Moses Lake Fishery Restoration Project

Annual Report
1998 - 1999

DOE/BP-00006320-1

December 2000

This Document should be cited as follows:

Burgess, Dave, "Moses Lake Fishery Restoration Project", Project No. 1995-02800, 167 electronic pages, (BPA Report DOE/BP-00006320-1)

Bonneville Power Administration
P.O. Box 3621
Portland, Oregon 97208

This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views in this report are the author's and do not necessarily represent the views of BPA.

Moses Lake Fishery Restoration Project
Project Number: 199502800

FY 1999 Annual Report

Prepared for Submission to the Bonneville Power Administration

Table of Contents

List of Figures

List if Tables

Abstract

The Moses Lake Project consists of 3 phases. Phase 1 is the assessment of all currently available physical and biological information, the collection of baseline biological data, the formulation of testable hypotheses, and the development of a detailed study plan to test the hypotheses. Phase 2 is dedicated to the implementation of the study plan including data collection, hypotheses testing, and the formulation of a management plan. Phase 3 of the project is the implementation of the management plan, monitoring and evaluation of the implemented recommendations.

The project intends to restore the failed recreational fishery for panfish species (black crappie, bluegill and yellow perch) in Moses Lake as off site mitigation for lost recreational fishing opportunities for anadromous species in the upper Columbia River.

This report summarizes the results of Phase 1 investigations and presents the study plan directed at initiating Phase 2 of the project. Phase 1of the project culminates with the formulation of testable hypotheses directed at investigating possible limiting factors to the production of panfish in Moses Lake. The limiting factors to be investigated will include water quality, habitat quantity and quality, food limitations, competition, recruitment, predation, over harvest, environmental requirements, and the physical and chemical limitations of the system in relation to the fishes.

Water quality parameters, such as temperature and dissolved oxygen, will be investigated to determine if they are limiting to fish survival and production. Nutrient concentrations will be investigated to determine if they are limiting to primary production. Phytoplankton production, composition, and bio-volume will be investigated to estimate the amount of possible forage for secondary production. Zooplankton and macroinvertebrate species composition, biomass and production will be established to determine the potential of the forage base, carrying capacity, and the probability for competitive interactions for various planktivorous and insectivorous fishes. Available habitat will be quantified and qualified by investigating habitat type, habitat complexity, habitat use and competition for habitat. Predator-prey interactions between piscivores and prey-fish will be quantified through diet analysis. Bioenergetics modeling will be used to provide quantitative estimates of the fishes' consumptive demands for comparison to forage supplies in relation to competitive interactions and the impact of predation on prey fish abundance. Finally, fish harvest by anglers will be quantified to estimate if over-harvest is limiting desired fish population levels in Moses Lake.

Identified limiting factors will be ranked to determine which have the greatest impact on the fishery, and a management plan that best addresses the limiters to the desired population structure in Moses Lake will be developed. Finally, implementation of the management plan, monitoring and evaluation of the implemented recommendations will complete the project.

Introduction

The Moses Lake Project consists of 3 phases. Phase 1 is the assessment of all currently available physical and biological information, the collection of baseline biological data, the formulation of testable hypotheses, and the development of a detailed study plan to test the hypotheses. Phase 2 is dedicated to the implementation of the study plan including data collection, hypotheses testing, and the formulation of a management plan. Phase 3 of the project is the implementation of the management plan, monitoring and evaluation of the implemented recommendations.

The project intends to restore the failed recreational fishery for panfish species (black crappie, bluegill and yellow perch) in Moses Lake as off site mitigation for lost recreational fishing opportunities for anadromous species in the upper Columbia River.

During the 1950s to the late 1970's Moses Lake was the premier fishery for resident fish species in central Washington, initially for black crappie (*Pomoxis nigromaculatus*), bluegill sunfish (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), and yellow perch (*Perca flavescens*) and in later years for rainbow trout (*Oncorhynchus mykiss*). Beginning in the late 1970's and throughout the 1980's, these fisheries experienced a long and steady decline. The decline of this fishery was probably due to a number of events, some of which have been postulated as changes in species composition, over-harvest, and changing habitat conditions. The individual impacts and interactions of these events were less well understood. In the past, the lack of both manpower and proper equipment had slowed efforts to evaluate these impacts and identify measures designed to reverse current trends.

Moses Lake and its watershed has been the subject of four major water quality and water control projects since 1977. The four major projects include a series of dilution water releases from the United States Bureau of Reclamation East Low canal made since 1977, elimination of direct sewage effluent discharge from the City of Moses Lake in 1984, a major non-point pollution source control program known as the Moses Lake Clean Lake Project which took place in the late 1980's, and a Moses Lake area monitoring project in 1991-1992 and 1997. These water quality programs provided information on nutrient concentrations and loadings to Moses Lake and focused on methods to improve water clarity and reduce nuisance algae growths. Analysis of the data collected from these projects indicated that physical parameters for water quality, such as temperature and dissolved oxygen, do not appear to be limiting to panfish recruitment, nutrient concentrations have remained relatively static, chlorophyll-a concentrations and secchi disk depth readings have gone down, and dilution flows have steadily increased since the initiation of the dilution project in 1977.

Surveys by the Washington Department of Fish and Wildlife, both creel and biological, indicated major shifts in the assemblage of harvestable fishes in Moses Lake.
Creel surveys were conducted in 1974, 1983, 1991, and 1996. These creel surveys have documented the shift in harvest of fish in Moses Lake from panfish to walleye (*Stizostedion vitreum vitreum*). The creel survey conducted in 1974 indicated that the

predominant fish harvested were black crappie and bluegill sunfish. This harvest trend continued through the 1980's. By 1983, walleye were detected in the fishery for the first time. Panfish continued to dominant the harvest, but yellow perch rather than black crappie or bluegill sunfish were the most numerous fish harvested. By 1991 the creel survey indicated the dominant warmwater fish harvested was walleye and harvest rates for panfish were at a recorded all time low. The most recent creel survey conducted in 1996 indicated that there has been a small rebound in harvest of panfish, with yellow perch as the most numerous in harvest, but the dominant fish in the harvest was still walleye.

Biological surveys were conducted on Moses Lake in 1978 and 1988. The 1978 and 1988 surveys gathered information detailing the species composition and abundance of fish species in Moses Lake. The 1978 survey indicated the population was dominated by largemouth bass and panfish. By 1988 the species composition had shifted to a population dominated by walleye, brown bullhead (*Ameirus nebulosus*) and common carp (*Cyprinus carpio*).

Baseline biological data were collected for spring and fall 1993 to 1998 and spring 1999. The baseline biological surveys collected information that was used to determined length at age and relative weights for all warmwater fish present in Moses Lake. The length at age and relative weight data indicated that growth and condition for all warmwater fish present in the Moses Lake was variable by species possibly indicating some predation or competition problems. Panfish exhibited growth rates and relative that exceeded the statewide average and national standards for all size classes. This could have possibly indicated low density populations that were obtaining forage easily. Predators, specifically walleye and smallmouth bass, exhibited growth rates that were consistent or slightly lower than the statewide averages for Washington State. In concert with these findings was the fact that both of these predators exhibited low relative weights in comparison to national standards. This may have indicated that there was low-density forage and high-density predators or possibly competition for the existing forage within Moses Lake.

Additional baseline biological information was collected during fall of 1999 and spring of 2000. This information was collected by Moses Lake Project staff, and was collected using the Washington Department of Fish and Wildlife standardized warmwater fish sampling strategy. These data were used to develop general warmwater indices and as comparative data to all other information that has been collected. Comparisons and the indices indicated that the species composition in number was dominated by yellow perch, but walleye were the dominant warmwater fish by biomass and common carp dominated the entire fish population in biomass. The warmwater fish population in Moses Lake was predator dominated. Growth and condition for warmwater fish were variable. Black crappie and bluegill sunfish had low-density populations, and the recruitment of panfish may be limited by competition or predation.

Based on the conclusions drawn from the analysis of the historical and current information (Phase 1), the Washington Department of Fish and Wildlife (WDFW) has proposed to restore the fishery through the systematic investigation of the individual aspects of the current situation. Limiting factors to be investigated include water quality, nutrient concentrations, habitat availability, food limitations, competition, predation and over harvest. Environmental conditions will be linked to the fishes habitat use to understand the physical and chemical limitations of the system. Water quality parameters will be collected to determine if at any time monthly, seasonal or annual deviations from specific life stage requirements will be limiting to panfish production.

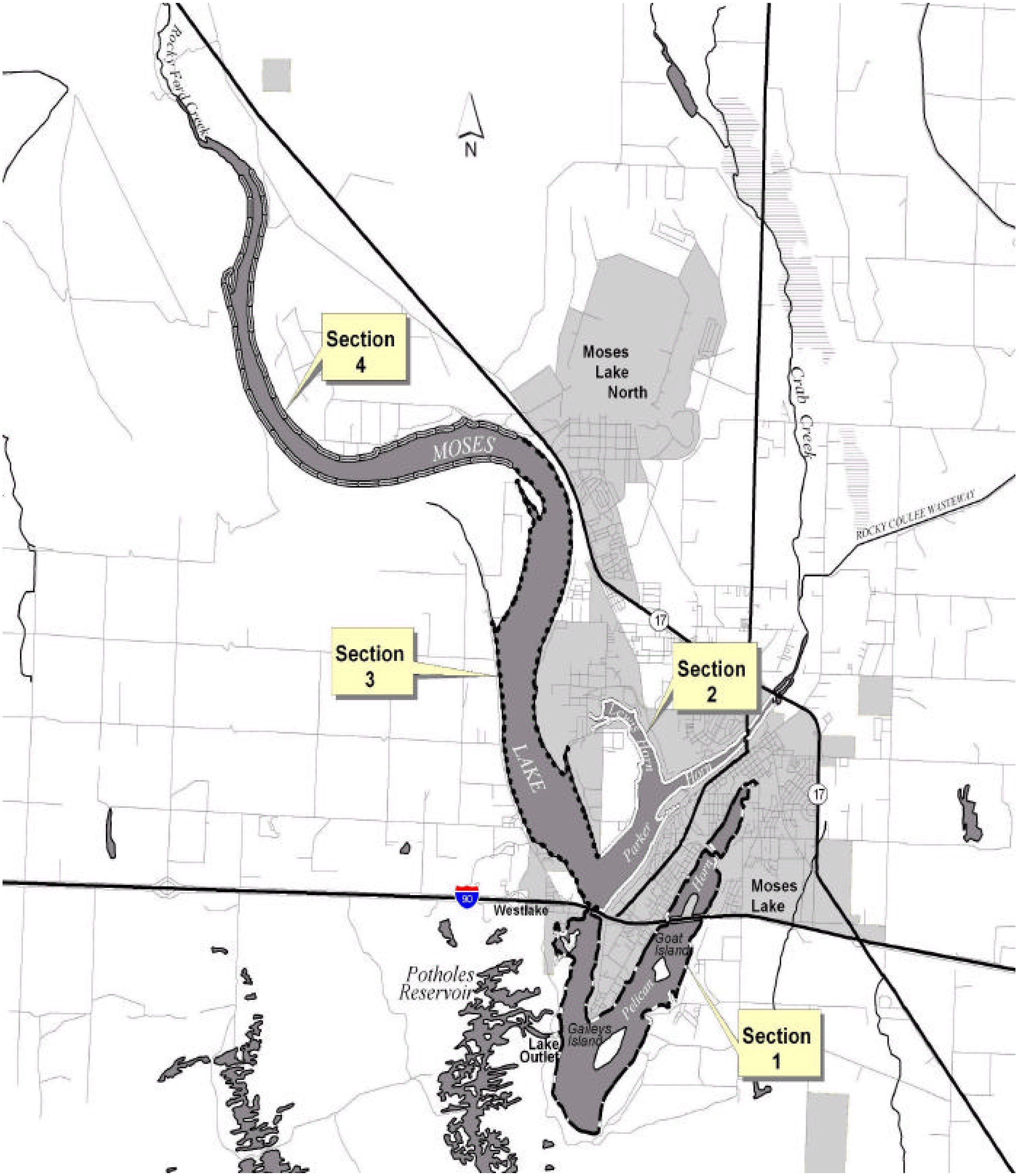
Information regarding monthly nutrient concentrations will be used to determine phytoplankton bloom species composition and timing and chlorophyll-a concentrations. Phytoplankton bio-volume, composition and production will be estimated to determine the availability of preferred forage at critical times in panfish life histories and seasonal density. Zooplankton and macroinvertebrate biomass, species composition and production will be estimated to establish the potential of the forage base, carrying capacity, and competitive interactions for various planktivorous and insectivorous fishes.

Habitat complexity will be determined before and after the fall drawdown and spring fill up to assess impacts to panfish production. Following drawdown, littoral habitat is dewatered and may force panfish into areas devoid of complex habitat possibly rendering panfish more susceptible to predation. Habitat utilization by panfish will be assessed and compared to preferred habitat. The possible impacts of drawdown or fill up limiting the use of optimum habitat by panfish will be estimated. Competition interactions for preferred habitat will be quantified. Drawdown and fill up may limit the amount of habitat available to panfish. Densities of fish exceeding the amount of habitat available may limit the amount of panfish capable of recruiting to the Moses Lake recreational fishery.

Diet electivity and selectivity in conjunction with stomach fullness will be used to estimate interspecific or intraspecific competition that may be limiting to panfish production. This information will be quantified in concert with the secondary productivity surveys. Predator prey interactions between piscivores and prey-fish will be quantified through diet analysis. Bioenergetics modeling will be used to provide quantitative estimates of fish consumptive demand to compare to forage supply. Population estimates and estimates of productivity per species will be established and panfish harvest will be quantified to determine if over-harvest is limiting panfish production in Moses Lake.

Identified limiting factors will be ranked to determine which have the greatest impacts on the fishery, and a priority based management plan that best addresses the limiters to panfish production in Moses Lake will be developed. Finally, Phase 3, the implementation of the management plan and monitoring and evaluation of the implemented recommendations will complete the project.

Figure 1 Map of Moses Lake, inflowing tributaries, outlets, adjoining reservoirs, and the surrounding area. Included in the map are the 4 sections, and the 400 meter transects that were used for the fall 1999 and spring 2000 baseline biological surveys. The 4 sections were used for the study design for Phase 2 of the project.



Description of Study Area

Moses Lake is the third largest natural lake in Washington and represents an invaluable asset for wildlife and fisheries propagation and recreational interest; see Figure 1 (Zook 1978). Native fish present in Moses Lake include: largescale sucker (*Catostomus macrocheilus*), longnose sucker (*Catostomus catostomus*), peamouth (*Mylocheilus caurinus*), and northern pikeminnow (*Ptychocheilus oregonensis*). Common carp, which have dominated the lake for the past 90 years, were first introduced to the lake when flood waters breached the outlet of the lake connecting it to the Columbia River in 1904 (Groves 1950). Gamefish species present in the lake include: black crappie, bluegill sunfish, yellow perch, pumpkinseed sunfish (*Lepomis gibbosus*), walleye, largemouth bass, smallmouth bass (*Micropterus dolomieui*), rainbow trout and lake whitefish (*Coregonus clupeaformis*). Sixteen species of fish are known to currently occupy Moses Lake.

Moses Lake is located centrally within the Columbia Plateau region. The lake covers a maximum of 6,800 acres (10.6 square miles), inundates 51.9 kilometers of shoreline, and is 16.75 kilometers long (Table 1). Tributaries to Moses Lake encompass approximately 2,041 square kilometers, principally within the Crab creek drainage (Bain 1993). The source of Crab Creek begins in Lincoln County near Davenport and the drainage area is approximately 1700 square kilometers. Crab Creek enters Moses Lake at Parker Horn. The longest part of the lake is fed by a spring fed tributary, Rocky Ford Creek. The source of this creek is a series of springs located about 4.2 kilometers east of Ephrata (Brown and Caldwell 1978). Following the development of the Columbia Basin Irrigation Project in the early 1950's, surface and subsurface runoff entering Moses Lake increased substantially.

Table 1 Physical characteristics of Moses Lake.

Area (acres)	**Max. Depth**	**Mean Depth**	**Drainage (sq km)**	
6800	11.6 m	5.8m	2567 km	
Volume (ac-ft)	**Shoreline (km)**	**Altitude (m abv msl)**	**Lat.**	**Long.**
131000	51.9	317	47 03 47	119 19 08

The climate of Moses Lake is semiarid to arid with hot, dry summers and moderately cold winters. The Cascade Mountain range, approximately 58 kilometers to the west of Moses Lake, acts as a precipitation barrier and funnels hot dry air in the summer and cold arctic air into the Columbia Basin in the winter. Average temperatures are 32° C in July and –5.5°C in January. Annual precipitation ranges from 15cm to 25cm a year with an annual snowfall in the Basin of 20cm to 25cm (Embrey and Block 1992). Ice Cover on Moses Lake is inconsistent in forming and rarely persists for extended periods of time due to the moderately cold winters.

The Columbia Plateau formed between 6 and 16.5 million years ago by the extrusion of basalt lava from northwest trending vents located in the central and southeast parts of the Plateau (Drost 1990). Tectonic action warped the region into a broad synclinal basin with several subbasins. Parts of the Plateau, as well as the basins, have been covered by

Pleistocene aged loess, a wind deposited silt. Caliche, a cement-like calcium carbonate deposit, underlies the loess in vast regions of the Columbia Plateau (Embrey and Block 1992). Moses Lake was most likely formed by natural aeolian processes of drifting sand and loess that dammed Crab Creek (Groves 1950).

The lake had no historical surface outlet until 1904 when floods channelized the aeolian processes formed dam, lowering the lake 2.4 to 3 meters (Groves 1950). In an attempt to restore the lake to historical water levels an earthen dam located on the southern end of the lake was built in 1909 (Groves 1950). This dam eventually failed and was rebuilt by the Moses Lake Irrigation District in 1929. The dam was rebuilt to use the lake as storage for late winter runoff as a source of irrigation water (Groves 1950). The Moses Lake hydrological regime was again altered by the construction of the Columbia Basin Reclamation Project. Moses Lake was connected to the Columbia Basin Reclamation Project in the 1950's. Water was pumped from the Columbia River above Grand Coulee Dam into Banks Lake and diverted by a series of canals and wasteways to Moses Lake. The Bureau of Reclamation built a second dam structure on the southern end of Moses Lake to obtain more efficient control of Moses Lake water levels and most specifically outflow of irrigation water to Potholes Reservoir. The second dam structure was constructed in 1963 (Brown and Caldwell 1978). The two aforementioned dam structures are still in existence and are currently used to fluctuate water storage levels on Moses Lake. Moses Lake water levels are regulated on an annual basis with fall drawdown and spring fill up. Drawdown generally occurs during late October and is refilled by early April. The lake level fluctuates between 315.5 meters and 317.5 meters.

The water level of Moses Lake is controlled by two entities, the Moses Lake Irrigation District and the Bureau of Reclamation. Only a limited amount of water is withdrawn from Moses Lake for the purpose of irrigation because only residents within the Moses Lake Irrigation and Rehabilitation District have withdrawal rights from Moses Lake itself (Brown and Caldwell 1978).

The area currently known as the City of Moses Lake was originally called Neppel. In 1938, the town of Neppel was incorporated, and the name of the town and the lake were changed to Moses Lake in honor of Chief Moses of the Nez Perce Tribe. At the time of incorporation the population of Moses Lake was approximately 300 and agriculture was the primary industry surrounding the lake. Today the population of Moses Lake is 14,190. The City of Moses Lake has occupied the south central part of the lake, and there has been significant shoreline development. Because Moses Lake was utilized for a large portion of the year, it was both economically and socially important to the local residents. Recreation is viewed as an industry, and a critical element to the Comprehensive Plan for the City of Moses Lake.

Historical and Current Management

Historically, harvest restriction and fish supplementation of warmwater fish in Moses Lake was limited. Bag and size limits for panfish, bass, and walleye were not implemented until recent times.

Current regulations for Moses Lake are:

a. Moses lake is a year round fishery for all fish present in the lake.
b. bluegill: 8" minimum, 5 fish daily limit.
c. black crappie: 10" minimum, 5 fish daily limit.
d. largemouth and smallmouth bass: 5 fish daily limit, 3 bass over 15 inches.
e. walleye: 18" minimum size, 5 fish daily limit, Only one fish over 24 inches.
f. rainbow trout: 5 fish daily limit, no size restriction.
g. lake whitefish: 15 fish daily limit, no size restriction.
h. All other fish present in the lake have no specific regulations for harvest.

Supplementation of fish populations has been a traditional management tool utilized to provide for fish harvest in Moses Lake. Many different types of fish have been stocked into Moses Lake. In spite of some large scale stocking strategies, few species have developed harvestable fisheries.

Warmwater fish supplementation has had an extensive history in Moses Lake (Table 2). WDFW has designed, organized and participated in two warmwater fish supplementation programs in the last 5 years. Walleye spawning and incubation has been a program on Moses Lake since the mid 1990's. This program was in conjunction with the Moses Lake Walleye Club. The program collected up to 2 million walleye eggs for incubation and rearing in a WDFW hatchery facility. These fish were used primarily for stocking in Eastern Washington lakes to initiate or supplement walleye fisheries. Additionally, in exchange for walleye eggs from Moses Lake walleye some of the reared walleye were stocked back into Moses Lake even though biological and harvest data (Tables 8 and 9) had not indicated that walleye required supplementation in Moses Lake. The amount of juvenile walleye sampled in the lake indicated that natural reproduction far exceeded the number of walleye needed to keep up with current angler harvest. As a result supplementation of walleye was suspended in Moses Lake. Those walleye supplemented in the past into Moses Lake were 2 to 3 inch fry, and based on the total amount stocked into the lake, were assumed to have recruited negligible numbers of fish to the recreational fishery.

The second warmwater supplementation program was for black crappie in Moses Lake, with the intent of increasing recruitment of black crappie into the Moses Lake fish population. This program was in its fifth year of implementation in 2001. An 80 acre section of the lake was closed at a small bridge using slatted gates to separate it from the main body of the lake. Each spring the 80 acre exclosure was stocked with between 1000 and 2000 adult spawner crappie. The black crappie were released early enough in the spring that they spawned in the exclosure, producing young-of –the-year that would rear in the exclosure for the entire growing season. Each fall during drawdown the exclosure gates were removed. The exclosure was virtually dewatered and most fish in the exclosure were pulled out into the main body of the lake. The gates were then replaced in the spring prior to lake fill up not allowing unwanted fish species to re-establish themselves in the exclosure area. Some fish remained behind following drawdown species such as, yellow perch, bluegill sunfish and walleye were collected following drawdown indicating that not all predators or competitors were removed from the exclosure. However, common carp prior to the project occurred in high densities in this area and following implementation of the exclosure carp occurred at a density much lower than the rest of the lake. The assumption behind the program was because the exclosure was devoid of almost all other fish species the black crappie produced would be in an environment free from predation, competition or disturbance.

Little has been done to document the programs efficacy. Surveys conducted during fall 1999 and fall of 2000 were directed at determining the total amount of black crappie young-of-the-year that were produced in the exclosure. In fall of 1999 a mark and recapture was conducted to determine the amount of young-of-the-year black crappie that were present in the exclosure. A rough estimate was made of approximately 10,000 young-of-the-year crappie. This same procedure was again done in fall of 2000. Rather than just mark each young-of-the-year black crappie each fish collected received a coded wire tag that would be recovered from the fish later as they recruited to the Moses lake population and fishery. This would allow for an estimate of total contribution of black crappie from the exclosure to the overall lake population, and act as a ground truthing method for black crappie population estimates by using the proportion of fish collected with coded wire tags in comparison to those collected without. The proportion could then be expanded to estimate total population of black crappie. The fall 2000 effort was stymied by the fact that few young-of-the-year black crappie were collected in the exclosure indicating poor production for the year. However, yellow perch, bluegill sunfish and walleye production in the exclosure appeared to be high. This may be an indicator that competition plays an integral role in black crappie production. This project has been monitored for crappie production since it's inception. Each year variable production has been recorded within the exclosure. This may be a microcosm of Moses Lake or production by virtue of isolation may not reflect what occurs in the main body of the lake. Regardless, the Moses Lake Project has encouraged the continuation of the program as to not disturb the current fish production cycle for panfish, and to provide another method to estimate black crappie populations in Moses Lake. Interrupting the program might disturb hypotheses testing and the current lake study. Current baseline biological information has not confirmed or denied that the program was producing more recruited black crappie

Rainbow trout have the longest and largest history of stocking in Moses Lake (Table 2). Cutthroat trout (*Oncorhynchus clarki lewisi* and *Oncorhynchus clarki bouvieri*), rainbow trout, coho (*Oncorhychus kisutch*), brown trout (*Salmo trutta*), and atlantic salmon (*Salmo salar*) were periodically stocked in Moses Lake beginning in 1916, but the lake was generally considered unsuitable for trout until 1968. Surface and subsurface water inputs from the Columbia Basin Irrigation Project increased water quality sufficiently for Moses Lake to support trout (Zook 1978). The large scale stockings that took place following 1968 were fry plants and were successful in producing large popular trout fisheries, by the late 1980's fry planting of trout was no longer a viable method of supplementation, and resulted in a failed trout fishery. This was possibly the result of predation and is consistent with the timing of the emergence of a highly dense walleye fishery and population in Moses Lake. To overcome the inability of rainbow trout to recruit to the fishery in the mid 1990's a net pen program to rear rainbow to a size where they were capable of avoiding predation was started. This program has proven to be so successful, and popular with local anglers, that it continues on an annual basis. Approximately 50,000 to 80,000 rainbow trout were reared in net pens from October to May, at which time they were released into the lake. This program was similar to the net pen programs conducted on Lake Roosevelt, Banks Lake and Potholes Reservoir. This net pen program was not funded by Bonneville Power Administration mitigation funding, but rather was independently funded by WDFW and other sources. The potential impacts of rainbow trout in relation to predation, prey or competition needs to be addressed and will be included in the hypotheses testing and study plan for this project.

Table 2 Washington Department of Fish and Wildlife stocking records for Moses Lake from 1968 to 1999 including species and number stocked. Size of fish stocked is not presented in this table.

Year	Rainbow trout	Coho	Atlantic Salmon	White crappie	BlackCrappie	Largemouth Bass	Bluegill	Walleye
1968	72,100							
1969	33,035							
1970	87,830	24,500						
1971	56,208							
1972	65,355							
1973	172,572							
1974	79,199							
1975	97,230		6,006					
1976	223,666							
1977	127,892							
1978	153,222							
1979	170,954							
1980	200,710							
1981	244,191							
1982	213,616							
1983	250,836							
1984	394,803							
1985	367,927							
1986	199,997							
1987	200,000							
1988	207,496							
1989	164,901					5,309	2,700	
1990	188,939							
1991	174,879							
1992	112,208							
1993	81,169							
1994	205,249						15	
1995	93,976				221			
1996	83,016				1,817			105,154
1997	156,917			853	3,410			358,346
1998	125,957				1,498			121,000
1999	30,707							90,000

Methods

Methodology for the Collection of Historical Baseline Water Quality Studies and Aquatic Plant and Macrophyte Surveys

Historical water quality data collected by Brown and Caldwell (1977) and Welch et al (1989) was compiled and used to address, mean seasonal temperature, dissolved oxygen (DO), total nitrogen, total phosphorus, chlorophyll-a, secchi disk, pH and annual dilution discharge. Water quality information collected during summer 2000 by the Washington Department of Ecology (WDOE), in conjunction with the Moses Lake Project addressed temperature, DO, pH and conductivity. Only a portion of this DOE data has been reported and additional information is still in process with DOE and was not available for this document. Specific methods of water quality collection done by WDOE are listed in the methods section of this document. The water quality information that will be collected for the duration of this project will be consistent with the WDOE sampling protocol. Additionally, several other water quality projects have been undertaken on Moses Lake. These studies have been cited in this proposal. For specific methods of collection for water quality information, these documents should be referenced.

The specific methods of collection for the aquatic plant and macrophyte survey can be obtained by contacting the Washington Department of Ecology.

Methodology for the Collection of Baseline Water Quality Information Collected by Washington Department of Ecology During Summer 2000

The following is a basic work plan for monitoring of Moses Lake during the summer of 2000 by Ecology's Environmental Monitoring and Trends (EMT) section. The goals for the project include

- Support WDFW monitoring requirements (evaluate primary production and nutrient status)
- Routine post-restoration monitoring, in accordance with 303(d) requirements
- Pre-TMDL (summer, 2001) baseline data collection
- Maintain EMTs Lake Water Quality Assessment program

Objectives:
The objectives are to
1) Conduct a standard water quality assessment of Moses Lake,
2) Evaluate the vertical distribution of chlorophyll and nutrients at one deep site, and
3) Evaluate post-growing season chlorophyll concentrations at two sites.

Schedule:
Most samples will be collected monthly from June through September 2000. My tentative schedule is to sample Moses Lake on June 28, July 26, August 30, and September 27. WDFW Moses Lake Project staff may collect additional samples (chlorophyll) monthly for eight more months. All samples described here will be

submitted to Ecology's Manchester Environmental Laboratory for analysis, including those collected by WDFW staff.

Stations:
Four stations will be sampled (EMT's station 3, which was east of the WDFW boat launch in Pelican Horn, will not be sampled):

Station 1: Northeast of the State Park access, just inside Parker Horn.
Station 2: Southeast of Connelly Park where the main lake turns south.
Station 4: Northwest of State Park access, about 1 mile up main lake, near west bank.
Station 5: The south end of the main lake, at the deep spot along west bank

Parameters:

Objective 1:

The following parameters will be collected monthly for four months at four stations (16 samples); nutrient samples will be composited from two strata (32 samples):

- Profiles: Temperature, pH, conductivity, dissolved oxygen
- Misc: GPS coordinates, Secchi Depth, observations
- Epilimnion composite of turbidity, chlorophyll, total phosphorus, soluble reactive phosphorus, total nitrogen (persulfate digestion), ammonia nitrogen, nitrate+nitrite nitrogen (nuts5); hypolimnion composite of nuts5.
-

Objective 2:

(12 additional nuts5; 12 additional chlorophyll)

- 2 meter discrete samples for chlorophyll (to six meters) and 3 meter discrete samples for nuts5 (to bottom) at one deep station (all months)

Objective 3:

(16 additional chlorophyll)

- Post-growing season chlorophyll samples at 2 stations monthly, October through May, 2001 (collected by WDFW)

Methodology for the Collection of Creel Survey Information for 1974, 1983, 1991 and 1996

Creel surveys from 1974, 1983 and 1991 were conducted by the Washington Department of Game. The 1996 creel survey was conducted by the Washington Department of Fish and Wildlife. All creel surveys were conducted in similar fashion and have comparable data. These studies have been cited in this proposal. For specific methods of collection for creel survey information, these documents should be referenced.

Methodology for the Collection of Baseline Biological Information from 1993 to Spring of 1999

Baseline surveys were done with a 5.5 meter Smith-Root 5.0 GPP Electrofishing boat. Using DC current at 60-120 cycles/sec at 4 to 6 amps of power. The electrofishing boat was propelled at a rate of less than .2meters/second following the shoreline of the lake maintaining a distance from shore that allowed for the inshore boom in its entirety to fish in the water. Water depth electrofished did not exceed 2 meters (Jeffrey Johnson 2000), and water transparency made it difficult to see fish that had been electroshocked at greater depths.

Seven index areas were chosen along the lake. The index areas were spread throughout the lake taking into consideration species and habitat distribution. Sampling occurred during night hours to maximize the number of species and fish collected for the sample. Several studies have shown that nighttime electrofishing catches more species, larger fish, and greater number of fish than daytime electrofishing (Murphy and Willis 1996; Kirkland 1965; Sanderson 1960; Witt and Campbell 1959; Loeb 1958). Sampling for baseline data occurred spring and fall 1993 to 1998 and spring 1999. Each sample event in the index area had approximately 1000 to 3000 seconds of electrofishing effort.

Each fish, with the exception of sculpin (*Cottis* spp.), was identified to species. All fish were measured to the nearest millimeter and most were weighed to the nearest gram. For some of the earlier years, scale samples were collected from most fish, and thereafter all larger fish.

Methodology for the Collection of Baseline Biological Information for Fall 1999 and Spring 2000

Moses Lake was surveyed by a standard WDFW methodology for warmwater sampling (Bonar et al 1999). The team conducted a fall survey October 1999 and a spring survey May 2000. Surveys were conducted pre-drawdown in the fall and post-fill up in the spring. Fish were captured using boat electrofishing (EB) and gill netting (GN). The electrofishing unit consisted of a 5.5 m Smith-Root 5.0 GPP "shock boat" using a DC current of 120 cycles / sec $^{-1}$ at 4 to 6 amps power. Experimental gill nets (45.7 m long x 2.4 m deep) were constructed of four sinking panels (two each at 7.6 m and 15.2 m long) of variable size (1.3, 1.9, 2.5, and 5.1 cm stretched mesh) monofilament.

Sampling locations were selected by dividing the lake into four representative sections and the shoreline of each section into consecutively numbered transects of approximately 400 meters. Section 1 consisted of 51 transect, Section 2: 39 transects, Section 3: 53 transects and Section 4: 50 transects. The nine islands within the lake were not included among the sites. The total amount of littoral area excluded from the survey by not sampling the islands was approximately 1.5 kilometers. This was a negligible amount of shoreline and would not contribute any additional data from what was found in the non-island littoral areas of the lake. The locations sampled were determined randomly. In each section, 15 sites were selected for electrofishing and 7-8 sites were selected for gill netting. The section to be sampled rotated each night to insure whole lake coverage should inclement weather prevent further sampling. Samples were standardized at a 2:1 ratio of electrofishing to gill netting (2:1- 1200 seconds boat electrofishing: 24 gill net hours) to reduce fish capture size and number bias between gear types (Fletcher et al. 1993, Bonar et al. 2000).

Electrofishing sampling was conducted during the evening hours. Several studies have shown that nighttime electrofishing catches more species, larger fish, and greater number of fish than daytime electrofishing (Murphy and Willis 1996; Kirkland 1965; Sanderson 1960; Witt and Campbell 1959; Loeb 1958). While electrofishing the boat was navigated along the shoreline at a slow, consistent speed, allowing for full coverage as well as maximizing netter efficiency. The shoreline of the lake was followed maintaining a distance from shore that allowed for the inshore boom to fish directly in the water, and in depths that were effective and practical for electrofishing. Shoreline areas with depths of less than or equal to 2 meters were targeted. Electrofishing has been found to be ineffective in capturing fish in depths exceeding 2 meters (Jeffrey Johnson 2000).

Gill nets were set overnight and placed perpendicular to the shoreline with the small mesh end attached onshore and the large mesh end anchored offshore. Only one gill net was set per 400 m transect.

Each fish captured was identified by species, measured for total length (TL, mm) and weighed (g). This sample included young-of-year or small juveniles (TL < 100mm). In the fall sample scales were collected to determine fish length at age. Scale samples (up to five per 10mm length class) were mounted and pressed, and the fish aged according to Jearld (1983) and Fletcher et al. (1993). Trout, carp, lake whitefish, northern pikeminnow, bullhead spp., *cottis* spp. and suckers were not aged.

Methods of Data Analysis

Baseline Biological Information from 1993 to Spring of 1999 Data Analyses

The Moses Lake Fisheries Restoration Project was unique in the sense that historical data was collected primarily with assistance from volunteers. Prior to the formation of the Moses Lake Fisheries Restoration Project a WDFW district biologist utilized the help of volunteers to obtain necessary baseline data (Korth 1999). When the Moses Lake project was brought online in 1999, data collection began immediately and was later analyzed along with the historical baseline data. One of the concerns using previously collected data was the possibility of collection bias with regards to netting primarily larger fish by the WDFW volunteers, and the use of more than two netters. Proper netting protocol demanded an unbiased approach with regards to netting shocked fish as developed in WDFW warmwater fish standardized sampling protocol.

Statistical Analysis

Analysis of variance with an alpha level of 0.05 was used to detect any differences in the length of fish captured during the spring and fall sample seasons of 1993 to 2000 (Zar 1996). The analysis was aimed at testing lengths for each species of fish between the years in which sampling occurred to detect differences of length in sampled fish over time. Historical data were statistically analyzed to determine if there was an annual difference in the length of fish within species that were sampled during the 1993 to 1999 spring and fall samples. This was done to detect a size bias or a trend in the size of fish captured in the baseline biological data. Analysis revealed that there was a significant difference in the mean length of fish captured in the baseline samples as compared to fish sampled in fall 1999 using the WDFW standardized sampling protocol. Because of this finding, recent historical data will not be used in generating the indices listed below. This information will still be used to develop length at age and relative weight indices.

Baseline Biological Data Analysis

Conventional Analysis and Sampling Indices

Conventional analysis and indices were conducted calculating species composition, biomass, catch per unit effort (CPUE), length frequency histograms, proportional stock densities (PSD), length at age, and relative weight (W_r). Using spreadsheet macros developed by WDFW staff on Corel® Quattro Pro, the following analyses were performed on data collected during the fall 1999 and spring 2000 surveys.

Species Composition and Biomass

Species composition was the percentage of total count of individual species sampled compared to the total count of individuals sampled from the fish community of Moses Lake. Species biomass was the percentage of total weight of individual species sampled compared to the total weight of the total individuals sampled from the fish community.

