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A REVIEW OF THE APPLICATION OF DATABASES IN FRESHWATER FISHERIES MANAGEMENT AND THE EFFECT OF WATER QUALITY ON THE MEAN RELATIVE WEIGHT OF LARGEMOUTH BASS, CRAPPIE, AND CHANNEL CATFISH IN OKLAHOMA LAKES

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BY

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Abstract

The subject of this thesis is the development and use of databases for use in fisheries management. The thesis consists of two chapters. The first is a literature review of fisheries databases and an overview of my work as a graduate research assistant with the Oklahoma Biological Survey and Oklahoma Fisheries Research Laboratory (OFRL) of the Oklahoma Department of Wildlife Conservation.

The *Standard Sampling Protocol* (SSP) is at the core of both chapters. In chapter 1, I reviewed the fisheries database literature to aid in the development of the *SSP Database* and emphasize some of the issues that commonly occur with database development and application. This information guided me in the development of a relational database for the SSP data. The resulting database includes approximately 1.6 million records for 150 fish species in Oklahoma. The database schema consists of five tables: Abiotic, Biotic, SSP Species List, OBIS Taxonomy, and OWRB Lake Data.

Chapter 2 employed the SSP database to determine if water quality parameters in 108 Oklahoma lakes influenced the relative weights of largemouth bass *(Micropterus salmoides)*, crappie *(Pomoxis annularis* and *Pomoxis nigromaculatus)*, and channel catfish *(Ictalurus punctatus)*. Discriminant analysis of eight water quality parameters resulted in the classification of said lakes into six classes. Mean relative weights for largemouth bass, crappie, and catfish ranged from 89.84-99.17, 91.99-98.17, and 86.90-94.01 respectively. Salinity, which was the most important explanatory variable in lake classification, ranged from 0.04-0.63 ppt among the six classes. This information could prove useful to the fisheries managers of Oklahoma by reclassifying similar lakes

regardless of management region, allowing for a different perspective on management practices.

Chapter 1: A Review of the Application of Databases in Freshwater Fisheries Management

Introduction

A database is “a collection of related data”, or records that have a shared meaning (Elmasri and Navathe 2011), while a data product consists of “a large data set in a format that requires little or no processing or programming” (TechTarget 2018). The collection of data alone does not prove to be very useful without some sort of structure and accessibility. If structure and accessibility are absent, the acquisition and manipulation of the information contained within a database becomes very tedious at best. The *Integrated Database System* was designed by Charles W. Bachman in 1960 and was the first data management system (Neufeld and Cornog 1986, DATAVERSITY 2017). Advances in technology have paved the way for the use of relational databases, or a collection of relations that link multiple tables together (Elmasri and Navathe 2011). This allows for the increased manipulation of varying types of data through Structured Query Language (SQL). The inception of the internet and the creation of the online platforms greatly increased the capabilities of database management and accessibility.

Relational databases are a standard tool in fish and wildlife management (adfg.alaska.gov, in.gov/dnr 2018). This literature review addresses the application of databases in fisheries management, with an emphasis on lentic systems. First, I will discuss existing fisheries databases followed by a review of how those systems have been used in fisheries management, data analyses, and as a public resource.

Legacy Data Sources

The following section discusses database examples that contain historical information regarding fisheries. By historical, I mean data that encompass multiple decades. *FishBase* (fishbase.org 2018) is one of the first online fisheries databases, providing global biodiversity information for all known fish species including museum records and observation records reported in the literature. There are approximately 33,000 species currently in *Fishbase,* compared to just 15,000 records in 1996 (Crawford 1997). Initially, the intent of *FishBase* was to monitor population dynamics for major commercial species. However, it now contains all known taxa of finfishes (no shellfish), including taxonomy, biology, trophic ecology, life history, commercial uses, and 250 years of historical data (presence/absence). This database provides vital information for the management, conservation, and protection of sustainable fisheries. These data are often used in meta-analyses, such as the work of Zaki et al. 2017 on the first observation of Pacific bluefin tuna (11 May 2017), *Thunnus orientalis,* off the coast of Sur, Sultanate of Oman. The authors were able to use *Fishbase* to determine the previously known range and environmental tolerances of the bluefin tuna.

The *Clodia Database* (dx.doi.org/10.6084/m9.figshare.1015506 2018) includes historical landing data from the Adriatic Sea dating from 1945-2013. Instead of providing presence/absence and location information, like *FishBase*, this database provides a long-term measurement of species abundance in the form of the weights of each species brought to market. This provides a record of change in abundance in specific communities with response to climate change, anthropogenic influence, and the modification of trophic relationships (Mazzoldi et al. 2014). These types of data provide for the evaluation of a particular region or even specific communities of fish.

IchthyMaps (dx.doi.org/10.5066/F7M32ST8 2018) is a USGS database comprised of historical stream fish distribution data for the conterminous USA. It contains a total of 606,550 presence/absence occurrence records from the years 1950-1990 for 1,038 species and subspecies. *IchthyMaps* is a publicly accessible tool. Data retrieved from this database have been used to address questions in conservation, biogeography, land use impacts, the tracking of invasive species, and climate change. It was created on the principles of metacommunity ecology, or the ecological interactions of a set of interacting communities. This database was developed with the creation of species distribution and habitat suitability models in mind (Frimpong et al. 2015).

The Value of Databases in Fisheries

International Databases

The geographic representation of a database affects the scope and scale of the questions researchers can address. Resources such as *FishBase* allow for the analysis and detection of changes in species abundance and distribution. Tedesco et al. (2017) and (Brosse et al. 2012) are two examples of global freshwater databases. Tedesco et al. (2017) created a database that describes the high diversity of freshwater fish species in relation to the total area of fresh water. They utilized over 1400 data sources (books, published papers, grey-literature, and web-based sources) and included species lists for 3119 drainage basins, representing over eighty percent of the Earth's surface.

The second article provides a similar example in that they applied a macroecological (large-scale patterns) approach to freshwater fish species richness at a larger drainage basin level (Brosse et al. 2012). The *Fish-SPRICH* database contains species richness data at a larger level than the previously mentioned article described by the authors as river basin grain. It is available as part of the *Global Freshwater Biodiversity Atlas* (atlas.freshwaterbiodiversity.eu 2018). It is comprised of 1054 river basins that cover a similar percentage (>80%) of the earth's land surface (Brosse et al. 2012). Essentially, Tedesco et al. (2017) continued the work of Brosse et al. (2012) by enhancing the quantity of data for smaller drainage basins. Both examples resulted in the creation of a database that facilitates macro scale research related to the ecology, biogeography, and conservation of freshwater fish species.

Global scale fisheries databases are also applied for detection and warning of fish diseases and toxic accumulation. Some examples include tracking mercury concentrations, the bioaccumulation of toxic substances in fishes, and methods for disease diagnosis in domestic fish stock (EPA 1999, Li et al. 2002, Weisbrod et al. 2007). The EPA's national survey of mercury concentrations in fish combines tissue samples from freshwater fish from 40 states and the District of Columbia. The database consists of data sources for each of these states, the EPA's *STORET* (STOrage and RETrieval) data, or a combination of the two. The information contained in this database includes location (usually coordinates), common and scientific names, total mercury concentrations, and weighted mercury concentrations (the number of fish in a sample) (EPA 1999). The *Fish-Expert* disease diagnosis system is a web-based system used by fish farmers in the North China region. The system is comprised of a database, knowledge base, and image base that allows for the diagnosis of 126 disease types for nine widely produced freshwater fish species (Li et al. 2002).

Sportfishing groups such as the International Game Fish Association (IGFA) maintain weight data for highly sought after recreational fish species and track world records (igfa.org 2018). The IGFA facilitates education and enables the exchange of information between recreational anglers and fisheries professionals (IGFA 2018). The IGFA sponsored the work of Friedlander et al. (2008), a project that collected catch and effort data of bonefish, movement patterns, recruitment dynamics, and ecology of nearshore fishes, as well as passive acoustic tracking of fishes in the northern Line Islands and the Palmyra Atoll. Most state fish and game agencies keep track of state and water body records for sought after sportfish species as well. The publication of record caliber fish can help promote interest in fishing and fisheries.

A final example, the *Global Biodiversity Information Facility (GBIF),* provides data for many lifeforms on earth (gbif.org 2018). Common standards and open-sourced tools allow users across the globe to share temporal and spatial information. Sources include museum specimens, traditional biological collections, and geotagged photographs. *GBIF* uses the *Darwin Core* standard for all of its data holdings (GBIF 2018). The *Fish-AMAZBOL* database was created in part using GBIF and an intensive literature survey of all fishes that reside in the major sub drainages of the Bolivian Amazon. The resulting database includes 802 species, 12 of which are non-native, that represent six percent of the freshwater fish species in the world (Carvajal-Vallejos et al. 2014).

National and Interstate Databases

This section covers databases that focus on fisheries at the national level. An example of a national level database for species ranges is the *NatureServe Explorer (2010)* database (explorer.natureserve.org 2018). It is comprised of distribution maps for freshwater fish by watershed, providing historical and present-day distributions that are more comprehensive than previously mentioned databases. The taxonomic reference is the *Integrated Taxonomic Information System (ITIS)* and each taxon is denoted as either native or introduced. Occurrence data are derived from regional ichthyologists, state heritage programs, and the published literature. These data provide valuable information to ichthyologists and conservation biologists in the lower 48 states.

The USFWS maintains the *National Wild Fish Health Survey (NWFHS)*, which was developed in response to the Salmonid Whirling Disease outbreak of 1996. Prior to this outbreak, no national system existed for the detection of fish pathogens. To allow for the comparison of data collected in different regions, the *NWFHS* laboratory procedures manual was created to ensure standardization. Data is provided through an interactive map that is searchable by pathogen, species, water body, and state. Beneficiaries of this database include fisheries managers, anglers, the aquaculture industry, and even state and national economy, through sustained income from recreational angling (NWFHS 2018).

The *Great Lakes Fish Stocking Database (GLFSD)* is an interstate data system that does not operate within the premise of state boundaries but provides information for the entire Great Lakes system (GLFSD 2018). This aids in the management of an entire freshwater system, regardless of political boundaries.

State Databases

State level databases and data products typically provide information such as species identification and ranges, fishery access points, lakes information, sampling records, and stocking reports. Every state has accessible fisheries databases provided by state agency and/or university websites (Table 1). Although many of the examples listed qualify as data products rather than databases, they are accessible to the public and provide information such as fishing access and stocking reports, taxonomy and species ranges, and even consumption warnings. State agencies from Kansas, New Hampshire, New Jersey and Rhode Island report data in a simple tabular format, while states like Georgia and Indiana provide access to a fully searchable database. The Alaska Department of Fish and Game (adfg.alaska.gov 2018) provides data for freshwater fish inventory, lake locations, sport fishing surveys, migratory fish counts, fish passage/stream crossings, and subsistence use information among other topics. The Washington Department of Fish and Wildlife Conservation (wdfw.wa.gov 2018) also provides regularly updated salmon population information, distribution, fish passage barrier locations, and priority habitats and species. Data access differs according to user groups, masking sensitive information, such as the location of a threatened species.

A final category of state level fisheries databases is stocking records. The Missouri Department of Conservation tracks stocking orders and information about fish production activities through the *Hatchery Information Management System (HIMS)*. *HIMS* combines hatchery recordkeeping, lake manager fish requests, and stocking reports that allow hatchery personnel and fishery professionals access to historical data (Valentine 2015). The *Alaska Lake Database (ALDAT)*, developed by the Alaska Department of Fish and Game (adfg.alaska.gov 2018), incorporates maps, pictures, sampling data, stocking records, and historical information (associated historical documents) of water bodies into an easily accessed interface for the interested angler or recreationist (Sportfish Staff 2013). The Indiana Department of Natural Resources provides a fish stocking database (in.gov/dnr 2018) with search capabilities of stocking records going back four years by county, species, and/or water body. The Wisconsin Department of Natural Resources Bureau of Fisheries Management produces fish stocking summaries for 141 lakes and streams at the county level (dnr.wi.gov 2018). The usability, defined by Petrie and Bevan (2009) as “the extent to which a product can be used… with effectiveness, efficiency and satisfaction in a specified context of use”, of the Wisconsin system is not quite as straightforward as the *ALDAT* system. However, it still provides the public and resource managers alike with stocking information, both current and historical.

Local Knowledge

The utility and application of local knowledge, particularly of native peoples, has increasing value in fisheries management and conservation. Local Ecological

Knowledge (LEK) is defined as "a set of perceptions and experiences of traditional communities regarding its surrounding natural environment" (Bender et al. 2014). The *NOAA Fisheries Alaska Native Traditional Environmental Knowledge Database* emphasizes Traditional Environmental Knowledge (TEK), which is similar to LEK, but includes "detailed, empirically grounded knowledge of local plants, animals, and places" (Hunn et al. 2005). *NOAA Fisheries Alaska Native Traditional Environmental Knowledge Database* emphasizes the relationship between local/native communities and fisheries and provides historical perspective on environmental phenomena, such as climate change. The TEK data also brings to light issues that may not be apparent through the regular process of scientific inquiry, such as an increased historical perspective that could pre-date scientific records (Lazrus and Sepez 2005). The LEK of fishermen can contribute additional information about the ecology, behavior, and abundance of fish in their local area, as well as enhance the results of fisheries surveys (Silvano and Valbo-Jørgensen 2008).

Database Creation, Manipulation, and Maintenance

Geospatial Databases

Global positioning systems (GPS), Geographic Information Systems (GIS), and remote sensing technologies have enhanced the efficiency of spatial analysis but rely significantly on biological databases (USFWS 2018). Kaeser and Litts (2010) used GIS with side scan sonar images to map instream habitat in order to be able to assess amounts of desirable habitat (for spawning, escape cover, nursery cover, etc.) during varying fluctuations in water level. These results allow for the collection of watershed level habitat data, to aid in management and research of freshwater ecosystems (Kaeser, Litts, and Tracy, 2013).

