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Biodiversity in Texas' Waters:
Many Diverse Aquatic Ecosystems Support a Vibrant Fishery

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Texas has an amazingly diverse freshwater fauna and flora. The tremendous decline in rainfall from forested East Texas (averaging nearly 60 inches rainfall per year), to the deserts of West Texas (average precipitation of 10 inches per year), the range in latitudes from subtropical South Texas to the temperate Panhandle, and the rise in elevation from Gulf beaches to West Texas mountains all contribute to a diversity of aquatic habitats without rival in the U.S. These aquatic ecosystems have fed humans and wildlife for thousands of years. The forests and brush along their banks provide shelter for many animals. Isolated springs throughout the state became refuges for living things during droughts. Ancient peoples lived around springs whenever possible. San Marcos springs of Central Texas is the oldest continuously inhabited site in North America.

Streams and rivers flow along more than 190,000 miles throughout the state (TNRCC, 1994). Nearly 20% of the stream miles are perennial and flow continuously during normal years. Many intermittent streams contain perennial pools during dry seasons, harboring aquatic life until water flows again. A state with few natural lakes, Texas stores water in 5,700 reservoirs of more than 10 surface acres, covering 3 million acres. Roughly 212 reservoirs contain more than 5,000 acre-feet (AF) of water. Freshwater wetlands cover more than 5 million acres (nearly twice the area covered by reservoirs). Water quality standards established by the Texas Natural Resource Conservation Commission (TNRCC) protect 36% of perennial stream miles and 55% of the reservoir surface acres.

Freshwaters serve Texans in many ways. In 1990, more than 2 billion gallons of surface water were used daily for agricultural irrigation, drinking water, cooling water for power generation and industries, process water, livestock water, and mining. In 1991, 2.1 million Texans spent more than $858 million fishing in Texas freshwaters. Roughly 1.6 million people engaged in outdoor recreational activities focused around Texas rivers and lakes, including swimming, boating, fishing, and wildlife watching.

Agricultural irrigation removes water from many streams. In 1990, irrigation of corn, cotton and rice accounted for 46% of the surface water used in Texas. Groundwater use by major urban areas and agricultural irrigation have dried up springs. People have changed the shapes of streams, channelizing them to minimize flooding, building reservoirs to store water, and crossing them with roads, rails and pipelines. With wastewater discharges, runoff and chemical spills, people have turned clear streams dirty, fresh streams salty, and clean lakes into waters choked with algae or devoid of oxygen.

Freshwater ecosystems, despite being used in many ways and modified for many reasons, still contribute immeasurably to the ecological, recreational and economic well-being of society. In today's Texas, this treasure of aquatic diversity is a newly recognized value. Increasingly, society believes we are healthy only when we are assured of the well-being of natural surroundings. Monitoring the diversity and health of freshwater aquatic ecosystems will help us better understand relationships between human activities and watersheds and will be important tools to guide efforts to protect native ecosystems.

Freshwater Monitoring

Steve Twidwell of TNRCC (left) and Dave Buzan of TPWD prepare to launch a boat onto the Trinity River. The boat will be used to sample fish by electroshocking.

Scientists are using new tools to monitor the health of freshwater ecosystems. For the past 20 years, water monitoring focused on measuring water quantity and quality. The U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), and the U.S. Fish and Wildlife Service (USFWS), conduct and support biological monitoring. The TNRCC and Texas Parks and Wildlife Department (TPWD) monitor water quality and quantity, freshwater fish, plants and invertebrates to protect aquatic ecosystems from pollution and losses of sensitive species. River authorities, cities and counties are expanding programs to monitor freshwater biota.

TPWD personnel gather fish from the South Fork of the San Gabriel River near Georgetown, TX.

Many students of all ages increase their awareness of aquatic ecosystem structure and function by participating in learning activities designed around monitoring. Through industry support, grants and independent research, universities throughout Texas have developed curriculums to train students to use new tools to assess aquatic biota. Prominent aquatic biology programs are in place at Southwest Texas State University, Tarleton State University, Lamar University, Stephen F. Austin State University, Texas A&M University, and Texas Tech University.

In the past three years, individuals have joined freshwater monitoring through the support of such volunteer programs as Texas Watch, Adopt-a-Wetland and the Colorado River Watch Network. These programs focus biological testing on monitoring benthic macroinvertebrate communities. Many conservation organizations also conduct and support biological monitoring in streams. Involving students and volunteer monitors in monitoring aquatic ecosystems helps build a society which understands the importance of healthy aquatic ecosystems and which will act as effective stewards.