Species composition and percent biomass were calculated separately for both electrofishing and gillnetting techniques and also pooled for the total species composition of all fish surveyed during each sampling season. Calculations conducted separately for both techniques were used to illustrate the bias between sampling gears. Pooling all the data for each sample season allowed for analysis of the entire spectrum of available fish. Young of year (YOY) were excluded from all analyses because mortality rates are high and unpredictable which could skew results.

Catch Per Unit Effort

Catch per unit effort (CPUE) was the calculation of the number of fish of all ages that are caught for a given effort and could be categorized as a unit of time or space (Hubert 1983). During surveys on Moses Lake, a unit effort for electrofishing and gillnetting was represented by 600 seconds and one overnight set (12 to 24 hours), respectively. CPUE was calculated for each of the individual species for both electrofishing and gillnetting sampling methods. Confidence intervals (CI) at 80% were determined for each species CPUE and by the method used to sample. Each CI was calculated using the following formula:

$$X \pm (t_{\alpha}^{(n-1)})\,(s/\sqrt{n})$$

Where X was the mean CPUE, $t_{\alpha}^{(n-1)}$ was the t critical value at a prescribed alpha level for the appropriate degrees of freedom $(n-1)$, and $(s/\sqrt{n})$ was the standard error of the mean CPUE. Understanding the amount of time needed to catch a given number of fish was useful in developing future projects and determining future assemblage composition.

Length and Age Frequency

Length frequency histograms represented the percentage of each size class of fish sampled. Percentages, rather than the number of fish sampled, were used for constructing length frequency histograms.

Length-frequency histograms described the size structure of fishes within Moses Lake, and were useful predictors of future recruitment or year class mortality (Jearld 1983). Length frequencies were determined separately for both gillnetting and electrofishing methods to determine differences in the size and/or species selectivity of each method. Length frequency histograms excluded young-of-the-year fishes.

Age frequency histograms represented the distribution of sampled fish based on age. Percentages, rather than the number of fish sampled, were used for constructing age frequency histogram because it is better for comparative reasons. Each age group was separated based on the minimum and maximum size at age as determined from the results of calculations using Lee's regression. Age frequency histograms were constructed for black crappie, bluegill sunfish, largemouth bass, smallmouth bass, walleye and yellow perch from fish sampled during the fall of 1999. As with the length frequency histograms, young-of-the-year fishes were excluded.

Proportional and Relative Stock Densities

Proportional stock densities (PSD) were a tool for examining the balance of a population. Both PSD and RSD indices were useful tools for managers as predictors of the quality of the fishery (Divens 1988). Proportional stock densities were an index of the proportion of quality size fish within the standing stock. Fish were categorized as either a stock or quality size with regard to length as determined by Gabelhouse (1983, 1984). The formula used to calculate PSD was:

PSD = (number ≥ minimum quality length fish / number ≥ minimum stock length) * 100

Relative stock density indices were developed as a modification of PSD's. Gabelhouse (1983, 1984) expanded the former quality length into stock, quality, preferred, memorable and trophy lengths. Sizes of fish in these categories were rated as a percentage of the world record for a particular fish. RSD was calculated using the following formula:

RSD = [(the number of fish ≥ specific length) / (number of fish ≥ stock length)] * 100

Table 3 Proportional Stock Density (PSD) and Relative Stock Density (RSD) nationally standardized length categories. Measurements are total length in millimeters for each category (Anderson and Neumann 1996).

Species	Stock	Quality	Preferred	Memorable	Trophy
black crappie	130	200	250	300	380
bluegill sunfish	80	150	200	250	300
largemouth bass	200	300	380	510	630
smallmouth bass	180	280	350	430	510
walleye	250	380	510	630	760
yellow perch	130	200	250	300	380
rainbow trout	250	400	500	650	800
common carp	280	410	530	660	840

Length at Age

Length at age of fishes sampled from Moses Lake was determined using the direct proportion method (Jearld 1983) and the Lee's modification of the direct proportional method (Carlander 1982). All age determinations were based on reading scales; i.e. determining the location of the focus, the distance between the focus and each annuli, and the total number of annuli. Total length at annulus formation using the direct proportion method was calculated as:

$$L_n=(A*TL)/S$$

where *A* was the radius of the fish scale at age n, *TL* was the total length of the fish captured and *S* was the total radius of the scale at capture. Whereas Lee's modification was calculated as:

$$L_n=a+A*(TL-a)/S$$

where *a* was the species-specific standard intercept from a scale radius-fish length regression.

For each species, the mean back-calculated length at age was presented for each year class as well as the overall mean length of each age class. An 80% confidence interval was applied for all mean lengths. The mean length for a given age was a useful comparative tool with respect to regional or statewide averages, between bodies of water and within a system during different times.

Relative Weight Index

Condition or relative weight index was used to analyze the weight of a given fish against the length specific national standard weight of a fish of the same length. Relative weight is calculated as:

$$W_r=(W/W_s) * 100$$

where W was the weight of the fish in question and W_s was the national standard weight. A fish with a relative weight of 100 was in average condition with regards to the national average (Anderson and Gutreuter 1983). Relative weights were useful indices for comparative analysis of fish within and between systems.

Results

Historical Aquatic Macrophyte and Plant Survey

A plant distribution and density survey was conducted to record plant species presence and density in Moses Lake (Table 4). The survey indicated that most aquatic macrophytes were not present in high densities in any section of the lake. Aquatic macrophyte densities and distribution were probably limited by bioturbation (common carp), and fall drawdown, that dewater and lead to desiccation of the macrophytes, preventing the establishment of dense complex macrophyte communities. Sago pondweed (*Potamogeton pectinatus*) was given the highest distribution value (3), indicating that it was growing in large patches, co-dominant with other plants. The remaining species of macrophytes identified were all given a value of 2, with exception of coontail: hornwort (*Ceratophyllum demersum*), which received a distribution value of 1. The most abundant shoreline plants were Bulrush (*Scirpus* spp.) and Reed canarygrass (*Phalaris arundinacia*), which were both assigned values of 3. All other shoreline plants received distribution values of 2 or 1.

Eurasian milfoil (*Myriophyllum spicatum*) had been reported in Moses Lake. Only a small piece of a milfoil was found, not enough to conclude that it was Eurasian milfoil. Other plant species of concern identified on Moses Lake included purple loosestrife (*Lythrum salicaria*), common reed (*Phragmites communis*), and yellow flag iris (*Iris pseudacorus*). Purple loosestrife is listed with the state as a class B noxious weed. Common reed and yellow flag iris are of concern, as they tend to be invasive.

Low density macrophyte growth may indicate reduced productivity in the lake. It may also be an indication that common carp were increasing turbidity not allowing for plant colonization in deeper water or were disturbing plant beds not allowing for widespread colonization of plants. Drawdown might have been contributing to the lack in plant density because during drawdown plants could be dewatered and desiccated preventing plant colonization. Low density macrophytes limit the complexity of habitat for panfish to use for avoiding predation. The survey indicates that very little dense macrophyte growth, or large macrophyte beds exist in Moses Lake.

Table 4 Summary and Distribution value of plants found in Moses Lake and along the shoreline of Moses Lake. The Washington Department of Ecology July 15, 1998 conducted the survey.

Scientific Name	Common Name	Distribution Value
Carex sp.	Sedge	1
Ceratophyllum demersum	Coontail: hornwort	1
Iris pseudacorus	Yellow flag	2
Junchus sp.	Rush	1
Lythrum salicaria	Purple Loosestrife	2
Myriophyllum sp.	Water milfoil	1
Phalaris arundinacia	Reed canarygrass	3
Phragmites communis	Common reed	2
Potamogeton crispus	Curly leaf pondweed	2
Potamogeton illinoensus	Illinois pondweed	2
Potamogeton pectinatus	Sago pondweed	3
Potamogeton sp. (thin leaved)	Thin leaved pondweed	2
Scirpus sp.	Bulrush	3
Typha latifolia	Common cat-tail	2

Distribution Value Definitions:

0 The value was not recorded (plant may not be submersed).
1 Few plants in only one or a few locations.
2 Few plants but with wide patchy distribution.
3 Plants growing in large patches, co-dominant with other plants.
4 Plants in nearly monospecific patches, dominant.
5 Thick growth covering the substrate at the exclusion of other species.

Historical Water Quality Surveys

The aquatic environment of Moses Lake has been studied extensively since 1963. The studies focused on water quality restoration of Moses Lake to improve the lake's aesthetics.
Moses Lake was considered hypereutrophic. Anecdotal stories indicated that the early settlers reported the algal blooms on Moses Lake appeared to be, " So dense that one could drive a wagon across the lake without fear of getting wet" (Korth 2001).
The Columbia plateau is naturally high in phosphorous, and the advent of irrigation and the subsequent use of fertilizers exacerbated high nutrient runoff into Moses Lake. Sylvester and Oglesby (1964) concluded that the excessive loading of phosphorus and nitrogen from the inflow of tributary streams and more recently the influence of treated sewage effluent caused the hypereutrophic condition of Moses Lake. Carp within Moses Lake have been implicated as contributing to the internal phosphorus loading, as well as the lake's high turbidity, through excretion and re-suspension of bottom sediments during feeding (Sylvester and Oglesby 1964). Sylvester and Oglesby recommended that low nutrient Columbia River water from the nearby East Low Canal be routed through Moses Lake to dilute and reduce nutrient concentrations (1964).

Following the conclusions of Sylvester and Oglesby, Clinton Connelly, Director of the Moses Lake Irrigation District, commissioned a project to restore and maintain desirable water quality in Moses Lake. Brown and Caldwell, consulting engineers from the University of Washington, were hired to design the Moses Lake Pilot Project. Designs were developed to route dilution water from the Bureau of Reclamation's East Low Canal into Parker Horn of Moses Lake. The project was implemented and operational by March of 1977. The dilution project continues to presently route dilution water through Moses Lake.

Brown and Caldwell (1978) concluded that dramatic improvements in water transparency and algal growth were observed in Parker Horn and in the lower portion of Moses Lake as a result of the dilution process. Visible improvements in water clarity and algal growth were more pronounced than were the nutrient concentration changes (Brown and Caldwell, 1978).

In 1982, The Moses Lake Dilution: Phase II Project to improve water quality in Pelican Horn was initiated based on the success of the dilution facility in Parker horn. Dilution did not work as effectively in this section of the lake. Improvements in water quality were not realized until 1984 when high phosphorus loaded sewage effluent was diverted from the lake (Welch 1989).

By 1985, additional water quality improvement projects were implemented. The Moses Lake Clean Lake Project developed Best Management Practices (BMP's). The BMP's recommended the construction of a settling pond to contain phosphorous lost via farming practices and from Rocky Ford Creek, which has naturally high phosphorous concentrations. Additionally, the dam was intended to prevent carp from migrating into

Rocky Ford creek preventing them from disturbing sediments in the creek and/or re-suspending nutrients that could have been carried to Moses Lake (Bain 1985).

The techniques applied during the four major projects have resulted in improved water quality. Moses Lake was still considered eutrophic, but not hypereutrophic as before treatment (Welch et al., 1989). This improvement in water quality had taken approximately twenty-five years to achieve. During this time the impact to the fishery had mostly been ignored. Bain states, "The District (Moses Lake Irrigation District) should continue to support fisheries enhancement programs." (1990). Additionally, Welch et al. (1983) states, "While the cause and effect relationships of algal changes and biotic factors, such as zooplankton, macrophytes, and fish, can only be speculated, it seems clear that a more thorough understanding of water quality dynamics both before and after pumping events requires that these factors be investigated in order to attribute the proper portion of the cause for algal control to dilution/flushing in Moses Lake…"

Temperature

The life associated with aquatic environments is actively regulated by water temperature. Fish, zooplankton, and benthic invertebrates are poikilotherms; therefore temperature affects their metabolic rate, growth rate and reproductive ability (McLellan 2000). The fish most sensitive to temperature present in the Moses Lake fish population are rainbow trout. Rainbow trout prefer temperatures less than 21°C and temperatures above 27°C are considered lethal (Wydoski and Whitney 1979). Warmwater fish have a greater tolerance to temperature variance. Bluegill sunfish, smallmouth bass, largemouth bass, and walleye have an upward range of at least 26°C. Bluegill sunfish can tolerate water temperatures up to 29°C and the walleye's range is even higher at 35°C (Wydoski and Whitney 1979).

Mean seasonal temperatures were generally within the tolerances of rainbow trout. During the summer of 1963 the mean seasonal temperature was 28.8°C±14.6 and exceeded the tolerance of rainbow trout (Table 5). The confidence interval size may have indicated that the seasonal temperatures were highly variable and possibly only reached lethal limits for short periods of time.

The most recent temperature data were collected by the Department of Ecology from Moses Lake (Table 6). The data indicated that Moses Lake during summer 2000 began to stratify from three meters to the bottom of the lake at seven meters for the month of June. Surface temperature was 24.07 °C and the temperature at six meters was 19.51°C. By July, the lake was stratified from five meters to the bottom. Surface temperature for July was 24.34°C, and the temperature at five meters was 21.31°C. In August the lake became isothermic the temperature at the surface of the lake was 21.84C°, and was 21.57C° at 7 meters. There was only a 0.33°C difference in temperature between top and bottom.

The existence of a popular rainbow trout fishery on Moses Lake could possibly indicate that the high water temperatures in Moses Lake did not negatively impact the trout population, and that the more tolerant warmwater species would not be influenced negatively by water temperature. However, subsurface springs resulting from increased irrigation in the basin and the input of cooler dilution water into the lake could provide thermal refugia from lethal temperatures. As temperatures increase in Moses Lake panfish may begin to seek areas with thermal refuge from temperatures exceeding their comfort ranges. Concentrations of panfish as a result of increased water temperatures may increase their susceptibility to predation. Higher water temperatures dictate metabolic rates; with higher temperatures consumption of by both zooplanktivores and predators may be at or above production for the lake. Over grazing or over predation may be controlling panfish production as a result of competition or predation.

The decrease in water temperatures may have increased survival for rainbow trout, allowing for increased competition or predation on panfish. Decreased water temperatures may also result in delayed spawn timing for panfish. This could potentially reduce the size and fat stores of young-of-the-year panfish resulting in decreased over winter survival.

Table 5 Water quality seasonal means for 1963, winter 1964, 1977, 1982, 1986, 1987 and 1988. Parameters presented are temperature, dissolved oxygen, total phosphorous (Total P) and total nitrogen (Total N). Confidence intervals (CI) were calculated for 95%. Data was taken from Sylvester and Oglesby (1964) Brown and Caldwell (1978) and Welch et al. (1989).

	Temperature C°			**Dissolved Oxygen mg/l**			**Total – P mg/l**			**Total N mg/l**		
	Mean	CI	n	Mean	CI	n	Mean	CI	n	Mean	CI	n
Spring 1963	13.4	3.3	11	7.6	1.6	4		0.3	8			
Summer 1963	28.8	14.6	28	7.9	1.0	26		0.1	24			
Fall 1963	9.1	7.8	7	9.2	2.7	7		1.2	4			
Winter 1964	2.5	5.5	3	19.4	9.4	3			0			
Winter 1977	5.1	0.2	32	13.0	0.4	29	58.4	18.2	29			
Spring 1977	12.3	0.4	360	9.4	0.3	319	73.8	5.3	351			
Summer 1977	21.3	0.4	180	7.9	0.6	120	118.6	11.3	177			
Fall 1977	14.5	0.4	39	7.4	0.6	20	84.4	10.1	40			
Winter 1982	5.3	0.1	14	11.1	6.8	5	138	72.7	16	1332.5	543	7
Spring 1982	14.4	1.0	96	9.4	1.1	29	87.9	24.2	107	532.2	75.3	53
Summer 1982	21.2	0.4	106	5.7	1.3	28	134.0	28.9	127	713	118.9	42
Fall 1982	13.5	0.7	42	7.9	0.5	12	136.4	26.2	46			
Winter 1986	6.0	2.1	9	12.4	5.2	3	101.6	17.2	30	1182.2	252.7	18
Spring 1986	16.7	0.9	129	1.9	1.3	24	71.1	6.7	188	583.6	159	65
Summer 1986	20.0	0.4	131	6.9	1.5	23	76.5	11.4	192	684.5	293.1	31
Fall 1986	13.7	1.2	30	10.4	1.0	5	86.0	13.7	27	1018.1	353.9	21
Winter 1986	3.5	1.1	14				134.6	53.3	9	1696.7	821.3	9
Spring 1987	13.2	0.8	101	8.0	1.3	20	61.6	7.3	168	746.9	292.4	33
Summer 1987	21.0	1.1	103	5.8	1.9	22	88.2	10.0	149	882.4	404.9	36
Fall 1987	11.2	2.0	36	6.8	4.4	4	98.9	14.5	41	595.8	546.2	5
Winter 1987	6.6	1.3	19				104.6	35.3	18	1184.5	556.2	10
Spring 1988	14.4	3.0	98	10.4	1.3	24	57.5	9.7	151	920.2	568.4	46
Summer 1988	18.1	0.6	93	8.0	1.2	42	90.8	10.4	128	1098.1	489.9	41
Fall 1988	13.0	2.0	6			0	113	82.8	6	7805.5	21471.8	4

Table 6 Data collected by Washington Department of Ecology during June, July and August 2000. Temperature was measured in degrees Celsius, dissolved oxygen (DO) was measured in mg/l, pH was measured in units, and Conductivity was measured in MicroSiemens/cm.

June						July						August				
Depth	Temp	DO	pH	Cond		Depth	Temp	DO	pH	Cond		Depth	Temp	DO	pH	Cond
0	24.07	12.4	9.0	245		0	24.3	12.2	9.2	224		0	21.8	6.8	8.9	278
1	23.91	12.4	9.0	247		1	24.4	12.2	9.3	224		1	21.8	6.5	8.9	278
2	23.34	12.3	9.0	251		2	24.3	12	9.3	224		2	21.8	6.3	8.9	280
3	20.46	9.4	8.9	246		3	24.1	10.9	9.2	225		3	21.7	5.8	8.9	280
4	20.31	8	8.8	251		4	24	10.9	9.2	226		4	21.7	5.8	8.9	282
5	20.05	6.6	8.7	266		5	23.4	9	9.1	238		5	21.7	5.7	8.9	281
6	19.51	3.6	8.4	276		6	21.3	1.6	8.4	261		6	21.7	5.7	8.9	279
7	18.77	0.25	8.1	274		6	20.8	0.16	8.2	270		6	21.7	5.7	8.9	280
						7	20.2	0.11	8	278		7	21.5	0.97	8.5	285

Dissolved Oxygen (DO)

Fish require oxygen for metabolic functions. The amount of DO within a body of water directly influences the ability of fish to survive. As with temperature, rainbow trout are more sensitive to lower DO levels than warmwater species. The Environmental Protection Agency sets the DO requirement for rainbow trout at 4.0mg/l or greater, but Boyd (1990) sets the requirement at 2.5mg/l or greater. Warmwater fish cannot survive less than 1mg/l and thrive in DO levels greater than 2.5mg/l (Boyd 1990).

The lowest recorded seasonal mean for DO in Moses Lake was 1.9mg/l ±1.3 in spring of 1986 (Table 5). DO levels appeared to have fallen below preferred levels for panfish, but it appears to be an aberrant seasonal mean because there is not another seasonal mean that indicates as low a DO concentration. Rainbow trout persist in Moses Lake through these periods of reduced DO and indicating that at least some portions of the lake have high enough concentrations of DO to allow for fish to persist.

The most recent data collected for DO was collected by the Department of Ecology from Moses Lake (Table 6). Profiles from the month of June indicated that DO was greater than 3 mg/l down to six meters, but at seven meters DO reduced to 0.25 mg/l. This supported the temperature data illustrating that the lake was beginning to stratify. By July, DO was greater than 9.0 mg/l down to four meters, but dropped 1.58 mg/l between four and five meters, 0.16 mg/l at six meters and 0.11 mg/l at seven meters. This would support the conclusion drawn from the temperature data that the lake stratified in the month of July. By August, DO levels were relatively static at a range from 6.78mg/l to 5.65mg/l from the surface to six meters. DO at seven meters was 0.97 mg/l. In support of the temperature data, it would appear that the lake was not stratified in August.

Reduced DO levels may decrease the amount of preferred habitat for panfish especially as the lake stratifies. As a result this may concentrate panfish in areas making them more susceptible to predation and increasing competition for forage. The overall reduction in habitat available in Moses Lake because of reduced DO levels would not appear to be limiting. The mean depth of Moses Lake is shallower than the areas that have low DO concentrations. As a result it would appear that little to no area critical to fish production would potentially be affected by the lack of DO in some of the isolated deeper areas within Moses Lake.

Nitrogen

Nitrogen is usually not toxic in the quantities found in lakes and rivers up to 10mg/l or 10000µg/l (Horne and Goldman 1994). Moses Lake did not usually exceed this limit. The exception was fall of 1988. Confidence intervals for fall 1988 indicated that nitrogen Levels could have exceeded the lethal limit for fish in Moses Lake. The highest recorded seasonal mean of total nitrogen occurred in fall 1988, 7805.5µg/l ±21,471.8. This mean and confidence interval were based on a small sample size, not accounting for variability of nitrogen concentration throughout the lake The lowest recorded seasonal mean of total nitrogen occurred in spring 1982, 532.2µg/l ± 75.3 (Table 5).

The trend line for seasonal mean total nitrogen concentrations for Moses Lake indicated that the concentrations of total nitrogen might have increased from 1977 to 1988 (Figure 2). The trend line equation indicated that the concentrations of total nitrogen were possibly increasing by 161.84µg/l per season sampled. This rate of increase could have been exacerbated by the fall 1988 seasonal mean of 7805.5µg/l ± 21,471.8.

Phosphorus

Phosphorus is essential for all living organisms. Phosphorous is generally the limiting nutrient for growth and can cause proliferations of algal growth (McLellan 2000). The amount of total phosphorus determines a lakes trophic status. A lake such as Moses Lake with an annual mean greater than 25µg/l is considered eutrophic. Moses Lake exceeds total phosphorus lake nutrient criterion established in Washington State water quality standards for surface water (Carrol et al 2000). The highest recorded seasonal mean for total phosphorous occurred in fall 1982, 136.4µg/l ± 26.2. The lowest recorded seasonal mean total phosphorous occurred in spring 1988, 57.5µg/l ± 9.7 (Table 5). For every seasonal mean from 1977 to 1988, Moses Lake annual means exceeded the standard. The major impacts on fish from high phosphorous concentrations are algal blooms that produce algal toxins. Fish mortality can be the result of toxins produced by algal growth or oxygen depletion from die off and decomposition of these algae (Boyd 1990).

A trend line for seasonal mean total phosphorous concentrations for Moses Lake indicated that the concentrations of total phosphorous might have decreased from 1977 to 1988 (Figure 2). The trend line equation indicated that the concentrations of total phosphorous may have actually decreased by 0.23µg/l per season sampled.

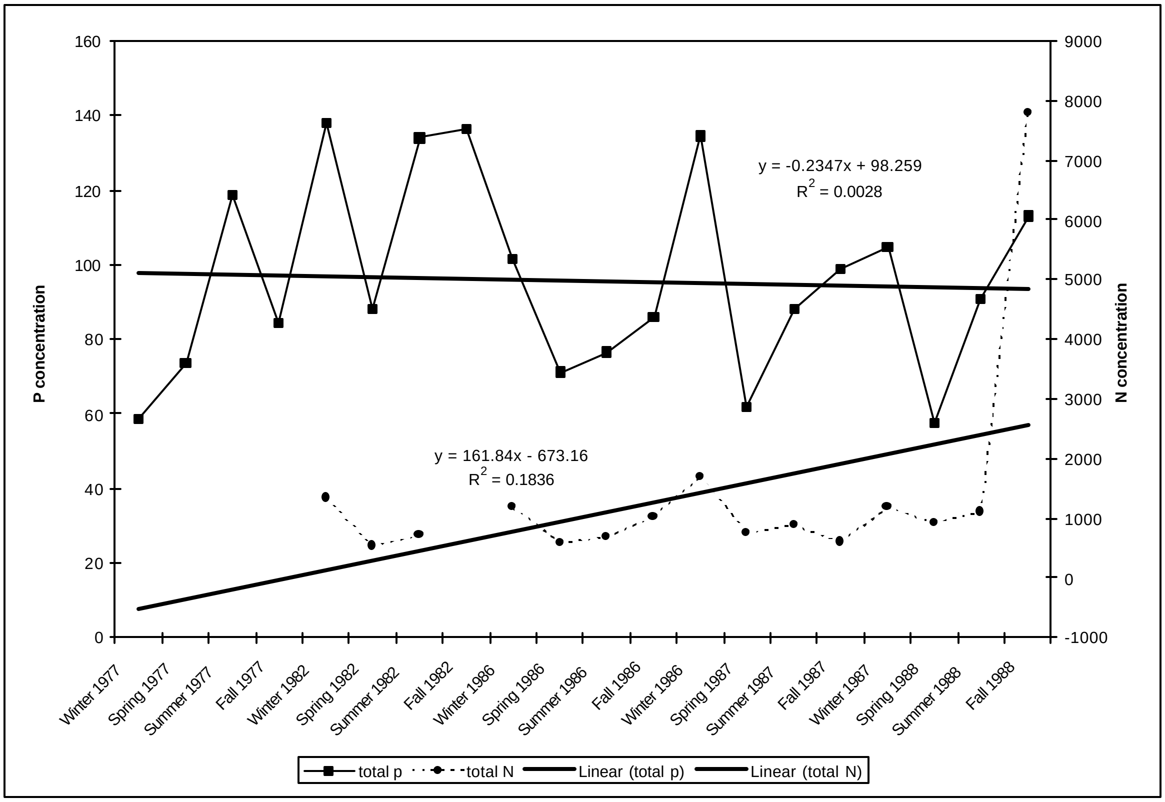


Figure 2 Seasonal mean concentrations of total nitrogen (Total n) and total phosphorous (Total P) from data collected during 1977 to 1988. Concentrations of both total nitrogen and total phosphorous were measured in mg/l. Data was taken from Brown and Caldwell (1978) and Welch et al. (1989).

Chlorophyll-a

Chlorophyll-a is one of the criteria to characterize a lakes trophic status. A lake with a chlorophyll-a greater than 10 ì g/l is considered eutrophic and highly productive. The chlorophyll-a measurements for Moses Lake exceeded the concentration standard for most samples. However, spring samples in 1986,1987 and 1988 were below the standard for eutrophic lakes. The highest recorded seasonal mean for chlorophyll-a occurred in winter 1981-82, 60.7μg/l ± 12.2. The lowest recorded seasonal mean chlorophyll-a occurred in spring 1988, 4.6μg/l ± 0.8 (Table 7).

The trend line equation for seasonal mean chlorophyll-a concentrations for Moses Lake for the years 1977 to 1988 indicated that the concentrations of chlorophyll-a decreased by 2.02μg/l per season sampled. The R^2 is 0.3716 indicating that the data was variable and might not accurately depict the trend. Separating by season it would appear that chlorophyll-a production was not only decreasing overall, but was decreasing seasonally over the time represented in the Figure 3. The reduction in chlorophyll-a productivity appears to be uniform for spring and fall samples. Current chlorophyll-a information will be acquired to determine if productivity has continued to decrease in this manner. This will be addressed in Phase 2 of the project.

Secchi Disk

Secchi disk measurements help to determine a lakes trophic status. A lake with a transparency of less than 2 meters is considered to be eutrophic. Overall Moses Lake Secchi disk measurements were low and rarely exceeded the 2 meter standard. The highest recorded seasonal mean for secchi disk occurred in spring 1977, 4.1m ± 0.3. The lowest recorded seasonal mean chlorophyll-a occurred in spring 1988, 0.6 m ± 0.3 (Table 7).

The trend line for seasonal mean secchi disk measurements for Moses Lake indicated that the secchi disk depths decreased from 1977 to 1988 (Figure 4). The trend line equation indicated that the secchi disk depths decreased by 0.12 m per season sampled. The R^2 was 0.2914, indicating that the data was variable and might not accurately depict the trend.

pH

A pH of 0-7 is considered acidic. A pH of 7 is considered neutral, and a pH of 7-14 is considered alkaline. Generally the accepted pH range for fish is 5 to 9. For warmwater fish the range is 6.5 to 9. A pH of 4 results in acid death, 4 to 5 in no reproduction, and 4 to 6.5 in slow growth (Boyd 1990). pH data indicated that the water in Moses Lake ranged from neutral to slightly alkaline (Table 7). While Moses Lake was more alkaline, pH 7.5 to 9, it fell within the tolerance range for all fish species within the lake, and does not appear to affect reproduction, recruitment or growth. The most recent pH data collected by the Department of Ecology from Moses Lake illustrated that pH values appeared to be consistent with what was collected in the 1977 to 1988 data.

Table 7 Water quality seasonal means for winter 1976, 1977, winter 1981, 1982, 1986, 1987 and 1988. Parameters presented are chlorophyll-a, secchi depth, and pH. Confidence intervals (CI) were calculated for 95%. Data was taken from Brown and Caldwell (1978) and Welch et al. (1989).

	Chlorophyll-a mg/l			**Secchi Depth depth in meters**			**pH**		
	Mean	CI	n	Mean	CI	n	Mean	CI	n
Winter 1976-77	59.4	18.2	16	2.1	0.8	15	8.7	0.1	31
Spring 1977	27.4	4.1	196	4.1	0.3	134	8.5	0.0	320
Summer 1977	45.2	7.5	98	3.7	0.4	72	8.6	0.1	180
Fall 1977	31.0	7.7	24	3.9	0.4	16	8.7	0.1	39
Winter 1981-82	60.7	12.2	16	1.3	1.9	5	8.5	0.2	14
Spring 1982	11.5	2.7	103	1.7	0.4	41	8.1	0.2	95
Summer 1982	23.4	3.8	121	1.1	0.2	47	8.5	0.1	163
Fall 1982	37.2	13.0	48	1.0	0.2	21	8.1	0.1	59
Winter 1985-86	31.4	10.0	12	.6	0.3	4	7.0	0.5	9
Spring 1986	7.7	1.0	129	3.4	3.6	40	8.7	0.1	130
Summer 1986	17.3	2.9	97	1.1	0.2	35	8.7	0.1	144
Fall 1986	34.3	11.5	20	.8	0.2	6	8.7	0.1	21
Spring 1987	6.6	1.1	122	1.3	0.2	28	Na		0
Summer 1987	27.0	8.0	108	1.3	0.2	27	8.0	0.3	120
Fall 1987	29.3	13.1	18	1.3	0.7	5	8.9	0.2	105
Spring 1988	4.6	0.8	94	1.8	0.5	29	8.7	0.1	18
Summer 1988	14.0	2.1	91	1.3	0.2	25	8.4	0.1	109

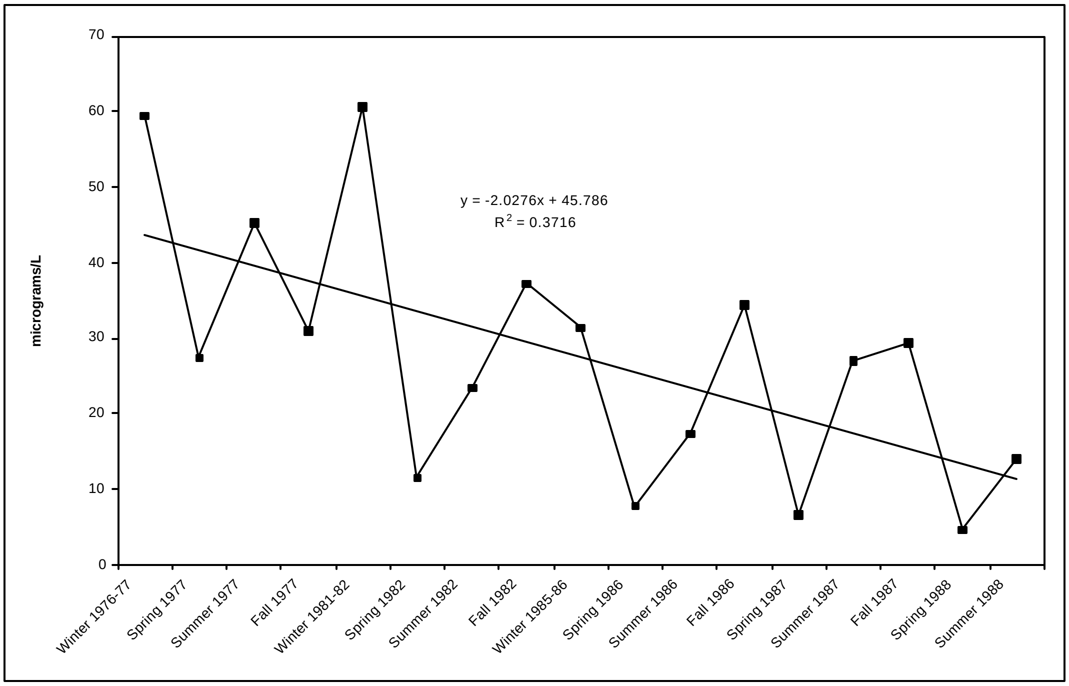


Figure 3 Seasonal mean concentrations of chlorophyll-a from data collected during 1977 to 1988. Concentrations of chlorophyll-a were measured in mg/l. Data was taken from Brown and Caldwell (1978) and Welch et al (1989).

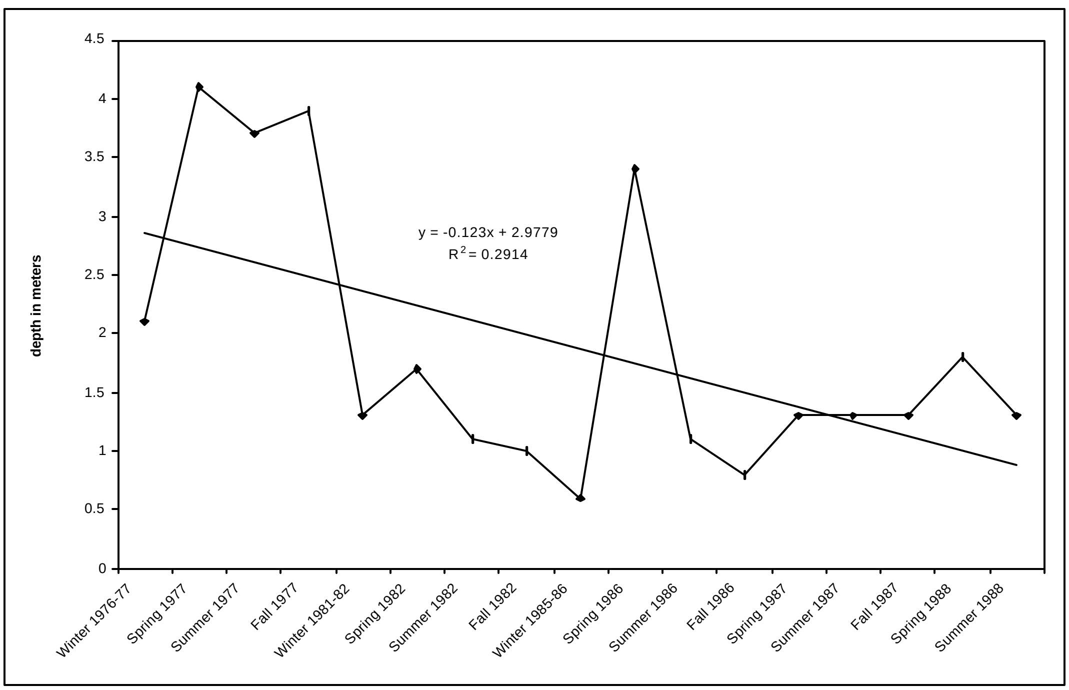


Figure 4 Seasonal mean secchi disk depth readings from data collected during 1977 to 1988. Secchi disk depth readings were measured in tenths of meters. Data was taken from Brown and Caldwell (1978) and Welch et al (1989).

Dilution Releases

Dilution for Moses Lake began as a demonstration in 1976. The project was fully initiated in 1977. In 1984, the cool summer precluded the dilution of Moses Lake. The total amount of dilution water flowing through Moses Lake has been variable in release amounts (Figure 5). A slight increasing trend in later years may indicate that the total amount of water released for dilution has increased. Current information in regards to dilution will be addressed in Phase 2 of the project.