The organization and manipulation of spatial data can be very complex. In order to combine multiple locations, attributes, and metadata into one relational structure, Shaw et al. (2004) patented the *Method and Apparatus for building and maintaining an object-oriented geospatial database*. They emphasize that a properly designed database allows for updates that preserve spatial linkage between objects. Proper design of the schema is of the utmost importance, not only for spatial linkage preservation, but also for the broad application of a particular design across multiple fields (querying multiple tables), as well as across multiple professional fields. These key points hold true regardless of the field of work, allowing for widespread application. A schema design that uses meta-concepts (ontologies, models, and concepts), rather than concepts with the potential to fluctuate in the domain, allows for this broad scale application (Brodaric and Gahegan 2002).

Nanson (1997) provides an early example of the appeal for the importance of online geospatial databases for information acquisition. The Ordnance Survey of the UK required a system that would link, combine, and allow easy access to the various geospatial datasets held by different organizations across the country. This would provide the user with a single location to access geospatial data, improve accuracy, make statistical analysis easier, and reduce data costs by eliminating duplication. These early discussions provided a basis for the creation and publication of geospatial databases online.

British Columbia Fisheries and Fisheries and Oceans Canada created the *Fisheries Information Summary System (FISS)* (env.gov.bc.ca/fish/fiss/background.htm 2018). It is a relational system that incorporates fish and fish habitat data, lake classification data (water quality and types of resource use), a digital stream network of British Columbia and the Yukon, and is fully accessible through website queries, maps, and reports. Attributes include species distribution, land use, water use, resource use, flow, and harvest, where many of the previously mentioned examples focus on recreational fishing opportunities (FISS 2018). This system is accessible to a variety of users, including public and private interests, and is continually growing, fulfilling the goals of an online geospatial database.

Issues to Address

Many issues can potentially affect the functionality and effectiveness of a database such as inclusion of species characteristics and traits, differences in standards for taxonomic classification, availability and accessibility of the data, and the integration and consolidation of multiple databases. These issues can be addressed in the database design phase to minimize their impact. Functional characteristics and species traits such as life-history, habitat preference, reproductive strategy, and the ecology, morphology, behavior, and physiology of a species can greatly enhance the value of a database by providing complementary information beyond the basic biological measurements of length, weight, age, etc. (Vieira et al. 2006).

Even today, some data that are stored digitally are not accessible through a web interface, limiting a majority of potential users (Ivanova and Shashkov 2016). As mentioned above, species traits data that are readily available enhance the effectiveness of a database (Frimpong and Angermeier 2009). The ability to access these data along with length and weight records increases the power of a relational fisheries database. In some cases, the compilation of large amounts of available information is necessary for meta-analyses. These "metatdata databases" include information from a large number, in some cases hundreds, of sources that span multiple disciplines, allowing for the simple navigation of related data (Cisneros-Montemayor et al. 2016). On this same note, flexibility in database development with regards to the design and composition of other data sets leads to the opportunity for multiple applications (Homer et al. 2004). In other words, databases that do not confine themselves to one professional field or application can prove to be applicable to a larger audience.

Quality Assurance and Quality Control

Quality assurance (QA) is process oriented and ensures that protocols are implemented to keep inaccuracies in the data at a minimum. Quality control (QC) is product oriented and is the process of verifying the quality of the output. Both QA and QC are continually considered by a database manager (Arthur 2018, Campbell et al. 2013). Quality data, and more specifically quality data entry results in a database that will provide the ability for more accurate and complete analyses. Examples of poor quality data include data measured using incorrect units or data that was recorded in the wrong column. An efficient storage system, double checking entries, and statistical summaries help ensure quality database content (USGS 2018a). Querying the data for values that exceed acceptable ranges, checking for blank cells or missing values, and copy/pasting/appending information with as little manual input as possible can speed up the QA/QC process. With the application of sensor networks, such as the *Oklahoma Mesonet*, large quantities of data can now be accessed almost instantaneously. QA/QC strategies for these networks have not kept up with the technology, revealing the importance of precise data collection and entry, as well as the need for automated QA/QC methods that can adequately keep up with new sensing technologies. In order to address this, the development of QA/QC standards across multiple disciplines could benefit the time it takes to perform checks, as well as improve operations between sensor networks (Campbell et al. 2013). As a final note, to ensure high quality, a consistent format and completeness are important when combining multiple datasets (EPA 2016). As I will illustrate in the methods section, this process can be extensive and time consuming.

When it comes to freshwater fisheries data collection, the standardization of collection methods to increase consistency in the data is critical. These guidelines became available in 2009 with the release of *Standard Methods for Sampling North American Freshwater Fishes* by the American Fisheries Society (Bonar et al. 2009). When sampling warm water species in reservoirs and lakes, specific techniques must be utilized to capture species associated with littoral and pelagic zones. Standard methods include the use of boat electrofishing in the littoral zone, fyke nets to bridge the gap between littoral and pelagic, and gill nets for pelagic species (Miranda and Boxrucker 2009). Miranda and Boxrucker (2009) also note that other gears, such as shoreline seine, toxicants, and trawls exist, but are more selective of habitat preference and do not necessarily provide as adequate a picture of fish groupings for a water body.

Water quality data is often used in conjunction with fish data in freshwater fisheries management. The collection of water quality data is also standardized, with examples spanning international to state and local levels. The USGS website offers several resources that monitor the water quality of rivers, streams, and various other resources that allow for public use of these data (USGS 2018b). The Oklahoma Water Resources Board's (OWRB) *Beneficial Use Monitoring Program (BUMP)* measures and publishes water quality parameters for lakes and streams across the state. The OWRB ensures the standardization of data collection with QA/QC methods that ensure proper collection methods and utilize blank, duplicate, and replicate samples at several steps throughout the sampling process. Examples include the creation of a QA manual that includes a policy statement, organizational structure, staff responsibilities, laboratory tests, sample handling procedures, and procedures for calibration, verification, and maintenance of equipment. QC methods include an initial and ongoing demonstration of capability, a method blank, a blank spike, a matrix spike and duplicate, calibration, control charts, QC acceptance criteria, and the definitions of a batch (OWRB 2016).

SSP Database Creation

The *Standard Sampling Protocol (SSP)* dataset, which was provided by Kurt Kuklinski of the Oklahoma Fisheries Research Lab of the Oklahoma Department of Wildlife Conservation (ODWC) served as a basis for the relational database we have created. This dataset contained abiotic, biotic, and descriptive data for all lakes and species sampled and managed by the ODWC. The original dataset included a species code designation, an individual count for the sample, length, and weight measurements, lake name, station, date, time, pool elevation, temperature, Secchi disk, conductivity, a gear type, gear length, habitat designation, a measurement of effort, serial number, and management region. Use of the SSP began in 1977 at a select number of lakes in Oklahoma, was adopted state-wide in 1980, and has been continuous to this day. Following each field season, ODWC personnel entered and saved the SSP data as a text file for analysis using SAS software (SAS Institute Inc., Cary, NC, USA). Therefore, prior to this project, the SSP data were contained in 36 individual text files. To facilitate the use of SSP data by ODWC biologists, fisheries professionals, and anglers, it was decided to combine these files into a relational database. The SSP database consists of five tables encompassing fish parameters, taxonomy, water bodies, water quality parameters, and geographic location.

Lessons learned from the literature review include the importance of schema design and the standardization of data entry and editing with regards to the original SSP data files. In the case of schema design, a relational data structure was selected to facilitate data entry and editing while maintaining table relations and limiting data entry errors. The creation of code columns containing a unique identifier for each record and the correct selection of primary keys ensured proper linkage.

In its original format (36 individual files), the SSP data were highly inaccessible and could not be manipulated for the analysis of trends overtime or spatial analysis. We addressed this issue by appending all the original files into Excel spreadsheets. Due to the volume of data, one spreadsheet was created for the temporal periods of 1980-89, 1990-99, and 2000-2015, respectively. After completing the initial editing and quality control procedures, all the data were appended in Microsoft Access. This presented challenges involving column alignment, blank rows, missing data, data standardization, and the creation of metadata.

Standardization issues in the 36 existing data files included inconsistent date and time formats and temperature. All data recording the year of sample collection was converted to a four-digit format. If not already recorded in this way, records of time were converted to 24-hour clock format. Temperature data were recorded in degrees Celsius some years and in degrees Fahrenheit in others, so all temperature values were standardized to degrees Celsius. The original SSP data files provided cells with serial numbers for each row in the text file, but this cell was not populated consistently and was missing for some years. Because the serial numbers were not referenced to other relevant data in the original files, the serial numbers were excluded and a new unique identifier was provided for each when appended into the new SSP database. Also, the ODWC fisheries region column was dropped because the region in which a lake occurs could be determined by a spatial join in the new database.

Preliminary quality control (QC) focused on the identification of records with unrealistic length or weight measurements by setting a cap for a range of values for each species and filtering out any value that exceeded it. Although this corrected many errors, further QC action will be necessary to ensure the quality of the data.

Finally, the original SSP files lacked metadata. Therefore, a metadata table was created for the new SSP database (Table 2). The metadata table includes definitions for each column heading, a summary of totals (i.e., lakes, species, etc.) in the database, and notes describing irregularities in the data.

The final component I contributed to this project was the initial schema for the database itself. This was created in Microsoft Access. Figure 1 illustrates the individual tables and the relationships between them. Currently, the database consists of five relational tables that include the Abiotic and Biotic features of the SSP data, a species code list for SSP data, taxonomic information for all species represented in the SSP data from the Oklahoma Biological Information System (OBIS) database (biosurvey.ou.edu 2018), and OWRB lake information for each water body represented in the SSP data. Code columns were created and added to facilitate the connections between each table.

The target audience for the SSP database includes fisheries professionals, students, recreational anglers, and anyone else interested in Oklahoma fisheries. The intent for future development is a user-friendly web based system available through the ODWC that will allow the recreational user quick, simple access to general information about each water body and species in the database. Increased access will be available to researchers or professionals with the potential for the development of a hierarchy of access, although this database does not contain sensitive information regarding species of concern.

Conclusion

In summary, the use of databases in fisheries management has and will continue to serve an important role. Data accessibility and usability are crucial for the timely application of statistical methods and their resulting contributions to the field. The web-based database serves a purpose for multiple user groups from research professionals to the public angler, providing the ability to the interested angler or wildlife enthusiast to access information on his or her favourite lake or species, while allowing the professional restricted access to more sensitive information.

Regarding our project, future requirements include additional quality control procedures and programming that will eventually result in a web interface comprised of a user friendly, spatially enabled map layer as well as a tool for the analysis of freshwater fish in Oklahoma’s reservoirs.

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Chapter 1 Tables

Table 1. State agency and university websites that provide fisheries information.

State	Freshwater	Marine	URL
Alabama	✓	✓	outdooralabama.com
Alaska	✓	✓	adfg.alaska.gov
Arizona	✓		azgfd.com
Arkanasas	✓		agfc.com
California	✓	✓	pisces.ucdavis.edu, wildlife.ca.gov
Colorado	✓		ndismaps.nrel.colostate.edu
Connecticut	✓	✓	cteco.uconn.edu, ct.gov
Deleware	✓	✓	dnrec.delaware.gov
Georgia	✓	✓	fishesofgeorgia.uga.edu, marinefishesofgeorgia.org
Florida	✓	✓	myfwc.com
Hawaii	✓	✓	cramp.wcc.hawaii.edu, dlnr.hawaii.gov
Idaho	✓		idfg.idaho.gov
Illinois	✓		inhs.illinois.edu
Indiana	✓		in.gov/dnr
Iowa	✓		iowadnr.gov
Kansas	✓		ksoutdoors.com
Kentucky	✓		app.fw.ky.gov
Louisiana	✓	✓	wlf.louisiana.gov, fishesoflouisiana.org
Maine	✓	✓	maine.gov/ifw, digitalcommons.library.umaine.edu/fisheries
Maryland	✓	✓	dnr.maryland.gov/Fisheries, gisapps.dnr.state.md.us
Massachusetts	✓	✓	mass.gov
Michigan	✓		michigandnr.com
Minnesota	✓		dnr.state.mn.us
Mississippi	✓	✓	cfr.msstate.edu/wildlife/fisheries, gsmfc.org/fin
Missouri	✓		mdc7.mdc.mo.gov/applications/mofwis
Montana	✓		fwp.mt.gov
Nebraska	✓		outdoornebraska.gov
Nevada	✓		ndow.org
New Hampshire	✓	✓	wildlife.state.nh.us
New Jersey	✓	✓	state.nj.us/dep/fgw/index
New Mexico	✓		bison-m.org
New York	✓	✓	dec.ny.gov
North Carolina	✓	✓	deq.nc.gov
North Dakota	✓		gf.nd.gov
Ohio	✓		wildlife.ohiodnr.gov
Oklahoma	✓		wildlifedepartment.com
Oregon	✓	✓	dfw.state.or.us
Pennsylvania	✓		pasda.psu.edu, fishandboat.com
Rhode Island	✓	✓	dem.ri.gov/programs/fish-wildlife

State	Freshwater	Marine	URL
South Carolina	✓	✓	dnr.sc.gov
South Dakota	✓		gfp.sd.gov
Tennessee	✓		tn.gov
Texas	✓	✓	fishesoftexas.org
Utah	✓		dwrcdc.nr.utah.gov
Vermont	✓		geodata.vermont.gov
Virginia	✓	✓	dgif.virginia.gov, vims.edu
Washington	✓	✓	wdfw.wa.gov
West Virginia	✓		wvdnr.gov
Wisconsin	✓		seagrant.wisc.edu
Wyoming	✓		wgfd.wyo.gov

Table 2. Metadata information regarding the Standard Sampling Protocol database.