Terry James of the TNRCC (left) and Jack Ralph of TPWD seine Alamito Creek near the Big Bend National Park to gather samples of fish and other aquatic species.

Photos courtesy of Dave Buzan / TPWD

Historical Perspectives

In evaluating how to best protect aquatic ecosystems, measured conditions are compared to established water quality goals. Some argue the goal should be water quality conditions which existed prior to human impacts. Humans have inhabited Texas for thousands of years, but major population centers and agriculture have only been present in Texas for roughly 200 years. Detailed descriptions of Texas' freshwaters have only been developed for the past 100 years. It is unlikely that we will ever know water quality conditions that existed prior to human impacts.

Instead, a major thrust of current monitoring activities of freshwater aquatic communities involves sampling the habitat, fish and benthic macroinvertebrates of minimally impacted waters to provide a benchmark of the best attainable conditions in different areas of the state. Minimally impacted waters (or best attainable waters) are streams in a watershed or region which have the least obvious impacts resulting from past and present human activities.

The earliest written accounts referring to Texas' aquatic ecosystems are found in *Naufragios*, Cabeza de Vaca's description of his travels through Florida, Texas and Mexico from 1527 to 1537. He describes abundant flowing streams as he traveled inland from the coast, and provides accounts of significant wetlands and streams with dense riparian vegetation in many areas. De Vaca describes moving inland and crossing four rivers (probably Bastrop Bayou, the Brazos and San Bernard rivers and Caney Creek). As he traveled inland, he described encountering many rivers and plagues of mosquitos. During a part of his passage (thought to have taken place near the San Marcos or San Antonio river), he described surviving a cold winter by building a fire with many branches gathered from trees along the river.

Most historical descriptions of freshwater biota in Texas focused on identifying the species of fish, benthic macroinvertebrate, plankton, and aquatic plants which were found in freshwaters. These studies cataloged much of Texas' freshwater flora and fauna, but did little to advance the understanding of how these ecosystems function and how freshwater biota are influenced by human activities. Current work in Texas describing freshwater systems is based on the characteristics of the physical and chemical habitat of streams, and fish and benthic macroinvertebrate communities in ecoregions. Knowledge of the structure and function of freshwater ecosystems within different regions is being applied to the evaluation of pollution impacts and regulation of waste discharges.

Water Quality Standards

A primary goal of the federal Clean Water Act is to restore and maintain the chemical, physical, and biological integrity of U.S. waters. The act requires states to develop water quality standards to protect their waters. Initially, states set water quality standards for many physical and chemical variables to protect biological communities.

An example involved setting dissolved oxygen (DO) standards. Initially, Texas set a water quality goal of 5 milligrams per liter (mg/l) for DO statewide. Conventional knowledge generalized that long-term healthy conditions required DO levels of higher than 5 mg/l. Although oxygen levels are important, biological monitoring shows that aquatic communities can persist in waters where DO concentrations rarely exceed 2 mg/l. Other waters may need 6 mg/l to support healthy aquatic communities.

Intervening years have shown that physical and chemical standards have not protected biota from habitat changes, nonpoint source pollution, or the combined effects of interactions from many complex physical and chemical factors.

The TNRCC sets water quality standards which are approved by EPA. Texas standards try to ensure that biological integrity is restored and maintained by designating specific aquatic life uses for water bodies. Aquatic life use designations range from exceptional to limited and are related to DO levels expected in the stream. "Exceptional" streams should have a daily average DO level of 6 mg/l or higher. TNRCC has set a "high" statewide aquatic life use designation (daily average DO levels as low as 5 mg/l) for waters which have not been assigned water quality standards.

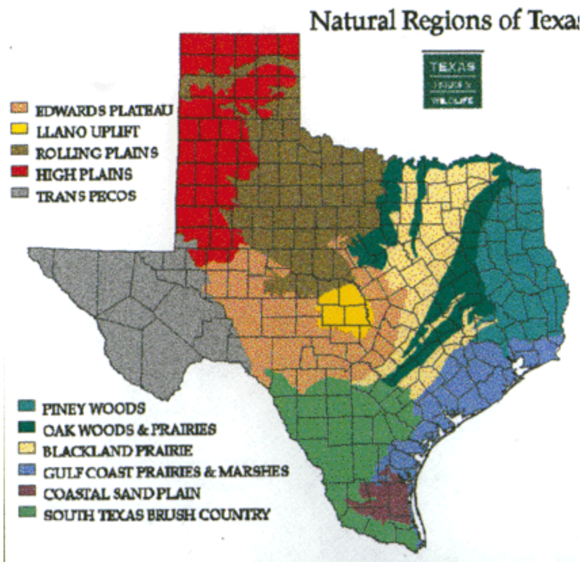
Texas has never been able to adequately monitor the many tens of thousands of miles of its smaller streams. Even now, less than 10% of the roughly 190,000 miles of streams in Texas have specific water quality standards and designated aquatic life uses. In recent years, monitoring biological attributes has been emphasized by federal monitoring guidance. EPA recently encouraged states to include biological criteria in water quality standards.