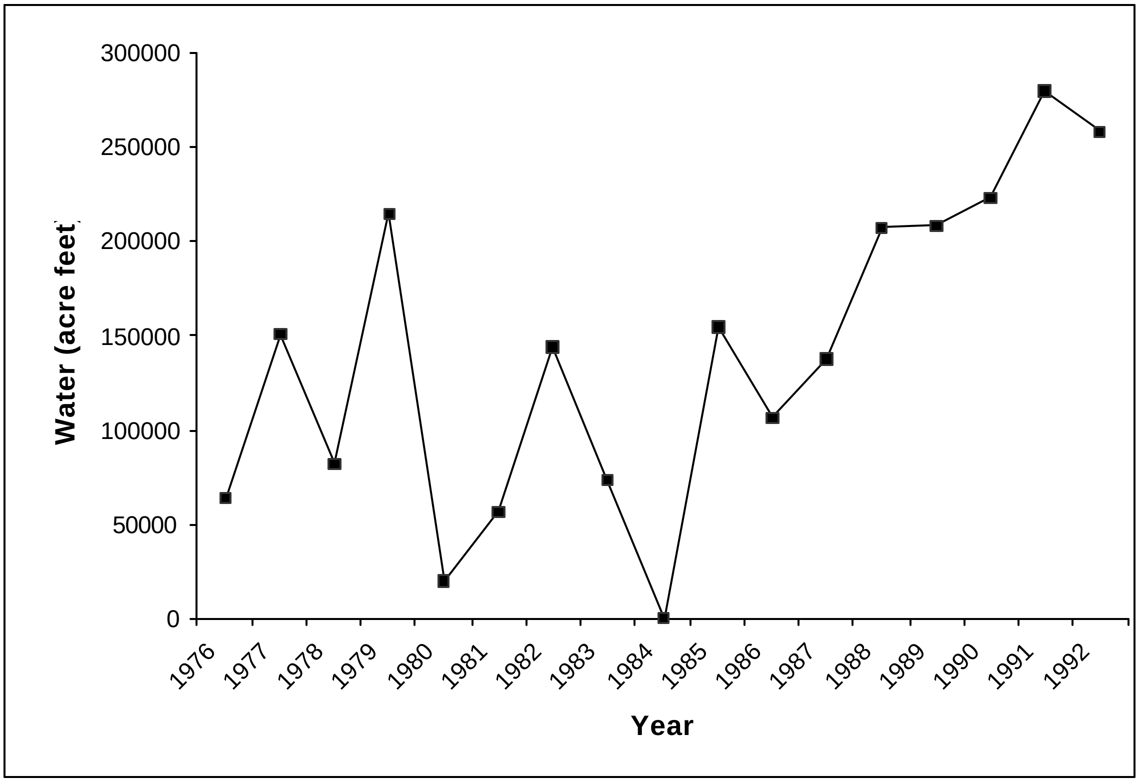


Figure 5 Dilution water release in acre-feet for the years 1976 through 1992 for Moses Lake. Data was taken from Bain 1993.

Secondary Productivity

Adequate information on secondary productivity, both zooplankton and macroinvertebrate production, is not be available from the historical information. The impacts of the possible reduction of primary productivity, dilution, and drawdown on zooplankton and macroinvertebrate production in Moses Lake are not known. If zooplankton and macroinvertebrate production are low, limited forage and competition for that forage, could affect the ability of panfish to recruit to the population.

Drawdown and Dilution in Relation to Water Quality, Primary Productivity and Secondary Productivity

Dilution and fall drawdown affect the amount of water flushed in and flowing out of Moses Lake (see discussion of drawdown on p. 7, and dilution on p. 38).

Drawdown in Moses Lake is from the top of the water column. Each October, 1.0 to 2.0 meters of water are released from the surface of the lake. This type of surface draw could potentially remove most of the primary and secondary productivity from the lake during critical pre-winter foraging times for panfish. As a result, increased competition for limited food resources may affect the body mass and fat stores of young-of-the-year and/or recruited panfish, ultimately limiting panfish recruitment and production.

Increased dilution input did not appear to significantly decrease nutrient concentrations, but dilution potentially reduced water retention times in the lake. Decreased water retention time may have resulted in a reduction in seasonal mean concentrations of chlorophyll-a. It appears that there might have been an inverse relationship between chlorophyll-a concentrations and dilution water input (Table 6, Figure 3, Figure 5). Reduced retention time may have reduced chlorophyll-a concentrations indicating that prior to peak production there was a decrease of useable forage densities for secondary production. The reduction in forage for zooplankton may have resulted in reduced production of zooplankton affecting the forage available for panfish.

The result could be seasonal differences in phytoplankton and zooplankton densities and distribution. This could be reflected by reduced amounts of forage available to panfish limiting growth and development of body mass and fat stores critical for overwinter survival and production of young-of-the-year and recruited panfish. In the end, decreased abundances or distribution of zooplankton may create inter or intraspecific competition for limited forage resources, or panfish might be forced to forage in pelagic areas devoid of habitat where they can avoid predation. Panfish might be exposed to seasonal episodes of extreme predation.

Water transparency appeared to have steadily reduced during the sampled period (Figure 4). This was contrary to the decline in chlorophyll-a concentrations (reductions in productivity should increase water transparency). Possible explanations for the increase were the input of highly turbid water for dilution into Moses Lake via the irrigation canal system, and/or common carp abundance increased in the lake from 1977 to 1988. Commercial carp harvest dropped significantly just previous to or early in the sample period, and creel surveys documented that very little sport harvest of common carp occurred during this time. This possible increase in common carp abundance could have resulted in higher rates of sediment and nutrient re-suspension, explaining why nutrient levels were not significantly reduced during the sample period. Even though dilution, in theory, should have reduced the concentrations of nitrogen and phosphorous in the system, the re-suspension of sediments increased nitrogen and phosphorous concentrations, and the system remained static regardless of dilution efforts.

To ascertain the current effect of dilution an drawdown on the system, current monthly and seasonal information on temperature, dissolved oxygen, secchi disk, pH, alkalinity turbidity, total dissolved solids, and conductivity. Current seasonal primary and secondary productivity information needs to be collected including chlorophyll-a, phytoplankton, zooplankton and macroinvertebrates. In addition, dilution flow and general water quality parameters need to be collected from the dilution water inputs to determine if impacts to water quality occur before the water enters Moses Lake.

Historical Creel Surveys

Creel surveys dating back as far as 1974 were compiled to determine the change in species harvest and angler effort over time (Table 8).

In 1974, the total number of fish harvested was 166,290 (Duff 1974). Warmwater fish accounted for 96 percent of the fish harvested. Black crappie comprised the largest portion of the harvest at 73 percent. Bluegill sunfish accounted for 16 percent, followed by yellow perch at 4 percent, largemouth and smallmouth bass combined represented 2 percent, and rainbow trout 4 percent. The dominant warmwater predator harvested for the year was largemouth bass accounting for 1,795 fish. Only 87 smallmouth bass were accounted for in the harvest. Largemouth and smallmouth harvest combined accounted for 1,882 fish. Rainbow trout accounted for 7,033 fish.

By 1983, the total number of fish harvested from Moses Lake was 169,269 (Jackson 1983). Warmwater fish accounted for 79 percent of the fish harvested. Yellow perch represented 37 percent of the fish harvest, followed by black crappie at 23 percent, rainbow trout 21 percent, and bluegill sunfish 11 percent. Yellow perch harvest markedly increased in comparison to 1974 from 6,257 fish to 62,409 fish. Black crappie and bluegill sunfish still comprised a large percentage of the harvest. Black crappie harvest was 121,109 in 1974; by 1983 harvest had reduced to 39,984. Bluegill sunfish harvest reduced from 26,619 fish in 1974 to 18,742 fish in 1983. This creel survey indicated a downward trend in the number and percentage of black crappie and bluegill sunfish caught by anglers in comparison to 1974. Walleye were less than 1 percent of the harvest. Walleye presence is significant because this is the first survey in which walleye were recorded in the fishery. It is unknown whether the introduction of walleye was from illegal stocking, or if they entered Moses Lake from Lake Roosevelt and Banks Lake via the irrigation system. The dominant warmwater predator harvested for the year was largemouth bass. Total harvest of largemouth bass and smallmouth bass increased in comparison to 1974, with a combined harvest of 4 percent. Largemouth contributed 5,905 fish and smallmouth accounted for 1578 fish. Rainbow trout harvest increased from 7,033 fish in 1974 to 35,766 fish in 1983, and accounted for 21 percent of the fish harvested.

In 1991, total harvest of fish was 20,481 fish (Korth 1991). Only 8,818 warmwater fish were harvested in the fishery. This is a 94.5 percent reduction in warmwater fish harvest in comparison to 1974. The creel survey illustrated that black crappie and bluegill sunfish harvest had declined to an all time recorded low. Black crappie were not represented in the harvest and bluegill sunfish comprised only 1 percent. The total number of bluegill sunfish harvested in 1983 was 18,742; by 1991 only 275 bluegill sunfish were recorded in the survey. Yellow perch also showed a decline in harvest as compared to the 1983 survey. In 1983, 62,409 yellow perch were harvested; by 1991 yellow perch only contributed 759 fish to the total harvest. Largemouth bass and smallmouth bass harvest accounted for 8 percent of the harvest, or 1,488 fish. For the first recorded time harvest of smallmouth bass, 1242 fish, was greater than largemouth bass, 246 fish. Even though the percentage of bass harvested increased in comparison to 1974 and 1983 there was a reduction in the total number of bass harvested. Only 1,588 bass were harvested compared to 1,882 for 1974 and 7,483 for 1983. The dominant warmwater predator harvested in the survey shifted from largemouth bass to walleye. Walleye harvest increased from 1 percent or 357 fish in 1983 to 12 percent or 2,484 fish in 1991. Brown bullhead harvest increased to 16 percent in comparison to 2 percent in 1974 and 1 percent in 1983. The actual number of brown bullhead harvested did not change considerably between 1974, 1983 and 1991, but the proportional contribution of brown bullhead to the harvest is larger due to the reduced harvest of gamefish. Rainbow trout harvest decreased to 11,663 fish, but accounted for 56 percent of the fishery

The most recent creel survey done on Moses Lake was in 1996 (Donley 1999). The total number of fish harvested continued to decline in comparison to past creel surveys. A total of 13,148 fish were harvested for the survey. Warmwater fish accounted for 95 percent of the harvest, or 12,519 fish. This is a 93 percent reduction in warmwater fish harvest as compared to 1974. Black crappie were only 1 percent of the harvest and bluegill sunfish were 7.5 percent. Harvest for these fish increased in comparison to 1991, but total numbers harvested did not return to the large historical numbers exhibited in 1974 and 1983. Yellow perch contributed to 23.5 percent of the harvest. The total number of fish harvest was 3,089 substantially lower than the highest recorded harvest of yellow perch in 1983 of 62,409 fish. Largemouth bass and smallmouth bass combined accounted for 12 percent of the harvest. More smallmouth bass were harvested than largemouth bass. Total numbers of smallmouth bass harvested was 1,075 and 498 for largemouth. These harvest numbers are comparable to what was harvested in 1991. The dominant warmwater predator harvested in 1996 was walleye. Walleye contributed 5,345 fish or 41 percent of the harvest for the survey. Walleye harvest increased by 46 percent in comparison to 1991. Rainbow trout harvest declined in comparison to the 1991 survey. Brown bullhead accounted for 16 percent of the harvest. Brown bullhead harvest reduced in comparison to 1974, 1983 and 1991. Proportionally brown bullhead accounted for a large portion of the harvest due to the reduced harvest of gamefish. Only 5 percent, or 629 rainbow trout were represented in the survey.

In 1974, angler effort was 163,012 hours. The total number of angler trips was 53,796; fish harvest per hour was 1.02 with a fish per trip average of 3.08. Shore fishing accounted for 95 percent of the angler effort, and 73 percent of the anglers were pursuing warmwater fish.

By 1983, total hours of effort had increased to 375,250; total trips increased to 117,970, fish per hour reduced to 0.45, and fish per trip diminished to 1.36. Shore fishing reduced to 33 percent of the angler effort, and angler effort directed at warmwater fish went down to 59 percent.

In 1991, total angler effort was 120,363 hours. The total number of angler trips was 42,668; fish per hour was 0.17, with a fish per trip average of 0.39. In comparison to 1974 and 1983, total effort and harvest declined. There was a 68 percent reduction in angler effort comparing 1983 to 1991, and a 64 percent reduction in angler trips. Additionally, fish per hour and fish per trip declined proportionally. Shore angling increased from 1983 to 40 percent. Anglers targeting warmwater fish for harvest decreased in comparison to 1983 to 47 percent.

In 1996, angler effort increased in comparison to 1991 to 132,350 hours of effort. The total number angler trips was 42,180 a comparable amount to 1991, but was reduced substantially in comparison to 1974 and 1983. Fish per hour was 0.1 and fish per trip was 0.31, the lowest numbers recorded in a creel survey. Shore angling accounted for 25 percent of the angler effort. This was the lowest amount of shore anglers recorded in a creel survey. The percentage of anglers pursuing warmwater fish increased to an all time recorded high of 92 percent.

The harvest of panfish from Moses Lake reduced substantially since 1974. The amount of harvest recorded may have indicated that overharvest contributed to the decline in the panfish population. The harvest of fish has shifted from panfish to walleye. This shift may have indicated that the fish population shifted from panfish dominated to walleye dominated. In 1996, a small rebound in the harvest of panfish was exhibited. This was the result of an increase in the number of yellow perch harvested. This harvest was still miniscule in comparison to the numbers of panfish harvested in 1974 and 1983. There was still a large disparity in the number of yellow perch harvested in comparison to walleye.

The effort by anglers appeared to be relatively consistent regardless of the amount of fish captured per trip or per hour. This may have indicated that the fishery resources were under serious demand from the angling public of Washington. The type of angler, whether shore or angler, varied with the species dominant in the fishery.

It has been communicated to members of the project that anglers miss " the old days" of harvesting large numbers of panfish and would like to see the return of this type of recreational fishery (Meseberg 2000). WDFW in response to the decline in panfish harvest, and under public pressure to do so, instituted harvest regulations in 1995 to conserve bluegill sunfish and black crappie populations (see p.8). Harvest limits and size restrictions were directed at preventing harvest of these fish species prior to allowing them to reach spawning size. The logic behind these regulations was to allow all bluegill sunfish and black crappie to spawn at least once prior to being subject to harvest.

Table 8 Creel survey information for 1974, 1983, 1991 and 1996 on Moses Lake. The 1974, 1983 and 1991 creel surveys were conducted by the Washington Department of Game. The 1996 creel survey was conducted by the Washington Department of Fish and Wildlife.

	1974		1983		1991		1996	
Total hours	163012		375250		120363		132350	
Total trips	53796		117970		42668		42108	
fish/hour	1.02		0.45		0.17		0.1	
fish/trip	3.08		1.36		0.39		0.31	
% boat	5		67		60		75	
%shore	95		33		40		25	
% trout	27		41		53		8	
%warmwater	73		59		47		92	
Species	# Harvested	% Total	# Harvested	% Total	# Harvested	% Total	# Harvested	% Total
brown bullhead	3420	2	2431	1	3382	16	1312	16
black crappie	121109	73	38984	23	0	0	237	1
bluegill	26619	16	18742	11	275	1	962	7.5
largemouth bass	1795	1	5905	3	346	2	498	4
rainbow trout	7033	4	35766	21	11663	56	629	5
smallmouth bass	87	<1	1578	1	1242	6	1075	8
walleye	0	0	357	<1	2484	12	5345	41
yellow perch	6257	4	62409	37	759	4	3089	23.5
Total Harvest	**166290**		**169269**		**20841**		**13148**	

Species Composition

Historical Species Composition

Historical biological surveys were compiled to compare species composition from 1978, 1988, and 1999 (Table 9).

In 1978, 10 species of fish were collected on Moses Lake. Panfish represented 79 percent of the fish sampled in the population. Black crappie accounted for 16.3 percent, bluegill sunfish accounted for 31.9 percent, and yellow perch 31 percent. Largemouth bass represented 16.3 percent of the sample and smallmouth bass were present in limited numbers, 0.4 percent. Warmwater predators combined represented 16.7 percent of the sampled population.

Non–gamefish (e.g. brown bullhead, largescale sucker, and sculpin *spp*.) represented 2.1 percent of the species composition. Common carp made up 1.8 percent of the fish collected.

By 1988, 14 species of fish were collected in Moses Lake. Panfish constituted 42 percent of the fish sampled in the population. Yellow perch accounted for 39.6 percent, black crappie 1.4 percent and bluegill sunfish 0.7 percent. Black crappie relative abundance reduced in comparison to the 1978 survey from 16.3 percent to 1.4 percent, and bluegill sunfish relative abundance reduced from 31.9 percent to 0.7 percent. Largemouth bass abundance reduced in comparison to 1978 from 16.3 percent to 0.1 percent in 1988. Smallmouth bass relative abundance increased in comparison to the 1978 survey from 0.4 percent to 0.9 percent in 1988. Walleye were sampled for the first time in a biological survey in Moses Lake. Walleye accounted for 19.4 percent of the fish sampled in the survey. Lake whitefish made up 2.1 percent of the species composition and rainbow trout accounted for 5.7 percent.

Non-gamefish (e.g. brown bullhead, largescale sucker, longnose sucker, northern pikeminnow and sculpin *spp*.) represented 21.3 percent of the fish sampled. The percentage of non-gamefish in the survey increased from 2.1 percent in 1978 to 21.3 percent for 1988. Common carp relative abundance accounted for 8.8 percent of the sample. Common carp relative abundance increased in comparison to 1978 (1.8 percent).

In 1999, 16 species of fish were collected in Moses Lake. Panfish accounted for 68.4 percent of the fish sampled in the population. Yellow perch represented 42 percent of the fish sampled, black crappie 11.1 percent and bluegill 15.3 percent of the survey. Yellow perch relative abundance was similar to other survey years. Black crappie relative abundance increased compared to 1988 from 1.4 percent to 11.1 percent, and bluegill sunfish increased from 0.7 percent to 15.3 percent. Largemouth bass accounted for 5.9 percent and smallmouth bass was 5.1 percent. This abundance of both bass species increased in comparison to 1988. Largemouth bass relative abundances were lower than in the 1978 survey. Walleye accounted for 11.5 percent of the surveyed population. Warmwater predators represented 22.5 percent of the species composition, and had a similar relative abundance in comparison to 1988.

Non-gamefish (e.g. brown bullhead, largescale sucker, longnose sucker, northern pikeminnow and sculpin *spp*.) represented 4.1 percent of the fish sampled. The abundance of common carp was 3 percent. Common carp relative abundance was reduced in comparison to 1988, but was higher than the relative abundance presented in 1978.

It appears that the species composition of Moses Lake went through a shift in species domination. The fish populations in Moses Lake shifted from a largemouth bass/panfish dominated population to a walleye dominated population. This species shift occurred somewhere between the 1978 and the 1989 biological surveys. Based on the 1983 creel survey only a negligible amount of walleye were captured by anglers (Table 8). It is important to note that until 1983 walleye were not recorded in Moses Lake as part of the population. It could be reasoned that this walleye population existed in the lake prior to 1983. As a result the walleye population increased and their numbers were not held in check by anglers. This may have allowed them to over-predate on the available forage. By 1989, it would appear that the walleye population had established itself in such large numbers that their predatory impact had significantly reduced the amount of prey species present in the fishery. Very few panfish, or gamefish, were sampled in the population. The most fecund fish and those most capable of avoiding predation were dominating the population. The 1991 creel survey indicated that anglers found the fishery and may have had some impact on the walleye population (Table 8). Angling pressure on walleye may have finally limited the walleye numbers present in the lake. Walleye harvest in the early

1990's was immense. It was not uncommon for WFDW employees to hear about or check walleye limits. Also walleye in excess of 15 pounds were harvested by anglers (Meseberg 2000, Korth 2000). The reduction in walleye numbers based on harvest in 1991 and 1996 may have reduced the walleye population sufficiently to increase the recruitment of panfish and other gamefish. This may account for the slight rebound in the fish population of Moses Lake that is illustrated by the harvest as recorded in the 1996 creel survey and the fall 1999 biological survey (Tables 8 and 9).

Table 9 Comparison of species composition from biological surveys conducted on Moses Lake during 1978, 1989 and 1999. # represents the number of fish collected in the survey. %n represents the percent of the total number of fish sampled for each given species collected in the survey.

Species Composition						
	1978		1989		1999	
Type of Fish	**(#)**	**(%n)**	**(#)**	**(%n)**	**(#)**	**(%n)**
black crappie	206	16.3	10	1.4	570	11.1
bluegill	402	31.9	5	0.7	787	15.3
brown bullhead	18	1.4	135	17.9	166	3.2
burbot	0	0.0	0	0.0	1	0.0
carp	31	1.8	62	8.8	155	3.0
lake whitefish	0	0.0	15	2.1	11	0.2
largemouth bass	206	16.3	1	0.1	304	5.9
largescale sucker	1	0.1	2	0.3	5	0.1
longnose sucker	0	0.0	18	2.6	33	0.6
northern pike-minnow	0	0.0	1	0.1	7	0.1
pumpkinseed sunfish	2	0.2	0	0.0	5	0.1
rainbow trout	0	0.0	40	5.7	80	1.6
sculpin	7	0.6	3	0.4	6	0.1
smallmouth bass	5	0.4	6	0.9	260	5.1
walleye	0	0.0	136	19.4	591	11.5
yellow perch	390	31.0	278	39.6	2155	42.0
TOTAL	**1268**		**712**		**5136**	

Fall 1999 and Spring 2000 Surveys

During the 1999 survey 4,923 age 1+ and older fish were sampled (Table 10). Panfish represented 67.3 percent of the fish sampled in the survey. Yellow perch accounted for 39.7 percent, black crappie 11.0 percent and bluegill 16.6 percent. Walleye relative abundance was 13.0 percent, largemouth bass 5.2 percent and smallmouth bass 5.0 percent. Warmwater predators represented 23.2 percent of the species composition. Lake whitefish made up 0.2 percent of the sample, and rainbow trout contributed 0.9 percent.

Non-gamefish (e.g. brown bullhead, largescale sucker, longnose sucker, northern pikeminnow and sculpin spp.) represented 4.3 percent of the fish surveyed. Common carp accounted for 3.1 percent of the fish surveyed.

Biomass per fish species was calculated for the 1999 survey (Table 10). The total biomass collected for the sample was 1,525.4 kg. Panfish biomass totaled 16.30 percent of the sample. Yellow perch accounted for 10.2 percent, black crappie 2.4 percent, and bluegill 3.7 percent. Walleye accounted for 29.4 percent of the biomass sampled, largemouth bass 3.4 percent, and smallmouth bass 2.8 percent. Predators made up 35.4 percent of the biomass sampled from the fish population. Lake whitefish and rainbow trout accounted for 4.9 percent of the biomass sampled.

Non-game fish represented 5.8 percent, and common carp accounted for 37.5 percent of the biomass sampled. Common carp had the highest combined biomass of all species in the survey.

During the 2000 survey 3169 age 1+ and older fish were sampled (Table 11). Panfish represented 34 percent of the fish sampled in the spring 2000 survey. Yellow perch accounted for 26.9 percent, black crappie 3.5 percent and bluegill 3.6 percent. Predators represented 32.1 percent of the fish surveyed. Walleye accounted for 18.4 percent, largemouth bass 1.6 percent and smallmouth bass 12.1 percent.
Rainbow trout contributed 2.7 percent of the fish sampled.

Non-gamefish (e.g. brown bullhead, largescale sucker, longnose sucker, northern pikeminnow and sculpin spp.) represented 15.4 percent of the fish surveyed. Common carp accounted for 15.7 percent of the fish surveyed.

Biomass per fish species was calculated for the spring 2000 survey (Table 11). The total biomass collected for the sample was 2399.5 kg. Panfish biomass totaled 3.6 percent of the sample. Yellow perch accounted for 2.6 percent, black crappie 0.7 percent, and bluegill 0.3 percent.
Predators made up 16.6 percent of the population. Walleye accounted for 12.7 percent of the sample, largemouth bass 1.9 percent, and smallmouth bass 2.0 percent.
Rainbow trout accounted for 2.1 percent of the biomass sampled.

Non-game fish (e.g. brown bullhead, largescale sucker, longnose sucker, northern pikeminnow and sculpin spp.) represented 4.7 percent, and common carp accounted for 73.1 percent of the biomass sampled. Common carp had the highest combined biomass of all species in the survey.

The fall 1999 and spring 2000 species composition indicated that the dominant gamefish by biomass was walleye. Total biomass for predators accounted for 35.4 percent of the fish biomass collected in fall 1999 and 16.6 percent for spring 2000. Panfish for the same surveys represented 16.3 percent and 3.6 percent respectively. These proportions indicated that predator biomass was substantially higher than prey biomass, most specifically the compressed centrarchids. Swingle's Biomass Model (Swingle, 1960) calculated to develop prey to predator ratios for Moses Lake's fish population further illustrated predator domination. Swingle calculated ratios of prey to predator that represented a balanced fish population. The ratios representing a "balanced population" ranged from 3.0 to 6.0. Ratios for Moses Lake do not indicate that the population is balanced. The ratio for fall 1999 was 0.50 excluding carp as a prey fish and 1.32 including carp as a prey fish. Ratios for spring 2000 were 0.20 excluding carp as a prey fish and 3.7 including carp as a prey fish. Including carp as a prey fish is not practical as they generally have fast growth rates precluding them from predation, and tend to occupy highly complex littoral habitat making it difficult for predators to forage on juvenile carp (Cooper, 1987).

The most abundant fish by biomass and potentially in number in Moses Lake is common carp, deriving their relative abundance in total number is difficult because carp habits and their efficiency at avoiding capture make them difficult to sample (Cooper, 1987). Irrespective of these facts the dominant amount of biomass sampled for both fall 1999 and spring 2000 was common carp (Tables 10 and 11). Literature suggests that the presence of carp can decrease the number of game fishes through competition for habitat and forage, reduction in primary and secondary production, increased nutrient loading, and the resuspension of sediments (Cooper 1987). All of these could potentially limit the production of panfish in Moses Lake. The review of historical information indicates that carp and panfish occupied Moses Lake consecutively as early as 1908 and 1924, and since their introduction all of these species have flourished at one time or another. In 1950, black crappie and bluegill sunfish made up 74 percent of the harvest in Moses Lake (Groves, 1951). During this same period it was reported that common carp were highly abundant in the lake and were affecting water quality and plant distribution through, "Constant rooting about in the vegetation, and causing high sediment suspension" (Groves, 1951). During a creel survey in 1974 black crappie, bluegill sunfish and yellow perch constituted 93 percent of the fish harvest. During this same time period carp were present in large enough numbers to drive a sizable commercial fishery. The amount of carp removed from Moses Lake on an annual basis was in the magnitude of 10 to 15 tons per year (Korth 2000). The commercial harvest of carp continued in Moses Lake for more than 10 years, and in that period the densities of carp were never reduced to the point where commercial harvest was not possible. Rather commercial harvest was suspended on Moses Lake as the commercial value of carp was reduced as to render it unprofitable to continue harvesting them. This suspension in commercial harvest may have allowed carp to establish a large enough population to reduce recruitment of panfish through forage and habitat competition, the reduction of primary and secondary productivity, or the increase in the resuspension of sediments and nutrients limiting water quality.

Table 10 Species composition (excluding young of the year) by weight (kg), percent of total weight, total number of each species sampled, percentage of each species in sample, and minimum and maximum sized fish for each species sampled during the fall 1999 survey of Moses Lake.

Species Composition						
Species	**(kg)**	**(%W)**	**(#)**	**(%n)**	**Min**	**Max**
black crappie	36.8	2.4	543	11.0	101	342
bluegill	56.4	3.7	817	16.6	66	300
yellow perch	155.5	10.2	1955	39.7	111	341
pumpkinseed sunfish	0.1	0.0	5	0.1	91	124
largemouth bass	51.7	3.4	258	5.2	116	501
smallmouth bass	42.7	2.8	245	5.0	117	376
walleye	449.1	29.4	642	13.0	191	796
rainbow trout	55.2	3.6	74	0.9	306	501
lake whitefish	15.3	1.0	11	0.2	221	554
brown bullhead	47.6	3.1	166	3.4	57	409
burbot	0.9	0.1	1	0.0	528	528
sculpin	0.0	0.003	6	0.1	45	114
largescale sucker	7.8	0.5	5	0.1	273	582
longnose sucker	32.9	2.2	33	0.7	105	521
northern pike-minnow	0.6	0.04	7	0.1	173	250
carp	572.7	37.5	155	3.1	71	845
TOTALS	1525.4		4923			

Table 11 Species composition (excluding young of the year) by weight (kg), percent of total weight, total number of each species sampled, percentage of each species in sample, and minimum and maximum sized fish for each species sampled during the spring 2000 survey of Moses Lake.

Species Composition						
Species	**(kg)**	**(%W)**	**(#)**	**(%n)**	**Min**	**Max**
black crappie	16.6	0.7	110	3.5	88	382
bluegill	8.1	0.3	113	3.6	30	210
yellow perch	61.5	2.6	853	27.5	79	276
pumpkinseed sunfish	0.1	0.0	3	0.1	100	121
largemouth bass	44.5	1.9	52	1.7	90	521
smallmouth bass	46.8	2.0	383	12.3	56	406
walleye	304.6	12.7	583	18.8	69	741
rainbow trout	49.5	2.1	86	1.6	236	502
brown bullhead	88.0	3.7	143	4.6	63	443
sculpin	2.00	0.08	265	8.5	52	146
largescale sucker	10.3	0.4	7	0.2	362	570
longnose sucker	4.8	0.2	6	0.2	142	484
carp	1754.1	73.4	499	16.1	345	860
TOTALS	2391.0		3103			

Fall 99 Young-of-the-year vs. Spring 2000 Age 1+ Comparison

Young-of-the-year fish collected during fall 1999 and age1+ fish collected during spring 2000 were compiled to compare the differences in the number and biomass collected for both samples (Table 12)

During the fall 1999 survey 5,508 age 0+ fish were sampled. Panfish represented 72.9 percent of the age 0+ fish collected. Yellow perch accounted for 61.4 percent of the age 0+fish collected, bluegill sunfish represented 8.8 percent, and black crappie were 2.5 percent of the age 0+ fish sampled. Warmwater predators accounted for 37.1 percent of the age 0+ fish sampled. Walleye accounted for 16.3 percent of the age 0+ fish collected, largemouth bass represented 9.4 percent and smallmouth bass accounted for 1.4 percent of the age 0+ fish sampled.

During the spring 2000 survey 921 age 1+ fish were collected. Panfish represented 51.3 percent of the age 1+ fish collected. Yellow perch accounted for 25.5 percent of the age 0+ fish collected, bluegill sunfish represented 4.13 percent, and black crappie were 2.8 percent of the age 1+ fish sampled. Warmwater predators accounted for 49.7 percent of the age 1+ fish sampled. Walleye accounted for 32.5 percent of the age 1+ fish collected, largemouth bass represented 0.43 percent and smallmouth bass accounted for 15.74 percent of the age 1+ fish sampled.

It appears that large year classes of young-of-the-year fish were sampled during fall 1999. This may indicate that spawning and incubation was not limited for any species. By spring of 2000 there was an 83 percent reduction in the relative abundance of the year class sample in fall of 1999. Of the fish sample in spring of 2000, panfish Age 1+ relative abundance reduced by 89.3 percent and warmwater predators relative abundance reduced by 70 percent.

Production of large year classes of fish could potentially be limiting to panfish recruitment. Competition for forage at early life stages may limit the panfish's ability to attain the body mass and/or fat stores to overwinter successfully. Based on comparisons between the fall 1999 and spring 2000 data proportionally more juvenile walleye and yellow perch were recruited to the population than black crappie and bluegill sunfish. Earlier spawning fish such as walleye and yellow perch may produce large crops of age 0+ fish that emerge earlier than black crappie and bluegill fry and are cropping off zooplankton production prior to the emergence of these competing panfish species.

Warmwater predator's relative abundance reduction was lower than the panfish indicating that predators may recruit at higher numbers than panfish. Walleye growth rates in Moses Lake were sufficient for walleye to grow to greater than 150 mm in length. At this length walleye are assumed to be recruited to piscivory (Carlander, 1967). It is possible that a large year class of walleye by early fall of their first growing season could predate heavily upon young-of-the-year panfish. This type of predation could affect the ability of panfish to recruit to the population.

It is understood that using this comparison is limited because there is seasonal bias in collecting these species. For example the marked increase in the capture of smallmouth bass from fall to spring (Table 12). However, the large reduction in the numbers of panfish in comparing fall to spring may possibly indicate that there is a potential limiter to recruitment that requires investigation.

Table 12 Species composition for young-of-the-year collected during the fall 1999 survey and age 1+ fish collected during the spring 2000 survey by weight (kg), percent of total weight, total number of each species sampled, percentage of each species in sample, and minimum and maximum sized fish for each species sampled.

	Fall 1999						Spring 2000					
Species	**(kg)**	**(%W)**	**(#)**	**(%n)**	**Min**	**Max**	**(kg)**	**(%W)**	**(#)**	**(%n)**	**Min**	**Max**
black crappie	1.70	2.12	135	2.45	61	100	0.53	2.03	26	2.82	88	125
bluegill	1.08	1.36	485	8.81	13	65	0.36	1.38	38	4.13	30	110
yellow perch	37.67	47.16	3400	61.37	55	110	6.70	25.47	409	44.41	79	142
largemouth bass	6.95	8.70	516	9.37	59	115	0.09	0.32	4	0.43	90	160
smallmouth bass	0.96	1.21	77	1.40	70	115	2.90	10.89	145	15.74	56	180
walleye	31.51	39.44	895	16.25	69	190	15.70	59.92	299	32.46	69	266
TOTALS	79.9		5508				26.28		921			

Catch Per Unit Effort

Fall 1999 and Spring 2000 Surveys

CPUE was calculated for each gear type used in the fall 1999 survey (Table 13). Electrofishing CPUE for black crappie was 14.2, 71.49 for bluegill and 86.43 for yellow perch. Electrofishing CPUE for largemouth bass was 6.52, 15.83 for smallmouth bass, and 15.65 for walleye. Non-gamefish (e.g. brown bullhead, largescale sucker, longnose sucker, northern pikeminnow, and sculpin) CPUE combined was 8.48. Common carp electrofishing CPUE was 7.25. Rainbow trout electrofishing CPUE was 3.86, and lake whitefish did not appear in the electrofishing sample. Electrofishing was more effective at capturing all fish species.

Gill net CPUE for black crappie was 0.54, 0.0 for bluegill, and 1.96 for yellow perch. Gill net CPUE for largemouth bass was 0, 0.14 for smallmouth bass, and 0.86 for walleye. Non-gamefish (e.g. brown bullhead, largescale sucker, longnose sucker, northern pikeminnow, and sculpin) gill net CPUE combined was 0.75. Common carp gill net CPUE was 0.25. Rainbow trout gill net CPUE was 0.43, and lake whitefish was 0.14.

CPUE was calculated for each gear type used in the spring 2000 survey (Table 14). Electrofishing CPUE for black crappie was 3.63, 5.15 for bluegill and 2.56 for yellow perch. Electrofishing CPUE for largemouth bass was 2.25, 9.65 for smallmouth bass, and 3.18 for walleye. Non-gamefish (e.g. brown bullhead, largescale sucker, longnose sucker, northern pikeminnow, and sculpin spp.) CPUE combined was 20.35. Sculpin spp. accounted for a CPUE of 13.74. Common carp electrofishing CPUE was 5.62. Rainbow trout electrofishing CPUE was 2.17, and lake whitefish did not appear in the electrofishing sample. Electrofishing was more effective at capturing all fish species except walleye.

Gill net CPUE for black crappie was 0.13, 0.0 for bluegill, and 6.03 for yellow perch. Gill net CPUE for largemouth bass was 0, 0.14 for smallmouth bass, and 6.13 for walleye. Non-gamefish (e.g. brown bullhead, largescale sucker, longnose sucker, northern pikeminnow, and sculpin) gill net CPUE combined was 1.86. Common carp gill net CPUE was 4.47. Rainbow trout gill net CPUE was 1.93. Gill nets were more effective at capturing walleye than electrofishing.

Comparing CPUE for fall 1999 to spring 2000 data indicated that panfish abundance between seasons reduced. This could be explained due to seasonal bias in sampling, but could also point to the fact that there is a limiter to panfish recruitment.

Table 13 Mean catch per unit effort by species and gear type, including 80 percent confidence intervals for the fall 1999 survey.

	Electrofishing			Gill Nets		
	# / hour	EB CI	Shock Sites	# / GN night	GN CI	GN nights
Species						
black crappie	14.2	2.81	62	0.54	0.36	28
bluegill	71.49	10.1	62	0	0	28
brown bullhead	6.16	2.18	62	0.71	0.54	28
burbot	0.1	0.12	62	0	0	28
carp	7.25	1.51	62	0.25	0.2	28
lake whitefish	0	0	62	0.14	0.18	28
largemouth bass	6.52	1.65	62	0	0	28
largescalesucker	0.39	0.39	62	0	0	28
longnose sucker	1.16	0.68	62	0.04	0.05	28
northern pike-minnow	0.19	0.17	62	0	0	28
pumpkinseed sunfish	0.29	0.21	62	0	0	28
rainbow trout	3.86	1.32	62	0.43	0.31	28
sculpin	0.58	0.42	62	0	0	28
smallmouth bass	15.83	3.82	62	0.14	0.14	28
walleye	15.65	2.57	62	0.86	0.55	28
yellow perch	86.43	22.7	62	1.96	1.23	28

Table 14 Mean catch per unit effort by species and gear type, including 80 percent confidence intervals for the spring 2000 survey of Moses Lake (Grant County).