Table	Column Name	Description
Abiotic	LAKE_NAME	name of water body in Oklahoma Water Resources Board database
	AB_ObsCode	unique code created from concatenating AB, Water_Body, and an ID number
	ObsYr	code created from concatenating Water_Body, Station, and YYYY columns
	Water_Body	ODWC code for each lake
	Station	identifier of each sample (random)
	M	month of sample taken
	DD	day of sample taken
	YYYY	four digit year
	T	record of time for each sample
	Pool_Elev	lake elevation at time of sampling
	C	temperature recorded in or converted to Celsius
	Secchi	gauge of water transparency by use of a Secchi disk
	Conductivity	measurement of the water's ability to conduct an electrical current
	Gear	number assigned to a specific sampling technique
		40-44: Bass focused spring electrofishing
		49: Saugeye focused fall electrofishing (sample could be skewed due to preference for age 0 fish)
		23: Fall experimental gill net
		31: Crappie focused Fall trap net
		10: Summer seine (1980s-1990s)
		36: Channel Catfish focused hoop net (3 net tandem set)
		98: Blue and Flathead Catfish focused low frequency electrofishing
	Gear_Length	measurement of various gear types
		electrofishing: minutes of pedal time at each location
		gill net: length of net used
		trap net: length of lead and trap net together
		hoop net: number of units with 3 sections per unit
	Habitat	only used for seine and electrofishing
		2 columns representing Substrate and Shoreline Cover
		Substrate codes: Sand=0, Gravel=1, Rock=2, Clay=3, Mud=4, Unknown=5
		Shoreline Cover codes: Vegetation=6, Rock=7, Brush/Timber=8, No Cover=9
		code number is assigned for Substrate and Shoreline Cover at each site (ex. 18 = Gravel Substrate (1) and Brush/Timber Shoreline Cover (8)
	Effort	measure of effort by gear type
		electrofishing is recorded as a standard unit of effort (5, 10, or 15 minutes of petal time) and always equals 1
		for netting gears, effort is equal to hours of fishing time
Biotic	LAKE_NAME	name of water body in Oklahoma Water Resources Board database

Table	Column Name	Description
	B_ObsCode	code created from concatenating Water_Body and and unique ID number
	AB_ObsCode	unique code created from concatenating AB, Water_Body, and an ID number
	ObsYr	code created from concatenating Water_Body, Station, and YYYY columns
	aCode	Heritage defined unique identifier for each taxon
	OFRL_Code	number assigned to each species sampled
	Individual_#	number of fish per sample
	Length	length of sample in millimeters
	Weight	weight of sample in grams
OWRB Lake Data	Water_Body	ODWC code for each lake
	Region	ODWC management region that the water body is located in
	FID	identifier of each sample (random)
	LAKE_NAME	name of water body in Oklahoma Water Resources Board database
	ALT_NAME	alternate waterbody name
	SHORT_NAME	short form waterbody name
	SIZE_TYPE	size type
	NIDID	National Inventory of Dams ID number
	WBID	OK WQS Waterbody ID number
	IR_WBID	Integrated Report Waterbody ID number
	WR_CODE	Water Rights Database ID code
	WQS_NAME	Water Quality Standards Name of Stream Segment
	WATERSUPP	water supply
	FWPROP	Fish and Wildlife Propagation beneficial use
	AG	agriculture beneficial use
	REC	recreation beneficial use
	NAV	navigation beneficial use
	AES	aesthetics beneficial use
	LIMIT	limitations for additional protection
	REMARK	Remarks
	INC	included watersheds
	ACRES	waterbody area
	TYPE	water type - NOT UP-TO-DATE
	SHAPE_AREA	area of feature in internal units squared
	SHAPE_LEN	length of feature in internal units
	ORIG_FID	original identifier
	Lat	lake coordinates
	Long	lake coordinates
	BUMP_URL	link to the Beneficial Use Monitoring Program (BUMP) report for a lake
	Status	BUMP trophic status designation

Table	Column Name	Description
OBIS Taxonomy	aCode	Heritage defined unique identifier for each taxon
	OFRL_Code	number assigned to each species sampled
	sName	scientific name
	scientificNameAuthorship	Authority
	family	Family
	genus	Genus
	species	Species
	subspecies	Subspecies
	variety	not applicable (plants)
	forma	not applicable (plants)
	elCode	Element Code: a NatureServe created unique identifier for each taxon
	gelode	Global Element Code: another NatureServe created unique identifier for each taxon
	iucncode	IUCN red list code
	g_rank	a NatureServe global element rank that assigns rarity throughout the world
	s_rank	a rarity rank on the state level assigned by Heritage biologists
	nativity	native or invasive status
	source	source of taxonomic information
	usda_code	not applicable (plants)
	itis_code	Integrated Taxonomic Information System code
	fed_status_id	ESA federal ranking
	st_status_id	ESA state ranking
	swap_id	State Wildlife Action Plan (ODWC rank)
	name	full scientific name and authorship
	sspscientificnameauthorship	not applicable (plants)
	varscientificnameauthorship	not applicable (plants)
	formascientificnameauthorship	not applicable (plants)
	tracked	indication of tracking by Heritage program
SSP Species List	OFRL_Code	number assigned to each species sampled
	Species	fish species or category
Totals	Years	36 (1980-2015)
	Records	1,597,202
	Species	150 (176 in state)
	Lakes	288 (206 OWRB)
	Surface Acreage	601,149.41 (OWRB)

Table	Column Name	Description
	*Eufala	Records for Eufala arms (NorCan, SouCan, DPFork, Gaines Creek, Central Pool) also recorded under Eufala
	*Texoma	Records for Texoma arms (TexRed, TexWas, TexRR, TexWR) also recorded under Texoma
	*Dates	could be multiple years of data contained in one year (file) from original data (ex. 2012 file contains some data from 2011)
	*Saugeye	Saugeye data could be skewed due to fall electrofishing sampling (Gear 49) targeting year 0 fish

Chapter 1 Figure

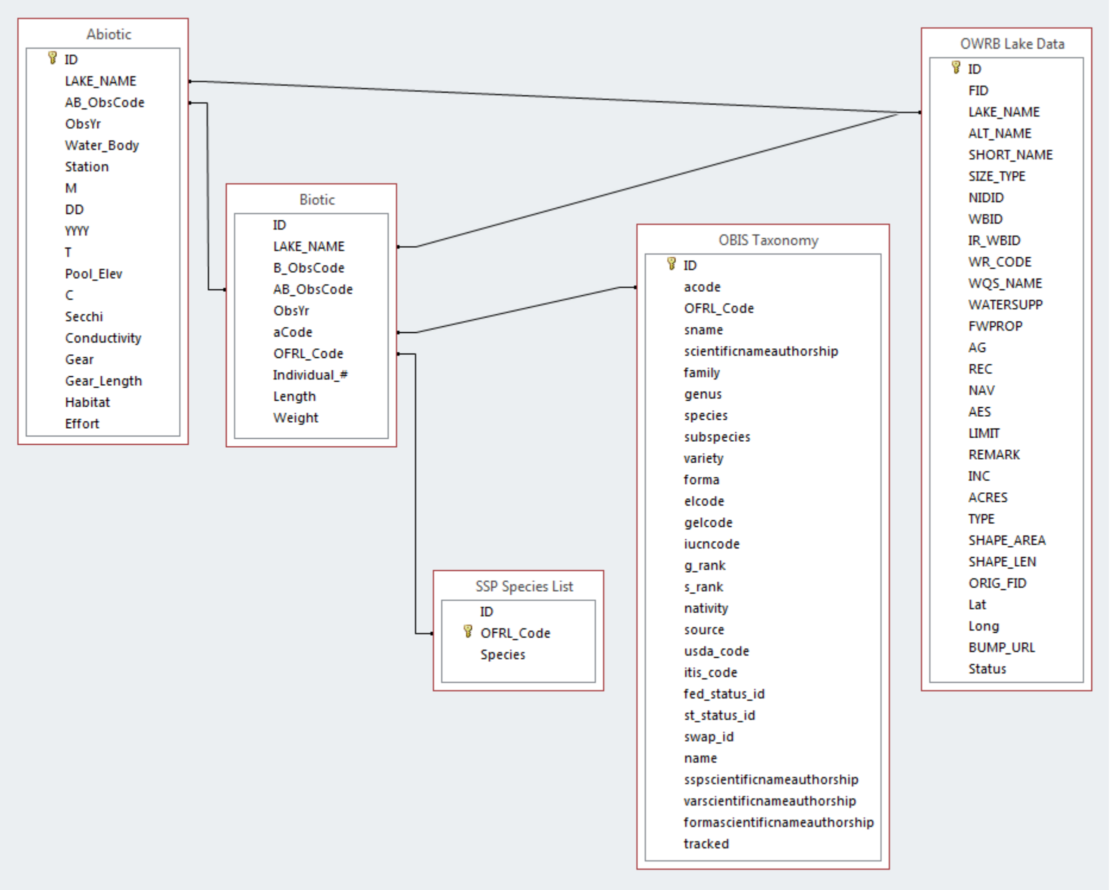

Figure 1. Standard Sampling Protocol Database schema.

Chapter 2: The effect of water quality on the mean relative weight of largemouth bass, crappie, and channel catfish in Oklahoma lakes

Introduction

A major goal for fisheries biologists is to have fast growing, healthy sportfish populations. One tool used to determine this is the relative weight (W_r) metric. The mean W_r, or body condition, is a measure of an individual fish's health. It is determined by comparing the relative weight of an individual fish to an index that gives typical W_r (by length class) for fish of the same species. It is assumed that a healthy fish will have a high ratio of actual weight to standard weight. This value is given as a percentage of an individual fish's actual weight compared to its normal weight (Bolger and Connolly 1989). Essentially, a high value for W_r equates to a fat, healthy fish, while a low W_r equates to a thin, malnourished fish (Wright 2000). Geographic variability and the factors associated with it can affect the W_r of fish in a particular system. Other physiological based indices, such as lipid content, exist to determine fish body condition. However, these analyses are expensive and require an advanced level of expertise to perform. For most applications, length and weight data provide adequate results for fish condition (Quist et al. 2009).

Abiotic and climatic factors can impact the growth rate and W_r of a fish. Dicenzo et al. (1995) noted that the W_r for Alabama spotted bass in ten reservoirs had a positive correlation to parameters including chlorophyll-a, drainage area, alkalinity, conductivity, and the morphoedaphic index, while having a negative correlation with Secchi disk transparency. Ecological (e.g., lake surface area, pH, Secchi depth) and anthropogenic variables (e.g., watershed stress and angling pressure), can impact a fishery. However, ecological variables had a larger impact on fish condition when compared to anthropogenic variables when assessing 693 Ontario lakes (Chu et al. 2015). Our project investigates ecological (water quality parameters) factors to describe resulting W_r.

In their 2015 study, Chu et al. noted that higher W_r was recorded for fish (anywhere from 2-24 species depending on the species richness in the lake) in eutrophic reservoirs than fish from oligotrophic and mesotrophic reservoirs, although these correlations were not seen across all length groups. It is also important to note that ecological and anthropogenic variables, such as pH, Secchi depth, and stresses on the watershed, can influence fish communities as a whole, including mean W_r for a particular species. However, both at the regional and local level, the influence of ecological variables had a greater significance (Chu et al. 2015). Although eutrophication of a particular water body can initially result in increased W_r for a given species, there is a threshold for this affect (lower for cool water species such as salmonids as compared to warm water species) that results in the “inhibition of natural reproduction” and the eventual replacement of existing taxa by “others that can survive” (Colby et al. 1972). This process has been observed within the Percidae family as well, where an initial increase in growth rate and production was followed by a similarly negative response (Leach et al. 1977). Mean W_r indices are established for sport fish species that are managed throughout Oklahoma, but do not consider a regional or more localized approach. The establishment of a target mean W_r for classes of lakes grouped according to water quality could provide additional information for biologists to utilize in the management of their lakes.

In order to examine the results of spatial variation between water bodies, multivariate techniques were utilized in our study. The use of multivariate techniques, including cluster analysis (CA) and discriminant analysis (DA), to analyze water-quality data has proven to be effective (Wunderlin et al. 2001, Singh et al. 2004, Shrestha and Kazama 2007, Shrestha et al. 2008). Both spatial and temporal variations in water quality were considered, as each of these previous studies worked with large river systems. This project takes the spatial variation of individual water bodies into consideration. A multivariate approach to the analysis of water-quality data is used extensively to determine freshwater quality and can also aid in the determination of spatial differences due to natural and anthropogenic factors (Singh et al. 2004).

Cluster analysis can group water bodies into classes based on similarities and differences of factors that relate to those objects (Singh et al. 2004). Clustering is an exploratory exercise and K-means is one of the most widely used examples (Jain 2010). DA allows for the statistical classification of the data. In order to use DA, it is necessary to perform an initial clustering analysis to determine the correct number of groups (Wunderlin et al. 2001). DA also reassigns objects into the correct group according to like properties and has been successfully utilized with multiple water quality data sets (Wunderlin et al. 2001, Singh et al. 2004, Shrestha and Kazama 2007, Shrestha et al. 2008).

We investigated the potential effect of water quality parameters for 108 water bodies across the state of Oklahoma on the mean W_r averages for largemouth bass

(*Micropterus salmoides*), black and white crappie (*Pomoxis nigromaculatus* and *Pomoxis annularis*), and channel catfish (*Ictalurus punctatus*). These species were chosen due to their wide distribution across the state and their popularity among recreational anglers. This resulted in larger amounts of data availability when compared to other sportfish species. Black and white crappie were combined into one "crappie" category according to current management practices which commonly consider each species as one taxon (Kuklinski pers.comm. 2016). First, we try to determine if spatial variation exists for mean W_r among Oklahoma lakes. Secondly, if variation in the mean W_r was detected, lake water quality variables were analyzed to determine which variable(s) might explain the differences. ANOVA was then used to determine that a significant effect existed between each taxon and the water quality parameters. K-means clustering and DA were used to determine the spatial variations in the water quality parameters of Oklahoma lakes while retaining those parameters that have significant influence. These same parameters were then used in a multiple regression analysis with each fish taxon to determine which, if any of the parameters directly correlated with relative weight.

The objective of this project is to determine if a correlation exists between the mean W_r of largemouth bass, black and white crappie, and channel catfish and eight different measures used to determine the water quality of 108 Oklahoma lakes, as well as spatially group said water bodies according to their water chemistry. In other words, though many environmental factors exhibit an east-to-west gradient or turnover, this may not be true for water quality. If a correlation is demonstrated between water quality and mean relative weight (an indicator of body condition), fisheries managers could evaluate the parameters in a given lake and utilize these results to aid management decisions.

