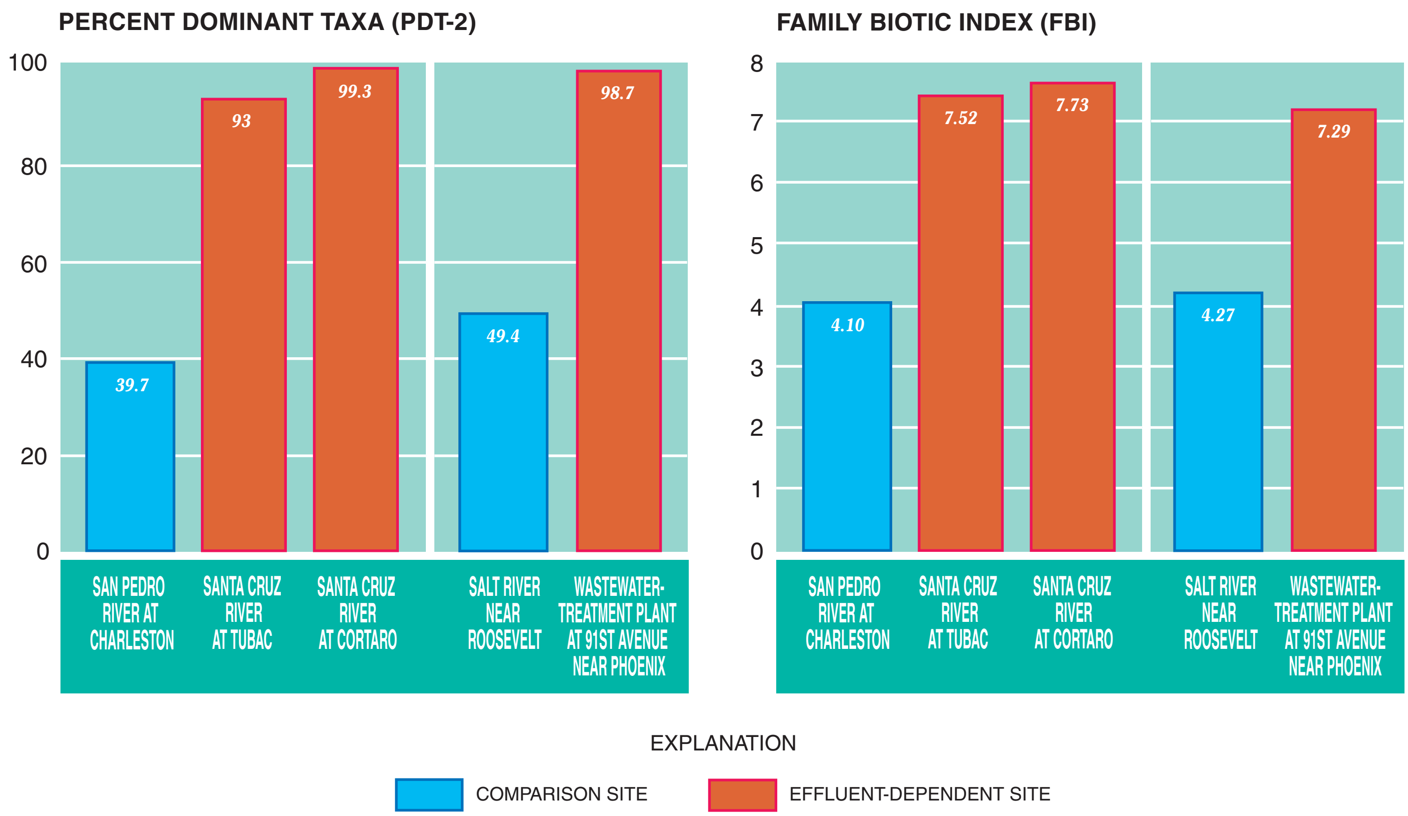

Figure 5. Results of computations of percent dominant taxa and Family Biotic Index for aquatic-invertebrate communities from effluent-dependent stream and comparison-stream reaches.