	Electrofishing			Gill Nets		
	# / hour	EB CI	Shock Sites	# / GN night	GN CI	GN nights
Species						
Black Crappie	3.63	1.50	60	0.13	0.10	30
Bluegill	5.15	1.69	60	0.00	0.00	30
Brown bullhead	6.61	2.32	60	1.50	0.37	30
Carp	5.62	2.51	60	4.47	0.78	30
Largemouth Bass	2.25	0.89	60	0.00	0.00	30
Longnose Sucker	0.00	0.00	60	0.13	0.10	30
Largescale Sucker	0.00	0.00	60	0.20	0.11	30
Rainbow Trout	2.17	0.96	60	1.93	0.78	30
Sculpin	13.74	5.04	60	0.00	0.00	30
Smallmouth Bass	9.65	3.23	60	0.17	0.11	30
Walleye	3.18	1.04	60	6.13	0.89	30
Yellow bullhead	2.56	0.96	60	0.03	0.04	30
Yellow Perch	13.60	5.56	60	6.03	1.68	30

Stock Density Indices

Fall 1999 and Spring 2000 Surveys

Proportional Stock Densities (PSD), and Relative Stock Densities (RSD) were calculated per species of fish collected for electrofishing and gill netting during the fall 1999 and spring 2000 surveys (Tables 15 and 16).

Satisfactory numbers of stock length fish were sampled for all warmwater species. Anderson (1980) recommended that at least 100 stock length or greater fish needed to be collected per species before PSD's or RSD's were meaningful. Electrofishing captured more stock length fish than gill nets. The large number of fish collected resulted in narrow confidence limits making interpretation with confidence possible.

Black crappie and bluegill sunfish exhibited populations that were low density with most of the individuals sampled represented as stock size. Not enough stock size fish were sampled, for either of these species, to make any decisions on the proportional make-up of their populations. The fact that very few stock size fish were captured may have indicated that the black crappie and bluegill sunfish population was low in numbers. The PSD's possibly illustrated that the black crappie and bluegill sunfish populations offered a low density mediocre fishery for stock size fish.

Yellow perch exhibited a higher density population with a large number fish represented as stock size. Yellow perch PSD's for electrofishing were 46 for fall 1999 and 70 for spring 2000. PSD's for gill netting were 61 for fall 1999 and 91 for spring 2000. Very few yellow perch regardless of gear type were represented in the RSD categories of preferred, or memorable. No trophy sized yellow perch were sampled.
Based on the information gathered it would appear that yellow perch offered a high density fishery for fair sized fish with a few larger individuals in the harvest.

Too few stock size largemouth bass were sampled to make any interpretations on the fishery. The fact that very few stock size fish were captured may have indicated that the largemouth population is small and provided a limited fishery.

Smallmouth caught with electrofishing gear had PSD's of 18 for fish caught in fall 1999 and 17 in spring 2000. Very few smallmouth bass regardless of gear type were represented in the RSD categories of preferred, or memorable. No trophy sized smallmouth bass were sampled. Based on the information gathered it would appear that smallmouth bass offered a low density fishery for fair sized fish with a few larger individuals in the harvest.

Walleye exhibited high density populations with a large number of stock size fish captured. Walleye caught with electrofishing gear had PSD's of 40 for fish caught in fall 1999 and 51 in spring 2000. Walleye capture with gill nets had PSD's of 85 for fall 1999 and 77 for spring 2000. A high proportion of walleye captured with gill netting appeared in the preferred category, 85 for fall 1999 and 77 for spring 2000. Only a few fish were represented in the memorable categories. Based on the data gathered walleye appeared to offer a high-density fishery for fair to larger sized fish.

Rainbow trout are release from net pens on an annual basis. The PSD's for these fish indicate that the majority of fish captured in the sample are first year release fish. Carryover for rainbow trout appears to be limited based on this information. The carryover rate in fall 1999 appeared to be greater than in spring 2000.

The best fishery represented in the PSD's and RSD's was common carp. The proportions present indicate that carp would provide a high density large sized fish fishery. This kind of carp fishery would be the envy of the european piscatorial world.

Table 15 Proportional and relative stock density indices for warmwater fish, rainbow trout and common carp collected during fall 1999. RSD-P represents preferred, RSD-M represents memorable, and RSD_T represents trophy. Confidence intervals (CI) were calculated for each category at 80 percent.

				Electrofishing					
Species	# Stock Length	**PSD**	PSD CI	**RSD-P**	RSD CI	**RSD-M**	RSD CI	**RSD-T**	RSD CI
Black Crappie	150	44	5	5	2	2	1	0	0
Bluegill	799	43	2	3	1	0	0	0	0
Carp	79	92	4	63	7	49	7	1	2
Largemouth Bass	70	39	7	17	6	0	0	0	0
Rainbow Trout	44	16	7	0	0	0	0	0	0
Smallmouth Bass	231	18	3	2	1	0	0	0	0
Walleye	196	40	4	12	3	2	1	0	0
Yellow Perch	921	46	2	1	0	0	0	0	0
				Gill Netting					
Species	# Stock Length	**PSD**	PSD CI	**RSD-P**	RSD CI	**RSD-M**	RSD CI	**RSD-T**	RSD CI
Black Crappie	56	48	9	9	5	0	0	0	0
Carp	75	91	4	69	7	41	7	0	0
Rainbow Trout	36	31	10	6	5	0	0	0	0
Smallmouth Bass	6	0	0	0	0	0	0	0	0
Walleye	241	85	3	37	4	5	2	0	1
Yellow Perch	448	61	30	1	0	0	0	0	0

Table 16 Proportional and relative stock density indices for warmwater fish, rainbow trout and common carp collected during Spring 2000. RSD-P represents preferred, RSD-M represents memorable, and RSD_T represents trophy. Confidence intervals (CI) were calculated for each category at 80 percent.

				Electrofishing					
Species	# Stock Length	**PSD**	PSD CI	**RSD-P**	RSD CI	**RSD-M**	RSD CI	**RSD-T**	RSD CI
Black Crappie	80	54	7	10	4	8	4	4	3
Bluegill	84	52	7	5	3	0	0	0	0
Carp	365	98	1	62	3	40	3	1	1
Largemouth Bass	48	65	9	38	9	4	4	0	0
Pumpkinseed Sunfish	3	0	0	0	0	0	0	0	0
Rainbow Trout	26	23	11	8	7	0	0	0	0
Smallmouth Bass	235	17	3	3	1	0	0	0	0
Walleye	104	51	6	13	4	1	1	0	0
Yellow Perch	279	70	4	3	1	0	0	0	0
				Gill Netting					
Species	# Stock Length	**PSD**	PSD CI	**RSD-P**	RSD CI	**RSD-M**	RSD CI	**RSD-T**	RSD CI
Black Crappie	4	75	28	0	0	0	0	0	0
Carp	134	99	1	69	5	37	5	0	0
Rainbow Trout	58	33	8	0	0	0	0	0	0
Smallmouth Bass	5	20	23	20	23	0	0	0	0
Walleye	184	77	4	44	5	4	2	0	0
Yellow Perch	181	91	3	2	1	0	0	0	0

Species Accounts

Black Crappie

Scales collected from black crappie permitted the development of a length at age table via back-calculation using Lee's modification and the direct proportion methods of aging. Means were developed for direct proportion and weighted means were developed for Lee's modification (Table 17). Comparisons of both indicated that length at age exceeded the state average.

Relative weights for black crappie collected in fall 1999 and spring 2000 indicated that conditions of fish were above the national average for black crappie. There was a downward trend in condition as the age of the black crappie increased. However, even older black crappie had relative weights that were above or close to the national average (Figures 6 and 7). Historical fall data beginning with 1993 and ending with 1999 was analyzed and the mean relative weights calculated for each year. Mean relative weights from 1993-99 remained above the national average and possibly indicated an upward trend (Figure 8). However, R^2 values for the assigned trend line were poor signifying an inefficient model prediction.

Length frequency histograms separating the electrofishing and gill netting capture techniques were constructed to visually detect any bias between sampling gears. During the fall 1999 survey 150 and 56 black crappie were captured using electrofishing and gillnetting techniques, respectively (Figure 9). During the spring 2000 survey 80 and 4 black crappie were captured electrofishing and gillnetting techniques, respectively (Figure 10). A two sample, two tailed t-test at an alpha level of 0.05 was used to determine whether or not there was a significant difference in length of fish captured between the two gear types. There was no significant difference in the length of black crappie that were captured during the 1999 fall survey (df=697, P= 0.15) nor during the spring 2000 survey (df=108, P= 0.67). Young-of-the-year fish were included in the analysis.

Combining gear types permitted the development of a complete length frequency histogram for fall 1999 and spring 2000 surveys (Figures 11 and 12). During the fall 1999 sample, age one fish represented the largest percent frequency of black crappie caught. However, during the spring 2000 survey black crappie between the size of 160 mm and 220 mm represented the largest percentage of the sample.

Table 17 Length at age of black crappie collected during fall 1999. Bolded values are weighted mean back-calculated lengths using Lee's modification (Carlander 1982). Unbolded values are mean back-calculated lengths at annulus using the direct proportion method (Fletcher et al. 1993). 80 percent confidence intervals were calculated for each Lee Modification mean length at annulus.

			Mean Total Length(mm)at Age											
	Year Class	# Fish	1	CI	2	CI	3	CI	4	CI	5	CI	6	CI
	1998	3	104											
		3	**110**	**4**										
	1997	8	63		122									
		8	**85**	**10**	**131**	**12**								
	1996	18	87		134		177							
		18	**107**	**5**	**145**	**5**	**181**	**5**						
	1995	9	60		118		178		225					
		9	**87**	**8**	**137**	**7**	**188**	**11**	**228**	**16**				
	1994	0	0		0		0		0		0			
		0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		
	1993	1	57		132		161		255		294		318	
		1	**86**	**0**	**154**	**0**	**180**	**0**	**264**	**0**	**299**	**0**	**321**	**0**
Direct proportion overall mean			74		126		172		240		294		318	
Direct proportion state avg.			46		111		157		183		220		254	
Lee's weighted mean			**97**		**140**		**183**		**232**		**299**		**321**	

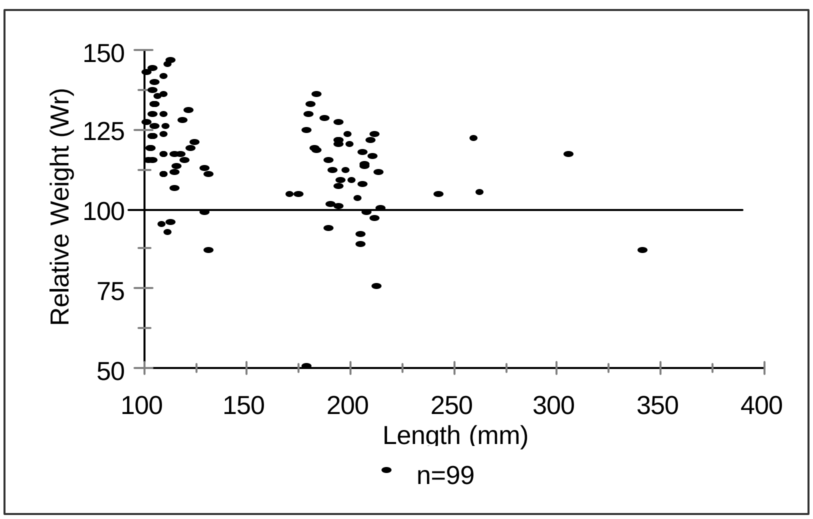


Figure 6 Relationship between total length and relative weight (Wr) of black crappie, excluding young of the year, compared to the national standard, collected fall 1999.

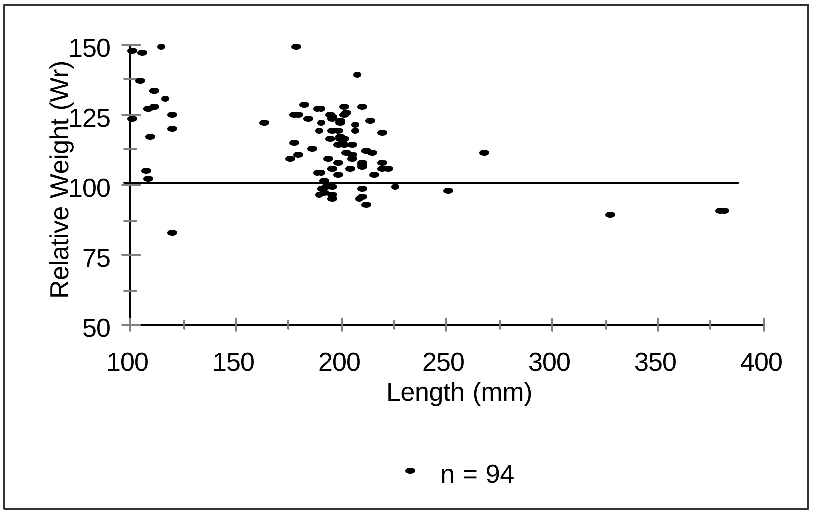


Figure 7 Relationship between total length and relative weight (Wr) of black crappie compared to the national standard, collected spring 2000.

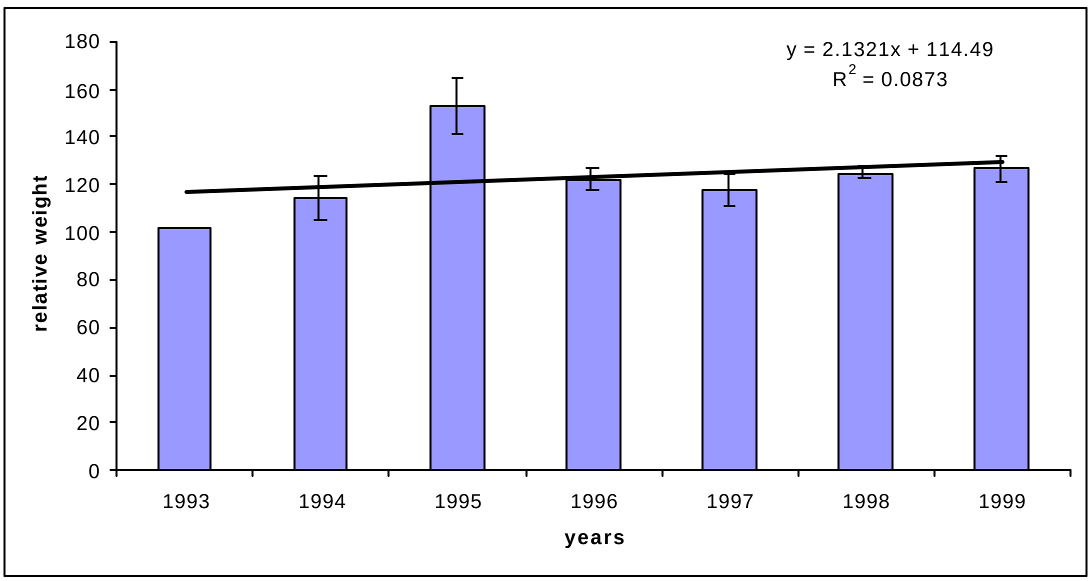


Figure 8 Comparison of mean relative weights, including trend line equation and R^2 value, for black crappie collected during surveys conducted fall 1993 to fall 1999. 95% confidence intervals and error bars are presented.

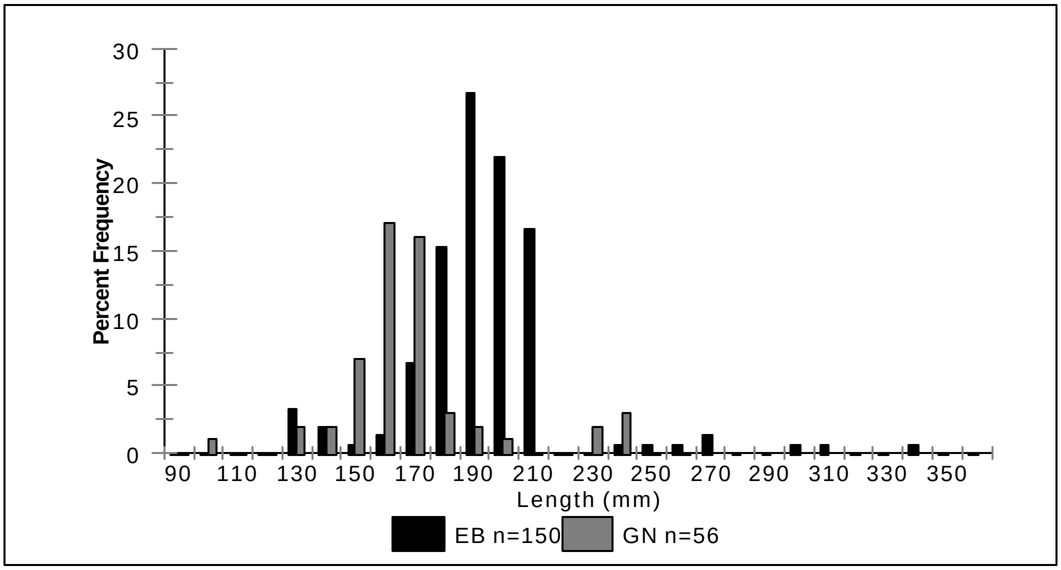


Figure 9 Length frequency distribution of black crappie, excluding young-of-the-year, sampled using electrofishing (EB) and gill netting (GN) for fall 1999.

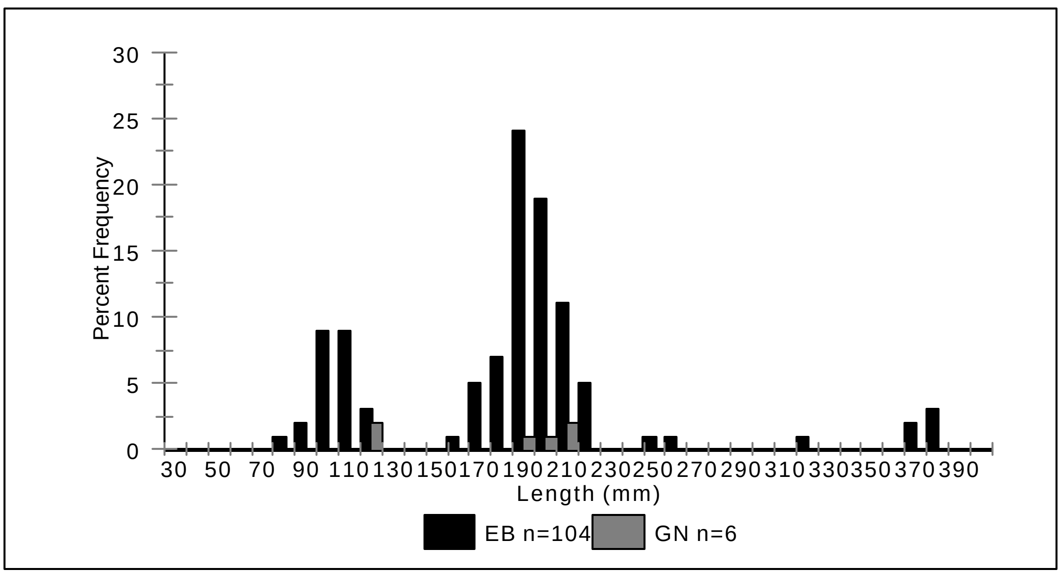


Figure 10 Length frequency distribution of black crappie sampled using electrofishing (EB) and gill netting (GN) for spring 2000.

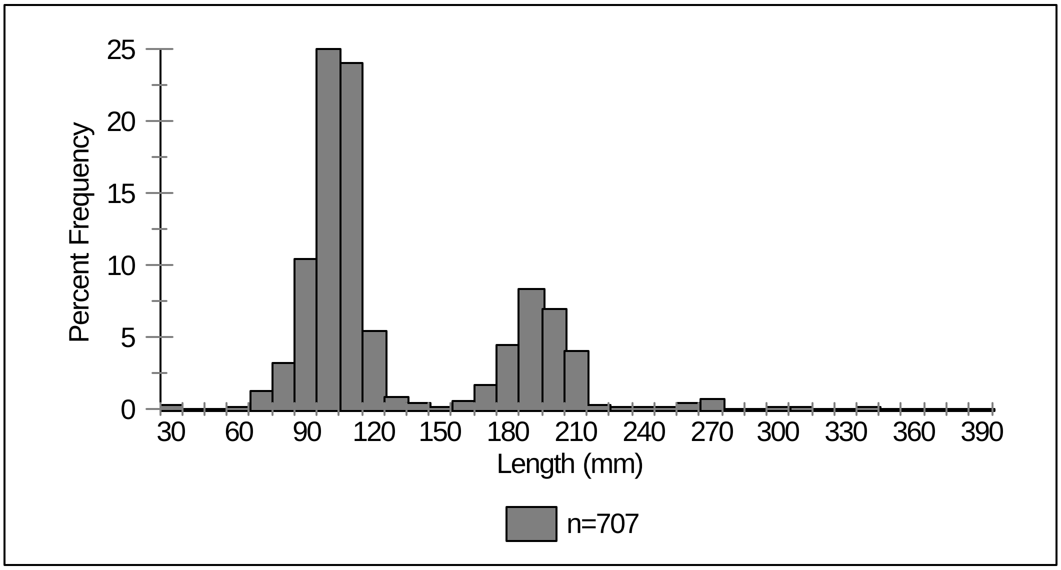


Figure 11 Length frequency distribution for black crappie with all gear types combined, including all fish sampled during the fall 1999 survey.

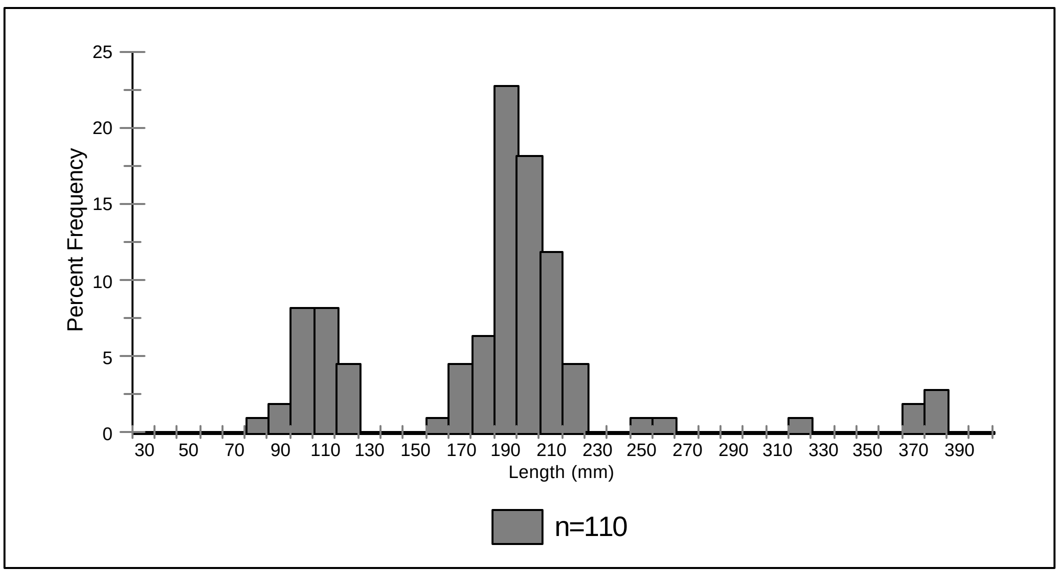


Figure 12 Length frequency distribution for black crappie with all gear types combined, including all fish sampled during the spring 2000 survey.

Bluegill Sunfish

Scales collected from bluegill sunfish permitted the development of a length at age table via back-calculation using Lee's modification and the direct proportion methods of aging. Means were developed for direct proportion and weighted means were developed for Lee's modification (Table 18). Comparisons of both indicated that length at age exceeded the state average.

Relative weights for bluegill sunfish collected in fall 1999 and spring 2000 indicated that conditions of fish were above the national average. During the fall of 1999 survey there appeared to be an upward trend in relative weights as length increased (Figure 13). The spring 2000 sample indicated that relative weights were maintained above the national average at virtually all lengths of bluegill sampled (Figure 14). Historical fall data beginning with 1993 and ending with 1999 was analyzed and the mean relative weights calculated for each year. Mean relative weights from 1993 to 1999 remained above the national average and possibly indicated an upward trend (Figure 15). However, R^2 values for the assigned trend line were poor signifying an inefficient model prediction.

Length frequency histograms separating the electrofishing and gill netting capture techniques were constructed to visually detect any bias between sampling gears. Gear bias was evident when sampling for bluegill sunfish because none were captured in gillnets, hence the lack of statistical analysis between gillnetting and electrofishing regarding a comparison of lengths. During the 1999 survey 799 bluegill were captured via electrofishing (Figure16). As for the 2000 survey 84 bluegill sunfish were captured by means of electrofishing (Figure 17).

Combining gear types permitted the development of a complete length frequency histogram for fall 1999 and spring 2000 surveys. Combined length frequency histograms for the fall 1999 survey (Figure 18) and the spring 2000 survey (Figure 17) yielded no apparent patterns. This was most likely due to the capability of bluegill to have multiple broods within one spawning season.

Table 18 Length at age of bluegill sunfish collected during fall 1999. Bolded values are mean back-calculated lengths using Lee's modification (Carlander 1982). Unbolded values are mean back-calculated lengths at annulus using the direct proportion method (Fletcher et al. 1993). 80 percent confidence intervals were calculated for each Lee Modification mean length at annulus.

			Mean Total Length(mm)at Age											
	Year Class	# Fish	1	CI	2	CI	3	CI	4	CI	5	CI	6	CI
	1998	8	42											
		8	**55**	**9**										
	1997	10	44		113									
		10	**58**	**7**	**117**	**10**								
	1996	31	48		97		137							
		31	**62**	**3**	**105**	**4**	**140**	**3**						
	1995	14	56		103		133		161					
		14	**70**	**9**	**112**	**9**	**139**	**9**	**163**	**11**				
	1994	3	40		93		134		165		185			
		3	**56**	**18**	**104**	**21**	**141**	**16**	**169**	**35**	**186**	**11**		
	1993	2	42		93		131		179		214		230	
		2	**59**	**27**	**105**	**17**	**140**	**19**	**184**	**118**	**216**	**29**	**230**	**65**
Direct Proportion Overall Mean			45		100		134		168		199		230	
Lee's Weighted Mean			**62**		**108**		**139**		**166**		**198**		**230**	

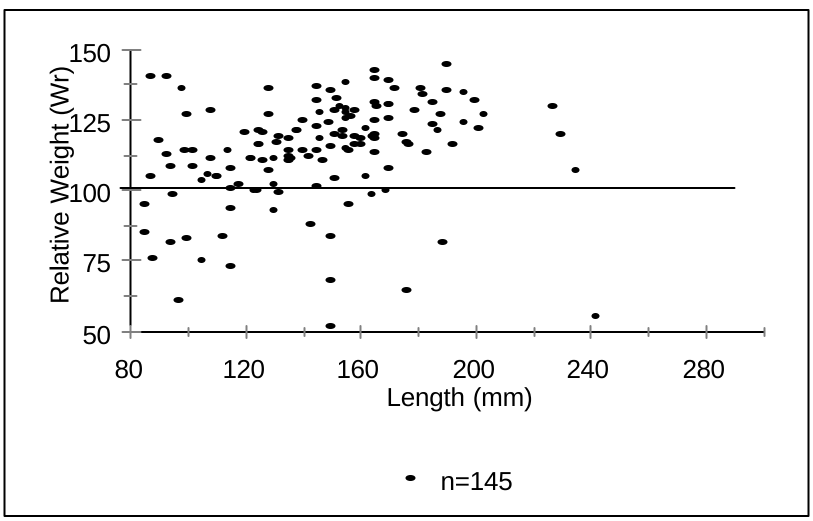


Figure 13 Relationship between total length and relative weight (Wr) of bluegill sunfish, excluding young of the year, compared to the national standard, collected fall 1999.

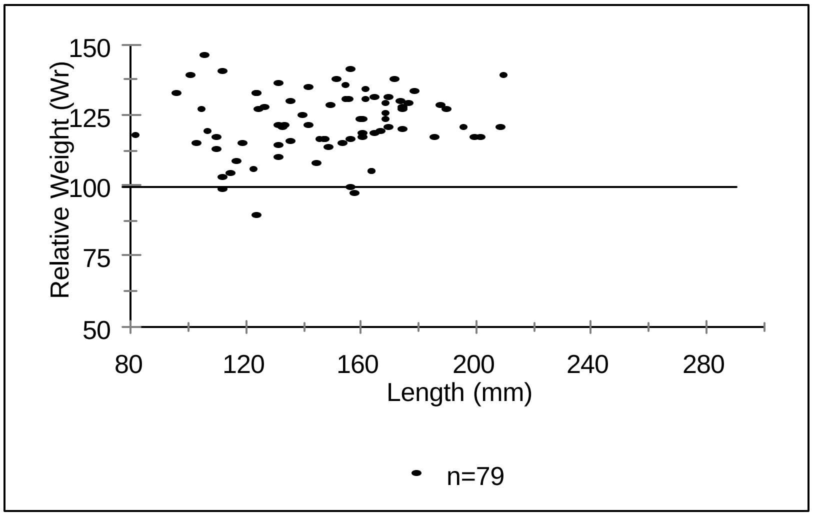


Figure 14 Relationship between total length and relative weight (Wr) of bluegill sunfish compared to the national standard, collected spring 2000.

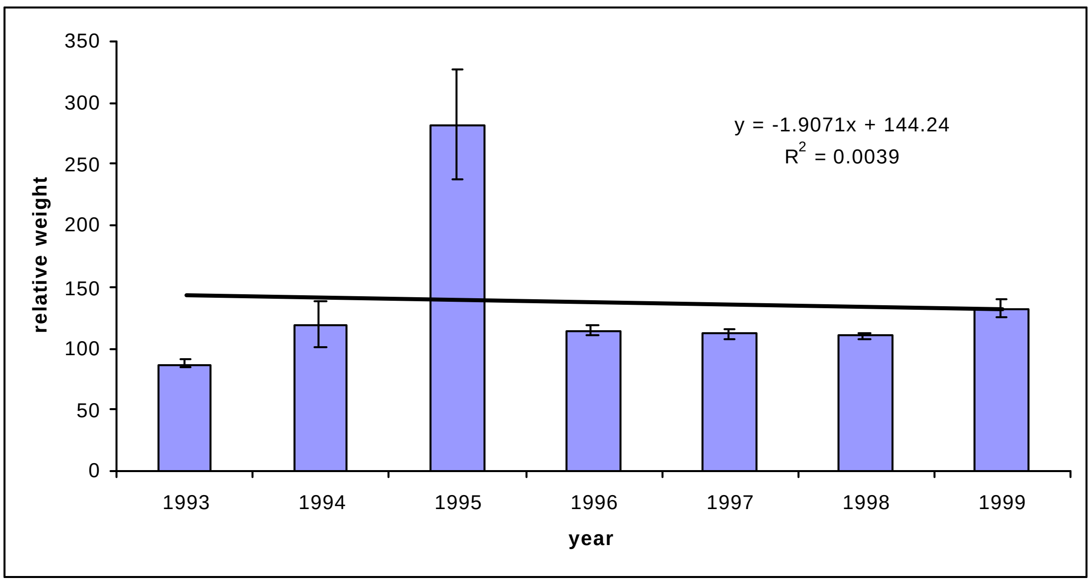


Figure 15 Comparison of mean relative weights, including trend line equation and R^2 value, for bluegill sunfish collected during surveys conducted fall 1993 to fall 1999. 95% confidence intervals and error bars are presented.

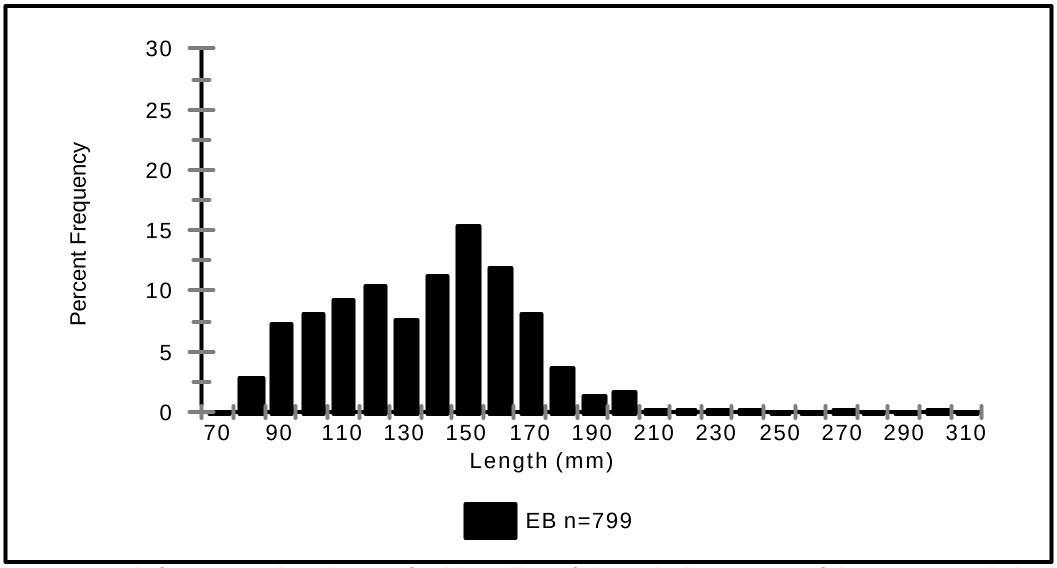


Figure 16 Length frequency distribution for bluegill sunfish, excluding young of the year, sampled using electrofishing (EB) for fall 1999.

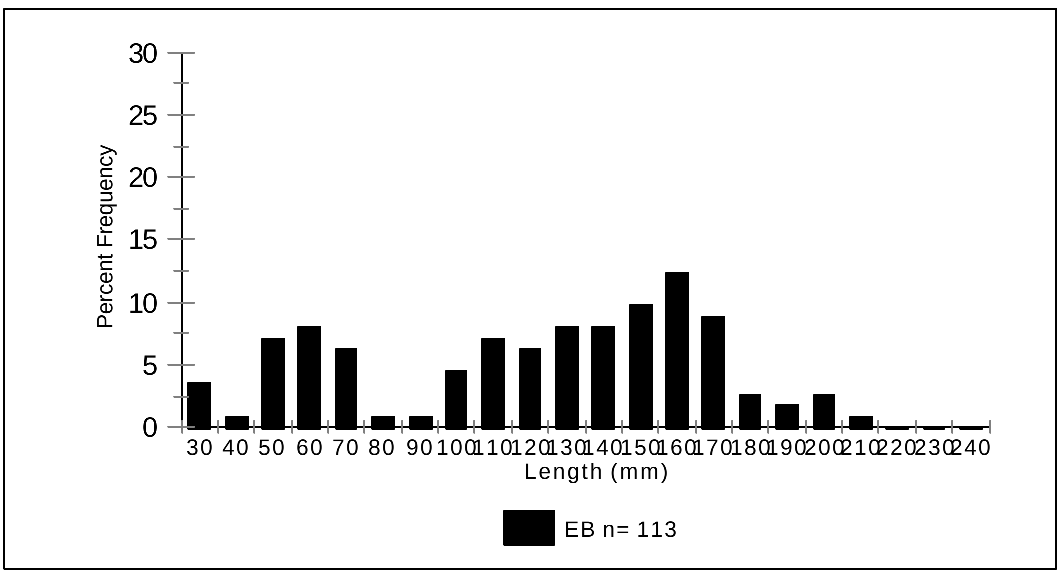


Figure 17 Length frequency distribution for bluegill sunfish sampled using electrofishing (EB), and length frequency for bluegill sunfish, with all gear types combined, including all fish sampled during the spring 2000 survey.

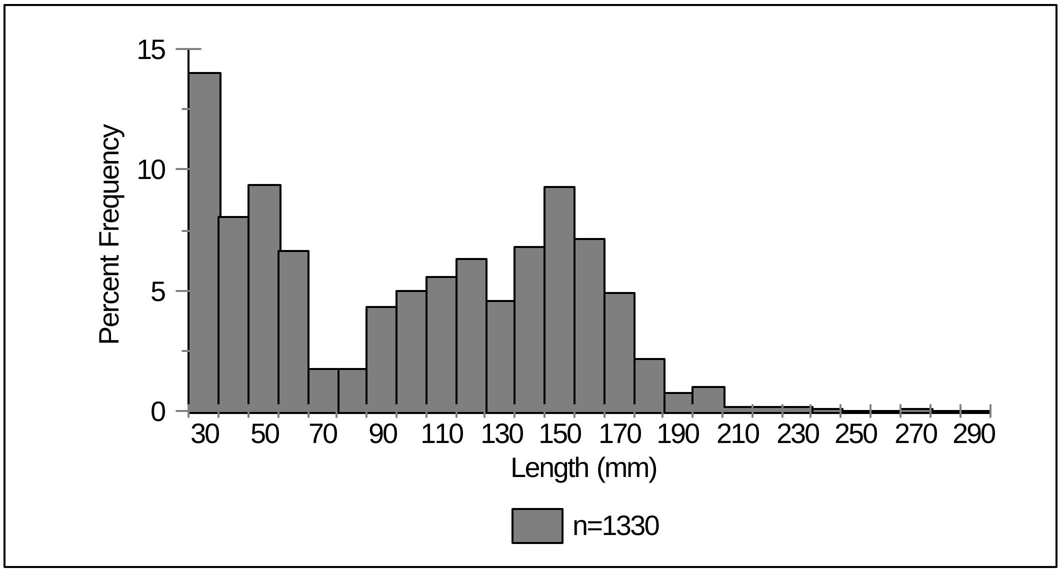


Figure 18 Length frequency distribution for bluegill sunfish with all gear types combined, including all fish sampled during the fall 1999 survey.