Methods

Study Area

The study area for this project encompasses the state of Oklahoma. Lakes with the largest surface areas are concentrated in the eastern portion of the state, with several smaller bodies of water located in the central and southwestern regions, decreasing in abundance moving northwest into the panhandle (Figure 1). This is in large part due to a significant variation in annual precipitation, which decreases from east to west across the state. Increased precipitation has been correlated to decreased salinity in some western Oklahoma streams (Pionke and Nicks 1970). Oklahoma's annual precipitation can vary from over 139 centimeters in the far southeast, to less than fifty centimeters at the western end of the Oklahoma panhandle (Mesonet 2017). As a result of this, the dominant vegetation cover transitions from heavily timbered areas in the East, to semiarid plains and Rocky Mountain foothill vegetation in the West. With a large portion of the state situated in the Southern Plains, Oklahoma experiences all seasons and can have large daily temperature swings. Costa et al. (2007) further illustrate the longitudinal gradient of multiple climatic and environmental parameters in addition to the previously mentioned variables. These include elevation, precipitation of the driest quarter, precipitation seasonality, minimum temperature of the coldest month, and temperature seasonality.

Ranching and agricultural land use is common throughout the state, particularly in the western half, while forestry is common in the southeast. Some lakes, such as Arcadia, Hefner, and Keystone are located adjacent to or within major population centers. Geologic factors, such as the contribution of salts to many western Oklahoma streams (the Cimarron River and Elm Fork of the Red River in particular) that drain the eastern edge of the Permian Basin likely contribute to high salinity levels in certain water bodies (Johnson 1981). Lastly, the ranges of the values for lake water quality parameters across the state (chlorophyll-a, average turbidity, average Secchi, salinity, and specific conductivity in particular [Appendix A]) are vast (as illustrated by salinity (ppt) and pH [Figures 1a and 1b]).

Data Sources and Analysis

This project utilized three data sources. Geospatial data for the *Lakes of Oklahoma* were acquired from the Oklahoma Water Resources Board (OWRB). Water quality data came from the Beneficial Use Monitoring Program (BUMP) of the OWRB. Length, weight, and water body data for each taxon of fish were taken from the *Standard Sampling Protocol (SSP)* dataset, which was provided by Kurt Kuklinski of the Oklahoma Fisheries Research Lab of the ODWC. This dataset contains abiotic and biotic data for all lakes and species sampled and managed by the ODWC. The biotic data includes a species code designation, an individual count for the sample, length, and weight measurements, as well as four code columns created to link additional tables. The abiotic variables include lake name, station, date, time, pool elevation, temperature (Celsius), Secchi disk, conductivity, a gear type, gear length, habitat designation, and a measurement of effort, as well as three additional columns created to link additional tables.

To determine if geographic variation exists for mean W_r, first the W_r were calculated for each taxon by lake. Length, weight, number of individuals (n), and lake location data for each taxon were acquired from the *SSP Dataset* for the years 2000-2015 to provide a sufficient sample size for the calculation of W_r. It is also important to note that largemouth bass are primarily sampled in the spring, while crappie and channel catfish are primarily sample in the late summer and fall. This could result in higher W_r means for largemouth bass due to the presence of enlarged gonads during the spawning season. Few publications address sample-size requirements for calculating W_r estimates (Quist et al. 2009). Wege and Anderson (1978) recommend a sample size of ten to twenty largemouth bass in lakes with densities larger than 50 bass per hectare, and a sample size greater than twenty for lakes with lower densities. Quist et al. (2009), acknowledging the work of Wege and Anderson (1978), suggested a sample size of at least 100 individuals for the calculation of the W_r when density data are not available. Recommended minimum sample sizes for populations range from 5 to 50 (Brown and Murphy 1996; Brouder et al. 2009). For the Oklahoma SSP dataset, the sample size for some taxa were low for particular lakes (Appendix B).

Mean relative weights (W_r) were calculated according to the following formulas, which are based on the range wide distribution of each taxon and serve as a North American standard (Appendix B). Also, minimum length limits exist for each taxon including ≥ 150, 100, and 70 millimetres for largemouth bass, crappie, and channel catfish respectively.

Largemouth Bass (Murphy et al. 1991)

$$\boldsymbol{Relative\ Weight = Weight/(10^{(-5.528+3.273*LOG10(Length))}) * 100}$$

Crappie (Neumann and Murphy 1991)

$$\boldsymbol{Relative\ Weight = Weight/(10^{(-5.642+3.332*LOG10(Length))}) * 100}$$

Channel Catfish (Brown et al. 1995)

$$\boldsymbol{Relative\ Weight = Weight/(10^{(-5.800+3.294*LOG10(Length))}) * 100}$$

Each taxon was individually analyzed using ANOVA to determine if a significant difference existed between water bodies for W_r.

The Oklahoma Water Resources Board (OWRB) annually samples water quality in Oklahoma lakes through the Beneficial Use Monitoring Program (BUMP). A multiparameter instrument, or sonde (either the Y.S.I. ® 6-series or the EXO^2), was used to collect data for parameters including, temperature, barometric pressure, dissolved oxygen (DO), dissolved oxygen percent saturation, pH, specific conductivity, salinity, depth, oxidation-reduction potential (ORP), total dissolved solids, and resistivity. Turbidity values were measured with a HACH portable turbidimeter. Secchi depth measurements were taken using a Secchi disk. To determine chlorophyll-a concentrations, surface samples were collected, filtered and ground at the OWRB laboratory according to their standard methods, and sent to a contract laboratory for analysis (OWRB 2016). Chlorophyll-a, average turbidity, average Secchi, salinity, specific conductivity, pH, oxidation-reduction potential, and dissolved oxygen values were used for the purposes of this project. Acceptable ranges for the survival of most fish species include > 2 mg/L for dissolved oxygen and an optimal pH between 6.5 and 8.2 (MTU 2018). Turbidity and Secchi measurements can vary greatly between water bodies and seasons and can affect species differently depending upon a species reliance on sight versus other senses. Maximum salinity tolerance for largemouth bass, crappie, and channel catfish adults is approximately 12, 5, and 10 ppt respectively (Stuber et al. 1982, Edwards et al. 1982, and McMahon and Terrell 1982).

Although the BUMP program monitors water quality at many of the study lakes annually, some are not sampled as often. It was determined that BUMP data were available for each lake in the study in the date range of 2006-2016 (Table 1). Appendix A lists the water quality parameters, units, and values from each project water body. When multiple sampling sites existed for a water body, as in the case of large lakes, the station furthest downstream (or dam adjacent) was used.

A combination of k-means clustering (utilized due to its simplicity, efficiency, and long history of success [Jain 2010]) and discriminant analysis (DA) techniques following Singh et al. (2004) was used to classify lakes based on the BUMP data. Multiple water quality studies have demonstrated the utility of DA for data reduction and the description of primary parameters (Wunderlin et al. 2001, Singh et al. 2004, Shrestha and Kazama 2007, Shrestha et al. 2008). A k-means cluster analysis was used to classify lakes based on water quality parameters. It uses a nearest neighbors approach to clustering that, when run multiple times (in this case 50), results in a corrected classification.

DA was performed using standard, forward, and backward stepwise modes. With forward stepwise DA, variables are added according to the largest contribution to the model in descending order as long as its entry probability is greater than the entry threshold value. Backward stepwise DA works the same way, but in the opposite order

(Singh et al. 2004). The analysis creates a discriminant function for each group, using this equation:

$$\boldsymbol{f(C_i) = k_i + \sum_{j=1}^{n} w_{ij}\, p_{ij}}$$

i is the number of classes (C), the constant for each group is k_i, the number of parameters used to classify a data set into a class is n, and w_j is the weight coefficient that DA assigns to the parameter (p_j) (Singh et al. 2004).

Multiple regression was used to identify one or more explanatory variables from the DA that might facilitate the prediction of fish W_r between water bodies. This analysis utilizes multiple explanatory variables, in our case water quality parameters, in order to model a quantitative dependent variable (fish W_r), which allowed for the measurement of the explanatory power of the water quality parameters, as well as the determination of whether that influence was negative or positive (Sliva and Williams 2001, XLSTAT 2018).

Results and Discussion

Based on an outlier analysis, Great Salt Plains, Chickasha, Sooner, Foss, Lugert-Altus, Canton, and Vanderwork were removed from subsequent analyses. Each of these water bodies had high values for salinity and specific conductivity that contributed to their outlier status. Also, Foss recorded an uncharacteristically low mean W_r for crappie and channel catfish while Great Salt Plains recorded a mean W_r of only 13.00 for channel catfish.

Largemouth bass, crappie, and channel catfish exhibit a high range of relative weights across the study lakes. Ranges were 77.63-129.43, 65.50-139.00, and 66.00-147.00 for each taxon respectively. Means for largemouth bass and crappie were approximately 94.00 and 89.00 for channel catfish. Standard deviations were ±7.31, ±10.39, and ±10.15 for each taxon respectively. The means for each taxon seemed relatively normal and fit well with the assumption that a fish with ≥90.00 W_r is a healthy fish (Stahl and Harper, 2008). However, the wide range in W_r standard deviation further illustrate the differences among Oklahoma lakes with regards to fish condition. Also, each species did not have the same number of observations due to a lack of data for some water bodies. Largemouth bass data was present for 97 lakes, crappie for 85 lakes, and channel catfish for 77 lakes.

Individual ANOVAs for each taxon resulted in the rejection of the null hypothesis, indicating a significant difference between water bodies for each taxon's W_r and the water quality parameters. The use of k-means clustering resulted in the assignment of each of the remaining lakes into one of six classes (Figure 2). The group structure of the data is determined by the elbow in the plot that corresponds to the correct number of classes, in this case 6. These classes were then utilized in a DA to determine which parameters most heavily influenced the establishment of classes. In all three DA modes (standard, forward, and backward stepwise), specific conductivity (µS/cm) and salinity (ppt) were highly positively correlated with the first axis. Oxidation-reduction potential (ORP units in mV) was positively correlated with the second axis (Figure 3). Bartlett's test for eigenvalue significance resulted in significant p-values (<0.000) for the first two axes across all modes and the percentage of variance explained by those axes was 94.83% for the standard DA, 95.39% for the forward stepwise, and 95.45% for the backward stepwise. The first axis explained 87.07% of the classifications with salinity and specific conductivity correlated at 99.60% and

99.70% respectively (Figure 3). The resulting lake classifications are listed in Appendix B.

There was minimal variation in the reclassification of the water bodies and the percent correct of well classified water bodies (Table 2), with the same percent correct assignation regardless of forward or backward stepwise DA. Cross-validation resulted in 86.11% correct assignations for the standard mode, 92.59% correct for forward stepwise, and 92.59% correct for backward stepwise (15 of 108 lakes were reclassified). All modes again indicate the importance of salinity and specific conductivity in reclassifying water bodies into the correct classes.

Summary statistics for the mean W_r of largemouth bass, crappie, and channel catfish with regards to the classes determined from the DA (Table 3) and water quality parameters were calculated (Table 4). The degree of standard deviation in largemouth bass is small (3.29-8.54) between the six classes when compared with crappie (7.49-14.89) and channel catfish (6.16-17.19). Class 2 water bodies in particular record the highest and lowest mean W_r for channel catfish and largemouth bass respectively. These water bodies are located primarily in southeastern Oklahoma and have some of the lowest salinities and pH values in the dataset. In class 6 water bodies, with high salinity and pH values, the opposite tendency occurs. This class is primarily comprised of western water bodies or main stem impoundments with western Oklahoma influence. A wide variation in salinity and specific conductivity between the six classes was observed, with chlorophyll-a, average turbidity, and average Secchi measurement showing a high range in standard deviations as well (Table 5). Dissolved oxygen and pH remained relatively constant with small variations in standard deviation between the six classes (0.66-1.40 and 0.16-0.42 respectively). The box plots show a high degree of variability between classes for salinity and specific conductivity (Figures 4a and 4b).

Water bodies clustered on the factor axes illustrated the discrimination between classes that were taken from the original explanatory variables. Classes 4-6 were separated along the axis, whereas classes 1-3 were clustered (Figure 5). When lakes are mapped by cluster, the geographic location of the lakes in each class is somewhat misleading (Figure 6). Class 2 represents most of the southeastern lakes while class 1 contains many northeast and central Oklahoma lakes. Class 6, with the highest salinity values, primarily represents western lakes and main stem impoundments situated on large drainages with a western Oklahoma influence. The remaining clusters are erratic (Figure 6).

The multiple regression analysis resulted in low R^2 values for each taxon, indicating that the water quality parameters used do not explain variation in W_r very well on their own. In other words, there are additional explanatory variables, possibly drainage area or anthropogenic variables, that could aid in the explanation of the model (Dicenzo et al. 1995, Chu et al. 2015). As can be seen by the low p-values (Figure 7), the largemouth bass and channel catfish results were significant, but the water quality parameters only accounted for 24-25 % of the variation in relative weight for these taxa. The results for crappie were not significant, which could be the result of lumping the two crappie species into one category. The single most influential variable for both largemouth bass and channel catfish was pH, although the correlation was not statistically significant for largemouth bass (Table 5). pH was positively correlated with largemouth bass W_r at 0.39 and negatively with channel catfish at 0.33.

Largemouth bass favor a slightly basic environment over slightly acidic when acclimated to a neutral pH, resulting in less stress and a potentially healthier fish (www.bassresource.com 2018). Largemouth bass W_r was also positively correlated to a lesser degree with chlorophyll-a, salinity, and specific conductivity, which is consistent with the results of Dicenzo et al. (1995) in Alabama spotted bass, which showed a positive correlation to chlorophyll-a and specific conductivity. Channel catfish W_r was negatively correlated with average turbidity at 24%.

The potential impact of interaction among the taxa studied, and/or other species is recognized. Largemouth bass and crappie are both primarily piscivorous, and potentially prey on each other, impacting the mean length (and potential mean W_r) of crappie in small water bodies (Boxrucker 1987). The primary food sources of largemouth include sunfish, frogs, crayfish, minnows, and shad (Garvey et al. 2002 and www.wildlifedepartment.com/fishing/species 2018). Crappie are highly prolific, which can lead to stunted growth and low W_r, particularly in small water bodies (Miller and Robison 2004 and Boxrucker 1987). Channel catfish are omnivorous and feed on a large array of organic matter, dead or alive (Miller and Robison 2004). This includes plant materials, filamentous algae, as well as invertebrate and vertebrate animals (Hubert 1999).