Streams with diverse biological communities containing species that cannot tolerate pollution may receive high or exceptional aquatic life designations from the TNRCC. When the TNRCC evaluates wastewater discharges to a stream, it requires levels of wastewater treatment necessary to ensure that the stream's biological community is not degraded below the levels found in the minimally impacted or best attainable stream in the same ecoregion.

TNRCC and TPWD study the aquatic life uses in Texas waters. Whenever a city or industry applies for a permit to discharge wastewater into a small unclassified perennial stream, biologists conduct a receiving water assessment. This involves an intensive, one-time assessment of the fish community, water quality and habitat at stations on the receiving stream. Once the aquatic life use is designated for a river or lake with a specific stream standard, TNRCC may conduct a use attainability analysis to verify that standards are appropriate. This involves sampling of fish, benthic macroinvertebrates, habitat and water chemistry at many sites. A key factor is awareness of the similarities within a particular ecoregion.

Monitoring Ecoregions

Ecoregions can be defined as homogenous geographic areas in ecological systems, or areas with similar relationships between organisms and the environments. The ecoregion concept plays a key role in studies of freshwater communities.



Omernik (1987) developed an ecoregion map for the U.S. that was intended to provide a geographic framework to organize ecosystem information. The work is based on the hypothesis that ecosystem components display regional patterns that are reflected in spatially variable combinations of causal factors. The map was created from existing documents and information for four components of land surfaces (land use, soil type, slopes, and natural vegetation).

During the late 1980s, the TNRCC and the TPWD began the Texas Aquatic Ecoregion Project (TAEP). The goal was to locate and characterize many minimally impacted streams. Minimally-impacted streams, or reference streams, lack urban development, obvious point sources of pollution, channelization, and man-made sources of nonpoint source pollution. Initially, candidate streams were selected for 11 of 12 Texas ecoregions (except for the area near the Guadalupe National Park in West Texas). Samples were taken from 72 minimally impacted streams.

The East Central Texas Plains and South Central Plains ecoregions are characterized by irregular plains with dominant natural vegetation assemblages including oak, hickory and pine trees. Dominant land uses are woodlands, forests and cropland. These areas of Texas receive the most acidic rainfall in Texas (pH below 4 in some cases), but no ecoregion in Texas is known to be suffering ill effects from acid rain. Some small streams in these areas experience naturally lower DO concentrations resulting from gently sloping stream beds and naturally high organic loading.

The Western Gulf Coastal Plain consists of typically flat plains with substantial amounts of agricultural cropland and livestock grazing. Natural vegetation is primarily plains grasses. Freshwater streams in these areas are typically sluggish with gently sloping beds which grade into estuarine systems. As major rivers and streams enter this ecoregion, levels of total suspended solids (TSS) increase, causing rivers and streams to become more turbid as they approach the coast. Oxbow lakes along the major rivers and resacas in South Texas along the Rio Grande are some of the Texas' few natural lakes. Fish diversity may be relatively high as estuarine fish occasionally enter these streams.

Three ecoregions in north-central Texas (the Central Great Plains, Texas Plains and the Texas Blackland Prairies), are primarily irregular plains where the dominant land use is cropland. The natural vegetation in these regions is prairie grasses. Natural sources of salt create elevated salinities in several freshwater streams in these areas.

The Central Texas Plateau ecoregion is characterized by plains and high hills with juniper, mesquite, and oak savanna. The primary land use is grazing. Many streams in this area are very clear with low levels of TSS, as many of the watersheds consist of limestone hills with a shallow soil mantle and little development. Many streams in this region maintain relatively high DO levels.

The Southern Deserts ecoregion encompasses most of the western half of the Texas Rio Grande watershed, while the Southern Plains ecoregion includes the eastern half of this watershed. The ecoregions grade from plains in the east to plains with high hills and mountains in the west. In the east, the natural vegetation is characterized by thorny scrub brush with mesquite, acacia savanna, and live oak savanna. As rainfall declines to the west, the natural vegetation is dominated by a shrub savanna including tarbush and creosote bush. Grazing and cropland are common land uses in the Southern Texas Plains ecoregion. Land use in the Southern Deserts is dominated by grazing. Relatively high salt levels, originating primarily from natural sources, are found in both ecoregions, and irrigation return flows contribute to elevated salt levels in some streams. Water quality in the Rio Grande basin ranges from some of the most polluted to some of the best in Texas.