Largemouth Bass

Scales collected from largemouth bass permitted the development of a length at age table via back-calculation using Lee's modification and the direct proportion methods of aging. Means were developed for direct proportion and weighted means were developed for Lee's modification (Table 19). Comparisons of both indicated that length at age exceeded the state average.

Relative weights for largemouth bass collected in fall 1999 and spring 2000 indicated that conditions of fish were above the national average. During the fall of 1999 the majority of fish sampled fell above the national average (Figure 19). As for the spring 2000 sample, relative weights appeared to increase as length increased (Figure 20). Historical fall data beginning with 1993 and ending with 1999 was analyzed and the mean relative weights calculated for each year. Mean relative weights excluding fall of 1993 data remained above the national average and showed an upward trend albeit variable (Figure 21). However, R^2 values for the assigned trend line were poor signifying an inefficient model prediction.

Length frequency histograms separating the electrofishing and gill netting capture techniques were constructed to visually detect any bias between sampling gears. A gear bias was noticed due to the lack of largemouth bass captured in gillnets for both the 1999 and 2000 surveys. During the 1999 survey 91 largemouth bass were captured using electrofishing methods (Figure 22). During the 2000 survey 48 largemouth bass were captured by means of electrofishing (Figure 23). No statistical analysis was performed due to the absence of largemouth bass caught in gillnets.

Combining gear types permitted the development of a complete length frequency histogram for fall 1999 and spring 2000 surveys. The length frequency histogram for the fall 1999 data resembled a typical distribution with the largest percentage of fish captured coming from the smallest size classes of largemouth bass within the population (Figure 24). During the spring 2000 survey largemouth bass within the 280mm class represented the largest percentage of fish sampled (Figure 23).

Table 19 Length at age of largemouth bass collected during fall 1999. Bolded values are mean back-calculated lengths using Lee's modification (Carlander 1982). Unbolded values are mean back-calculated lengths at annulus using the direct proportion method (Fletcher et al. 1993). 80 percent confidence intervals were calculated for each Lee Modification mean length at annulus.

			Mean Total Length(mm)at Age											
	Year Class	# Fish	1	CI	2	CI	3	CI	4	CI	5	CI	6	CI
	1998	14	98											
		14	**103**	**4**										
	1997	3	81		137									
		3	**92**	**15**	**142**	**38**								
	1996	9	115		186		238							
		9	**127**	**8**	**192**	**19**	**240**	**17**						
	1995	14	100		176		246		301					
		14	**114**	**9**	**186**	**11**	**252**	**20**	**303**	**24**				
	1994	2	134		237		315		377		442			
		2	**148**	**46**	**247**	**40**	**322**	**127**	**381**	**123**	**443**	**99**		
	1993	1	90		167		238		283		344		380	
		1	**106**	**0**	**179**	**0**	**247**	**0**	**290**	**0**	**348**	**0**	**382**	**0**
Direct proportion overall mean			103		181		259		320		393		380	
Direct proportion E. WA. avg.			69		136		189		249		300		351	
Lee's weighted mean			**113**		**187**		**253**		**312**		**411**		**382**	

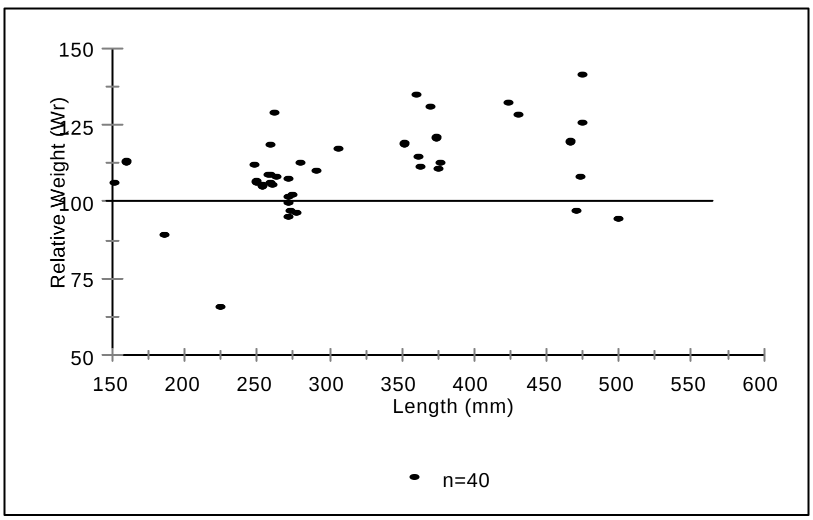


Figure 19 Relationship between total length and relative weight (Wr) of largemouth bass, excluding young of the year, compared to the national standard, collected fall 1999.

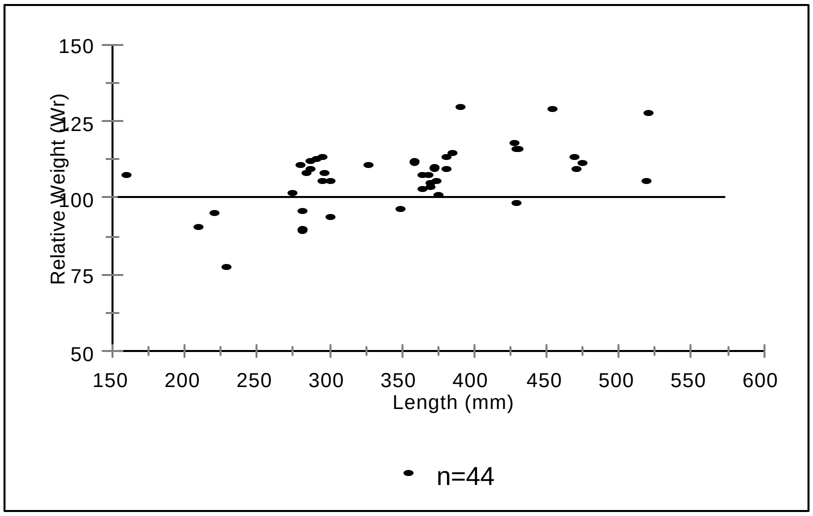


Figure 20 Relationship between total length and relative weight (Wr) of largemouth bass compared to the national standard, collected spring 2000.

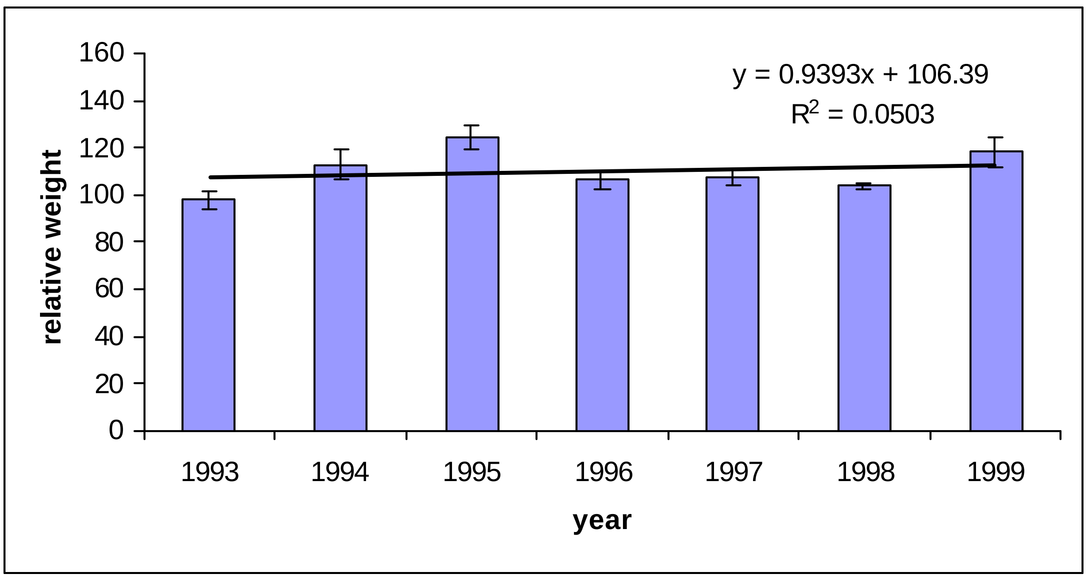


Figure 21 Comparison of mean relative weights, including trend line equation and R^2 value, from largemouth bass collected during surveys conducted fall 1993 to fall 1999. 95% confidence intervals and error bars are presented.

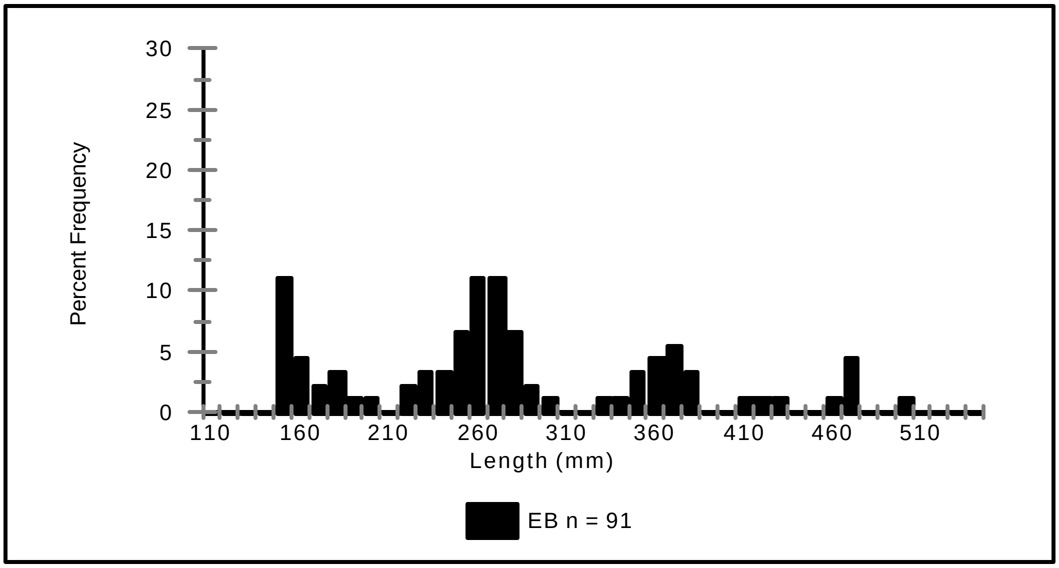


Figure 22 Length frequency distribution for largemouth bass, excluding young of the year, sampled using electrofishing (EB) during the fall 1999 survey.

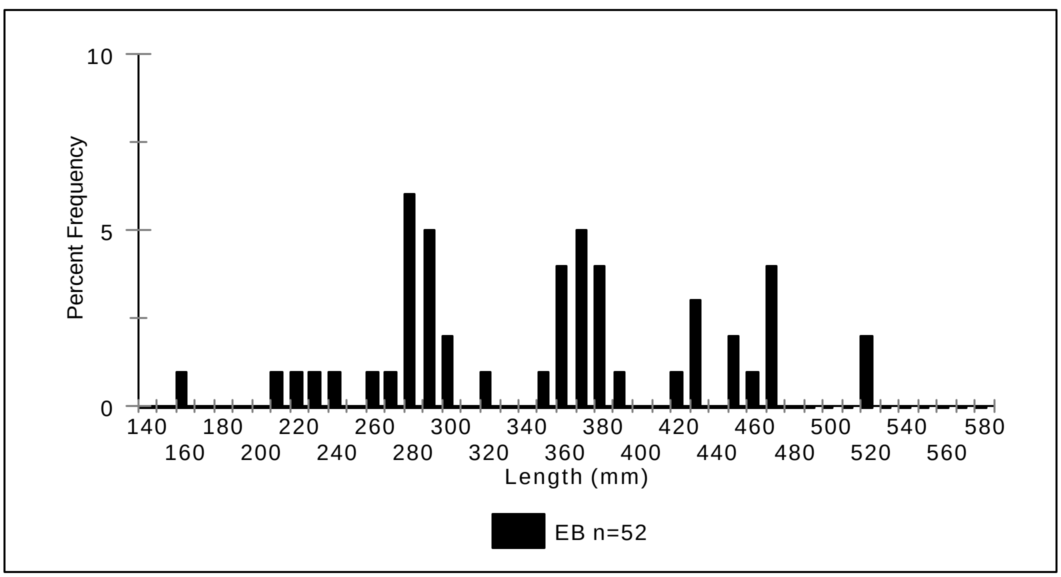


Figure 23 Length frequency distribution for largemouth bass sampled using electrofishing (EB), and length frequency for largemouth bass, with all gear types combined, including all fish sampled during the spring 2000 survey.

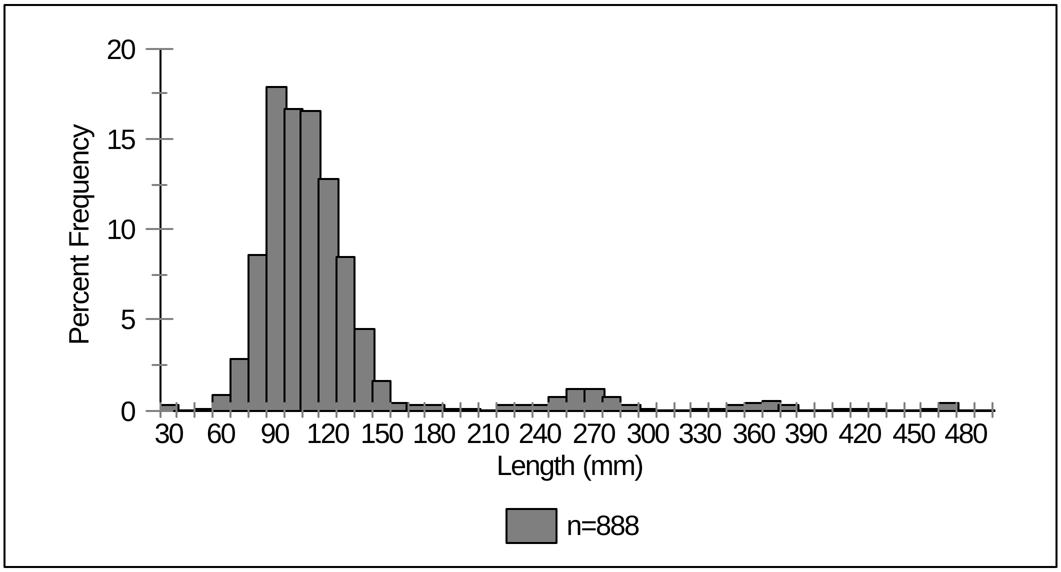


Figure 24 Length frequency distribution for largemouth bass, with all gear types combined, including all fish sampled during the fall 1999 survey.

Smallmouth Bass

Scales collected from smallmouth bass permitted the development of a length at age table via back-calculation using Lee's modification and the direct proportion methods of aging. Means were developed for direct proportion and weighted means were developed for Lee's modification (Table 20). Comparisons of both indicated that length at age exceeded the state average.

Relative weights for smallmouth bass collected in fall 1999 and spring 2000 indicated that conditions of fish were below the national average. The majority of smallmouth bass in Moses Lake collected during the fall of 1999 were in poor condition and below the national average regarding relative weight (Figure 25). During the spring 2000 sample, relative weights appeared to decrease in relation to size increase (Figure 26). Historical fall data beginning with 1993 and ending with 1999 was analyzed and the mean relative weights calculated for each year. Mean relative weights for fall 1994 to 1996 were above the national average. However, mean relative weights for the years 1993, 1997 and 1998 were below the average (Figure 27). R^2 values for the assigned trend line were very poor signifying an inefficient model prediction.

Length frequency histograms separating the electrofishing and gill netting capture techniques were constructed to visually detect any bias between sampling gears. The majority of smallmouth bass sampled were captured via electrofishing techniques. During the 1999 survey 241 and 7 smallmouth bass were captured using electrofishing and gillnetting techniques, respectively (Figure 28). During the 2000 survey 235 and 5 smallmouth bass were captured using electrofishing gillnetting methods, respectively (Figure 29). A two sample, two tailed t-test at an alpha level of 0.05 was used to determine whether or not there was a significant difference in length of fish captured between the two gear types. There was no significant difference between gillnetting and electrofishing regarding the length of fish caught during the fall 1999 survey (df=330, P=0.86) and the spring 2000 survey (df=381, P=0.07). Young-of-the-year fish were included in the analysis.

Combining gear types permitted the development of a complete length frequency histogram for fall 1999 and spring 2000 surveys. The size class of 200mm represented the largest percentage of fish captured during the fall 1999 (Figure 30). During the spring 2000 survey smallmouth bass within the 90mm class represented the largest percentage of fish sampled (Figure 31).

Table 20 Length at age of smallmouth bass collected during fall 1999. Bolded values are mean back-calculated lengths using Lee's modification (Carlander 1982). Unbolded values are mean back-calculated lengths at annulus using the direct proportion method (Fletcher et al. 1993). 80 percent confidence intervals were calculated for each Lee Modification mean length at annulus.

			Mean Total Length(mm)at Age							
	Year Class	# Fish	1	CI	2	CI	3	CI	4	CI
	1998	2	116							
		2	**126**	**24**						
	1997	20	100		176					
		20	**118**	**5**	**181**	**8**				
	1996	24	92		171		225			
		24	**114**	**5**	**183**	**11**	**229**	**12**		
	1995	6	86		157		206		252	
		6	**110**	**11**	**173**	**23**	**217**	**30**	**257**	**31**
Direct proportion overall mean			98		168		215		252	
Direct proportion state avg.			70		146		212		268	
Lee's weighted mean			**116**		**181**		**227**		**257**	

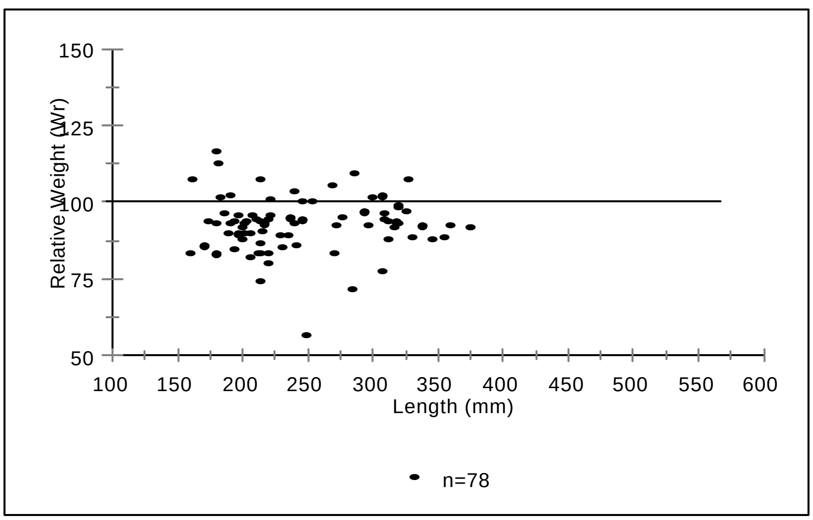


Figure 25 Relationship between total length and relative weight (Wr) of smallmouth bass, excluding young of the year, compared to the national standard, collected fall 1999.

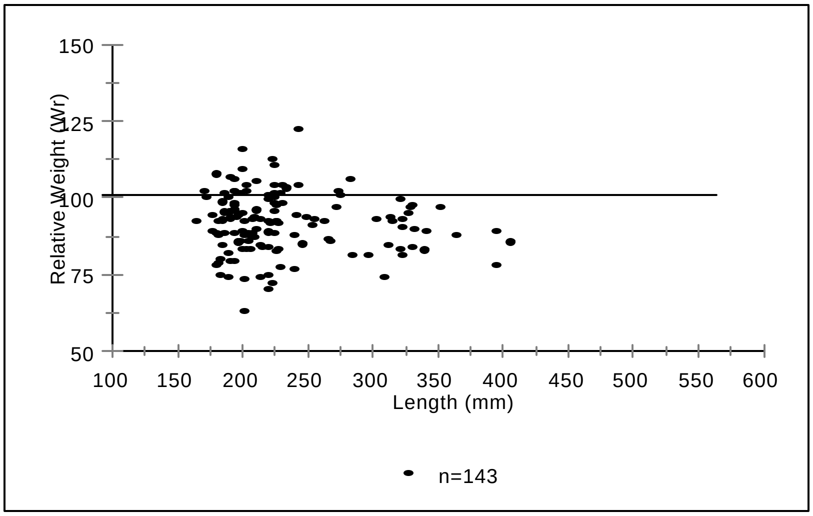


Figure 26 Relationship between total length and relative weight (Wr) of smallmouth bass compared to the national standard, collected spring 2000.

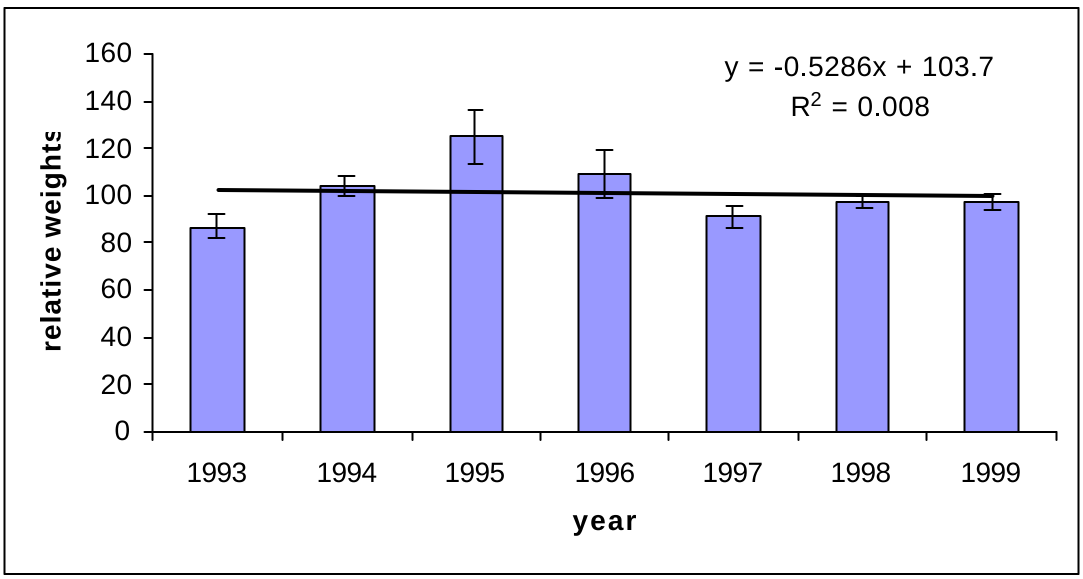


Figure 27 Comparison of mean relative weights, including trend line equation and R^2 value, from smallmouth bass collected during surveys conducted fall 1993 to fall 1999. 95% confidence intervals and error bars are presented.

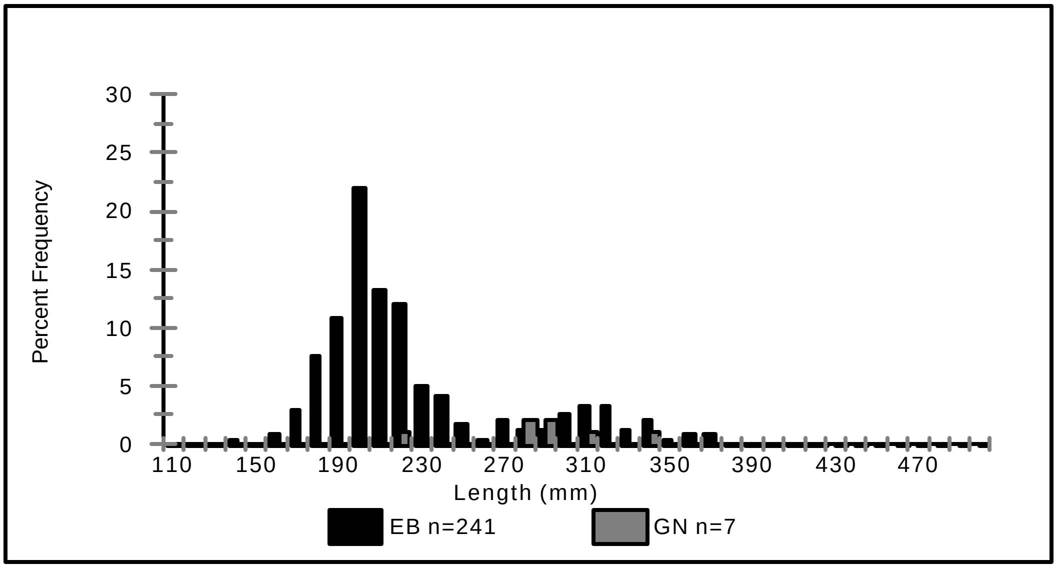


Figure 28 Length frequency distribution for smallmouth bass, excluding young of the year, sampled using electrofishing (EB) and gill netting (GN) for fall 1999.

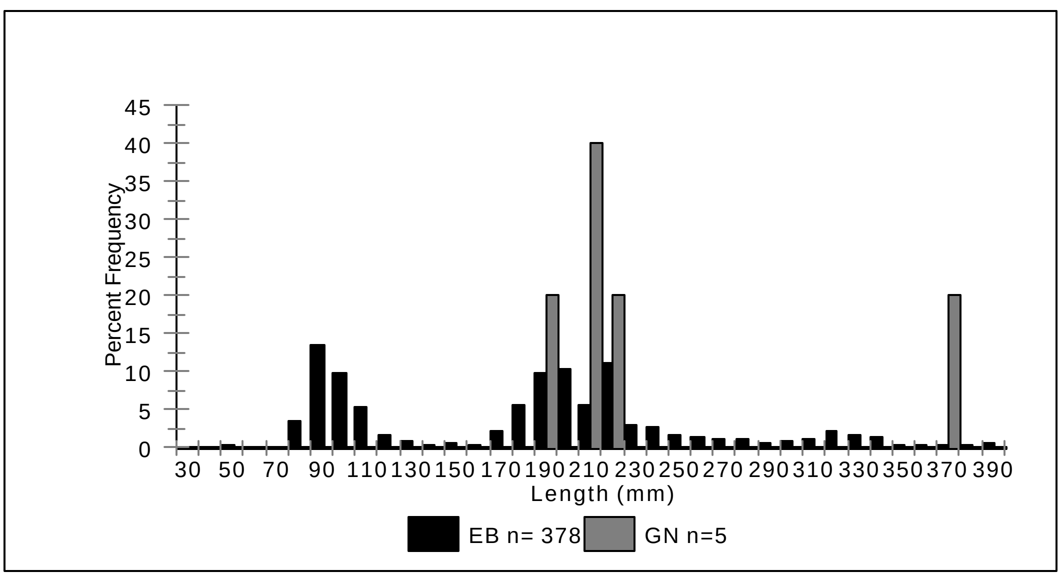


Figure 29 Length frequency distribution for smallmouth bass, excluding young of the year, sampled using electrofishing (EB) and gill netting (GN) for spring 2000.

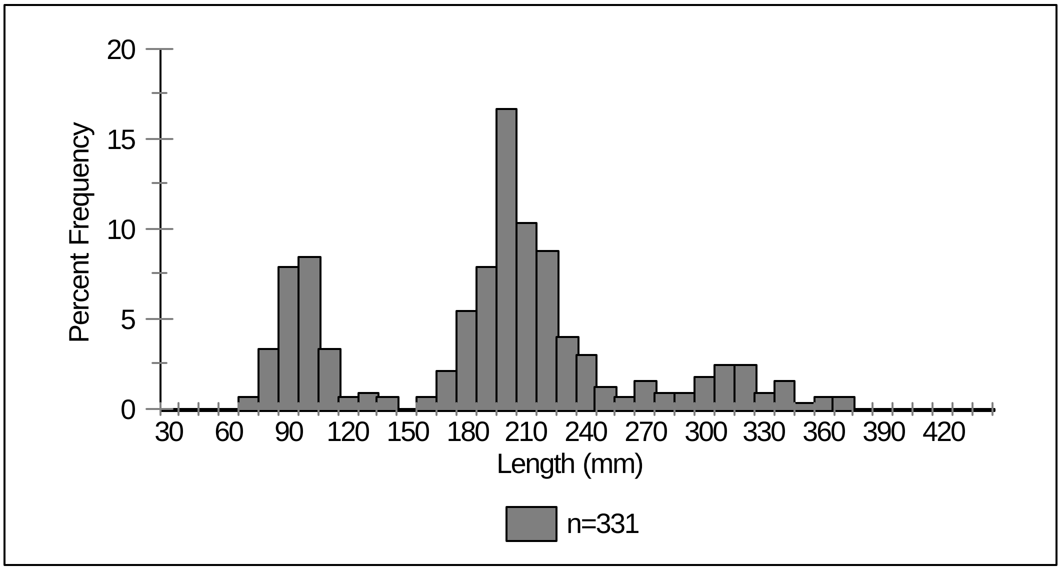


Figure 30 Length frequency distribution for smallmouth bass, with all gear types combined, including all fish sampled during the fall 1999 survey.

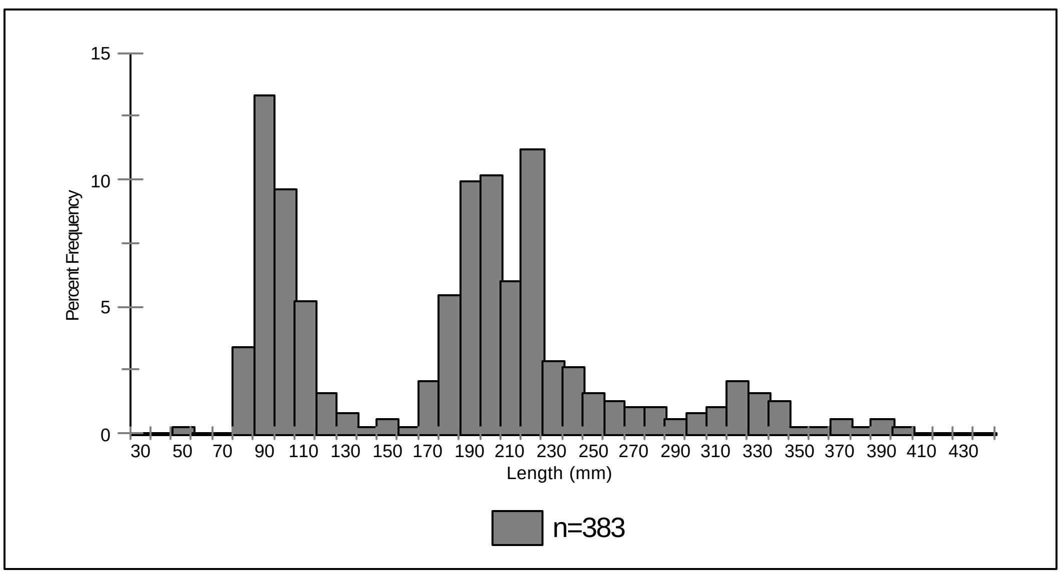


Figure 31 Length frequency distribution for smallmouth bass, with all gear types combined, including all fish sampled during the spring 2000 survey.

Walleye

Scales collected from walleye permitted the development of a length at age table via back-calculation using Lee's modification and the direct proportion methods of aging. Means were developed for direct proportion and weighted means were developed for Lee's modification (Table 21). Comparisons of both indicated that length at age exceeded the state average.

Relative weights for walleye collected in fall 1999 and spring 2000 indicated that conditions of fish were below the national average. The majority of walleye in Moses Lake collected during the fall of 1999 were below the national average regarding relative weight. As length increased the relative weight or condition of walleye decreased (Figure 32). During the spring 2000 sample, relative weights appeared to decrease in relation to size increase (Figure 33). Historical fall data beginning with 1993 and ending with 1999 were analyzed and the mean relative weights calculated for each year. Walleye fell below the national average regarding relative weights for all years sampled. However, there does appear to be an upward trend in relative weights (Figure34). R^2 values for the assigned trend line were very poor signifying an inefficient model prediction.

Length frequency histograms separating the electrofishing and gill netting capture techniques were constructed to visually detect any bias between sampling gears. During the 1999 survey 162 and 184 walleye were captured using electrofishing and gillnetting techniques, respectively (Figure 35). During the 2000 survey 383 and 2000 walleye were captured using electrofishing and gillnetting methods, respectively (Figure 36). A two sample, two tailed t-test at an alpha level of 0.05 was used to determine whether or not there was a significant difference in length of fish captured between the two gear types. There was a significant difference between gillnetting and electrofishing regarding the length of fish caught during the fall 1999 survey (df=1560, P=4.4E-203) and the spring 2000 survey (df=580, P=1.4E-75). Young-of-the-year fish were included in the analysis.

Combining gear types permitted the development of a complete length frequency histogram for fall 1999 and spring 2000 surveys. During the fall 1999 survey the 160mm-size class represent the largest percentage of walleye sampled (Figure 37). The 170mm-size class represented the largest percentage of walleye sampled during the spring 2000 survey (Figure 38).

Table 21 Length at age of walleye collected during fall 1999. Bolded values are mean back-calculated lengths using Lee's modification (Carlander 1982). Unbolded values are mean back-calculated lengths at annulus using the direct proportion method (Fletcher et al. 1993). 80 percent confidence intervals were calculated for each Lee Modification mean length at annulus.

		Mean Total Length(mm)at Age													
Year Class	# Fish	1	CI	2	CI	3	CI	4	CI	5	CI	6	CI	7	CI
1998	3	145													
	3	**164**	**14**												
1997	17	174		269											
	17	**199**	**6**	**279**	**7**										
1996	23	161		255		330									
	23	**193**	**7**	**274**	**13**	**339**	**15**								
1995	20	161		258		336		389							
	20	**196**	**9**	**282**	**10**	**350**	**12**	**394**	**29**						
1994	21	163		254		349		424		461					
	21	**201**	**13**	**282**	**15**	**368**	**17**	**435**	**17**	**466**	**26**				
1993	13	134		222		307		389		465		474			
	13	**176**	**14**	**255**	**17**	**332**	**19**	**406**	**17**	**474**	**16**	**478**	**53**		
1992	13	123		203		283		359		427		486		543	
	13	**166**	**8**	**239**	**10**	**312**	**13**	**380**	**15**	**442**	**18**	**495**	**21**	**547**	**21**
Direct proportion overall mean		151		243		321		390		451		480		543	
Minnesota, direct prop. (Wydoski)		117		218		305		381		460		521		582	
Lee's Weighted Mean		**190**		**271**		**343**		**407**		**462**		**487**		**547**	
Canada, Lee's reg. (Carlander)		**162**		**231**		**303**		**357**		**400**		**438**		**478**	
Sprague Lake (Lee's regression)		**158**		**246**		**335**		**390**		**441**		**453**			
Lake Roosevelt (Lee's regressio		**173**		**279**		**363**		**425**		**478**		**535**		**618**	

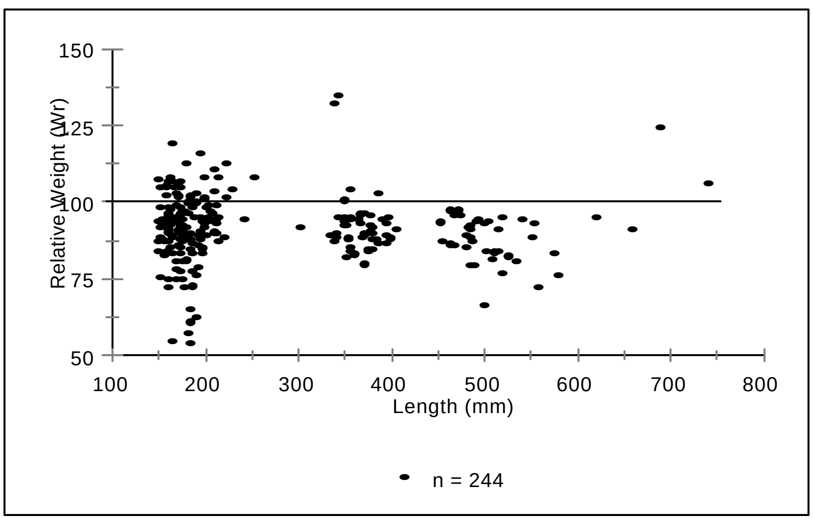


Figure 32 Relationship between total length and relative weight (Wr) of walleye, excluding young of the year, compared to the national standard, collected fall 1999.

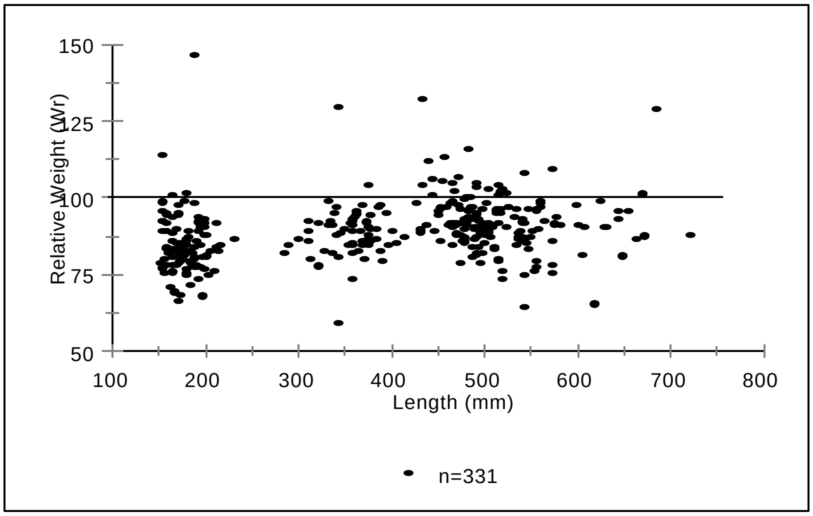


Figure 33 Relationship between total length and relative weight (Wr) of walleye, excluding young of the year, compared to the national standard, collected spring 2000.