Conclusion

Water quality parameters can have an effect on the mean W_r of fish (Chu et al. 2015). For this project, k-means clustering classified 108 water bodies in Oklahoma into six classes based on the similarities of eight water quality parameters. Subsequent discriminant analysis resulted in reclassification with 95% correct assignations, and identified salinity and specific conductivity as the two primary parameters used in classification.

A correlation between water quality, and mean relative weight could assist with decision-making for fisheries managers based on the water quality parameters rather than geographic location alone. For example, Lake Etling, located in far northwestern Oklahoma, clustered with lakes in eastern Oklahoma based on water quality parameters, rather than other lakes in western Oklahoma. This similarity is likely the result of geologic substrate; Lake Etling is located on Paleozoic sandstones that lack halide deposits. Therefore, should this lake be managed with the expectation of fish achieving a W_r akin to nearby lakes or eastern lakes? The explanatory power of the multiple regression model could potentially be strengthened, however, with the inclusion of additional variables such as: land use/land cover, surface geology, drainage basin size, and variation in lake surface area.

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Chapter 2 Tables

Table 1. Water body name, code, and the most recent year in which it was sampled for the Oklahoma Water Resources Board's lakes Beneficial Use Monitoring Program.

NAME	Water Body	BUMP Year
American Horse Lake	AMHORS	2008
Ardmore City Lake	ARDCIT	2007
Atoka Reservoir	ATOBLU	2015
Bell Cow Lake	BELLCO	2015
Birch Reservoir	BIRCH	2016
Bixhoma Lake	BIXHOM	2015
Bluestem Lake	BLUEST	2014
Boomer Lake	BOOMER	2015
Broken Bow Lake	BRBOW	2016
Brown Lake	BROWN	2016
Brushy Creek Reservoir	BRUSHY	2015
Canton Lake	CANTON	2014
Carl Blackwell Lake	CARLBL	2016
Carter Lake	CARTER	2008
Cedar Lake	CEDAR	2016
Chandler Lake	CHANDL	2008
Cleveland Lake	CLEVEL	2016
Comanche Lake	COMANC	2011
Copan Lake	COPAN	2015
Crowder	CROWDE	2015
Cushing Lake	CUSHIN	2012
Dripping Springs Lake	DRSPGS	2015
Elk City Reservoir	ELKCIT	2006
Elmer Thomas Lake	ELMERT	2016
Eufaula Lake	EUFAUL	2015
Fairfax City Lake	FAIRFA	2016
Fort Cobb Reservoir	FTCOBB	2014
Fort Gibson Lake	FTGIBS	2015
Fort Supply Reservoir	FTSUPP	2016
Foss Reservoir	FOSS	2016
Grand Lake O' the Cherokees	GRAND	2015
Great Salt Plains Reservoir	GRSALT	2014
Greenleaf Lake	GREENL	2014
Guthrie Lake	GUTHRI	2016
Healdton Lake	HEALDT	2006
Heyburn Lake	HEYBUR	2016
Hugo Lake	HUGO	2015

NAME	Water Body	BUMP Year
Hulah Lake	HULAH	2014
Kaw Lake	KAW	2015
Keystone Lake	KEYSTO	2014
Lake Arcadia	ARCADI	2015
Lake Carl Albert	CARLAL	2008
Lake Carl Etling	ETLING	2013
Lake Chickasha	CHICKA	2016
Lake Claremore	CLAREM	2014
Lake El Reno	ELRENO	2012
Lake Ellsworth	ELLSWO	2014
Lake Eucha	EUCHA	2015
Lake Frederick	FREDER	2015
Lake Fuqua	FUQUA	2016
Lake Hefner	HEFNER	2016
Lake Henryetta	HENRY	2012
Lake Holdenville	HOLDEN	2013
Lake Hominy	HOMINY	2007
Lake Hudson	HUDSON	2014
Lake Jean Neustadt	JNEUST	2012
Lake Konawa	KONAWA	2014
Lake Lawtonka	LAWTON	2016
Lake Lloyd Vincent	VINCENT	2011
Lake Louis Burtschi	BURTSC	2006
Lake McMurtry	MCMURT	2014
Lake Murray	MURRAY	2014
Lake Nanih Waiya	NWAIYA	2008
Lake of the Arbuckles	ARBUCK	2016
Lake Overholser	OVERHO	2014
Lake Ozzie Cobb	OZCOBB	2008
Lake Ponca	PONCA	2016
Lake Raymond Gary	RAYGAR	2009
Lake Texoma	TEXOMA	2016
Lake Thunderbird	THBIRD	2015
Lake Vanderwork	VANDER	2008
Lake Wayne Wallace	WAYWAL	2012
Lake Wetumka	WETUMK	2007
Langston Lake	LANGST	2016
Liberty Lake	LIBERT	2016
Lone Chimney Lake	LONECH	2016
Lugert-Altus Reservoir	ALTUSL	2016
McGee Creek Reservoir	MCGEE	2015

NAME	Water Body	BUMP Year
Meeker Lake	MEEKER	2009
Okemah Lake	OKEMAH	2014
Okmulgee Lake	OKMULG	2016
Oologah Lake	OOLOGA	2014
Pauls Valley Lake	PVALLY	2015
Pawhuska Lake	PAWHUS	2008
Pawnee Lake	PAWNEE	2007
Perry Lake	PERRYC	2015
Pine Creek Lake	PCREEK	2016
Prague Lake	PRAGUE	2008
Purcell Lake	PURCEL	2008
R.C. Longmire Lake	LONGMI	2014
Robert S. Kerr Reservoir	RSKERR	2016
Sahoma Lake	SAHOMA	2015
Sardis Lake	SARDIS	2016
Shawnee Twin Lakes #1	SHAWN1	2016
Shawnee Twin Lakes #2	SHAWN2	2016
Shell Lake	SHELLC	2013
Skiatook Lake	SKIATO	2015
Sooner Lake	SOONER	2015
Spavinaw Lake	SPAVIN	2014
Sportsman Lake	SPORTS	2014
Stanley Draper Lake	DRAPER	2016
Stilwell City Lake	STILWE	2016
Stroud Lake	STROUD	2014
Talawanda Lake #1	TALAW1	2016
Talawanda Lake #2	TALAW2	2016
Taylor Lake	TAYLOR	2014
Tecumseh Lake	TECUMS	2008
Tenkiller Lake	TENKIL	2015
Tom Steed Reservoir	STEED	2015
Waurika Lake	WAURIK	2015
Webbers Falls Reservoir	WFALLS	2016
Wes Watkins Reservoir	WESWAT	2016
Wewoka Lake	WEWOKA	2015
Wiley Post Memorial Lake	WIPOST	2013
Wister Lake	WISTER	2016

Table 2. Confusion and cross-validation matrix totals showing the percent correct classified observations for each type of Discriminant Analysis by class.

Confusion Matrix **Classes**	**1**	**2**	**3**	**4**	**5**	**6**	**Total**	**% correct**
Standard DA mode								
1	35	0	0	0	0	0	35	100.00%
2	3	22	0	0	0	0	25	88.00%
3	1	0	16	0	0	0	17	94.12%
4	1	0	0	11	0	0	12	91.67%
5	0	0	0	0	8	0	8	100.00%
6	0	0	1	0	0	10	11	90.91%
Total	40	22	17	11	8	10	108	94.44%
Stepwise (forward) DA mode								
1	35	0	0	0	0	0	35	100.00%
2	2	23	0	0	0	0	25	92.00%
3	1	0	16	0	0	0	17	94.12%
4	1	0	0	11	0	0	12	91.67%
5	0	0	0	0	7	1	8	87.50%
6	0	0	0	0	0	11	11	100.00%
Total	39	23	16	11	7	12	108	95.37%
Stepwise (backward) DA mode								
1	35	0	0	0	0	0	35	100.00%
2	2	23	0	0	0	0	25	92.00%
3	1	0	16	0	0	0	17	94.12%
4	1	0	0	11	0	0	12	91.67%
5	0	0	0	0	8	0	8	100.00%
6	0	0	1	0	0	10	11	90.91%
Total	39	23	17	11	8	10	108	95.37%

Table 3. Summary statistics for the relative weights of each study species according to the discriminant analysis classifications for 108 water bodies.

Class	**# of lakes**	**Bass Wr**				**Crappie Wr**				**Channel Catfish Wr**			
		Mean	**Median**	**Range**	**StDev**	**Mean**	**Median**	**Range**	**StDev**	**Mean**	**Median**	**Range**	**StDev**
1	40	95.36	95.30	49.14	8.54	92.63	91.59	41.33	8.25	88.44	88.00	27.00	6.87
2	22	89.84	89.39	23.86	5.47	94.75	93.55	39.00	9.70	94.01	88.50	67.25	17.19
3	17	98.36	98.00	20.09	5.43	98.17	93.33	57.00	14.89	87.10	86.75	22.67	6.16
4	11	94.27	95.92	21.87	6.40	92.44	89.20	33.07	9.84	88.75	87.25	39.00	11.62
5	8	96.89	96.26	9.81	3.29	91.99	96.00	39.33	13.97	86.90	88.75	17.75	7.00
6	10	99.17	98.77	17.42	6.14	97.66	96.40	22.00	7.49	88.46	90.75	20.50	7.00

Table 4. Summary statistics for each water quality parameter according to the discriminant analysis classifications for 108 water bodies.

Class	**# of Lakes**	**Mean**	**Median**	**Range**	**StDev**	**Mean**	**Median**	**Range**	**StDev**
		Chlorophyll-a (mg/m^3)				***Average Turbididty (NTU)***			
1	40	9.87	8.80	26.01	8.12	19.43	9.50	141.00	28.43
2	22	6.49	6.00	25.20	6.94	17.68	10.00	132.00	5.86
3	17	13.17	12.31	31.00	8.48	28.35	19.00	75.00	21.39
4	11	19.11	17.80	42.00	11.79	32.55	17.00	126.00	42.07
5	8	24.31	21.20	52.50	17.77	19.63	13.50	49.00	16.96
6	10	23.74	14.80	60.60	22.27	15.80	13.00	28.00	8.77
		Average Secchi (cm)				***Salinity (ppt)***			
1	40	86.65	79.50	230.00	55.14	0.12	0.13	0.14	0.00
2	22	78.64	72.50	228.00	50.26	0.04	0.04	0.07	0.02
3	17	50.65	48.00	103.00	29.43	0.20	0.20	0.10	0.03
4	11	60.73	62.00	107.00	30.79	0.10	0.09	0.16	0.06
5	8	60.38	62.00	98.00	35.44	0.63	0.62	0.26	0.09
6	10	54.20	49.50	79.00	22.59	0.34	0.33	0.16	0.06
		Specific Conductivity (µS/cm)				***pH***			
1	40	258.76	264.87	257.32	53.15	7.80	7.82	0.77	0.19
2	22	96.71	88.01	146.97	42.08	7.10	7.18	1.19	0.29
3	17	422.18	338.74	247.53	61.32	7.99	8.02	0.64	0.16
4	11	204.42	195.09	321.30	115.81	7.39	7.47	1.53	0.42
5	8	1251.74	1236.67	505.19	172.81	8.21	8.31	0.78	0.29
6	10	687.92	656.13	322.91	115.42	8.17	8.20	0.53	0.20
		Oxidation Reduction Potential (mV)				***Dissolved Oxygen (mg/L)***			
1	40	338.32	346.88	272.85	54.69	7.40	7.37	4.36	0.97
2	22	368.82	365.39	175.34	51.91	6.92	7.10	5.68	1.36
3	17	332.57	338.74	247.53	61.32	7.96	8.21	3.35	0.94
4	11	135.62	153.36	163.34	60.01	6.58	6.60	3.98	1.40
5	8	295.63	298.17	272.36	83.30	8.02	7.69	3.80	1.39
6	10	310.81	327.97	245.94	81.17	8.15	7.89	1.96	0.66

Table 5. Type III Sum of Squares p-values for each water quality parameter by species. Significant values are listed bold.

	Bass	**Crappie**	**Catfish**
Chlorophyll-a	0.197	0.877	0.786
Avg. Turbidity	0.287	0.473	0.170
Avg. Secchi	0.329	0.798	0.657
Salinity	0.372	0.885	**0.009**
Spec. Conductivity	0.345	0.853	**0.008**
pH	0.069	0.196	**0.002**
ORP	0.408	0.670	0.726
DO	0.506	0.095	**0.916**

Chapter 2 Figures

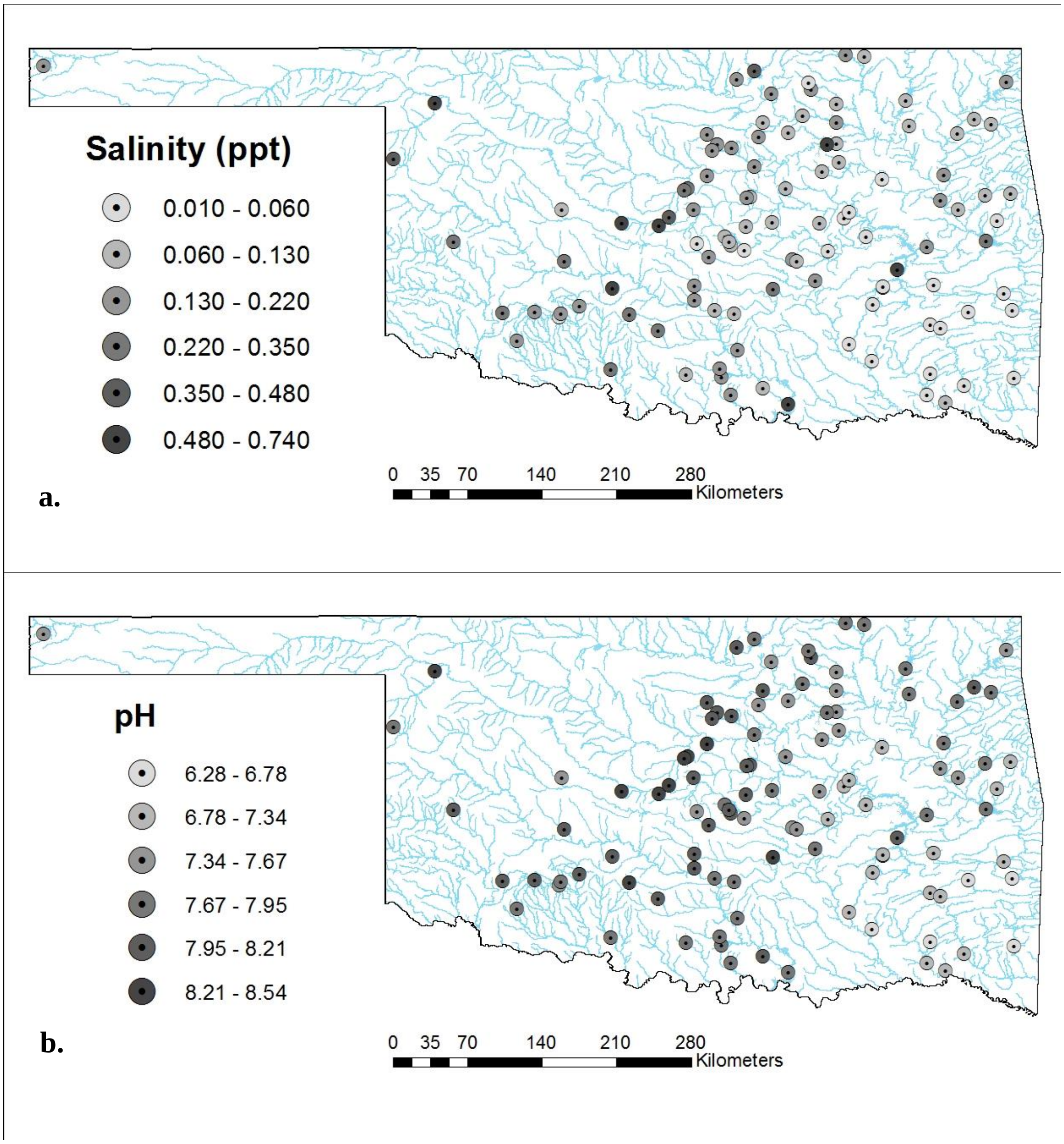


Figure 1. Salinity (a) and pH (b) range and location of study lakes adapted from the Beneficial Use Monitoring Program Nutrient Status figure in Lakes of Oklahoma.