The Western High Plains and the Southwestern Tablelands ecoregions cover northwest Texas. The Southwestern Tablelands exhibit moderate to high relief while the Western High Plains are smooth to irregular plains. Natural vegetation in both areas is primarily grama and buffalo grass. Cropland and grazing are the major land uses. Some freshwaters in this part of Texas experience higher than normal salt levels, resulting from natural brine seeps and springs. Some freshwater streams experience higher than normal temperatures during the Summer because they flow in wide, shallow stream beds with little or no shade.

Ecoregion maps can be used to compare similarities and differences of land and water relationships, and to establish water quality standards in tune with regional patterns. These maps can be used to locate monitoring, demonstration, or reference sites; to extrapolate from existing studies; and to predict the effects of changes in land use and pollution controls.

Omernik's efforts occurred concurrently with the development of multimetric indices of biological integrity (IBI) developed by James Karr (1986). Those efforts culminated in the publication of EPA protocols for rapid bioassessments of fish and benthic macroinvertebrate communities in streams and rivers (EPA, 1989). Scientists use these methods to assess the impacts of habitat modifications and chemical changes on aquatic communities.

Texas Diverse Fish Species

Texas' freshwaters are inhabited by 45 families and 247 species of fishes (Hubbs and others, 1991). This is nearly 33% of all known freshwater species in the U.S. TPWD lists more than 20 of those species as threatened or endangered. Nearly half of the native fish species in Texas' Southern Deserts ecoregion (west of the Pecos River) are threatened with extinction or are already extinct. This ecoregion has been impacted by groundwater use, the drying up of perennial springs, and diversions of surface waters for agricultural irrigation. Five species have become extinct and three other species have been extirpated from their ranges. Humans have introduced 18 non-native or exotic species in Texas.

An intensive long-term study of Texas' fishes compares the results of statewide surveys of freshwater fishes in 1953 and 1986 conducted at the same sites using the same sampling methods. The field surveys were led by Clark Hubbs of the University of Texas at Austin and the analyses were conducted by Allison Anderson of Texas A&M University (Anderson and others, 1995). Hubbs ensured that the same sites were sampled in both surveys and that catch per unit effort was uniform. Results suggest that 20% of freshwater species need conservation efforts and that fish communities in many regions of Texas have become more similar to each other because of human impacts.

The study showed that suckers, minnows, pupfishes, catfishes and darters had lower relative abundances statewide in 1986 than in 1953. Relative abundances of such opportunistic species as mosquitofish and silversides increased over the same time. East Texas waters showed the greatest changes, with decreases in local species diversity and changes in community composition. Environmental changes that likely affected fish communities include reservoir construction (which replaces flowing habitats with still waters and alters natural flows downstream) and proliferation of exotic species (particularly in the Rio Grande basin and near springs). Other factors include increasing municipal and agricultural water use, dredging, pollution, and salinization. Nationwide, major causes of declines in fishes include the loss, degradation and alteration of habitats, chemical pollution, overexploitation, and competition from exotic species (Warren and Burr).

Preliminary analyses of fish communities of minimally impacted streams sampled during the TAEP show that East Texas communities support more species than other ecoregions in Texas (Hornig, and others. 1995). Less diversity (10 or less species) was observed in the Panhandle and West Texas. Analyses of fish communities was based on intensive fish sampling of all instream habitats and led to preliminary development of an IBI that was modified to reflect regional patterns in fish communities. The IBI was based upon 12 metrics falling within three broad categories (species composition, trophic composition, and fish abundance and condition).

Fish are good indicators of long-term effects and broad habitat conditions for many reasons. Fish account for nearly half the endangered vertebrate species and subspecies in the U.S. Healthy fish communities represent a variety of trophic levels (omnivores, insectivores, and piscivores) and integrate effects of lower trophic levels. Fish community structure reflects integrated environmental health. Fish are at the top of the aquatic food chain and are consumed by humans, making them important subjects in assessing contamination. Also, fish are relatively long-lived, mobile, and easy to collect and identify to the species level. Most specimens can be sorted and identified in the field and released unharmed. The environmental requirements of common fish are well known. Information on life histories and fish distributions are available for most species. Monitoring fish communities provides direct evaluation of fishability, which is important to recreational and commercial fishermen.