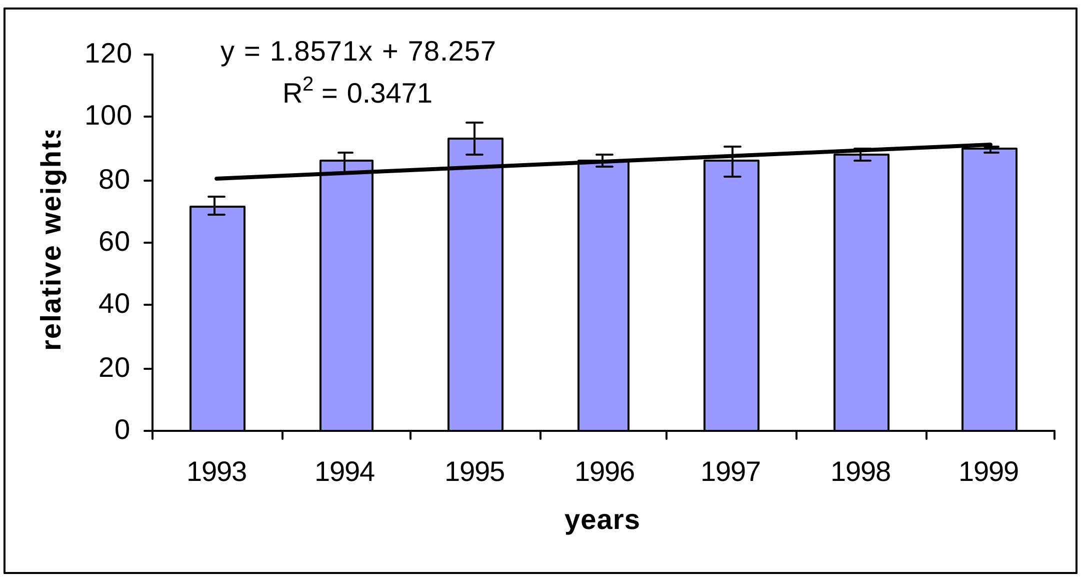


Figure 34 Comparison of mean relative weights, including trend line equation and R^2 value, from walleye collected during surveys conducted fall 1993 to fall 1999. 95% confidence intervals and error bars are presented.

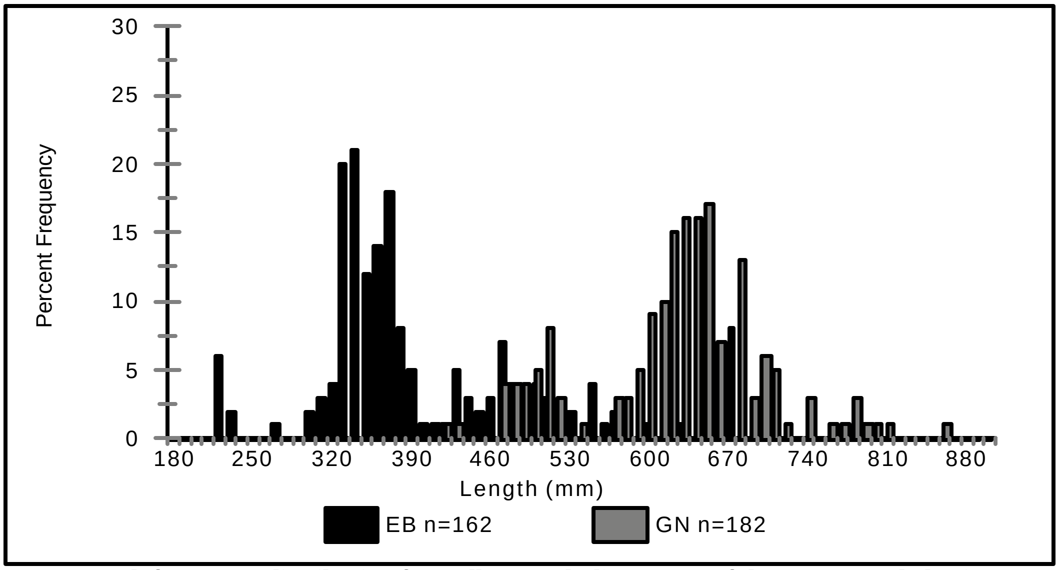


Figure 35 Length frequency distribution for walleye, excluding young of the year, sampled using electrofishing (EB) and gill netting (GN) for fall 1999.

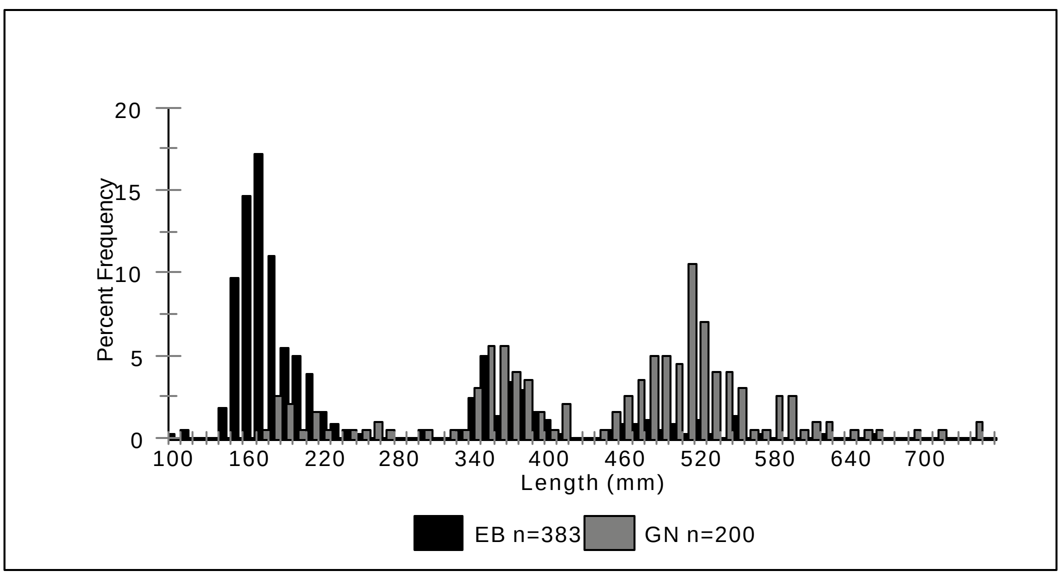


Figure 36 Length frequency distribution for walleye sampled using electrofishing (EB) and gill netting (GN) for spring 2000.

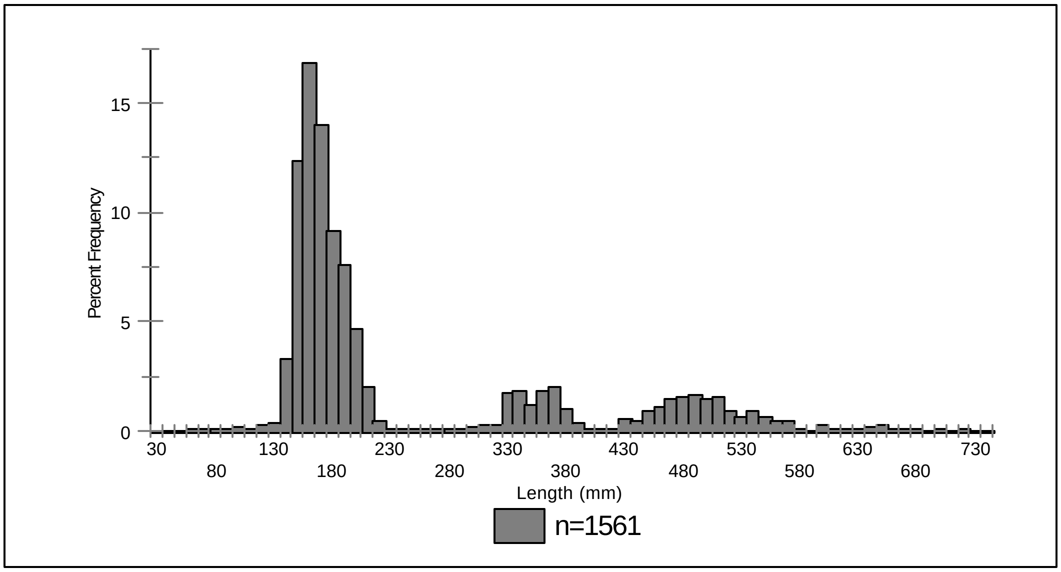


Figure 37 Length frequency distribution for walleye, with all gear types combined, including all fish sampled during the fall 1999 survey.

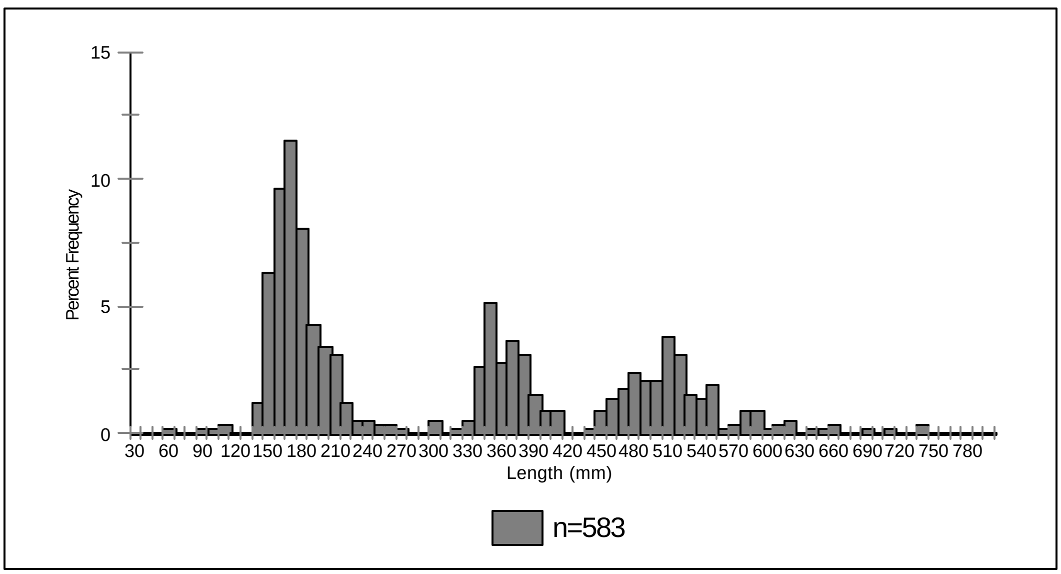


Figure 38 Length frequency distribution for walleye, with all gear types combined, including all fish sampled during the spring 2000 survey.

Yellow Perch

Scales collected from yellow perch permitted the development of a length at age table via back-calculation using Lee's modification and the direct proportion methods of aging. Means were developed for direct proportion and weighted means were developed for Lee's modification (Table 22). Comparisons of both indicated that length at age exceeded the state average.

Relative weights for yellow perch collected in fall 1999 and spring 2000 indicated that conditions of fish were below the national average. The majority of yellow perch in Moses Lake collected during the fall of 1999 were below the national average regarding relative weight. As length increased the relative weight or condition of yellow perch decreased (Figure 39). However, during the spring 2000 sample, relative weights appeared to be distributed evenly about the national average (Figure 40). Historical fall data beginning with 1993 and ending with 1999 was analyzed and the mean relative weights calculated for each year. Throughout all the years surveyed the relative weights of yellow perch fell below the national average (Figure 41). R^2 values for the assigned trend line were very poor signifying an inefficient model prediction.

Length frequency histograms separating the electrofishing and gill netting capture techniques were constructed to visually detect any bias between sampling gears. Twice as many fish were caught via electrofishing methods compared to gillnetting methods during the fall of 1999. However, larger yellow perch were generally caught in gillnets compared to electrofishing methods (Figure 42). Considerably less yellow perch were caught during the spring 2000 sample. Electrofishing and gillnetting resulted in the capture of 279 and 181 yellow perch, respectively. Interestingly, gillnetting caught larger yellow perch than electrofishing techniques (Figure 43). A two sample, two tailed t-test at an alpha level of 0.05 was used to determine whether or not there was a significant difference in length of fish captured between the two gear types. There was a significant difference between gillnetting and electrofishing regarding the length of fish caught during the fall 1999 survey (df=5560, P=1.2E-241) and the spring 2000 survey (df=851, P=1.15E-45). Young-of-the-year fish were included in the analysis.

Combining gear types permitted the development of a complete length frequency histogram for fall 1999 and spring 2000 surveys. During the 1999 fall survey the 100mm size class accounted for over 30% of the yellow perch captured (Figure 44). The 100mm size class during the spring 2000 survey also represented the largest percentage of yellow perch sampled (Figure 45).

Table 22 Length at age of yellow perch collected during fall 1999. Bolded values are mean back-calculated lengths using Lee's modification (Carlander 1982). Unbolded values are mean back-calculated lengths at annulus using the direct proportion method (Fletcher et al. 1993). 80 percent confidence intervals were calculated for each Lee Modification mean length at annulus.

			Mean Total Length(mm)at Age					
	Year Class	# Fish	1	CI	2	CI	3	CI
	1998	8	91					
		8	**103**	**5**				
	1997	37	100		153			
		37	**115**	**10**	**160**	**7**		
	1996	9	69		142		194	
		9	**90**	**3**	**154**	**5**	**200**	**4**
Direct proportion overall mean			87		147		194	
Direct proportion state avg.			60		120		152	
Lee's weighted mean			**109**		**159**		**200**	

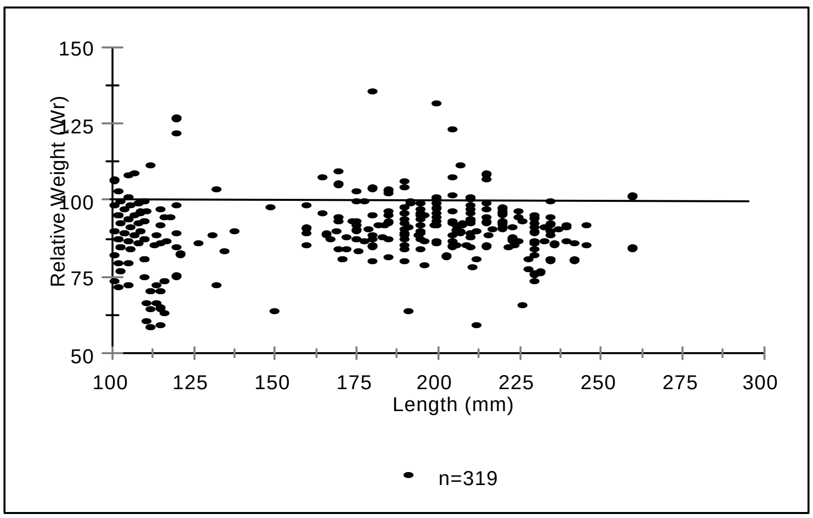


Figure 39 Relationship between total length and relative weight (Wr) of yellow perch, excluding young of the year, compared to the national standard, collected fall 1999.

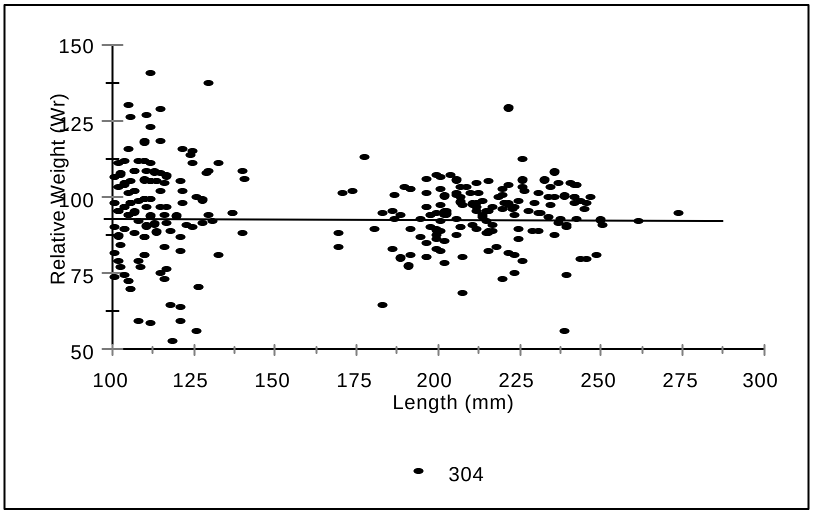


Figure 40 Relationship between total length and relative weight (Wr) of yellow perch, excluding young of the year, compared to the national standard, collected spring 2000.

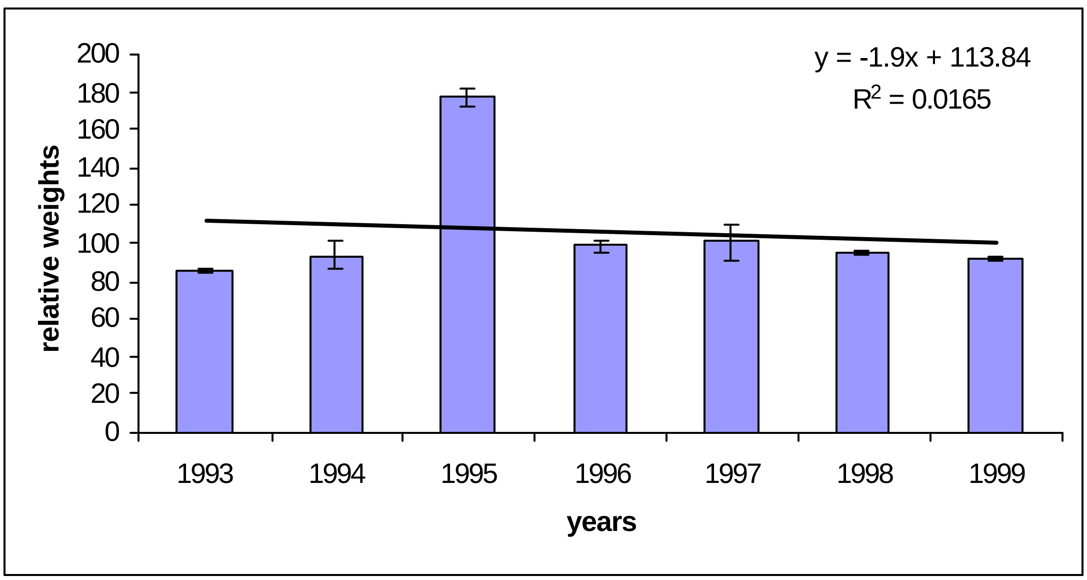


Figure 41 Comparison of mean relative weights, including trend line equation and R^2 value, from yellow perch collected during surveys conducted fall 1993 to fall 1999. 95% confidence intervals and error bars are presented.

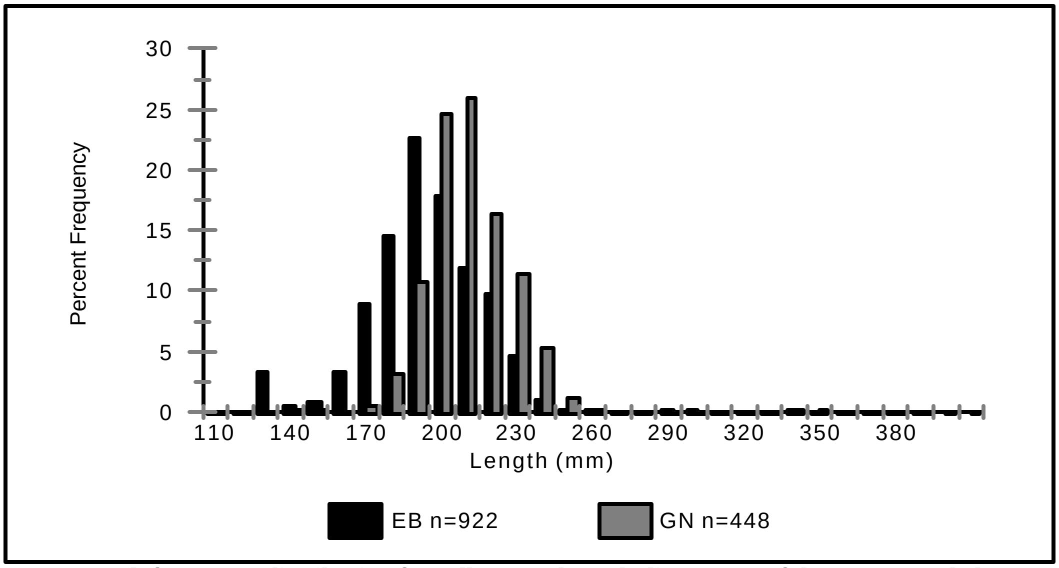


Figure 42 Length frequency distribution for yellow perch, excluding young of the year, sampled using electrofishing (EB) and gill netting (GN) for fall 1999.

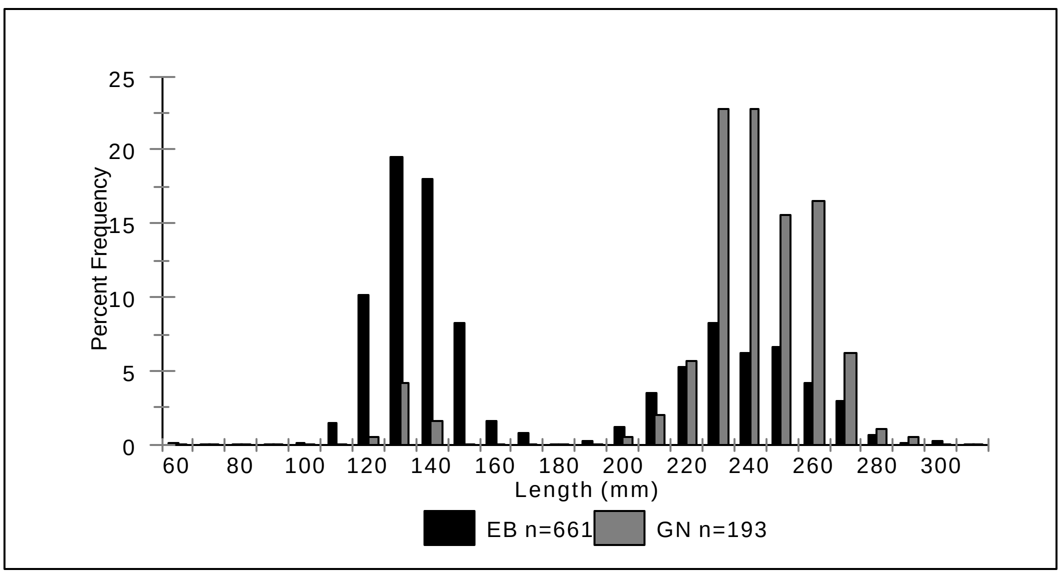


Figure 43 Length frequency distribution for yellow perch, excluding young of the year, sampled using electrofishing (EB) and gill netting (GN) for spring 2000.

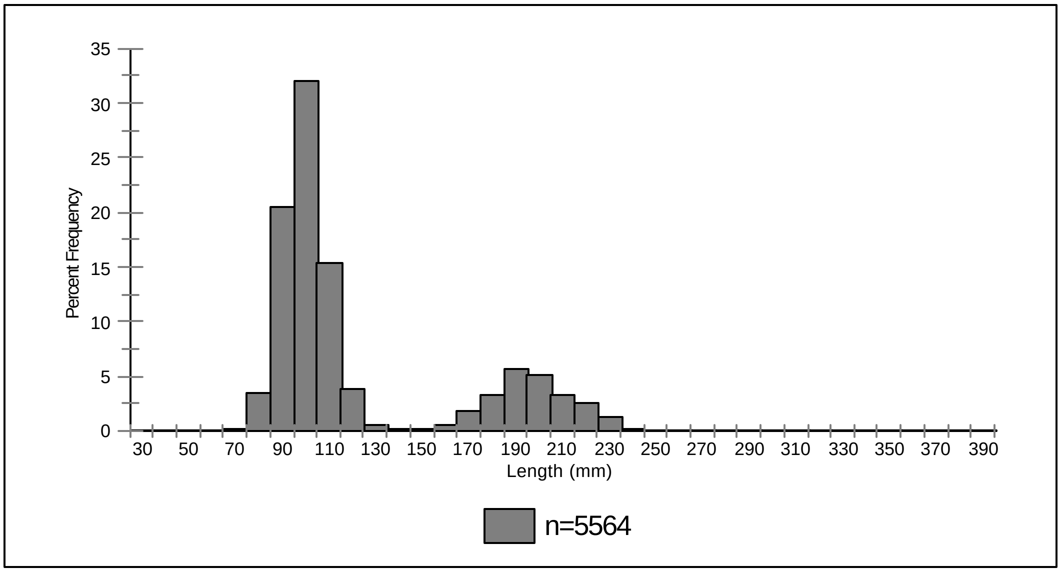


Figure 44 Length frequency distribution for yellow perch, with all gear types combined, including all fish sampled during the fall 1999 survey.

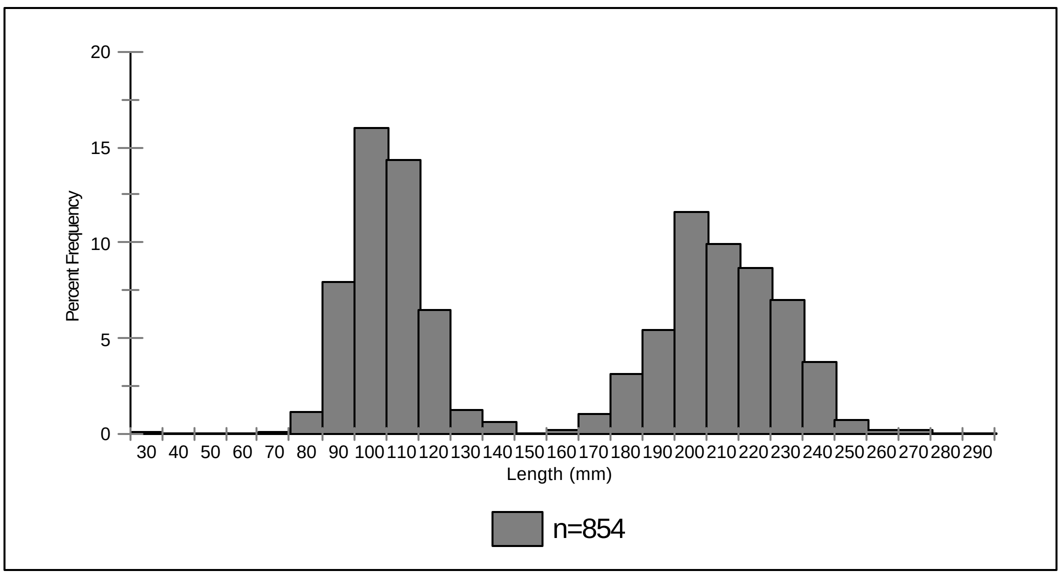


Figure 45 Length frequency distribution for yellow perch, with all gear types combined, including all fish sampled during the spring 2000 survey.

Discussion

The data and results obtained from Phase 1 of the Moses Lake Project provided a basic understanding of Moses Lake and the fishery therein. In and of itself, this information was not adequate to discern the cause and effect relationships necessary to formulate management actions intended to achieve desirable fish populations, nor was Phase 1 meant to elucidate the more complicated aspects of this system. The Phase 1 information suggested the hypotheses most pertinent to understanding these relationships. Historical baseline information related to the chemical, physical, and biological conditions in Moses lake, in conjunction with the preliminary baseline data, was also used in the design of studies for the collection of data that would best address the hypotheses and ultimately answer the questions regarding the decline in panfish production within Moses Lake.

Moses Lake has been a dynamic system that has changed substantially over the last 20 years regarding the richness and abundance of fish species within its community. As with any community, changes in species composition also altered species interactions, and directly and indirectly affected the flow of energy through all dimensions of the trophic web (Vanni et al. 1997; Carpenter 1988). Understanding these interactions will aid the investigators and managers in restoring and managing the Moses Lake fisheries.

The original causes for the decline in panfish within Moses Lake, specifically black crappie and bluegill sunfish, remains unknown. However, historical WDFW creel studies have documented a dramatic decrease in the harvest of panfish within Moses Lake (Duff 1974; Jackson 1983; Korth 1991; Donley 1999). Biological surveys throughout the 1990's and Moses lake Project surveys conducted during the fall of 1999 and the spring of 2000 confirmed the decrease in abundance of panfish within Moses Lake.

During the decline of panfish, the aesthetic value of water quality has improved in Moses Lake. This was most likely due to the dilution facility that pumped clean Columbia River water into Moses Lake. Although nutrient levels and chlorophyll-*a* concentrations have decreased slightly or remained static, water clarity decreased. The cause of the reduction in water clarity may have been due to an overabundance of carp. With the reduction in water clarity, the depth of the effective euphotic zone would have also decreased, potentially reducing the amount of primary productivity in the lake. A loss of primary productivity may have affected grazers, such as zooplankton, and reduced secondary productivity. Decreased zooplankton production may have decreased the amount of available prey for panfish and ultimately panfish recruitment. Additional water quality and primary and secondary productivity information is necessary to determine whether physical or chemical limitations to the recruitment of panfish in Moses Lake exist.

The effects of drawdown on the availability of aquatic habitat of Moses Lake have not been studied. A common problem confronted when managing fisheries within reservoirs is the seasonal de-watering of the wetted basin because the littoral zones are an important habitat for some or all life history stages of many fishes (Beauchamp et al. 1994). Drawdowns decrease the amount of wetted shoreline that may once have been utilized by fish. Hence, many species may be forced to occupy sub-optimal habitat. Ontogenetic changes including food requirements, behavior, and an organism's size will ultimately shift the habitat requirements of many aquatic organisms to and from littoral habitats (Leis and Fox 1996). A study of Kansas reservoirs indicated that anthropogenic drawdown had deleterious affects on densities of all ages of largemouth bass by decreasing the amount of available vegetative habitat (Willis 1986). The effect of drawdowns and the reduction of littoral habitat greatly impacts the survival of small forage fishes due to the loss of refuge from predators (Paller 1997). Draw down may increase prey vulnerability by decreasing habitat complexity, which increases visual detection of prey by predators (Savino and Stein 1982). Habitat complexity also decreases as depth increases due to the reduction in primary productivity below the euphotic zone (Beauchamp et al. 1994). Therefore, as the water level recedes, the clearer, deeper homogenous habitat becomes the littoral habitat.

Schriver et al. showed that an increase in vegetation density greatly altered the phytoplankton, zooplankton and fish communities within an experimental enclosure (1995). Complex habitat such as aquatic vegetation or rocky substrate offers refuge for not only fishes but also acts as a substrate to promote macro- and microinvertebrate growth. Increased invertebrate production will ultimately increase food availability for fishes. Consequently, there is a bottom up effect regarding habitat complexity as related to modeling the food web in the aquatic community. Intermediate levels of macrophyte density appear to stimulate the highest level of species richness, survival and fitness within the fish assemblage utilizing the habitat (Kilgore et al. 1989; Miranda and Pugh 1997). The lack of macrophytes, or an overabundance of macrophytes, creates a habitat that is homogeneous in nature, which does not stimulate aquatic community health.

Ideally, habitat should resemble a mosaic pattern offering a variety of spatial niches that can be utilized as optimal habitat by the species of the community. Such habitat is often located in the littoral zones of a lake. Inappropriate densities of habitat can actually increase the likelihood of predation (Bettoli et al. 1992). Overall, it can be assumed that drawdowns affect habitat complexity and may directly or indirectly affect the biota within Moses Lake.

Length at age of black crappie and bluegill sunfish were above the Washington statewide average. Likewise, their relative weights were above the national average. Therefore, the growth and health of individual recruited black crappie and bluegill sunfish were probably not impaired, but rather their ability to recruit as a population was negatively impacted. Predation by other species may have reduced the numbers of panfish within Moses Lake and in turn reduced intraspecific and/or interspecific competition amongst black crappie and bluegill sunfish. However, interspecific competition for space and resources within Moses Lake with other species may have contributed to the declining numbers of panfish. Competition may be qualified as temporal or spatial and may be direct or indirect between varieties of species. Phase 1 data suggested that perch were very abundant in Moses Lake. Competition for food and space may be present at various stages of life between species. Although panfish and yellow perch, excluding young-of-the-year, all had relative weights that fell around and above the national average, the possibility of perch depressing the abundance of panfish exists. Because yellow perch spawn prior to panfish populations and are highly fecund, young-of-the-year yellow perch may out-compete young-of-the-year black crappie and bluegill sunfish by virtue of an earlier emergence time. Walleye, too, have a similar reproductive strategy. Additionally, common carp are a highly fecund fish that could produce enormous amounts of young-of-the-year that could be competing with young-of-the-year panfish for forage during critical early life history stages.

Length at age and relative weights for all predatory warmwater fish (walleye, smallmouth bass, and largemouth bass) were comparable to statewide averages, and in the case of walleye, to distribution wide averages. As walleye and smallmouth bass relative weights decreased as the fish increased in size. This could indicate over-predation and interspecific or intraspecific competition among walleye and smallmouth bass. The overall reduction in panfish abundance may have reduced the prey base sufficiently to negatively affect the condition of larger predators, specifically walleye and smallmouth bass, within Moses Lake. Therefore, food could be limiting which translates into slower growth and/or lower relative weights. (Wege and Anderson 1978; Murphy et al. 1991; Marwitz and Hubert 1997). Such limitations can and do occur within reservoirs (Schneidervin and Hubert 1987; Griffith 1988; Persson and Grenberg 1990; Tabor et al. 1996). More specifically, there is often an inverse relationship regarding the abundance of walleye and panfish, specifically black crappie (Carline, 1981).

Upon introduction to Moses Lake, walleye numbers apparently increased rapidly. There were no evolutionary checks which controlled population growth. An overabundance of walleye within Moses Lake may have contributed substantially to the decline in black crappie by means of extreme levels of predation. This is often the case when a non-native predator is introduced to a system. The inflated numbers of walleye may increase intraspecific competition and in turn decrease the relative weights of walleye.

Largemouth bass did not exhibit the same growth or relative weight trend. This might occur because largemouth bass were more littorally keyed, potentially avoiding overlap in foraging areas with the other two predatory species. The densities of largemouth bass also appeared to be low which could preclude intraspecific competition for forage.

Predators such as largemouth and smallmouth bass have co-evolved with bluegill sunfish and black crappie and, in some instances, rely heavily upon them as a food source (Boxrucker 1987; Howic and O'Brien 1983; Ross et al. 1995). However, many other factors may influence the balance of these populations, and, if other prey is available, predation on decreased panfish numbers may inhibit a return to their abundance.

The data collected during the fall 1999 and 2000 spring survey suggested an overabundance of carp within Moses Lake. It has been well documented that common carp can greatly decrease the abundance of desirable gamefish (Rach et al. 1994; Marking 1992; Cooper 1987). Carp may retain much of a system's limited nutrients in biomass. They can also increase turbidity, which decreases primary productivity, denigrates water quality, and suppresses macrophyte growth (Lougheed et al. 1998). In Moses Lake, carp potentially occupy much of the same habitat as adult and juvenile panfish, which may increase interspecific competition for forage, and ultimately displace the panfish to sub-optimal habitat. Occupying sub-optimal habitat may increase the risk of predation or mortality due to lack of forage or lethal water conditions. However, it should be noted that carp and panfish have at times sympatrically existed in abundance in Moses Lake.

WDFW continues to promote carp as a gamefish, and bowfishing tournaments occur annually on Moses Lake. Commercial harvest is encouraged; however, markets have been depressed or erratic. The eradication of common carp from Moses Lake is not feasible, and even control of the carp population through other means would require immense and varied resources. The decision to commit the resources to pursue control measures would require nearly irrefutable evidence that carp were the over-riding obstacle to panfish production in Moses Lake.

A complete and systematic investigation of all the impacts to Moses Lake specific to common carp is beyond the scope of the project. However, it will be possible to infer the impacts common carp have on Moses Lake through the investigations that the project is proposing. Previously collected data indicates that common carp make up a large proportion of the fish population in Moses Lake based both on number and biomass. Through bioenergetics modeling, the flow of energy through the biotic system will be ascertained. For example, if turbidity is limiting the primary productivity, in turn limiting secondary productivity, the impacts of common carp through bioturbation could be inferred. Should secondary productivity in critical panfish habitat be limited and carp densities found to be high in these same areas, competition for with common carp for forage could be inferred. Thus, the issue of carp as a limiter to panfish production will be identified in one or more aspects of the study through the process of elimination.

In summary, several possibilities that may have attributed to the decline in panfish have been identified. At this stage of the Moses Lake Project, no one factor can be attributed to the decline in panfish. The most likely scenario is a combination of factors resulting in a negative synergistic effect that has substantially decreased the panfish abundance. To investigate the possible agents of decline, the Moses Lake Fisheries Restoration Project proposes to collect data that will address predation, competition, macroinvertebrate, zooplankton, and phytoplankton abundance, habitat quantification, and water quality within Moses Lake. The project will continue to employ an adaptive approach to the study of Moses Lake. As areas of the study that require less or more intense investigation to test hypotheses or develop new hypotheses are recognized, they will be incorporated or eliminated as the project progresses.