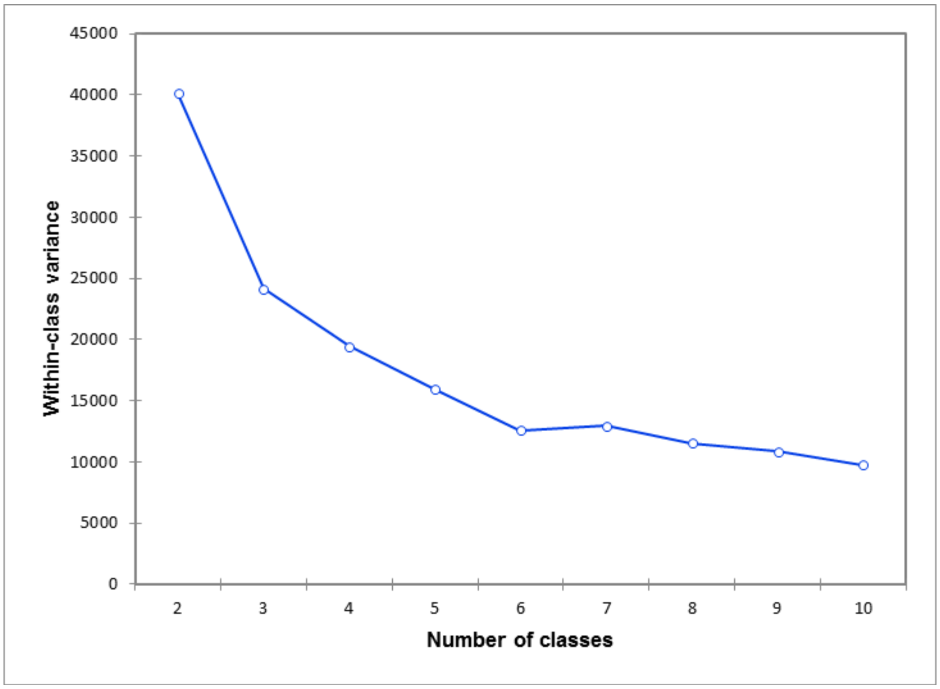
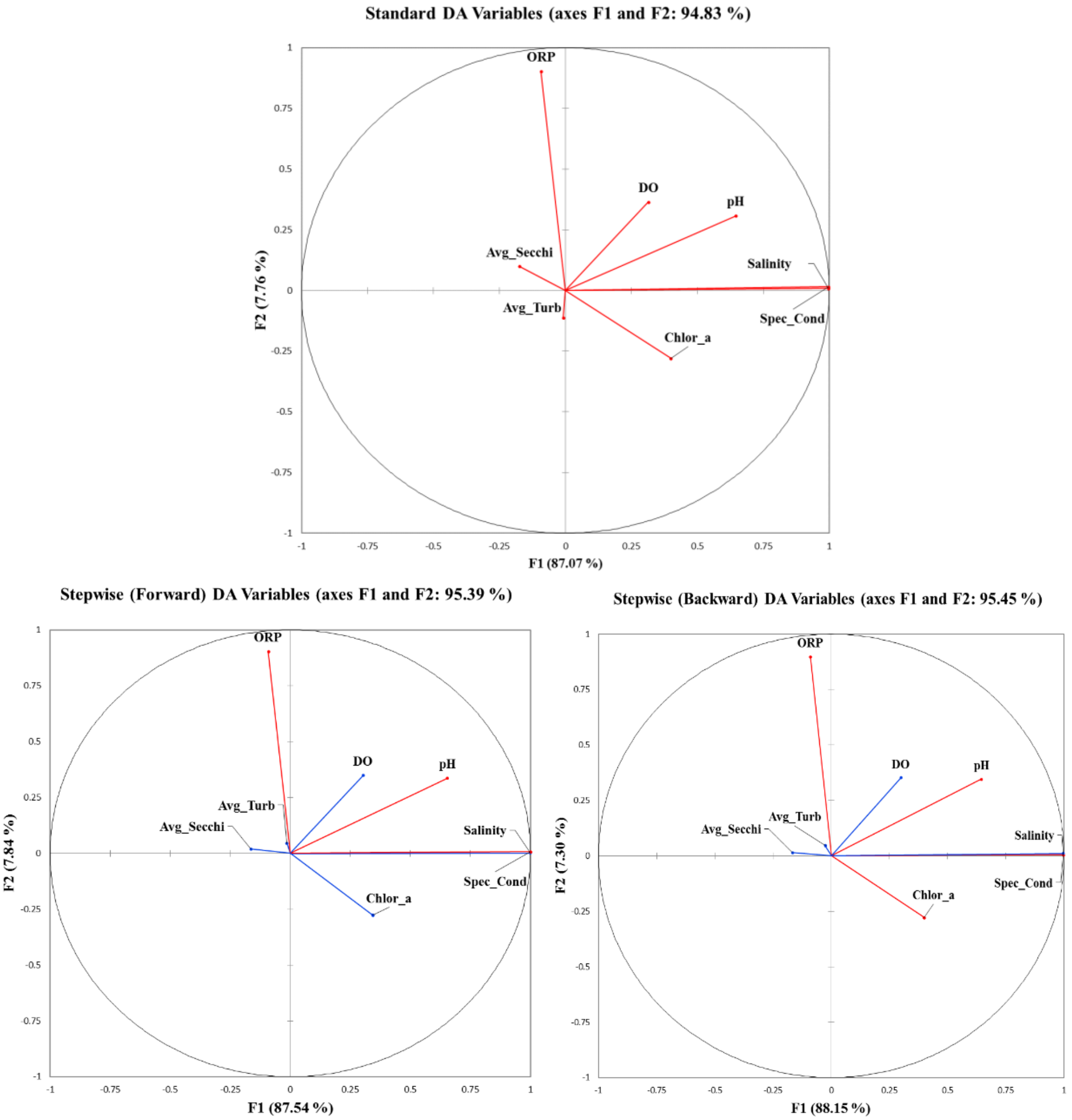


Figure 2. Scree plot showing the k-means clustering within-class variance and illustrating the elbow at 6 classes.



Standard DA Variables (axes F1 and F2: 94.83 %)

Stepwise (Forward) DA Variables (axes F1 and F2: 95.39 %)

Stepwise (Backward) DA Variables (axes F1 and F2: 95.45 %)

Figure 3. Ordination diagrams depicting results for the standard, forward stepwise, and backward stepwise discriminant analysis of water quality variables.

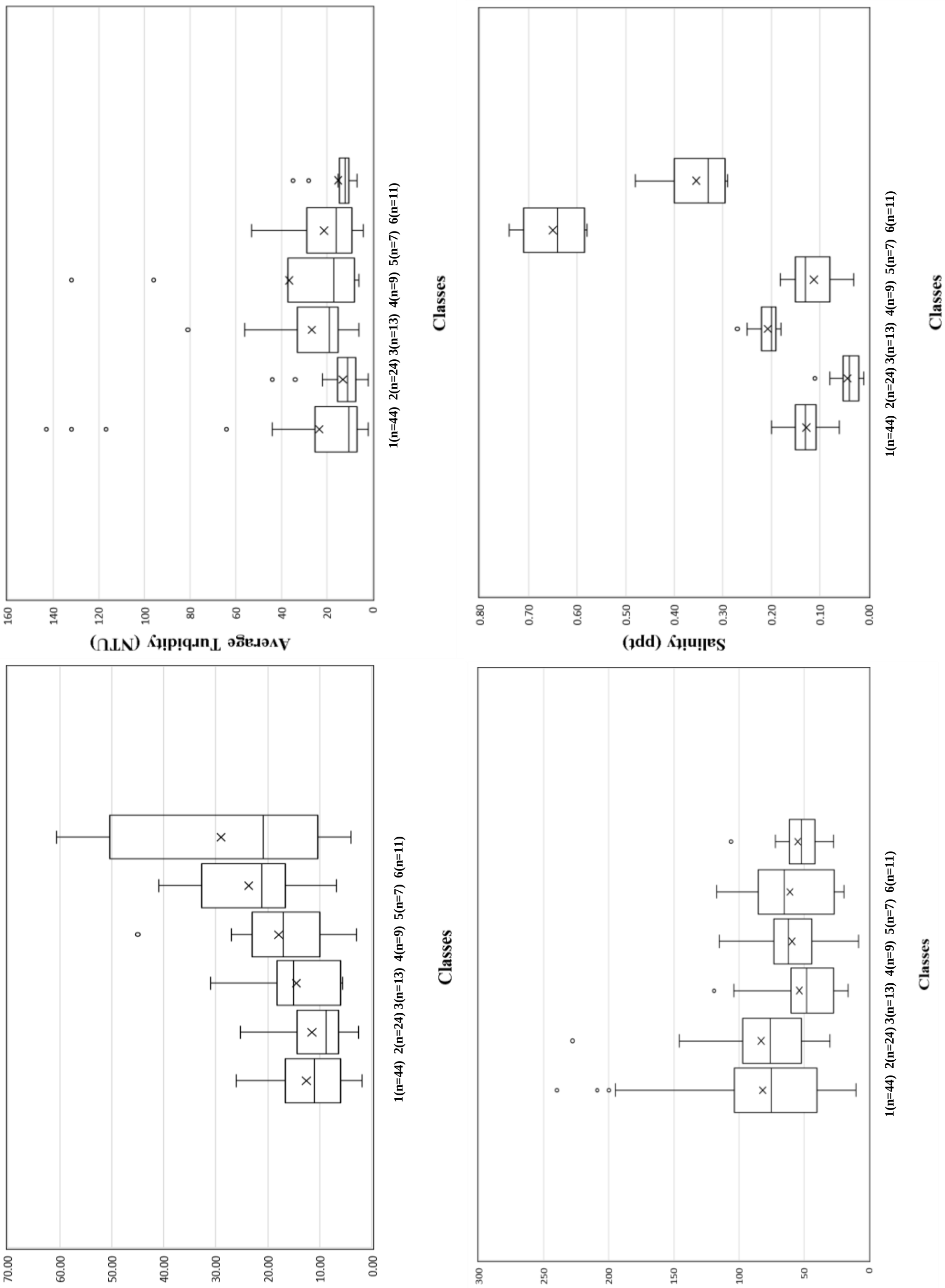


Figure 4a. Box and whisker plots for each water quality parameter according to discriminant analysis classes. The number (n) of water bodies in each class is listed next to the class number.