TNRCC and TPWD biologists used a modified IBI to analyze fish communities of the Upper Prairie Dog Town Fork of the Red River. The fish community was sampled immediately downstream from a point where municipal effluent enters the river. A low IBI score was generated, suggesting there was a substantial impact. Above-normal accumulations of silt, low DO concentrations, and elevated ammonia were major contributing factors to the poor quality of the fish community. Fish communities further downstream from the effluent discharge showed increasing IBI scores. One IBI metric revealed the stark differences between the sites. Only the pollution-tolerant western mosquitofish was collected immediately downstream of the effluent discharge, while eight species (including the plains minnow, the Red River shiner and the plains killifish) were collected from the site furthest downstream of the wastewater discharge.

TNRCC evaluations of the fish communities along the Pecos River in West Texas revealed a fish community comprised of primarily salt-tolerant species like pupfish and rainwater killifish (TNRCC, 1996). Salt levels and severe flow fluctuations contributed to fish communities with low IBI scores. The portion of the river with the highest IBI score had the lowest salt concentrations and a diverse instream habitat with riffles, pools, stable stream banks, high channel sinuosity, and stable substrate.

Benthic Macroinvertebrates

Comprehensive statewide analyses of benthic macroinvertebrate communities are conducted by the TNRCC, which has monitored many sites for 20 years. The TNRCC Surface Water Quality Monitoring program has analyzed benthic macroinvertebrate communities during synoptic surveys of Texas stream systems since 1979. During TAEP, 518 macroinvertebrate taxa were identified from 81 collections (Hornig, and others, 1995).

Roughly 58 collections represented by 193 invertebrate taxa were used to illustrate geographic similarities in community composition. Invertebrate samples from three East Texas ecoregions were similar to each other and were different from the rest of the samples. Other samples were divided into groups representing communities in North and Central Texas. Similarities between communities cross many ecoregion boundaries.

Kirk Smith of TNRCC collects benthic macroinvertebrates from the South Fork of Rocky Creek for use in a rapid bioassessment.

Photo courtesy of Dave Buzan / TPWD

Macroinvertebrate communities are valuable tools for analyzing ecosystem structure and function. Many macroinvertebrates have limited migration patterns (a sessile mode of life) and are well suited for assessing site-specific impacts in upstream and downstream studies. They integrate the effects of short-term environmental variations. Many taxa are easy to identify to individual families and many intolerant taxa can be identified to lower taxonomic levels. Sampling is relatively easy, requires few people and inexpensive gear, and has no detrimental effect on resident biota. Macroinvertebrates serve as a primary food source for many recreationally and commercially important fish. Many small streams which naturally support a diverse macroinvertebrate fauna, only support a limited fish fauna.

Few published studies have characterized regional differences in other freshwater communities. Mussels and crustaceans, which may not be included in typical benthic macroinvertebrate samples, are diverse in Texas. Many species are at risk of becoming rare or extinct. More analysis of the regional variations in mussels is needed.

TAEP found many habitat and chemical parameters exhibit geographical patterns. Canopy cover increases from west to east, corresponding to rainfall patterns. Central Texas "Hill Country" streams have higher percentages of gravel and cobble than the bottoms of North or East Texas streams. Salt levels (total dissolved solids) were lowest in East Texas, averaging about 100 mg/l, and increased in the South and West where levels exceed 5,000 mg/l in some areas. Highest phosphate levels are found along the Gulf Coast, while DO levels tend to be lowest in the eastern and coastal ecoregions. TSS and fecal coliforms show no apparent regional patterns.

Future Directions

Holistic analysis of river ecosystems will continue to develop in the future. Texas universities are training scientists who will utilize the interrelationships among biota, water chemistry, water quantity, geography and climate to improve management of stream ecosystems. Research by state and federal agencies, as well as universities, is providing greater information and perspectives on the diverse populations of aquatic species that are found in Texas. Perhaps most importantly, this work yields critical insights into trends that may tell us which specific species may be in trouble or which watersheds, rivers, and ecosystems need special protection.

Historically, biologists believed stable and diverse aquatic communities were desirable, but they often did not have information to assess how biota would be affected by different management decisions. Biological analysis of samples was time-consuming and data were not available for months. Emphasis on biological analyses was largely abandoned and replaced with an emphasis on chemical and physical analyses. Water managers hoped careful control of chemical conditions would indirectly protect healthy biological communities.

Time has shown that water chemistry alone does not give us all the information we need to be effective water managers. The development of ecoregion concepts that are applied to water quality parameters, water quantity requirements, and biological indices are complementary tools that can be used in combination with water chemistry. They provide the opportunity to truly advance the management of aquatic ecosystems. As we continue to use and develop these tools, we will have healthier aquatic ecosystems.

For More Information

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