Based on the information compiled and analyzed from Phase 1, the Moses Lake Project made these final conclusions:

A. Historical water quality information did not indicate that water quality parameters, most specifically temperature and dissolved oxygen, were limiting to panfish production in Moses Lake. Sufficient amounts of current water quality data have not been collected to detect if parameters are currently within acceptable limits for panfish production.

B. Historical water quality information was inadequate to determine whether nutrient levels were sufficient to derive primary productivity, and in turn secondary productivity capable of providing adequate forage to fish. Chlorophyll-a, phytoplankton and zooplankton densities and volumes need to be investigated to determine if productivity is limiting the recruitment of panfish in Moses Lake.

C. The impacts of dilution, drawdown, and fill up on primary and secondary productivity are not well documented. Chlorophyll-a, phytoplankton and zooplankton densities and volumes need to be investigated to determine if productivity is limiting the recruitment of panfish in Moses Lake.

D. Limited amounts of information on habitat quality and quantity existed in relation to Moses Lake. Further information in regards to available habitat, habitat complexity, the impact of common carp on habitat, the impact of urban development on habitat, and the impact of drawdown and fill-up on habitat needs to be accumulated.

E. Historical creel surveys indicated that angler harvest has shifted from panfish dominated to walleye dominated. Historical creel and biological surveys, and recent biological surveys indicate that a species shift from a prey dominated to a predator dominated population has occurred in the last two decades. Densities of predators to prey indicated that the fish population was not "balanced". Current baseline biological surveys indicated that juvenile panfish were not recruiting in consistent or large numbers. Total abundances of panfish were well below what had been surveyed in historical baseline biological surveys.

F. Current baseline biological surveys indicate that warmwater fish growth and condition is within expected parameters. Panfish exhibited growth rates well above statewide averages. Current baseline biological data indicated that predator's growth and relative weights might have revealed that competition for forage was limiting for walleye and smallmouth bass. This may illustrate that densities of predators in Moses Lake is affecting the panfish population through over predation. In support of this, low-density largemouth bass populations do not reflect the growth or condition of walleye and smallmouth bass. Largemouth bass have different habitat requirements; the partitioning of largemouth bass into different habitats would preclude them from competition possibly explaining the better growth rates and relative weights.

G. Current baseline biological surveys indicated that the dominant fish in biomass was common carp. Common carp could potentially limit water quality, habitat quality and quantity, primary and secondary productivity and fish production.

Based on the conclusions drawn from the analysis of the historical and current information (Phase 1), the Washington Department of Fish and Wildlife (WDFW) has proposed to restore the fishery through the systematic investigation of the individual aspects of the current situation. Limiting factors to be investigated include water quality, nutrient concentrations, habitat availability, food limitations, competition, predation and over harvest. Environmental conditions will be linked to the fishes habitat use to understand the physical and chemical limitations of the system.

Water quality parameters will be collected to determine if at any time monthly, seasonal or annual deviations from specific life stage requirements will be limiting to panfish production. Information regarding monthly nutrient concentrations will be used to determine phytoplankton bloom species composition and timing and chlorophyll-a concentrations. Phytoplankton bio-volume, composition and production will be estimated to determine the availability of preferred forage at critical times in panfish life histories and seasonal density. Zooplankton and macroinvertebrate biomass, species composition and production will be estimated to establish the potential of the forage base, carrying capacity, and competitive interactions for various planktivorous and insectivorous fishes.

Habitat complexity will be determined before and after the fall drawdown and spring fill up to assess impacts to panfish production. Following drawdown, littoral habitat is dewatered and may force panfish into areas devoid of complex habitat possibly rendering panfish more susceptible to predation. Habitat utilization by panfish will be assessed and compared to preferred habitat. The possible impacts of drawdown or fill up limiting the use of optimum habitat by panfish will be estimated. Competition interactions for preferred habitat will be quantified. Drawdown and fill up may limit the amount of habitat available to panfish. Densities of fish exceeding the amount of habitat available may limit the amount of panfish capable of recruiting to the Moses Lake recreational fishery.

Diet electivity and selectivity in conjunction with stomach fullness will be used to estimate interspecific or intraspecific competition that may be limiting to panfish production. This information will be quantified in concert with the secondary productivity surveys. Predator prey interactions between piscivores and prey-fish will be quantified through diet analysis. Bioenergetics modeling will be used to provide quantitative estimates of fish consumptive demand to compare to forage supply. Population estimates and estimates of productivity per species will be established and panfish harvest will be quantified to determine if over-harvest is limiting panfish production in Moses Lake.

Identified limiting factors will be ranked to determine which have the greatest impacts on the fishery, and a priority based management plan that best addresses the limiters to panfish production in Moses Lake will be developed. Finally, Phase 3, the implementation of the management plan and monitoring and evaluation of the implemented recommendations will complete the project.

Study Plan Goals, Objectives, Tasks and Methods

Overall Objective: Maintain and enhance a balanced productive warmwater recreational fishery to near historical records in Moses Lake, with emphasis on maximizing the recreational panfish fishery. Further refinement of this objective to specific abundance goals, harvest, and angler effort will require continued data collection to understand the biological interactions and carrying capacity of the system. This overall objective will be achieved through a series of studies that seek to determine the limiting factors for various fish species (or groups of species). Management recommendations will be provided to the Washington Department of Fish and Wildlife and Bonneville Power Administration regarding potential changes to harvest, slot limit, stocking numbers and timing, habitat enhancement, fish removal projects or other recommendations to increase and maintain the Moses Lake fishery.

Phase 1:

Objectives and tasks for Phase 1 were accomplished by September of 2000 (see Section e. Project History). Phase 1 was culminated with the development of testable hypotheses directed at determining the limiters to panfish recruitment in Moses Lake. These hypotheses will be tested in Phase 2 of the Moses Lake Project. Below are the objectives and tasks for Phase 2 and Phase 3.

Phase 2:

GOAL: Determine what factors limit the recruitment of panfish to the Moses Lake recreational fishery.

Objective 1: Test if the recruitment of panfish to the Moses Lake recreational fishery is limited by current water quality or habitat conditions.

Task 1-a: Test if the recruitment of panfish to the Moses Lake recreational fishery is limited by water quality.

H_{o1}: Recruitment of panfish is not limited by temperature.

H_{o2}: Recruitment of panfish is not limited by dissolved oxygen.

H_{o3}: Recruitment of panfish is not limited by pH.

H_{o4}: Recruitment of panfish is not limited by Alkalinity.

H_{o5}: Recruitment of panfish is not limited by Turbidity.

H_{o6}: Recruitment of panfish is not limited by phosphorous concentrations.

H_{o7}: Recruitment of panfish is not limited by nitrogen concentrations.

Justification:

Historical water quality information did not indicate that water quality parameters deviated from what was required for the production of panfish on a regular basis (see water quality p. 26). Only on rare occasions, and usually in isolated areas of the lake, did water quality parameters indicate that physical conditions within the lake could have been limiting to panfish production. However, rainbow trout, which are known to require higher standards of water quality than panfish, have thrived in Moses Lake in the last few decades. Rainbow trout can be viewed as the "canary in the coal mine" for Moses Lake. The assumption can be made that if these fish make it through all seasons in the lake, there should be little overall impact on warmwater fish.

Seasonal, monthly and weekly deviations could play roles in limiting the production or recruitment of panfish to the population. Low temperatures, low dissolved oxygen, increased pH, alkalinity or turbidity during critical spawning and incubation periods could substantially reduce the ability of panfish to reproduce effectively in Moses Lake. Likewise, microenvironments inhospitable to rearing or recruited panfish may exist periodically, especially during hydrologic changes or times of ice cover.

Water quality parameters will be collected to track deviations in water quality that may affect growth, condition, reproduction, or survival of panfish. This information will be linked to the habitat surveys, species tolerances and bioenergetics modeling (fish metabolic rates, growth and condition) to test whether water quality conditions impact survival, incubation success, growth rates, condition, competition, or predation. Water quality could influence spawning incubation success or early survival for panfish. As a result few to no panfish could be produced on an annual basis. Additionally, poor water quality may concentrate fish in areas where they can persist. These concentrations may draw panfish out of refuge areas, making them more susceptible to competition or predation. Fish density information gathered during habitat assessment, diet study, and population assessment will be used to examine if enough juvenile panfish are appearing in the sample to indicate adequate spawning and incubation success. If juvenile panfish are abundant in the fall samples, it could be assumed that spawning success was adequate.

The input of spring fill up and dilution water could potentially limit the amount of nutrients available for primary production in Moses Lake. Historical and current nutrient concentration information will be examined to test whether enough nutrients are available during critical bloom times to provide for adequate amounts of primary productivity in Moses Lake. Chlorophyll-a and phytoplankton information will be linked with phosphorous and nitrogen concentrations to determine if adequate amounts of nutrients are available to produce adequate primary productivity and, in turn, secondary productivity to support the fish population of Moses Lake. Nutrient concentrations and chlorophyll-a indices from historic data will be compared to current information on these parameters to test if primary productivity has dropped as a possible result of reduced nutrient concentrations. This could indicate that lower density panfish populations are a result of reduced productivity and carrying capacity, in turn due to dilution and/or flushing.

Method 1-a:

The Washington Department of Ecology conducted water quality sampling and analysis monthly for April through September of 2000 (WDOE methods p. 19). Data such as temperature, chlorophyll-a concentrations and nutrient composition were measured throughout the strata of Moses Lake. Sampling occurred within four sections of the lake (Figure 1). Specific site locations were determined and sampling occurred at that these sites for each sample period.

Data sharing with the DOE regarding Total Maximum Daily Load surveys will continue. Shared information will include monthly temperature, DO, pH, turbidity, conductivity, and alkalinity, nutrient loads, both nitrogen and phosphorous, chlorophyll-a and phytoplankton information for each section of the lake.

The Moses Lake Project will continue monthly collection of temperature, DO, pH, turbidity, conductivity, and alkalinity for the duration of the project using a Hydrolab®, and the WDOE collection design and designated collection sites. Timing for sampling can be reviewed in Table 23.

Thermographs will be deployed in two sections of Moses Lake and will record temperatures every two meters from substrate to surface. One thermograph station will be placed in Section 3 in 36 feet of water; the other will be placed in Section 1 in 34 feet of water (Figure 1). Each thermograph will be set to record temperature data once a day, which will permit the detection and time of thermocline formation. This information is critical for bioenergetics modeling, for which a key requirement is understanding the fish's thermal experience.

Task 1-b: Test if the recruitment of panfish to the Moses Lake recreational fishery is limited by spawning habitat.

H_{o8}: Recruitment of panfish is not limited by quantity of spawning habitat.

H_{o9}: Recruitment of panfish is not limited by quality of spawning habitat.

Task 1-c: Test if the recruitment of panfish to the Moses Lake recreational fishery is limited by rearing habitat.

H_{o10}: Recruitment of panfish is not limited by quantity of rearing habitat.

H_{o11}: Recruitment of panfish is not limited by quality of rearing habitat.

Justification:

The total amount of habitat available for spawning panfish in Moses Lake is not known. If critical spawning habitat is limited in total area in the lake, there may be competition and interactions that limit the production of panfish as a result.

The amount of spawning habitat will be quantified and compared to a population estimate to determine if production is limited by spawning habitat quantity. Interspecific competition for the spawning habitat will be quantified to determine if this limits panfish production. Fish distribution and habitat occupation is a portion of the methodology for the habitat assessment. The diet study and population assessment will record where and when fish are collected, species and the densities of each species collected in each habitat type. This information will be combined to determine what is the favored habitat for each species of concern and whether there is competition for this type of habitat with other species observed in the sample.

Fill-up and dilution of Moses Lake are consistent factors in the lake's hydrologic regime. The disturbance of spawning behavior or habitat by virtue of hydrologic manipulation is not well documented. The fill up and dilution in-flow of water during critical spring spawning may keep the lake at artificially lower temperatures in certain sectors of the lake. This artificially cooler temperature may preclude the later spawning fish such as bluegill and black crappie from spawning early enough to produce young-of-the-year capable of recruiting through the winter months, or artificially cooler temperatures limit the amount of available spawning habitat for late spawners, exacerbating competition for limited optimum spawning habitat. Fish distribution and spawning activity will be noted during monthly diet sampling, population assessment sampling and habitat assessment surveys. Comparison to accepted literature and bioenergetics modeling will be used to assess whether body mass and condition of juvenile panfish is adequate to provide for overwinter survival regardless of spawn timing.

The drawdown hydrologic regime of Moses Lake could limit the amount and location of rearing areas for panfish, especially during late fall through early spring. Fall drawdown dewaters much of the complex littoral habitat available to panfish. The lack of complex habitat available after fall drawdown could be limiting to the amount of critical rearing areas for panfish in late fall and winter. The habitat assessment methodology will quantify the total amount of habitat available for rearing pre and post drawdown. The diet study will test if rearing area reduction following drawdown exposes panfish to higher rates of predation and will track the distribution of fish. Primary and secondary productivity surveys pre and post drawdown will determine if forage distribution is influencing the distribution of fish or is limiting growth and/or condition.

In concert with these possible limiters, carp are known to inhabit some of the littoral areas of Moses Lake. Dense habitation by common carp may reduce or preclude these areas as viable spawning sites for panfish species through turbation of nests, nest predation or disturbance. Carp could also preclude panfish form critical rearing areas through reducing littoral productivity or creating enough disturbance to force rearing panfish to relocate to other areas of the lake that are not as favorable. During the Spring 2000 baseline biological survey, few panfish were found in areas densely inhabited by carp. Areas with high densities of common carp will be surveyed during the diet study and population assessment samples, and the densities of carp and other species of interest will be recorded. Based on the amount of area sampled, the total area that is affected by carp can be compared with the total available area for spawning and rearing panfish to test if carp are excluding species of interest from the significant amounts of habitat in Moses Lake.

Shoreline development on Moses Lake has steadily increased over the past few decades. The total amount of development and the impact to spawning and rearing panfish is not understood. The habitat assessment will quantify the total amount of development and the habitat available or lost in those developed areas. This will be done by comparing an historical shoreline development surveys done in 1991 to a current survey to detail the loss of shoreline habitat over the last ten plus years. The total impact of development and the potential for limiting panfish production by virtue of shoreline habitat loss has not been investigated.

Methods 1-b and 1-c:

Habitat Assessment

At high water Moses Lake has 60.5 miles of shoreline and considerably less at low water. Consequently there may be a sharp change in available habitat between the low and high water seasons. The objective of this portion of the project is to determine the type and amount of available habitat in the littoral zone of Moses Lake during both high and low water periods.
Below in tabular format, are the classifications to be used in categorizing the littoral zone.

***Shoreline Development:**

1. agricultural
2. industrial/business
3. residential
4. undisturbed
5. Bulkhead
    a. Presence or absence: If "present", length of affected area in meters

*****A total number of meters of shoreline that is occupied with each one of these categories will be established. This will be compared to a similar survey done in 1991 by the Bureau of Reclamation to track changes and/or habitat loss since the last survey.

Shoreline vegetation: vegetation that is growing on or adjacent to the shoreline.

1. tree
2. shrub
3. reed/bulrush
4. grass/forbes

5. sparse vegetation
6. exposed soil or bedrock (none)
7. Total linear meters of shoreline occupied by the dominant shoreline vegetation or lack thereof.

Submerged Aquatic macrophytes: aquatic macrophytes visible along the shoreline and offshore. Break the assessment into offshore macrophytes and near shore macrophytes.

1. present yes or no.
2. dominant species
3. density: high, medium, low
4. Total number of square meters occupied by the dominant submerged aquatic macrophyte.

Substrate type: substrate type that is visible from shoreline to end of visibility in the water.

1. silt
2. sand
3. gravel: less than 4 inches in diameter
4. cobble: 4 to 12 inches in diameter
5. boulder: greater than 12 inches in diameter
6. bedrock
7. Total number of linear meters along the shoreline dominated by the substrate type.

Fish presence:

1. Detail any spawning activity noted during survey
2. Detail any fish observed, species and approximate number of individuals

The entire shoreline of Moses Lake will be examined and the habitat type recorded twice, once during fool pool and once following drawdown, to record the differences in available habitat between the two hydrologic scenarios. During diet study sampling and population estimate sampling data detailing fish capture rates, and distribution will be taken.

The aforementioned information will be used to develop GIS coverage maps detailing habitat types, fish density and fish distribution to detect trends in habitat use during different times of the year, and thus habitat types can be quantified. This will be useful to infer potential areas of habitat competition or critical habitat for panfish rearing or reproduction.

This portion of the study will be relatively time consuming and depending on conditions should take two to three weeks of field time. Habitat assessments will be done in July and October of 2000. Timing for sampling periods can be reviewed in Table 23.

Objective 2: Test if the recruitment of panfish to the Moses Lake recreational fishery is limited by trophic interactions.

Task 2-a: Test if the recruitment of panfish to the Moses Lake recreational fishery is limited by primary productivity.

H_{o12}: Recruitment of panfish is not limited by primary productivity.

Justification:

Production of phytoplankton may be interrupted or inadequate as a result of fall drawdown, spring fill up, dilution water input or reduced nutrient loading. Top-draw fall drawdown may remove a large portion of the primary productivity in the lake. As a result, the amount of forage available for secondary production may be limited. Both spring fill up and dilution water inputs may reduce water temperature affecting the timing of phytoplankton blooms reducing the amount of forage available for secondary production. In addition to these effects, the input of water for spring fill up and dilution could reduce the nutrient concentrations by diluting or flushing the nutrients in Moses Lake, reducing the overall production of forage for secondary production.

Primary productivity in Moses Lake will be measured to determine the density, composition, and bio-volume of forage available for secondary productivity in Moses Lake. The density, composition, and bio-volume of phytoplankton will be linked with the density, species composition, and biomass of secondary productivity to determine if the proper type and amount of forage is available during critical production times for secondary productivity.

Task 2-b: Test if the recruitment of panfish to the Moses Lake recreational fishery is limited by secondary productivity.

H_{o13}: Recruitment of panfish is not limited by secondary productivity.

Justification:

Secondary productivity will be measured to determine what density, species composition, and estimated biomass is available as forage for fish in Moses Lake. Estimates of secondary productivity will be linked to fish competition indices and bioenergetics modeling to determine if there are any marked disruptions in production reflected in this stage of fish production.

Fall drawdown of Moses Lake is a top draw removal of water from the lake. This type of water withdrawal may result in the removal of a portion of the secondary productivity from the lake. Density, species composition, and biomass of zooplankton will be sampled just prior to and just post drawdown. This will be used to determine if there was a total loss in estimated biomass pre and post drawdown. This loss of secondary productivity may limit forage for panfish preventing juvenile fish from obtaining enough forage to reach critical body mass and fat stores to successfully overwinter. If production is limited competition for forage with earlier spawned juvenile fish such as walleye and yellow perch could limit the amount of forage available to later spawned juvenile panfish. Additionally, secondary productivity may be significantly reduced in density, creating competition for limited resources and/or forcing panfish to leave complex habitat in search of forage which would in turn expose them to higher rates of predation.

High density carp populations occupying littoral areas may reduce the overall productivity of the littoral areas. In concert with the habitat information collected, the total amount of habitat for rearing available to juvenile fish and the amount of estimated productivity for these areas would be ascertained. This will be compared to diet analysis to determine whether productivity exists in littoral areas to support rearing panfish. Diet studies may also indicate that juvenile panfish are regularly, seasonally, or never forced to forage for low density forage outside of complex littoral habitats making them more susceptible to predation and therefore increasing the amount of predation on panfish in Moses Lake.

Method 2-a and 2-b:

Phytoplankton and Zooplankton Sampling

Beginning in April 2001, the Moses Lake Project will collect phytoplankton samples on a seasonal basis, and zooplankton samples on a monthly basis. The months for collection of phytoplankton samples will be April, July, October and January. In the event that the lake is ice covered, the winter sample will be taken when the ice cover recedes, but no later than early March. The samples will be taken in triplicate for each of the four lake sections (Figure 1 and Table 23).

The euphotic zone will be determined by multiplying a secchi disk measurement by three. Once the euphotic zone is determined, an integrated core sampler will be inserted to the bottom of the euphotic zone and a sample of the entire column will be taken. This sample will be placed in a 20,000 ml bottle and stirred to evenly distribute the phytoplankton sampled. A 1000 ml bottle of phytoplankton will be taken from this container for processing (USEPA 1998).

A total of 12 samples will be taken during each sample period. The samples will be processed by a contracted limnologist to determine composition, density, and bio-volume of phytoplankton within Moses Lake.

Monitoring the phytoplankton abundance will permit the detection of any changes over seasons, and/or lake sections. Analysis of the phytoplankton data will include a Chi^2 to test whether or not a change in abundance is significant. An analysis of variance (ANOVA) will be conducted to determine if there is a significant difference in the abundance of the various genera sampled during each season.

Zooplankton samples will also investigate the possible differences in pelagic and littoral zone productivity. Pelagic zooplankton samples will be collected using a Clarke-Bumpus plankton sampler. Vertical plankton tows will be conducted from substrate to surface. Sampling the entire water column will reduce the probability of missing zooplankton that migrate vertically (De Stasio 1993). Littoral zooplankton samples will be taken at the same time as the pelagic samples. The samples will be taken using a 265-micron D-net. The D-net will be run along the shoreline area.

To calculate the number of zooplankton for a given volume of water passed through the sampling device. The volume of water sampled will be calculated using the following formula:

$$V=D*A$$

Where D is the distance traveled, and A is the area of the opening of the sampling device.

The total density of zooplankton (D_z) will be calculated using the following equation:

$$D_z=n/V$$

Where n is the number of zooplankton and V is the volume of water sampled.

At the end of each tow, zooplankton samples will be preserved in Lugol's solution and held in whirl packs to be processed at a later date. During each sampling event a total of 12 pelagic and 12 littoral samples will be taken. Processing will be done by a contracted limnologist. Zooplankton samples will be processed to determine species composition, density, and estimated biomass.

Monitoring the zooplankton abundance will permit the detection of any changes over months, seasons, and/or lake sections. Analysis of this data will include a Chi^2 to test whether or not a change in abundance is significant. An analysis of variance (ANOVA) will be used to investigate whether significant differences exist in the abundance of the various genera sampled during each season. This data will be incorporated into the bioenergetics model to determine total consumption of prey items in Moses Lake.

Macroinvertebrate Sampling

Beginning in April 2001, the Moses Lake Project will collect littoral and benthic macroinvertebrate samples on a seasonal basis. The months for collection of samples will be April, July, October and January. In the event that the lake is ice covered the winter sample will be taken when the ice cover recedes, but no later than early March. The samples will be taken in triplicate for each of the four lake sections mentioned above (Figure 1 and Table 23).

Benthic macroinvertebrate samples will be taken using a Ponar dredge. Two transects with two benthic samples will be collected from a cross section of the lake (USEPA 1998). In each of the four sections of the lake littoral macroinvertebrate samples will be taken using 0.5-meter diameter and length substrate baskets, with native substrates enclosed. Two baskets will be deployed for each of the four sections in the lake and left in place for three months upon which time they will be removed and macroinvertebrates collected.

During each season a total of 16 samples will be collected for Moses Lake. Samples will immediately be sorted and preserved in alcohol and at a later date identified. The samples will be processed by a contracted aquatic entomologist to determine species composition, species density, estimated biomass, and for littoral samples colonization rates.

Analysis of macroinvertebrate data will include a Chi^2 to test whether or not a change in abundance is significant. An analysis of variance (ANOVA) will be conducted to determine if there is a significant difference in the abundance of the various genera sampled during each season. This data will be incorporated into the bioenergetics model to determine total consumption of prey items in Moses Lake.

Task 2-c: Test if the recruitment of panfish to the Moses Lake recreational fishery is limited by competition.

H_{o14}: Recruitment of panfish is not limited by interspecific competition for forage.

H_{o15}: Recruitment of panfish is not limited by intraspecific competition for forage.

Justification:

Total available forage for prey and predator fish in Moses Lake is not known. Yearly, seasonal, or monthly limitations in production of forage could alter competitive interactions between fish species in Moses Lake and affect recruitment of panfish to the Moses Lake recreational fishery. The diet study, electivity, and selectivity indices will be linked to the secondary productivity samples to determine if there is possibly a limitation in the amount of secondary productivity available to fish in Moses Lake. If high densities of preferred forage items are present in the sample, gut fullness for planktivores and insectivores is high, and the condition of sampled fish is high, it would indicate that limitations in secondary productivity do not exist. Population estimates will be utilized to determine the total amount of prey fish available as forage for predators. This will be linked with the diet information to determine if predator consumption exceeds prey production, indicating probable competition for prey items between predators. The bioenergetics model will be linked with all of the aforementioned information to determine if consumption exceeds production indicating increased probabilities of negative competitive interactions affecting panfish recruitment.

As previously discussed, fall drawdown of Moses Lake is a top draw removal of water from the lake. This type of water withdrawal may result in the removal of a portion of the secondary productivity from the lake. This loss of secondary productivity may limit forage for panfish resulting in competition for limited available forage. As a result of competition for limited forage juvenile panfish may be prevented from obtaining enough forage to reach critical body mass and fat stores to successfully overwinter, or recruited panfish may not acquire enough forage to support their metabolic requirements, resulting in death.

Spring fill up or Dilution may result in reduced primary productivity that could result in reduced zooplankton production during critical spring months following the emergence of panfish larvae. The reduction in secondary production may have results similar to that discussed above, thus affecting the recruitment of panfish to the Moses lake recreational fishery. Spring fill up may artificially influence water temperatures in the lake delaying spawn timing for panfish. As a result earlier spawning fish could emerge sooner and have a competitive advantage for the available forage in Moses Lake. If production is limited, competition for forage with earlier spawned juvenile fish such as walleye and yellow perch could limit the amount of forage available to later spawned juvenile panfish.

Fall drawdown, spring fill up, and dilution may force panfish in to suboptimal habitat to find forage as a result these fish may be more susceptible to predation. The densities of predators in Moses Lake is high and competition for forage and/or over consumption of prey fish could result in negative competitive interactions between predators affecting the recruitment of panfish to the Moses Lake recreational fishery.

Task 2-d: Test if the recruitment of panfish to the Moses Lake recreational fishery is limited by predation.

H_{o16}: Recruitment of panfish is not limited by predation.

Justification:

The current and historical data indicated that the fish population of Moses Lake has a dense warmwater predator population. Over predation reducing panfish recruitment may be the result of predator densities that are too high and are tapping the carrying capacity of the forage fish in the Moses Lake fish population. Using the bioenergetics model linked with the diet study and the population estimate, the project will investigate the amount, size, and species of fish consumed, and the species and size of the consumer. Bioenergetics will be used to determine if consumption of prey fish is greater than the amount of prey fish potentially produced, and if predation on each given species of panfish is ultimately limiting their recruitment to the Moses Lake recreational fishery.

Fall drawdown of the lake dewaters most of the complex littoral habitat. As a result, panfish may be forced to occupy suboptimal habitat making them more susceptible to predation. Spring fill up and dilution may in turn reduce or limit secondary productivity forcing fish to leave complex littoral habitat in search of forage, also rendering them more susceptible to predation. The result of these factors will be investigated using the aforementioned tactics.

Method 2-c and2-d:

Diet study/ Fish Stomach Content

Monthly surveys for fish diet samples will be conducted on Moses Lake starting in October of 2000 and will be collected until November of 2002. Fish will be collected during daylight and night hours using boat electrofishing, gill netting and angling. Using multiple gear types will eliminate gear sampling bias and allow for the collection of multiple species and size classes of fish. Fish will be sampled from randomly selected areas within each of the four lake sections (Figure 1).

Three individuals for each age group, young of year, juvenile and adult will be collected from each of the four Moses Lake sections. For each species a total of 36 individuals will be sampled monthly within Moses Lake for night and day samples. A total of 72 fish will be sampled each month from the species of interest. Samples will be collected from species of interest such as walleye, black crappie, bluegill sunfish, yellow perch, small mouth bass, largemouth bass and rainbow trout. All other fish will be secondary species of interest. The sample size for secondary species will not exceed a maximum of 20 individual fish sampled per month.

Stomach contents will be collected via gastric lavage methods. Upon capture, a fish's stomach will be pumped using a modified handheld pesticide sprayer with an elongated hose that is inserted into the stomach orally. Once in place water pressure will be pumped into the subject fish emptying the contents into a tray. The fish will then be released and the contents preserved in 95% alcohol to be identified at a later date. The method of gastric evacuation (GR) has been used successfully on a variety of sizes and species of fish (Singh-Renton and Bromley 1996; Ruggerone 1989; Brown 1995; Hartleb and Moring 1995). It is important that stomach contents are removed rapidly from captured fish as soon as possible to prevent the loss of food items via digestion or regurgitation due to increased stress levels. Therefore, gill nets will need to be checked hourly, fish removed and contents preserved.

Stomach contents will be identified to order for macroinvertebrates, order for zooplankton and to species for fish whenever possible. Zooplankton and macroinvertebrate size and wet weight will be measured, for each individual, from each order detected in the sample. Contents will be identified using Pennack's key, freshwater invertebrates of the United States (1989) for invertebrates and Wydoski and Whitney's Inland Fishes of Washington Key for fish (1979) as well as a WDFW generated bone key.

With the stomach contents of individual fish collected and identified, further determination of the percentage of food items for each individual species will be compiled. This could be achieved using percentage method (Marreo and Lopez-Rojas 1995). Further analysis will include parametric tests, such as the *t* and ANOVA. Tests will be conducted to determine differences between species and monthly changes within species. A correlation between the zooplankton and macroinvertebrate data and diet data will be performed. Some studies point to a positive correlation between zooplankton abundance and fish diets (Bremigan and Stein 1994), other studies do not (Westerlund et al. 1998). This data will be incorporated into the bioenergetics model to determine total consumption of prey items in Moses Lake.

Reproductive Studies

Reproductive studies will be done on Moses Lake to determine the sex ratio of spawning fish within Moses Lake. Data collected from spawning fish will allow for the development of a ratio of body weight with and without gonads (GSI). This information will also be applied to the Wisconsin 3 bioenergetics model to quantify a one-time seasonal weight loss associated with spawning. Finally, we will determine the age at spawning maturation for species of interest. The species of interest for these activities are black crappie, bluegill sunfish, yellow perch, largemouth bass, smallmouth bass and walleye.

Fish will be collected and sacrificed via electrofishing, gill netting and trap netting, as well as, asking anglers to volunteer fish from their creel. Data collected will include scale samples, length and weight of fish with and without gonads, weight of gonads, and sexual identification. The WDFW fish-aging lab in Olympia, Washington will age scales, and other calcified structures, collected from Moses Lake.

Population Estimate

The population estimate will not be implemented until April of 2002. Presented here are the basic methods in preparation for continuing this portion of the project. Continued consultation with a WDFW biometrician will lead to final methods prior to implementation of this portion of the project.

There are a variety of models and methods that can be used to estimate the population of fish within Moses Lake. However, before a model can be selected, several assumptions must be met. All tags or marks must remain or be detectable on the fish. Regardless of the technique or the model used to capture fish, the procedure of marking fish will be static. All fish will receive a caudal hole clip whereas walleye and bass will receive an additional Floy® tag to be place on the left side adjacent to the dorsal fin. The goal of inserting a tag in this region is to increase the probability of tag retention. Pterygiophores the structures located within the body of the fish become spines or fin rays outside of the body. These structures will serve as an anchor for the tags once inserted into the fish. Because it is not financially feasible to tag every fish captured with Floy® tags, the additional caudal clip will be employed. If fish are being recaptured with only the caudal clip remaining then a retention rate can be calculated. Due to continual fin growth, clips may fill in over time. Prior to selecting a population model, an investigator must first determine whether or not the system in question is open or closed. For example a closed model such as the Lincoln-Peterson Model that requires no additions or emigration of fish may not be valid for a system such as Moses Lake. With the influence of Crab Creek flowing into Moses Lake and two outlets at the south end, there could be a substantial loss or addition of fish, making Moses Lake a perfect candidate for the application of an open model.

An open model such as the Jolly-Seber Model that is robust enough to accommodate immigration and emigration of fishes is probably the best model for Moses Lake. Jolly-Seber open population models require multiple mark and recapture events with a minimum of three of each. However, sampling may be continual and may consist of a variety of techniques necessary to capture fish as long as three of the mark and recapture events are extensive. During the three extensive surveys, multiple WDFW boats will be used to ensure a good marking and recapturing event. Two other events that will take place on Moses Lake are the Walleye Tournament in June and the Bass tournament in July. At each of the tournaments, fish that are marked will be recorded and fish without a mark will be marked. Analysis will employ a software package called Jolly® (Pollock et al. 1989). The analysis will also allow for a running population estimate to be calculated after each entry into the database.

Prior to marking any fish, an estimate regarding the number of fish necessary to tag must first be made. Following the formula from Beard et al. (1997), we were able to calculate a walleye population estimate from the 1996 creel data. The formula used was

$$A/(C*S)=B$$

Where A is the angler catch rate per hour, C is the constant as derived by Beard (.018) and S is the total surface acreage of the lake. The estimated population of walleye in Moses Lake (B) is 52,800. Based on CPUE data and proportional estimating, it can be assumed that smallmouth bass have a similar population size.

Hightower and Gilbert (1984) stated that in populations greater than 10,000 fish at least 5% of the individuals should be marked for a successful recapture event. Therefore, 2600 walleye and smallmouth bass need to be marked prior to the initiation of recapture events. Based on a CPUE mean of 9.5 for walleye and 12.5 for smallmouth bass, approximately 275 hours of electrofishing will need to be done to mark the minimum number of fish. Two to six boats will be used during each of the mark and recapture events.

Objective 3: Test if the recruitment of panfish to the Moses Lake recreational fishery is limited by angling exploitation.

Task 3-a: Test if the recruitment of panfish to the Moses Lake recreational fishery is limited by angling exploitation.

.

H_{o17}: Recruitment of panfish to the Moses Lake recreational fishery is not limited by angling exploitation.

Justification:

A recent creel survey detailing monthly harvest by species and angler effort has not been conducted since 1996. A 12 month creel survey will be conducted to determine the impacts of harvest on panfish populations. The creel survey and the population estimate will be linked to determine the percent of the panfish population, and the size and age distribution of panfish harvested on an annual basis. Information from the bioenergetics model detailing trophic interactions in concert with the creel information, and the population assessment information will be incorporated into the Fisheries Analysis Simulation Tools (F.A.S.T.) model to develop harvest regulations to maximize and protect the panfish fishery in Moses Lake.

Method 3-a:

Four large creel surveys were conducted during 1974-1975, and 1983**,** 1991, and 1996-97 (Duff 1976; Jackson 1985; Korth 1992, Donley et al 1999). All consisted of questioning boat and shore anglers to determine the number and species of fish caught, and the amount of time spent fishing. The size of Moses Lake and the number of accesses required expansion of the interview data.

Moses Lake is 6,800 acres and has multiple accesses, which hinders an absolute creel survey (Bain 1987). Hence it is neither economically or logistically feasible to strictly adhere to either a roving or access point creel design. An access point creel survey requires a clerk to remain at an access and interview anglers as they leave (Hayne 1991). Due to the multiple access sites on Moses Lake this is not a practical method. When a clerk moves through a fishery following a prescribed route and interviews anglers this is called a roving creel survey (Robson 1991). Within this survey type, there are several dimensional parameters such as time and distance and random start time, which are quantified and used in calculating the creel estimate. For large bodies of water, such as Moses Lake**,** the bus stop survey method may be the most applicable. This survey requires the clerk to move along a predefined route, interview anglers for a set amount of time, and then move to the next site (Hahn et al. 2000). For the purposes of the Moses Lake Fisheries Restoration Project, much of the same protocol will be used as in previous surveys. Consistency of protocol will allow for comparative analysis between different sampling dates. The three main components that are consistent for the previous and future creel surveys are index counts, creel data, and effort (Korth 2000). The methods described in the following text are the survey protocol to be used on Moses Lake.

Angler Harvest and Effort Sampling

- Interviews will be conducted on four weekdays and four weekend/holidays per month.
- Each day will be divided into two sample periods. Each sample period is one half of the total daylight for the day.
- Ideally a minimum of 10 complete angler trips is required per day.

Expansion Methods

- Index counts will be conducted twice during each creel-surveying period: Once during the half of the shift and once during the second half of the shift. Index times will be randomly selected. Below is a list of index sampling sites that will be adhered to.

- Total counts will be conducted twice a month (one week day and one weekend) via an aircraft. Counts will not be done simultaneously with interviews. Total count days will be randomly selected.
- Total counts will be done in conjunction with additional index counts.
- All types of recreation watercraft and activities will be counted and separated into either fishing or other types of activities.

The selection of angler interview days, eight hour sampling periods within each day, time of index and day and time for total counts will be randomized with the following qualifications:

- Sampling periods will be divided evenly between morning and afternoon periods for both weekday and weekend strata within a given month.
- Sampling periods will occur only once each weekend and once each week.
- Index counts during any single angler interview day will be at least two hours apart.
- Scheduled survey periods, which are missed due to unavoidable circumstances, will shift to the next available day or time within a given month.

Index Sites. Moses Lake

1. Airman's Beach- Located off of highway 17. Boat, shore and vehicle counts.
2. Cascade Valley- Located on Valley Rd. within Lewis Horn. Boat, shore and vehicle counts.
3. Moses Lake Park (formerly state park)- Located off of I-90 exit 174. Shore and vehicle. Shore anglers on I-90 Bridge will be included within this site.
4. Penisula Drive Boat ramp- Located on the west side of Pelican Horn. Shore (minimal), and vehicle.
5. Alder St. Bridge- Shore.