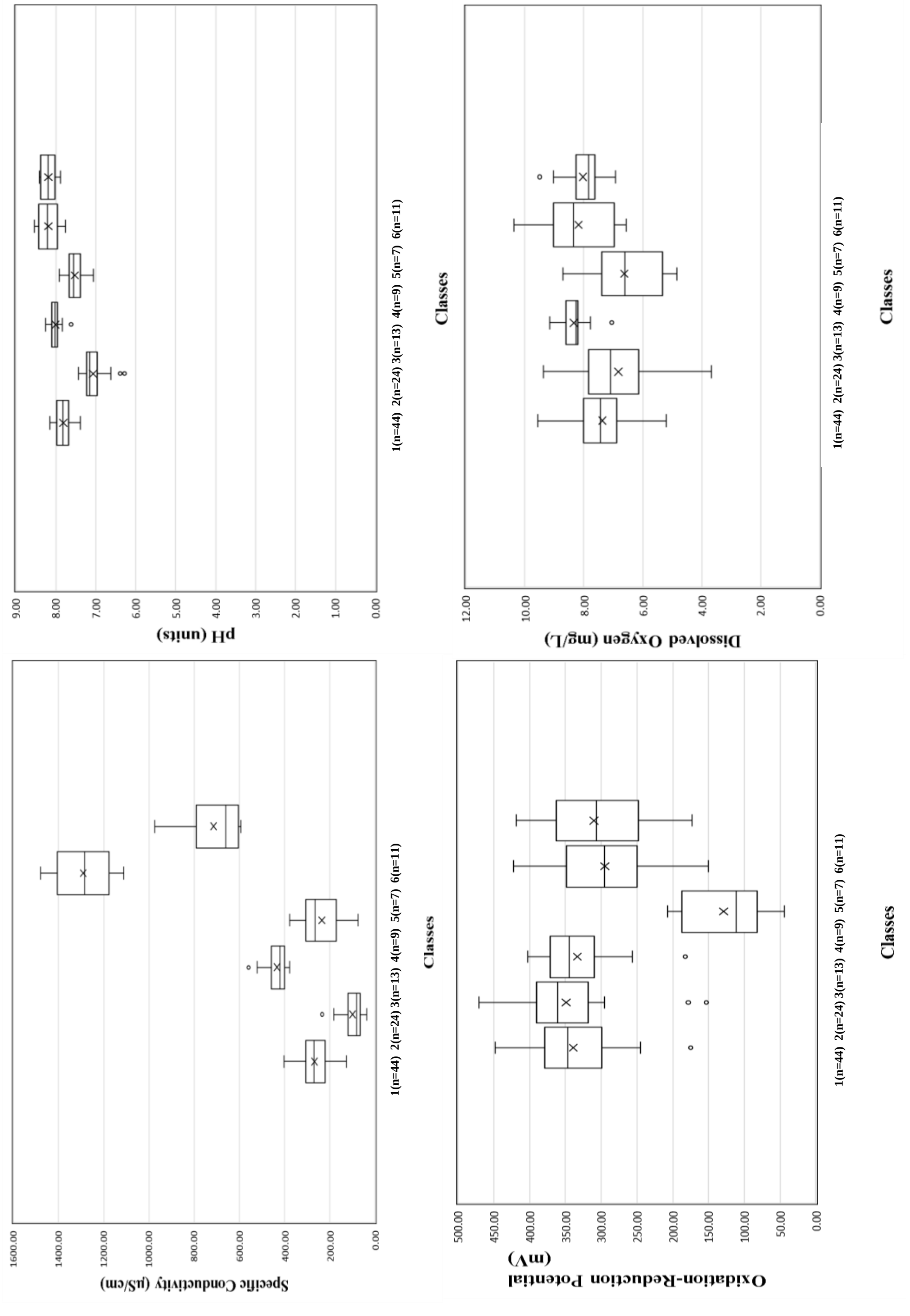


Figure 4b. Box and whisker plots for each water quality parameter according to discriminant analysis classes. The number (n) of water bodies in each class is listed next to the class number.

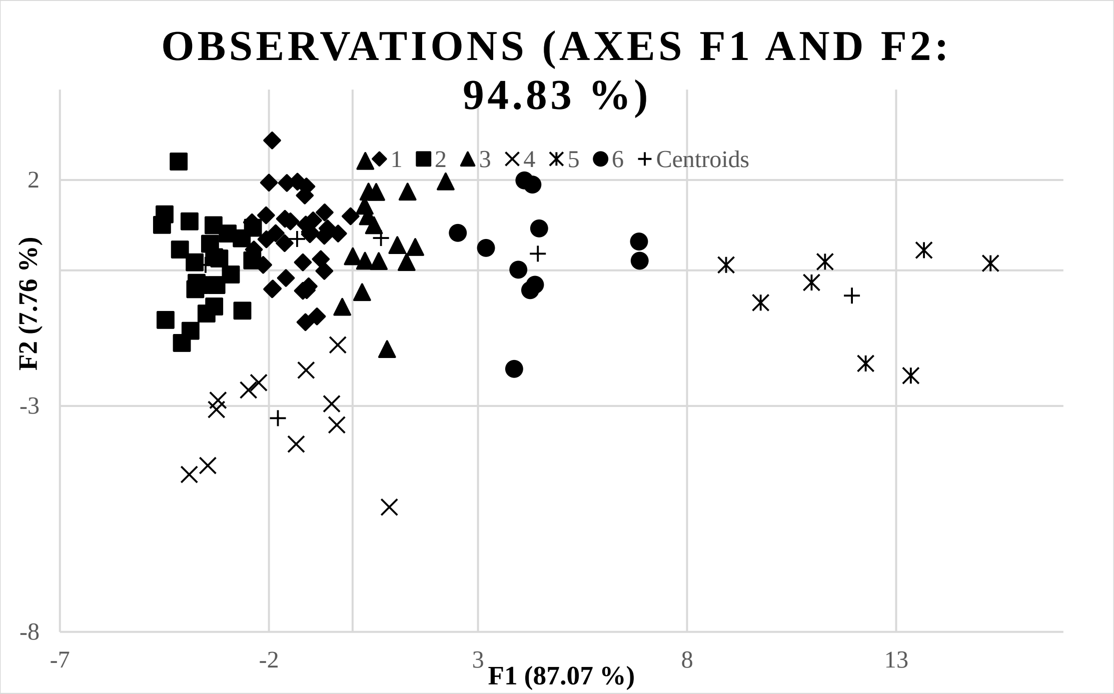


Figure 5. Water body class centroids and clusters with respect to axes 1 and 2.

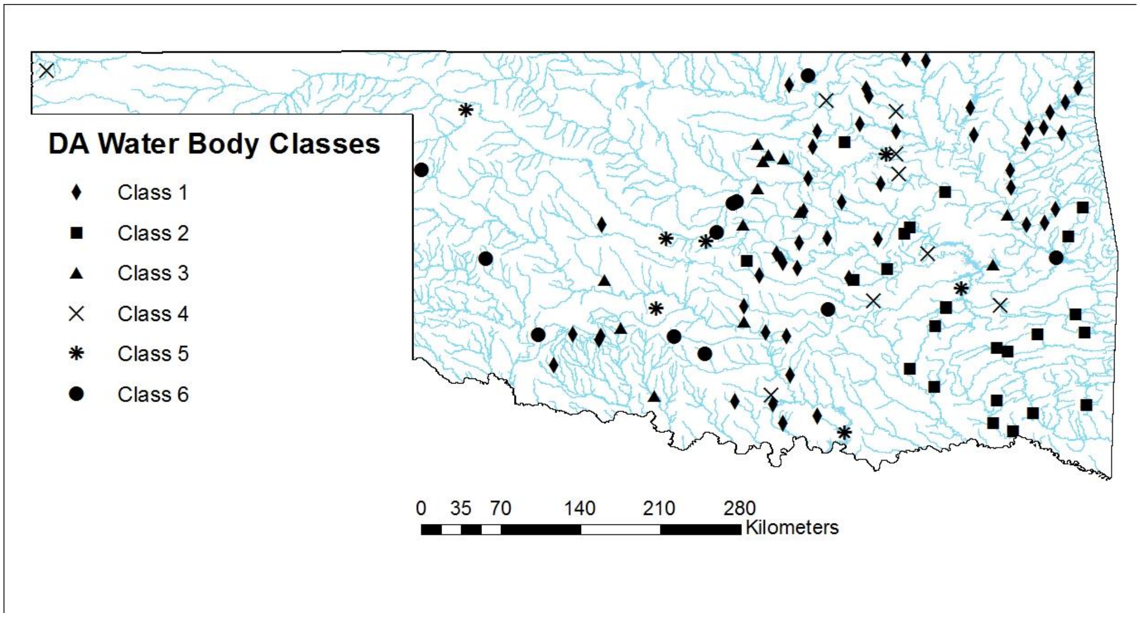


Figure 6. Discriminant analysis classification of 108 Oklahoma water bodies.

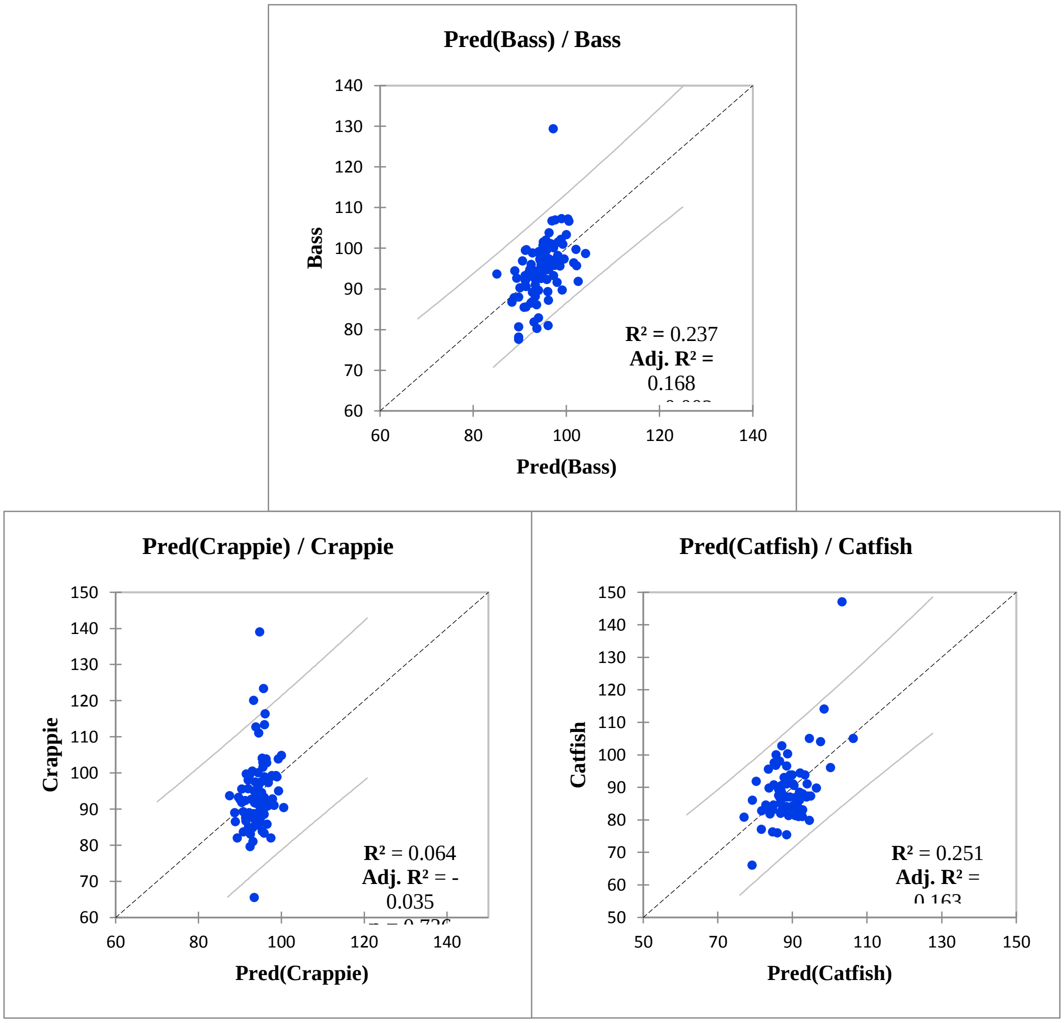


Figure 7. Predicted relative weights of each fish compared to the observed relative weights.

Appendix A. Water quality categories, units, and values for 115 Oklahoma water bodies. Data and collection methodology available from the Oklahoma Water Resource Board (www.owrb.ok.gov/quality/monitoring/monitoring.php).

Water Body	Chlor a mg/m^3	Avg Turb NTU	Avg Secchi cm	Salinity ppt	Spec Cond µS/cm	pH Units	ORP mV	DO mg/L
AMHORS		13	118	0.11	233.20	7.57	365.00	6.38
ARDCIT		10	106	0.15	304.40	7.88	341.00	7.19
ATOBLU	9.00	44	30	0.05	95.51	7.23	314.83	8.01
BELLCO	23.00	14	58	0.18	386.96	8.02	338.74	7.78
BIRCH	17.80	8	62	0.09	195.09	7.39	186.85	5.34
BIXHOM	7.00	4	146	0.05	111.12	7.21	397.16	7.78
BLUEST	4.70	25	54	0.12	256.08	7.81	376.44	6.96
BOOMER	31.00	15	37	0.21	434.07	8.10	306.16	8.53
BRBOW	5.00	2	228	0.02	36.11	6.28	393.26	3.68
BROWN				0.04	78.38	7.34	389.00	8.30
BRUSHY	13.00	8	79	0.03	73.79	7.13	322.10	7.12
CANTON	50.01	39	25	0.90	1764.41	8.19	421.06	9.30
CARLBL	15.40	25	39	0.18	382.42	8.07	344.52	8.85
CARTER		7	121	0.11	230.70	7.98	448.00	7.93
CEDAR	25.30	7	92	0.02	56.86	6.39	153.36	4.73
CHANDL		29	39	0.12	291.40	8.04	383.00	7.68
CLEVEL	14.90	14	49	0.11	234.38	7.39	378.00	7.13
COMANC	8.00	12	86	0.15	307.86	8.01	346.00	8.84
COPAN	10.00	117	14	0.12	253.29	7.70	380.63	8.21
CROWDE	41.00	16	65	0.58	1164.13	8.07	337.43	9.39
CUSHIN	7.00	44	25	0.17	356.58	7.86	260.35	7.51
DRSPGS	7.00	9	76	0.06	126.19	7.23	364.33	6.95
ELKCIT		15	56	0.35	676.80	8.20	419.00	8.47
ELMERT	5.10	2	209	0.06	135.88	7.38	312.62	5.20
EUFAUL	6.00	19	86	0.20	420.63	7.88	402.19	7.97
FAIRFA	12.90	8	71	0.14	296.10	7.67	185.29	4.84
FTCOBB	18.26	15	60	0.25	521.98	8.21	386.62	8.53
FTGIBS	22.00	7	76	0.15	308.41	7.79	347.06	8.04
FTSUPP	36.20	53	19	0.74	1479.19	8.41	359.81	8.34
FOSS	11.80	11	88	1.20	2339.69	8.01	346.69	6.19
GRAND	6.00	3	191	0.14	288.84	7.60	281.34	6.99
GRSALT	308.25	198	8	4.26	7099.36	8.46	411.99	10.72
GREENL	16.60	4	103	0.08	161.31	7.56	332.16	6.87
GUTHRI	60.60	14	47	0.29	594.46	8.35	250.02	7.94
HEALDT	14.80	29	31	0.10	204.02	7.76	289.56	7.03
HEYBUR	14.60	32	31	0.13	275.74	7.63	255.60	7.01
HUGO	22.00	34	32	0.03	73.15	7.16	366.45	9.36
HULAH	16.30	65	24	0.14	299.93	7.90	375.72	8.07