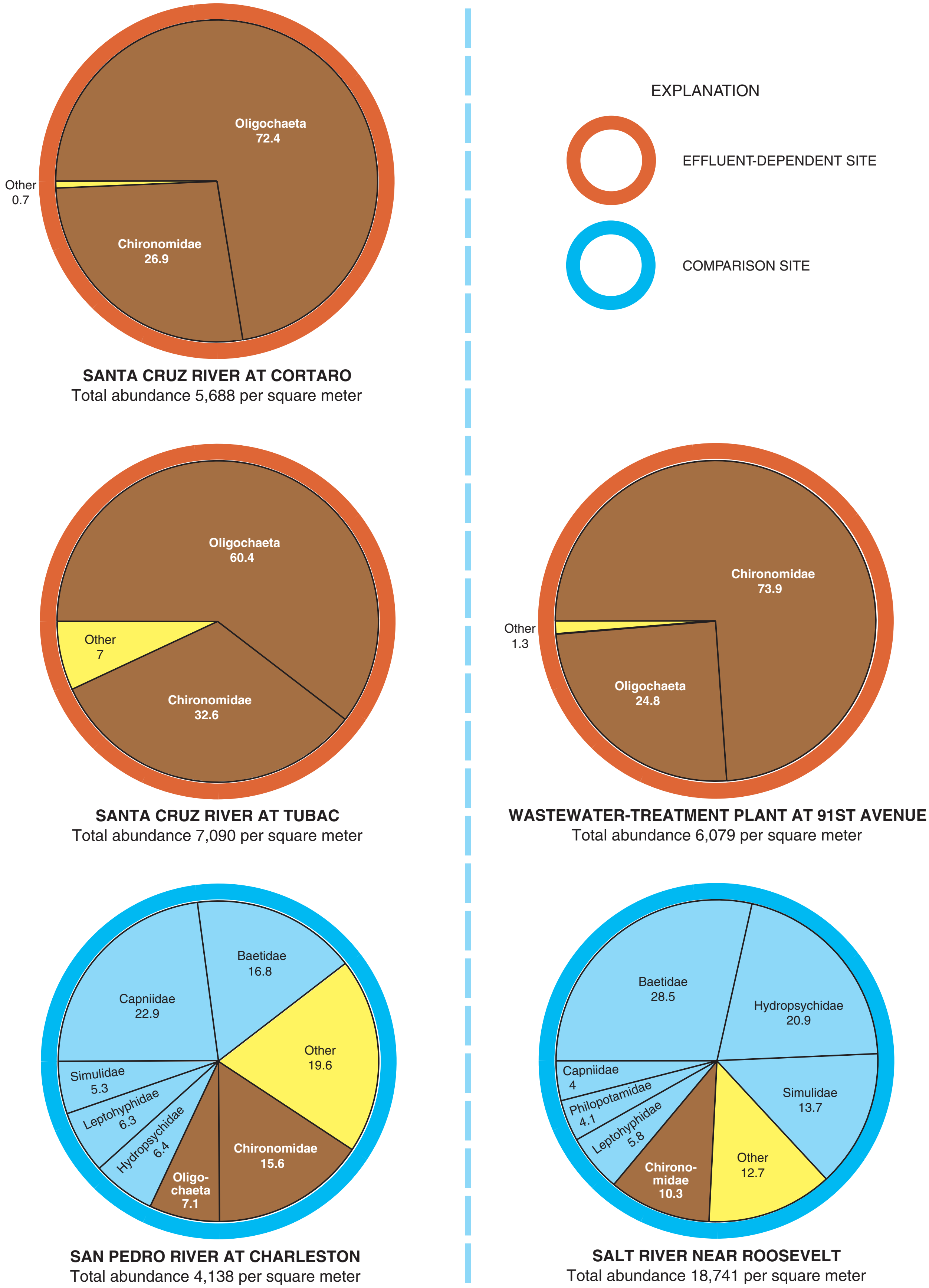

Figure 6. Taxonomic composition, in percent, and total abundances of aquatic invertebrates from effluent-dependent stream and comparison-stream reaches.

SIMILARITIES AND DIFFERENCES AMONG EFFLUENT-DEPENDENT STREAMS AND NATURAL STREAMS

High concentrations of chlorophyll *a* and lack of sensitive taxa, low taxonomic richness, and high abundances of tolerant taxa of aquatic invertebrates at the sampling sites close to wastewater-treatment plant outfalls (Cortaro and 91st Avenue) are consistent with patterns reported in scientific literature on effects of sewage effluent on aquatic biota. Increased taxa richness of aquatic invertebrates at the sampling station farther downstream in an effluent-dependent stream (Tubac) corresponds to the general pattern reported in the scientific literature of increasing taxa richness that results from improving water quality with increasing downstream distance from the source of organic loading. Such recovery at Tubac, however, is minimal as indicated by (1) the dominance of tolerant taxa in the community and 92) the low abundance and low taxonomic richness of sensitive taxa. Dilution of effluent by localized ground-water inflow may account for this pattern, and if so, the conclusion that invertebrate communities exhibit any degree of recovery with increasing distance from the source of effluent would be false in this case.

Aquatic-invertebrate taxa that are sensitive to water-quality degradation dominated the community structure of the comparison sites at San Pedro River at Charleston and Salt River near Roosevelt. TTR and EPT taxa richness were high in these streams. Total diversity of aquatic-invertebrate groups in the comparison sites was similar to the diversity found in other desert streams without sewage-effluent inflows. For example, about 30 families of aquatic invertebrates were collected from the San Pedro River at Charleston and from the Salt River near Roosevelt in this study. Bruns and Minckley (1980) found more than 45 families of aquatic invertebrates in Arivaipa Creek in ARizona. Gray (1981) found more than 45 families in Sycamore Creek Arizona; whereas, Lewis and Burraychak (1979) found more than 35 families in Pinto Creek, Arizona, which was affected by copper-mining operations.