Water Body	**Chlor a**	**Avg Turb**	**Avg Secchi**	**Salinity**	**Spec Cond**	**pH**	**ORP**	**DO**
	mg/m^3	**NTU**	**cm**	**ppt**	**μS/cm**	**Units**	**mV**	**mg/L**
KAW	4.00	9	106	0.45	915.08	7.90	358.25	7.84
KEYSTO	15.60	7	98	0.71	1402.84	7.76	422.21	6.90
ARCADI	25.00	7	119	0.20	411.28	7.97	315.12	8.21
CARLAL		14	90	0.01	45.10	6.69	450.00	7.31
ETLING	45.00	37	26	0.18	378.16	7.47	44.06	5.07
CHICKA	54.60	13	35	1.33	2568.52	8.22	403.22	8.56
CLAREM	26.01	9	46	0.13	264.63	7.84	326.72	9.56
ELRENO	20.00	36	25	0.64	1284.21	8.54	149.85	10.37
ELLSWO	12.31	33	26	0.22	462.94	8.04	395.76	8.60
EUCHA	21.00	3	104	0.12	254.84	7.82	346.69	7.93
FREDER	7.00	64	25	0.19	397.57	7.78	322.02	5.81
FUQUA	11.70	12	47	0.30	613.61	8.19	306.93	7.73
HEFNER	52.50	8	59	0.48	974.00	8.41	301.33	6.92
HENRY	3.00	132	8	0.05	98.76	7.33	207.40	8.71
HOLDEN	17.00	17	48	0.16	328.00	7.73	91.56	7.33
HOMINY		9	101	0.12	251.14	7.93	267.00	5.25
HUDSON	13.40	8	84	0.12	248.40	7.75	417.82	8.21
JNEUST	23.00	17	44	0.15	305.14	7.92	111.45	6.55
KONAWA	23.90	7	72	0.33	660.82	8.27	401.64	7.54
LAWTON	25.70	7	68	0.16	335.27	7.86	378.43	6.54
VINCENT	8.00	14	63	0.45	869.61	7.88	349.00	9.04
BURTSC		11	72	0.58	1111.00	8.21	295.00	7.03
MCMURT	5.70	19	48	0.19	399.20	8.14	353.37	8.26
MURRAY	1.90	8	200	0.14	291.42	7.83	404.53	7.38
NWAIYA		9	98	0.02	82.70	7.20	471.00	8.08
ARBUCK	14.40	4	108	0.15	312.71	7.81	301.12	6.15
OVERHO	22.40	22	28	0.59	1189.12	8.45	273.96	8.66
OZCOBB		12	56	0.01	65.20	6.78	444.00	7.56
PONCA	20.00	8	71	0.16	327.71	8.15	175.15	5.49
RAYGAR		11	55	0.08	175.82	7.13	356.81	6.21
TEXOMA	6.80	4	117	0.71	1409.46	7.86	225.43	6.57
THBIRD	21.00	14	59	0.18	377.40	7.99	311.25	6.00
VANDER		9	59	0.93	1748.70	7.87	388.00	7.66
WAYWAL	27.00	6	115	0.03	73.63	7.06	81.55	6.60
WETUMK		18	59	0.05	118.10	7.21	335.00	5.99
LANGST	5.60	6	104	0.18	378.36	8.26	256.77	8.20
LIBERT	57.30	12	52	0.29	592.17	8.40	237.00	7.80
LONECH	10.70	10	78	0.14	294.23	7.55	306.77	6.23
ALTUSL	18.70	10	53	1.10	2155.46	8.10	434.00	8.04
MCGEE	7.00	6	96	0.03	66.08	6.63	309.30	5.71
MEEKER		143	10	0.10	216.54	8.00	395.02	9.02

Water Body	Chlor a mg/m^3	Avg Turb NTU	Avg Secchi cm	Salinity ppt	Spec Cond µS/cm	pH Units	ORP mV	DO mg/L
OKEMAH	4.50	8	81	0.08	172.00	7.57	348.88	7.79
OKMULG	6.20	8	94	0.05	101.24	7.07	299.59	7.07
OOLOGA	9.60	20	40	0.13	282.97	7.83	395.05	8.00
PVALLY	11.00	32	31	0.13	265.11	7.80	277.84	7.97
PAWHUS		3	195	0.20	393.20	8.07	373.00	8.70
PAWNEE		22	44	0.13	274.30	8.11	337.00	7.35
PERRYC	6.00	56	22	0.20	407.23	8.03	309.75	9.16
PCREEK	25.20	13	47	0.02	52.15	6.91	319.02	4.28
PRAGUE		12	74	0.11	222.40	7.76	380.00	7.02
PURCEL		14	57	0.20	403.30	8.11	430.00	7.67
LONGMI	21.50	17	45	0.13	265.88	7.93	369.81	6.74
RSKERR	17.90	28	36	0.32	651.44	7.93	173.06	8.08
SAHOMA	5.20	96	85	0.08	171.58	7.56	195.38	7.40
SARDIS	8.70	17	63	0.02	48.99	6.99	400.38	7.07
SHAWN1	5.50	9	86	0.09	187.81	7.97	293.78	8.01
SHAWN2	5.70	11	73	0.10	198.85	8.02	274.29	7.93
SHELLC	10.00	8	73	0.13	264.57	7.64	56.67	7.79
SKIATO	8.00	14	103	0.15	316.29	7.67	326.55	7.16
SOONER	3.00	3	194	1.24	2412.41	8.21	354.11	9.45
SPAVIN	16.20	5	96	0.09	193.05	8.04	381.65	7.91
SPORTS	5.44	8	90	0.15	306.41	7.54	245.39	8.43
DRAPER	2.70	8	104	0.06	121.72	7.44	380.68	5.11
STILWE	9.60	14	69	0.08	173.85	7.27	295.66	6.18
STROUD	4.70	5	108	0.09	199.23	7.62	370.61	6.88
TALAW1	5.80	4	120	0.04	79.45	7.14	330.49	7.29
TALAW2	2.60	4	136	0.04	93.31	7.23	346.30	6.93
TAYLOR	44.00	12	36	0.29	592.70	8.41	245.51	9.50
TECUMS		132	11	0.06	126.50	7.47	448.00	8.26
TENKIL	13.00	7	240	0.13	272.52	7.69	350.37	7.63
STEED	10.00	35	27	0.35	712.46	8.12	367.73	7.54
WAURIK	15.00	20	53	0.27	558.61	7.84	370.82	7.06
WFALLS	8.60	81	16	22.00	459.29	7.62	367.84	8.95
WESWAT	23.40	26	38	0.10	217.90	7.95	277.25	7.26
WEWOKA	12.00	18	41	0.08	183.08	7.44	380.66	8.00
WIPOST	17.00	36	27	0.20	419.24	7.96	182.47	8.26
WISTER	24.00	22	44	0.04	80.75	7.10	178.21	8.01

Appendix B. Sample sizes for each water body by species as well as discriminant analysis classifications. Sample sizes under twenty individuals are listed in bold text.

Water Body	**Bass**		**Crappie**		**Catfish**		**DA Class**
	W_r	**n**	**W_r**	**n**	**W_r**	**n**	
ALTUSL	102.00	**14**	94.50	**19**	90.25	57	
AMHORS	98.83	168					1
ARBUCK	92.57	548	95.60	180			1
ARCADI	102.00	88	98.83	87	91.75	54	3
ARDCIT	92.43	102	87.20	32			1
ATOBLU	89.14	58	93.20	35	83.00	**11**	1
BELLCO	98.00	106	92.33	378	83.50	95	3
BIRCH	92.57	102	91.80	30	87.25	23	4
BIXHOM	88.00	148	91.00	**4**	105.00	**7**	2
BLUEST	89.33	91	88.00	65	83.00	24	1
BOOMER	95.63	154	87.67	103	98.00	40	3
BRBOW	93.67	169	100.00	**4**	96.00	**1**	2
BROWN	85.50	196					2
BRUSHY			103.17	48			2
BURTSC	92.33	194					5
CANTON			97.33	**11**	101.00	102	
CARLAL	80.67	112	95.00	**2**	147.00	**19**	2
CARLBL			88.50	209	87.00	75	3
CARTER	80.29	98					1
CEDAR	94.43	122	88.67	**5**	105.00	**1**	2
CHANDL	102.17	80	85.80	295	104.00	**6**	1
CHICKA			86.20	23	107.75	204	
CLAREM	100.63	71					1
CLEVEL	97.00	101	93.00	314	88.00	35	2
COMANC	94.63	61					1
COPAN			98.00	46	77.00	**8**	1

Water Body	Bass		Crappie		Catfish		DA Class
	W_r	**n**	**W_r**	**n**	**W_r**	**n**	
CROWDE	96.38	93					5
CUSHIN	100.86	56					1
DRAPER	93.00	69	83.67	112	83.00	26	2
DRSPGS	90.63	513	83.80	**11**	82.67	34	2
ELKCIT	96.13	30					6
ELLSWO	101.00	103	113.33	368	75.33	**3**	3
ELMERT	90.25	164					1
ELRENO	95.67	29	104.83	282			5
ETLING	98.00	46					4
EUCHA			101.50	**11**	93.75	**15**	1
EUFAUL	94.75	881	103.83	1053	86.75	165	3
FAIRFA	93.00	103	89.00	84	86.00	34	4
FOSS			67.60	**2**	55.25	90	
FREDER			82.00	146	85.00	26	1
FTCOBB	107.29	149	116.33	197	84.00	67	3
FTGIBS	101.50	502	123.33	93	93.00	50	1
FTSUPP			92.75	**7**	84.50	44	5
FUQUA	98.25	112					6
GRAND	96.89	497	104.00	96	82.75	67	1
GREENL	96.00	245	86.80	26	90.50	**17**	1
GRSALT			112.00	**6**	13.00	**1**	
GUTHRI	91.83	23	92.67	127	87.50	40	6
HEALDT	99.50	44	99.67	125	95.50	40	1
HEFNER	98.71	162	65.50	**14**	91.50	73	6
HENRY			85.00	**5**	66.00	**1**	4
HEYBUR	81.00	73	83.00	37	83.75	30	1
HOLDEN	99.00	311	79.60	82	91.00	77	4

Water Body	**Bass**		**Crappie**		**Catfish**		**DA Class**
	W_r	**n**	**W_r**	**n**	**W_r**	**n**	
HOMINY	82.86	69	86.50	35	89.33	**9**	1
HUDSON	97.25	629	102.75	**13**	88.00	55	1
HUGO	86.14	135	98.83	256	83.00	33	2
HULAH	103.38	35					1
JNEUST	97.88	69	93.17	322	84.50	78	4
KAW	106.71	197	103.83	70	93.75	**19**	6
KEYSTO	102.14	230	90.33	71	88.75	45	5
KONAWA	89.75	834	111.00	**3**	82.75	199	6
LANGST	100.33	**19**	87.00	48	82.00	162	3
LAWTON	100.13	245	88.20	29	87.00	39	1
LIBERT	99.71	21	89.00	112	90.75	160	6
LONECH	99.14	23	100.50	194	94.33	**16**	1
LONGMI	129.43	**17**	86.67	126			1
MCGEE	86.71	232	104.00	**11**	114.00	**4**	2
MCMURT	93.25	257	86.60	55	86.75	66	3
MEEKER			92.33	244	80.75	**15**	1
MURRAY	94.75	151	90.20	**4**	81.25	31	1
NWAIYA	94.33	66					2
OKEMAH	95.00	401	83.33	172	84.25	85	1
OKMULG	92.63	448	91.20	**14**	88.50	**12**	2
OOLOGA	101.14	79	94.50	88	90.50	37	1
OVERHO			99.25	**10**	76.00	96	5
OZCOBB	93.14	36					2
PAWHUS	85.57	93					1
PAWNEE	103.83	99					1
PCREEK	88.14	253	92.60	78	89.75	22	2
PERRYC	91.63	83					3

Water Body	**Bass**		**Crappie**		**Catfish**		**DA Class**
	W_r	**n**	**W_r**	**n**	**W_r**	**n**	
PONCA	95.60	51	93.67	78	89.75	44	1
PRAGUE	94.38	171	95.00	28	81.75	43	1
PURCEL	87.20	**17**	93.33	177			1
PVALLY	94.57	31	91.67	618			1
RAYGAR	93.86	65					2
RSKERR	96.14	182	97.50	28	91.50	58	6
SAHOMA	97.40	**10**	89.20	79	97.50	43	4
SARDIS	93.14	103	92.00	96	87.00	58	2
SHAWN1	91.00	65	91.50	29	83.00	64	1
SHAWN2	93.00	95	84.80	33	91.75	67	1
SHELLC	93.29	60	112.67	25	100.25	67	4
SKIATO	89.67	222	89.50	38	81.00	46	1
SOONER	85.71	102	91.00	**1**	93.75	48	
SPAVIN			95.00	**16**	100.00	**4**	1
SPORTS	99.63	54	82.00	22	91.00	**3**	1
STEED	107.17	26	96.40	41	96.75	**15**	6
STILWE	86.83	140	120.00	**10**	91.00	24	2
STROUD	81.86	42	85.50	44	81.00	23	1
TALAW1	87.86	33					2
TALAW2	78.14	56					2
TAYLOR	106.67	65	93.25	**16**	76.25	28	6
TECUMS			99.50	134	86.00	**13**	1
TENKIL	92.00	370	97.25	**12**	87.75	35	1
TEXOMA	96.13	366	99.25	28	93.75	49	5
THBIRD	97.63	72	95.50	169	96.50	80	1
VANDER	100.43	96					
VINCENT	99.29	28					6

Water Body	**Bass**		**Crappie**		**Catfish**		**DA Class**
	W_r	**n**	**W_r**	**n**	**W_r**	**n**	
WAURIK	101.50	**17**	139.00	77	83.75	20	3
WAYWAL	77.63	98					4
WESWAT	95.75	184	87.50	149	102.75	71	1
WETUMK	86.50	250	81.00	**14**	87.25	31	2
WEWOKA	95.86	27	85.75	769	79.75	31	2
WFALLS	97.33	177	90.83	59	92.00	51	3
WIPOST	107.00	**4**	97.50	475			3
WISTER	99.50	42	102.83	143	81.25	79	2