SUMMARY

As part of the NAWQA program of the USGS, aquatic biota were sampled at two effluent-dependent reaches on the Santa Cruz River and one on the Salt River and at comparison sites on the San Pedro and Salt Rivers. Nationally standardized methods were used to collect periphyton samples from riffles for analysis of chlorophyll *a* and to collect aquatic invertebrates from riffle and multiple habitats for community assessments. Aquatic-invertebrate data were evaluated using TTR, EPT taxonomic richness, percent contribution of the two most dominant taxa, and a modified FBI.

Analyses of concentrations of chlorophyll *a* and aquatic-invertebrate communities indicated that water quality in three effluent-dependent streams was poor compared with water quality in two comparison sites. Concentrations of periphytic chlorophyll *a* in the effluent-dependent stream reaches were greater than in the comparison sites. This finding correspond to increases of algal standing crop downstream from sewage-effluent sources documented in other studies.

Aquatic-invertebrate taxa in the effluent-dependent streams were the same as taxa that inhabit severely degraded zones of streams reported in many similar studies during the last 100 years throughout the world. Oligochaetes and chironomids, which are tolerant of organic loading and are indicators of water-quality degradation, dominated communities of the effluent-dependent stream reaches. These organisms were in great abundances, which indicates that these streams are capable of supporting aquatic life but are precluded form supporting sensitive taxa because of limitations imposed by water quality.

The results of this study show that the pattern of biological responses in selected effluent-dependent streams in southern Arizona is identical to that reported for effluent-dependent streams in other parts of the world. One potential difference is that intolerant taxa may not be able to colonize downstream areas of effluent-dependent streams because water quality is not sufficiently improved by dilution from inflows of natural water.

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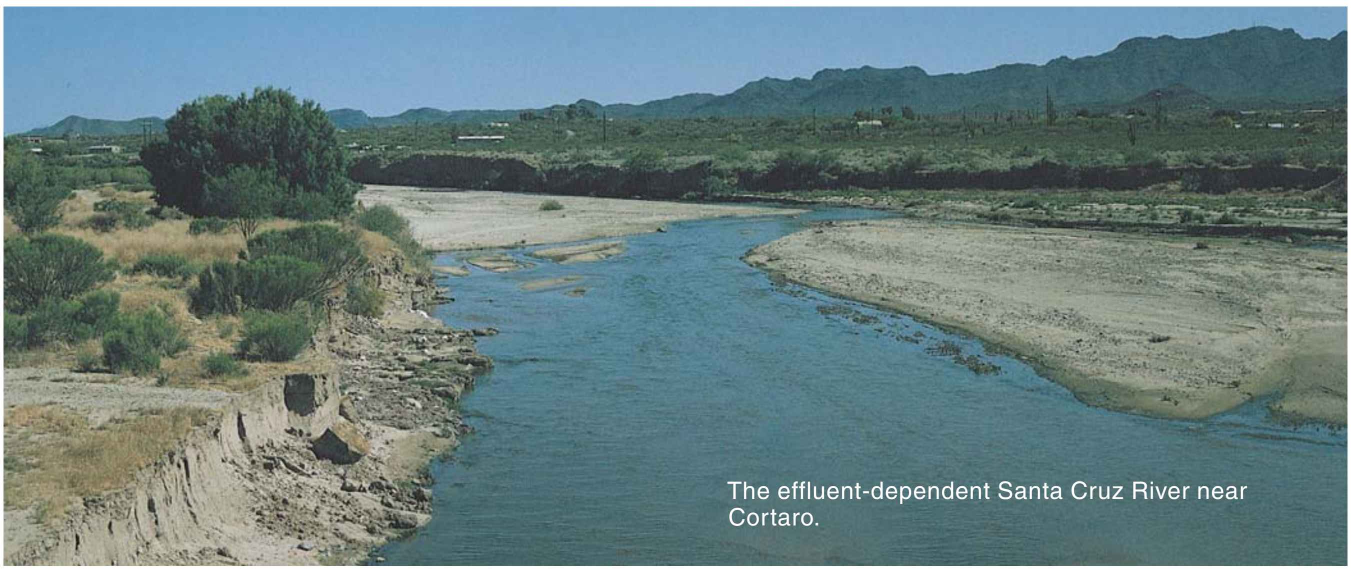
Biological communities and water quality were sampled along the effluent-dependent reach of the Santa Cruz River at Tubac.



The effluent-dependent Santa Cruz River near Cortaro.

Top photograph:
Biological communities and water quality were sampled along the effluent-dependent reach of the Santa Cruz River at Tubac.

Bottom photograph:
The effluent-dependent Santa Cruz River near Cortaro.

Natural (noneffluent streamflow in the San Pedro River at Charleston, comparison site.