Data from each creel survey will be collected using the WDFW angler survey form. Data collected will include:

1. Party size.
2. Time checked or finished.
3. Determine age of party members.
4. Hours fished.
5. Satisfied or dissatisfied with trip.
6. Angler type: boat, shore, and float tube, ice.
7. Gear type: lure, bait, flies.
8. Species caught: Abbreviations will be consistent with state protocol.
9. Number and species of fish kept.
10. Number and species of fish released
11. Length (mm)
12. Counts: The number of boats and shore anglers fishing.

Compiling total count, and data from the assigned index sites will permit the expansion of total anglers at any given time.

Other data collected will include air and water temperatures, barometric pressure and current weather conditions (raining, clear, cloudy, windy). If anglers are cooperative, scale samples, lengths and weights will be collected from fish that are kept which in turn will permit the development of a length and age frequency for angled fish.

Creel and expansion data will permit such calculations as how many fish of which species are caught per a given amount of time by boat and shore anglers, (the total number of fish harvested and the total effort that was expended in doing so). With this data, managers will receive an accurate census of the current status of angling on Moses Lake and combined with relevant data mitigation measures may be employed if it is deemed necessary.

The proposed start date for this creel survey is the 1st of April 2001. We are estimating that the proposed study will occupy approximately 20 days per month, leaving one to three days for miscellaneous tasks such as data entry, maintenance and or assisting the Moses Lake Project Staff with a variety of tasks.

PHASE 3:

Objective 5: Develop, implement and monitor and evaluate management plan.

Task 5-a: Using the information collected in Phase 2, test and prove or disprove the proposed hypotheses. Following hypotheses testing, the project will provide management recommendations intended to maximize the production and harvest of the panfish fishery in Moses Lake.

Task 5-b: Implement the management recommendations.

Task 5-c: Monitor and evaluate the efficacy of the proposed and implemented management plan.

Table 23 A brief summary of the monthly schedule to be followed during FY-2001 for the Moses Lake Project. Listed are the studies within the project design that will require blocks of time throughout the year. Water quality, zooplankton, phytoplankton and macroinvertebrate data will be collected concurrently.

	Water Quality	Zooplankton	Phytoplankton	Macroinvert.	Diet	Habitat	Creel
Jan	X	X	X	X	X		X
Feb	X	X			X		X
Mar	X	X			X		X
Apr	X	X	X	X	X		X
May	X	X			X		X
Jun	X	X			X		X
Jul	X	X	X	X	X	X	X
Aug	X	X			X		X
Sep	X	X			X		X
Oct	X	X	X	X	X	X	X
Nov	X	X			X		X
Dec	X	X			X		X

Literature Cited and References

Anderson R.O. and R.M. Neumann 1996. Length, Weight and Associated Structural Indicies. Pages 283-300 in B. R. Murphy and D. W. Willis, editors. Fisheries Techniques. American Fisheries Society, Bethesda, MD.

Bain R.C. Jr., 1987. Moses Lake Clean Lake Project, Final Stage 3 Report. Moses Lake Conservation District. Moses Lake, WA.

Baldwin, C. B., D. A. Beauchamp, and J. J. VanTassell 2000. Bioenergetic assessment of temporal food supply and consumption demand by salmonids in the Strawberry Reservoir food web. Transactions of the American Fisheries Society 129:429-450.

Beauchamp, D. A., M. G. LaRiviere, and G. L. Thomas. 1995. Evaluation of competition and predation as limits to juvenile kokanee and sockeye salmon production in Lake Washington. North American Journal of Fisheries Management 15:193-207.

Beauchamp, D.A. 1990. Seasonal and diel food habits of rainbow trout stocked as juveniles in Lake Washington. Transactions of the American Fisheries Society 119:475-482.

Boreman, J., and C. P. Goodyear. 1988. Estimates of entrainment mortality for striped bass and other fish species inhabiting the Hudson River Estuary. American Fisheries Society Monographs 4:152-160.

Boyd, C.E. 1990. Water Quality in Ponds for Aquaculture. Birmingham Publishing Co. Birmingham, Alabama. 482 pp.

Boxrucker, J. 1987. Largemouth bass influence on size structure of crappie populations in small Oklahoma impoundments. North American Journal of Fisheries Mangement. 7:273-278.

Brandt, S. B. 1996. Acoustic assessment of fish abundance and distribution. Pages 385-432 in B. R. Murphy and D. W. Willis, editors. Fisheries Techniques. American Fisheries Society, Bethesda, MD.

Brandt, S. B., and K. J. Hartman. 1993. Innovative approaches with bioenergetics models: future applications to fish ecology and management. Transactions of the American Fisheries Society 122:731-735.

Bremigan M.T., R.A. Stein. 1994. Gape-dependent Larval foraging and zooplankton size: Implication for fish recruitment across systems. Canadian Journal of fisheries and aquatic Sciences. Vol. 51.

Brooks, J. L. and S. I. Dodson. 1965. Predation, body size, and composition of plankton. Science 150:28-35.

Brown and Caldwell. 1977. Moses Lake Clean Lake Project Pilot study. Moses Lake Irrigation and Rehabilitation District.

Brown T.G. 1995. Stomach contents, distribution, and potential of fish predators to consume juvenile chinook salmon (Oncorhynchus tshawytscha) in the Nechako and Stuart Rivers, B.C. Canadian Technical Report of Fisheries and Aquatic Sciences 2077:1-39.

Carpenter, S. R. 1988. Complex interactions in lake communities. Springer-Verlag, New York.

Cartwright, M. A., D. A. Beauchamp, and M. D. Bryant. 1998. Quantifying cutthroat trout (Oncorhynchus clarki) predation on sockeye salmon (Oncorhynchus nerka) fry using a bioenergetics approach. Canadian Journal of Fisheries and Aquatic Sciences 55:1285-1295.

Cichosz, T. A., J. P. Shields, K. D. Underwood, A. Scholz, and M. B. Tilson. 1997. Lake Roosevelt Fisheries and Limnological Research, Annual Report 1996. Project Number 94-043, Contract Number 94BI32148.

Clark, C. W., and D.A. Levy. 1988. Diel vertical migrations by juvenile sockeye salmon and the antipredation window. The American Naturalist 131:271-290.

Crowder, L. B., M. E. McDonald, and J. A. Rice. 1987. Understanding recruitment of Lake Michigan fishes: the importance of size-based interactions between fish and zooplankton. Canadian Journal of Fisheries and Aquatic Sciences. 44:141-147.

Cooper, E.L. 1987. Carp in North America. American Fisheries Society. Bethesda, Maryland. 84 pp.

D. J. Stouder, K. L. Fresh, R. J. Feller, editors. Theory and Application in Fish Feeding Ecology. University of South Carolina Press, Columbia.

De Stasio B.T. Jr. 1993. Diel vertical and horizontal migration by zooplankton: population budgets and the diurnal deficit. Bulletin of

Marine Science. 53(1):44-64.
Dettmers J. M. and R. A. Stein. 1996. Quantifying linkages among gizzard shad, zooplankton, and phytoplankton in reservoirs. Transactions of the American Fisheries Society 125:27-41.

Donley, C.L. 1999. Unpublished WDFW creel data.

Duff R.L. 1976. A year's survey of the Lake Moses Fishery. State of Washington Department of Game. Olympia, WA.

Eggers, D. M. 1982. Planktivore preference by prey size. Ecology 63:381-390.

EPA (United States Environmental Protection Agency). 1986. Quality Criteria for Water, 1986. Office of Water Regulations and Standards. Washington D.C. EPA 440/5-86-001.

Fletcher, D., and 4 co-authors. 1993. Analyzing warm water fish populations in Washington State. Warmwater Fish Survey Manual. Olympia, WA.

Galbraith, M. G. 1967. Size-selective predation on Daphnia by rainbow trout and yellow perch. Transactions of the American Fisheries Society 96:1-10.

Galbraith M.G., Jr. 1975. The use of large daphnia as indicies of fishing quality for rainbow trout in small lakes. Internationale Vereinigung fur Theoretische und Angewndte Limnologie Verhandlungen. 19:2485-2492.

Griffith, J. S. 1988. Review of competition between cutthroat trout and other salmonids. American Fisheries Society Symposium 4:134-140.

Hahn P., S. Zeylmaker, S.Bonar. 1993. WDFW methods manual: Creel information from sport fisheries. Washington Department of Fish and Wildlife, Fish Program. Technical Report # 93-18.

Hanson, P. C., T. B. Johnson, D. E. Schindler, and J. F. Kitchell. 1997. Fish Bioenergetics 3.0. Center for Limnology, University of Wisconsin-Madison WISCU-T-97-001.

Hartleb C.F., J.R. Moring. 1995. An improved gastric lavage device for removing stomach contents from live fish. Fisheries Research. 24:261-265.

Hartman, K. J., and S. B. Brandt. 1995. Predatory demand and impact of striped bass, bluefish, and weakfish in the Chesapeake Bay: applications of bioenergetics models. Canadian Journal of Fisheries and Aquatic Sciences 52:1667-1687.

Hayne D.W. 1991. The access point creel survey: Procedures and comparison with the roving-clerk creel survey. American Fisheries Society Symposium. 12:123-138.

Horne, A.J., and C.R. Goldman. 1994. Limnology, Second Edition. McGraw Hill, Inc. United States. 576 pp.

Howick, G.L. and W.J. O'Brien. 1983. Piscivorous feeding behavior of largemouth bass: An experimental analysis. Transactions of the American Fisheries Society. 112: 508-516.

Hyatt, M. W. and W. A. Hubert. In Press. Proposed-Standard weight (Ws) equations for kokanee, golden trout and bull trout. Journal of Freshwater Ecology.

Jackson S.Y. 1985. 1983 Moses Lake Creel Survey. Washington Department of Game. Fish Management Division. Olympia, WA.

Juanes, F. 1994. What determines prey size selectivity in piscivorous fishes? Pages 79-100 in D. J. Stouder, K. L. Fresh, and R. J. Feller, editors. Theory and application in fish feeding ecology. University of South Carolina Press, Columbia.

Kerfoot, W. C., and A. Sih. 1987. Predation: Direct and Indirect Impacts on Aquatic Communities. University Press of New England, Hanover and London.

Klein D.R. 1968. The introduction, increase and crash of reindeer on St. Matthew Island. Journal of Wildlife Management. 32:350-367.

Knight, R. L., and B. Vondracek. 1993. Changes in prey fish populations in western Lake Erie, 1969-88, as related to walleye, Stizostedion vitreum, predation. Canadian Journal of Fisheries and Aquatic Sciences 50:1289-1298.

Korth J. 2000. Washington Department of Fish and Wildlife. Personal communications related to the past and future of creel surveys on Moses Lake.

Krebs C.J., M.S. Gaines, B.L. Keller, J.H. Meyers, R.H. Tamarin. 1973. Population cycles in small rodents. Science. 179:35-41.

Lott, J.P., D.W. Willis, D.O Lucchesi. 1998. Zooplankton structural indices as indicators of yellow perch population characteristics. The Prairie Naturalist. 30(2):112-121.

Lougheed V.L., B. Crosbie, P. Chow-Fraser. Predictions on the effect of common carp (Cyprinus carpio) exclusion on water quality, zooplankton, and submergent macrophytes in a Great Lakes wetland. Canadian Journal of Fisheries and Aquatic Sciences. 55: 1189-1187.

Luecke, C., and D. Teuscher. 1994. Habitat selection by lacustrine rainbow trout within gradients of temperature, oxygen, and food availability. pp. 133-149.

Lyons, J., and J. J. Magnuson. 1987. Effects of walleye predation on the population dynamics of small littoral-zone fishes in a northern Wisconsin lake. Transactions of the American Fisheries Society 116:29-39.

Marking, L.L. 1992. Evaluations of Toxicants for the control of carp and other nuisance fishes. Fisheries. 17(6): 6-13.

Marrero C., H. Lopez-Rojas. 1995. Quantitative evaluation of the point method for fish stomach contents analysis. Journal of Fish Biology. 47:914-916.

Marwitz, T. D., and W. A. Hubert. 1997. Trends in relative weight of walleye stocks in Wyoming reservoirs. North American Journal of Fisheries Management. 17:44-53.

McLellan, H.J. 2000. Limnological and Fisheries Evaluation of Rock Lake. Thesis. Eastern Washington University. Biology Department. Cheney, Washington. 208 pp.

McMahon, T. E., and D. H. Bennett. 1996. Walleye and northern pike: boost or bane to Northwest fisheries? Fisheries 21:6-13.

McMillan, J. 1984. Evaluation and enhancement of the trout and walleye fisheries in the North Platte River system of Wyoming with emphasis on Seminoe Reservoir. Wyoming Game and Fish Department, Fish Division, Federal Aid in Sportfish Restoration, Project F-44-R, Completion Report, Cheyenne.

Meseberg, M. 2000. Mar don Resort owner. Personal communications related to the past warmwater fish harvest on Moses Lake.

Mills, E. D., J. F. Forney. 1983. Impact on Daphnia pulex of predation by young yellow perch in Oneida Lake, New York. Transactions of the American Fisheries Society 112:154-161.

Murphy, B. R., D. W. Willis, and T. A. Springer. 1991. The relative weight index in fisheries management: status and needs. Fisheries. 16:30-38.

Ney, J. J. 1990. Trophic economics in fisheries: Assessments of Demand-Supply relationships between predators and prey. Reviews in Aquatic Sciences 2:55-81.

Noble, R.L. 1975. Growth of young yellow perch (Perca flavescens) in relation to zooplankton populations. Transactions of the American Fisheries Society. 104:731-741.

Noble, R.L. 1975. Growth of young yellow perch (Perca flavescens) in relation to zooplankton populations. Transactions of the American Fisheries Society. 104:731-741.

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife monographs, No. 62.

Paine, R.T. 1988. Food webs: road maps of interactions or grist for theoretical development. Ecology 69(6):1648-1654.

Paragamian, V. L., and E. C. Bowles. 1995. Factors affecting survival of kokanees stocked in Lake Pend Oreille, Idaho. North American Journal of Fisheries Management 15:208-219.

Pennak, R.W. 1989. Freshwater invertebrates of the United States, 3rd ed. John Wiley and Sons, New York, NY.

Persson, L., and L. A. Greenberg. 1990. Juvenile competitive bottlenecks: the perch (Perca fluviatilis)-roach (Rutilus rutilis) interaction. Ecology 71:44-56.

Polis, G. A. and K. O. Winemiller. 1996. Food webs: integration of patterns and dynamics. Chapman and Hall, New York.

Pollock K.H., J.D. Nichols, C. Brownie, J.E. Hines. 1989. Statistical inference for capture-recapture experiments. Wildlife Monographs, 107:1-97.

Porath M.T., E.J. Peters. 1997. Walleye prey selection in Lake McConaught, Nebraska: A comparison between stomach content analysis and feeding experiments. Journal of Freshwater Ecology. 12 (4):511-520.

Rach, J.J., J.A. Luoma, and L.L. Marking. 1994. Development of an Antimycin-impregnated bait for control common carp. North American Journal of Fisheries Management. 14: 442-446.

Rahel, F. J., and J. W. Nutzman. 1994. Foraging in a lethal environment: fish predation in hypoxic waters of a stratified lake. Ecology 75:1246-1253.

Ransom, B. H. and five co-authors. 1999. Using hydroacoustics for fisheries assessment. Companion Manual to the Short Coarse, Publication number SCMN-000-005, Seattle, WA.

Rieman, B. E., R. C. Beamesderfer, S. Vigg, and T. P. Poe. 1991. Estimated loss of Juvenile Salmonids to predation by northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:448-458.

Robson D.S. 1991. The roving creel survey. American Fisheries Society Symposium. 12:19-24.

Ross, L.M., J. Savitz, and G. Funk. 1995. Comparison of diets of smallmouth bass (Micropterus dolomieui) collected by sport fishing and by electrofishing. Journal of Freshwater Ecology. 10(4):393-398.

Ruggerone G.T. 1989. Gastric evacuation of single and multiple meals by piscivorous coho salmon (Oncorhynchus kisutch). Environmental Biology of Fishes. 26:143-147.

Schindler, D. E., and six coauthors. 1996. Food web structure and littoral zone coupling to pelagic trophic cascades In G. A. Polis, K. O. Winemiller, editors. Food webs: integration of patterns and dynamics. Chapman and Hall, New York.

Schneidervin, R. W. and W. A. Hubert. 1987. Diet overlap among zooplanktophagous fishes in Flaming Gorge Reservoir, Wyoming-Utah. North American Journal of Fisheries Management 7:379-385.

Sing-Renton S., P.J. Bromley. 1996. Effects of temperature, prey type and prey size on gastric evacuation in small cod and whiting. Journal of Fish Biology. 49:702-713.

Snucins, E. J., and J. M. Gunn. 1995. Coping with a warm environment: behavioral thermoregulation by lake trout. Transactions of the American Fisheries Society 124:118-123.

Stewart, D. J., J. F. Kitchell, and L. B. Crowder. 1981. Forage fishes and their salmonid predators in Lake Michigan. Transactions of the American Fisheries Society 110:751-763.

Tabor, R., C. Luecke, and W. Wurtsbaugh. 1996. Effects of Daphnia availability on growth and food consumption of rainbow trout in two Utah reservoirs. North American Journal of Fisheries Management 16:591-599.

Travnichek, V. H., A. V. Zale, and W. L. Fisher. 1993. Entrainment of ichthyoplankton by a warmwater hydroelectric facility. Transactions of the American Fisheries Society 122:709-716.

Tuescher, D., and C. Luecke. 1996. Competition between kokanees and Utah chub in Flaming Gorge Reservoir, Utah-Wyoming. Transaction of the American Fisheries Society 125:505-511.

USEPA. 1989b. Rapid bioassessment protocols for use in streams and rivers: Benthic macroinvertebrates and fish. EPA/440/4-89-001. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

USEPA. 1990d. Near Coastal Plan for 1990: Estuaries. EPA 600/4-90/033. U.S. Environmental Protection Agency. Office of Research and Development, Environmental Research Lab, Narragansett, RI.

USEPA. 1998. Lake and reservoir bioassessment and biocriteria: Technical guidance document. EPA 841-B-98-007. Environmental Protection Agency. Office of Wetlands, Oceans and Watersheds, Office of Science and Technology, Office of Water, Washington D.C.

Vanni, M.J., G.D. Layne, and S.E. Arnott. 1997. Top-down trophic interactions in lakes: effects on nutrient dynamics. Ecology. 78(1): 1-20.

Vigg, S., Poe T. P., L. A. Pendergast, and H. C. Hansel. 1991. Rates of Consumption of juvenile salmonids and alternative prey fish by northern squawfish, walleyes, smallmouth bass, and channel catfish in John Day Reservoir, Columbia River. Transactions of the

American Fisheries Society 120:421-438.

Wege, G. J., and R. O. Anderson. 1978. Relative weight (Wr): an new index of condition for largemouth bass. Pages 79-91 in G. D. Novinger and J. G. Dillard, editors. New North Central Division, Special Publication 5, Bethesda Maryland.

Welch, Eugene B., C.A Jones, R.P Barbiero. 1989. Moses Lake Quality: Results of Dilution, Sewage Diversion and BMPs- 1977 through 1988. Water Resources Series Technical Report No. 118. University of Washington Department of Civil Engineering Environmental Engineering and Science.

Westerlund J.E., P.C. Jacobson, H.K. Van Offelen, J.K. Hirsch. 1998. Use of limnetic zooplankton sampling in assessments of fish community structure in Minnesota bass-panfish lakes. Minnesota Department of Natural Resources, Investigational Report, 467 pp.1-21.

Wetzel R.G., G.E. Likens. 1991. Limnological Analysis. 2nd edition. Springer-Verlag New York Inc. pp.168-170.

Wydoski, R.S., and R.R. Whitney. 1979. Inland Fishes of Washington. University of Washington Press. United States. 220 pp.

Yule, D. L., and C. Luecke. 1993. Lake trout consumption and recent changes in the fish assemblage of Flaming Gorge Reservoir. Transactions of the American Fisheries Society 122:1058-1069.

Appendix A

Appendix A is presented as satisfaction to a contractual commitment with Bonneville Power Administration. This portion of the document contains a list of all information, gray literature, primary literature and Moses Lake specific studies that have been reviewed during the last contract year.

Aging

Bailey, K.M., A.L. Brown, A. Nishimura, and M.T. Reilly. 1995. Three dimensional imaging of walleye pollock otoliths: Reconstruction from serial sections and fluorescent laser cytometry. Journal of Fish Biology. 47:671-678.

Beamish, R.J. 1981. Use of fin-ray sections to age walleye pollock, pacific cod and albacore, and the importance of this method. Transactions of the American Fisheries Society. 110:287-299.

Beamish, R.J., and G.A. Mc Farlane. 1983. The forgotten requirement for age validation in fisheries biology. Transactions of the American Fisheries Society. 112:735-743.

Brooks, R.C., R.C. Heidinger, and C.C. Kohler. 1994. Mass-marking otoliths of larval and juvenile walleyes by immersion in oxytetracycline, calcein, or calcein Blue. North American Journal of Fisheries Management. 14:143-150.

Campana, S.E., and J.D. Neilson. 1985. Microstructure of fish otoliths. Canadian Journal of Fisheries and Aquatic Sciences. 42:1014-1031.

Campana, S.E. 1990. How reliable are growth back-calculations based on otoliths? Canadian Journal of Fisheries and Aquatic Sciences. 47:2219-2227.

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Transactions of the American Fisheries Society. 124:131-138.

Carlander, K.D. 1982. Standard intercepts for calculating lengths from scale measurements for some Centrarchid and Percid fishes. Transactions of the American Fisheries Society. 111:332-336.

Chilton, D.E., and M. Stocker. 1987. A comparison of otolith and scale methods for aging Pacific herring. North American Journal of Fisheries Management. 7:202-206.

Davis, R.D., T.W. Storck, and S.J. Miller. 1985. Daily growth increments in the otoliths of young-of-the-year gizzard shad. Transactions of the American Fisheries Society. 114:304-306.

Erickson, C.M. 1983. Age determination of Manitoban walleyes using otoliths, dorsal spines, and scales. North American Journal of Fisheries Management. 3:176-181.

Francis, R.I.C.C. 1990. Back-calculation of fish length: A critical review. Journal of Fish Biology. 36:883-902.

Green, D.M., and R.C. Heidinger. 1994. Longevity record for largemouth bass. North American Journal of Fisheries Management. 14:464-465.

Hoyer, M.V., J.V. Shireman, and M.J. Maceina. 1985. Use of otoliths to determine age and growth of largemouth bass in Florida. Transactions of the American Fisheries Society. 114:307-309.

Maceina, M.J. 1988. Simple grinding procedure to section otoliths. North American Journal of Fisheries Management. 8:141-143.

Miller, S.J., and T. Storck. 1982. Daily growth rings in otoliths of young-of-the-year largemouth bass. Transactions of the American Fisheries Society. 111:527-530.

Ogle, D.H., G.R. Spangler, and S.M. Shroyer. 1994. Determining fish age from temporal signatures in growth increments. Canadian Journal of Fisheries and Aquatic Sciences. 51:1721-1727.

Perry, L.G., and J.A. Tranquilli. 1984. Age and growth of largemouth bass in a thermally altered reservoir, as determined from otoliths. North American Journal of Fisheries Management. 4:321-330.

Pierce, C.L., J.B. Rasmussen, and W.C. Leggett. 1996. Back-calculation of fish length from scales: Empirical comparison of proportional methods. Transactions of the American Fisheries Society. 125:889-898.

Scarnecchia, D.L. 1987. Rapid Removal of otoliths from Salmonids. North American Journal of Fisheries Management. 7:312-313.

Schlueter, L.R. 1989. Simple removal of sagitta otoliths from walleyes. North American Journal of Fisheries Management. 9:123.

Schneidervin, R.W. and W.A. Hubert. 1986. A rapid technique for otolith removal from Salmonids and Catostomids. North American Journal of Fisheries Management. 6:287.

Schramm, H.L. Jr. 1989. Formation of annuli in otoliths of bluegills. Transactions of

The American Fisheries Society. 118:546-555.

Schramm, H.L. Jr., S.P Malvestuto, and W.A. Hubert. 1992. Evaluation of procedures for back-calculations of lengths of largemouth bass aged by otoliths. North American Journal of Fisheries Management. 12:604-608.

Schultz, D.L., and R.S. Taylor. 1987. Preparation of small otoliths for microscopic examination. North American Journal of Fisheries Management. 7:309-311.

Smith, D.G. 1989. Role of museums in studies of early life history stages of fishes. Transactions of the American Fisheries Society. 118:214-217.

Taubert, B.D, and J.A. Tranquilli. 1982. Verification of the formation of annuli in otoliths of largemouth bass. Transactions of the American Fisheries Society. 111:531-534.

Temple, A.J., D.J. Price, and B.R. Murphy. 1985. An inexpensive method for sectioning otoliths of large fish. Management Brief. North American Journal of Fisheries Management. 5:612.

Tsumura, K. 1987. Simple technique to improve microfiche prints of fish scales. North American Journal of Fisheries Management. 7:441-443.

Weisberg, S. 1993. Using hard-part increment data to estimate age and environmental effects. Canadian Journal of Fisheries and Aquatic Sciences. 50:1229-1237.

Welch, T.J., M.J.V. Avyle, R.K. Betsill, and E.M. Driebe. 1993. Precision and relative accuracy of striped bass age estimates from otoliths, scales and anal fin rays and spines. North American Journal of Fisheries Management. 13:616-620.

Angling

Austen, D.J., and D.J. Orth. 1988. Evaluation of a 305-mm minimum- length limit for smallmouth bass in the New River, Virginia and West Virginia. North American Journal of Fisheries Management. 8:231-239.

Baccante, D. 1995. Assessing catch inequality in walleye angling fisheries. North American Journal of Fisheries Management. 15:661-665.

Cole, R.A., and F.A. Ward. 1994. Optimum fisheries management policy: Angler opportunity versus angler benefit. North American Journal of Fisheries Management. 14:22-33.

Green, A.W., G.C. Matlock, and J.E. Weaver. 1983. A method for directly estimating the tag-reporting rate of anglers. Transactions of the American Fisheries Society. 112:412-415.

Gigliotti, L.M., and R.B. Peyton. 1993. Values and behaviors of trout anglers and their attitudes towards fishery management, relative to membership in fishing organizations: A Michigan case study. North American Journal of Fisheries Management. 13:492-501.

Holland, S.M., and R.B. Ditton. 1992. Fishing trip satisfaction: A typology of anglers. Journal of Fisheries Management. 12:28-33.

Jones, C.M., D.S. Robson, H.D. Lakkis, and J. Kressel. 1995. Properties of catch rates used in analysis of angler surveys. Transactions of the American Fisheries Society. 124:911-928.

Lockwood, R.N. 1997. Evaluation of catch rate estimators from Michigan access point angler surveys. North American Journal of Fisheries Management. 17:611-620.

Malvestuto, S.P. 1995. Book Review: Angler survey methods and their applications in fisheries management. North American Journal of Fisheries Management. 15: 238-240.

Novinger, G.D. 1987. Evaluation of a 15.0-inch minimum length limit on largemouth bass and spotted bass catches at Table Rock Lake, Missouri. North American Journal of Fisheries Management. 7:260-272.

ODWC. 1998. Effects of a minimum length limit and daily creel reduction on the white crappie population structure and angler creel on Arbuckle Reservoir. Oklahoma Department of Wildlife Conservation Federal Aid Grant F-50-R.

ODWC. 1999. Effects of a minimum length limit and daily creel reduction on the white crappie population structure and angler creel of Ft. Supply Reservoir. Oklahoma Department of Wildlife Conservation Federal Aid Grant F-50-R.

Petering, R.W., G.L. Isbell, and R.L. Miller. 1995. A survey method for determining angler preference for catches of various fish length and number combinations. North American Journal of Fisheries Management. 15:732-735.

Phippen, K.W., and Bergersen, E.P. 1987. Angling definitions and their effects on the accuracy of count-interview creel survey harvest estimates. North American Journal of Fisheries Management. 7:488-492.

Quinn, S.P. 1992. Angler perspectives on walleye management. North American Journal of Fisheries Management. 12:367-378.

Schill, D.J., and P.A. Kline. 1995. Use of random response to estimate angler noncompliance with fishing regulations. North American Journal of Fisheries Management. 15:721-731.

Spencer, P.D., and G.R. Spangler. 1992. Effect that providing fishing information has on angler expectations and satisfaction. North American Journal of Fisheries Management. 12:379-385.

Spencer, P.D. 1993. Factors influencing satisfaction of anglers on Lake Miltona, Minnesota. North American Journal of Fisheries Management. 13:201-209.

Spiller, K.W., A.W. Green, and H.R. Osburn. 1988. Increasing the efficiency of angler surveys by canceling sampling during inclement weather. North American Journal of Fisheries Management. 8:132-138.

Tarrant, M.A., M.J. Manfredo, P.B. Bailey, and R. Hess. 1993. Effects of recall bias and nonresponse bias on self-report estimates of angling participation. North American Journal of Fisheries Management. 13:217-222.

WDFW. 1996. A 1995 survey of resident game fish anglers in Washington State. Washington Department of Fish and Wildlife Technical Report: IF96-04.

WDFW. 1996. Warmwater fish of Washington. Washington Department of Fish and Wildlife Report: FM93-9.

Wilde, G.R. and R.B. Ditton. 1994. A management-oriented approach to understanding diversity among largemouth bass anglers. North American Journal of Fisheries Management. 14:34-40.

Wilde, G.R., R.K. Riechers, and R.B. Ditton. 1998. Differences in attitudes, fishing motives, and demographic characteristics between tournament and non-tournament black bass anglers in Texas. North American Journal of Fisheries Management. 18:422-431.

Black crappie

Allen, M.S., and L.E. Miranda. 1995. An evaluation of the value of harvest restrictions in managing crappie fisheries. North American Journal of Fisheries Management. 15:766-772.

Allen, M.S., M.V. Hoyer, and D.E. Canfield Jr. 1998. Factors related to black crappie occurrence, density and growth in Florida lakes. North American Journal of Fisheries Management. 18:864-871.

Baker, S.C., and R.C. Heidinger. 1996. Upper lethal temperature tolerance of fingerling black crappie. Journal of Fish Biology. 48:1123-1129.

Guy, C.S., and D.W. Willis. 1995. Population characteristics of black crappies in South Dakota waters: A case for ecosystem-specific management. North American Journal of Fisheries Management. 15:754-765.

Kruse, C.G., C.S. Guy, and D.W. Willis. 1993. Comparison of otolith and scale age characteristics for black crappie collected from South Dakota waters. North American Journal of Fisheries Management. 13:856-858.

Maceina, M.J., and M.R. Stimpert. 1998. Relations between reservoir hydrology and crappie recruitment in Alabama. North American Journal of Fisheries Management. 18:104-113.

McInerny, M.C., and T.K. Cross. 1999. Effects of lake productivity, climate warming, and intraspecific density on growth and growth patterns of black crappie in southern Minnesota lakes. Journal of Freshwater Ecology. 14(2):255-264.

Parsons, B.G., and J.R. Reed. 1998. Angler exploitation of bluegill and black crappie in four west-central Minnesota lakes. Minnesota Department of Natural Resources, Investigational Report 468.

Pope, K.L., W.T. Geraets, and D.W. Willis. 1996. Egg development in a high-density black crappie (*Pomoxis nigromaculatus*) population. South Dakota Agricultural Experiment Station Journal Series: 2912.

Pope, K.L., and D.W. Willis. 1998. Larval black crappie distribution: Implications for sampling impoundments and natural lakes. North American Journal of Fisheries Management. 18:470-474.

Quinn, S. Crappies today, crappies tomorrow. The In-Fisherman. 109:78-84.

Travnichek, V.H., M.J. Maceina, and R.A. Dunham. 1996. Hatching time and early growth of age-0 black crappies, white crappies, and their naturally produced F1 hybrids in Weiss Lake, Alabama. Transactions of the American Fisheries Society. 125:334-337.

Smiley, P.C. Jr., and G.R. Parsons. 1997. Effects of photoperiod and temperature on swimming performance of white crappie. Transactions of the American Fisheries Society. 126:495-499.

Bluegill

Coble, D.W. 1988. Effects of angling on bluegill populations: Management implications. North American Journal of Fisheries Management. 8:277-283.

Cross, T.K., M.C. McInerny, and D.H. Schupp. 1995. Seasonal variation in trap-net catches of bluegill in Minnesota lakes. North American Journal of Fisheries Management. 15:382-389.

Drake, M. T., J.E. Claussen, D.P. Philipp, and D.L. Pereiera. 1997. A comparison of bluegill reproductive strategies and growth among lakes with different fishing intensities. North American Journal of Fisheries Management. 17:496-507.

Hayse, J.W., and T.E. Wissing. 1996. Effects of stem density of artificial vegetation on abundance and growth of age-0 bluegills and predation by largemouth bass. Transactions of the American Fisheries Society. 125:422-433.

Johnson, D.L., R.A. Beaumer, and W.E. Lynch Jr. 1988. Selection of habitat structure interstice size by bluegills and largemouth bass in ponds. Transactions of the American Fisheries Society. 117:171-179.

Johnson, S.L. 1993. Cover choice by bluegills: Orientation of underwater structure and light intensity. Transactions of the American Fisheries Society. 122:148-154.

Kelsch, S.W. 1996. Temperature selection and performance by bluegills: Evidence for selection in response to available power. Transactions of the American Fisheries Society. 125:948-955.

Knights, B.C., B.L. Johnson, and M.B. Sandheinrich. 1995. Responses of bluegills and black crappie to dissolved oxygen, temperature, and current in backwater lakes of the upper Mississippi River during winter. North American Journal of Fisheries Management. 15:390-399.

Knights, B.C., and B.A. Lasee. 1996. Effects of implanted transmitters on adult bluegills at two temperatures. Transactions of the American Fisheries Society. 125:440-449.

Lynch, W.E., and D.L. Johnson. 1989. Influences of interstice size, shade and predators on the use of artificial structures by bluegills. North American Journal of Fisheries Management. 9:219-225.

Muoneke, M.I. 1992. Seasonal hooking mortality of bluegills caught on natural baits. North American Journal of Fisheries Management. 12:645-649.

O'Brien, W.J., N.A. Slade, and G.L. Vinyard. 1976. Apparent size as the determinant of prey selection by bluegill sunfish (*Lepomis macrochirus*). Ecology. 57:1304-1310.

Werner, E.E., and D.J. Hall. 1974. Optimal foraging and the size selection of prey by the bluegill sunfish (*Lepomis macrochirus*). Ecology. 55:1042-1052.

Bullhead

Kline, J.L., and B.M. Wood. 1994. Food habits and diet selectivity of the brown bullhead. New York Cooperative Fish and Wildlife Research Unit, Department of Natural Resources. Cornell University.

Carp

Cooper, E.L. 1987. Carp in North America. American Fisheries Society. Bethesda, Maryland.

Fajt, J.R., and J.M. Grizzle. 1993. Oral toxicity of rotenone for common carp. Transactions of the American Fisheries Society. 122:302-304.

Fajt, J.R., and J.M. Grizzle. 1998. Blood respiratory changes in common carp exposed to a lethal concentration of rotenone. Transactions of the American Fisheries Society. 127:512-516.

Marking, L.L. 1992. Evaluations of toxicants for the control of carp and other nuisance fishes. Fisheries. 17(6):6-13.

Mc Kay, A.E. 1968. A survey of year-class abundance of spawning carp, *Cyprinus carpio linnaeus*, in Moses Lake. Washington State University.

Rach, J.J., J.A. Luoma, and L.L. Marking. 1994. Development of an antimycin-impregnated bait for controlling common carp. North American Journal of Fisheries Management. 14:442-446.

Schwartz, F.J. 1986. A leadless stackable trap for harvesting common carp. North American Journal of Fisheries Management. 6:596-598.

Tiihonen, K., and M. Nikinmaa. 1991. Substrate utilization by carp (*Cyprinus carpio*) erythrocytes. Journal of Experimental Biology. 161:509-514.

Tonn, W.M., I.J. Holopainen, and C.A. Paszkowski. 1994. Density-dependent effects and the regulation of crucian carp populations in single- species ponds. Ecology. 75(3):824-834.

Verrill, D.D, and C.R. Berry Jr. 1995. Effectiveness of an electrical barrier and lake drawdown for reducing common carp and bigmouth buffalo abundances. North American Journal of Fisheries Management. 15:137-141.

Channel catfish

Newcomb, B.A. 1989. Winter abundance of channel catfish in the channelized Missouri River, Nebraska. North American Journal of Fisheries Management. 9:195-202.

Condition Factors

Cargnelli, L.M., and M.R. Gross. 1997. Fish energetics: Larger individuals emerge from winter in better condition. Transactions of the American Fisheries Society. 126:153-156.

Gabelhouse, D. W. Jr. 1984. A length-categorization system to assess fish stocks. North American Journal of Fisheries Management. 4:273-285.

Hayward, R.S., D.B. Noltie, and N. Wang. 1997. Notes: Use of compensatory growth to double hybrid sunfish growth rates. Transactions of the American Fisheries Society. 126:316-322.

Hewett, S.W., and C.E. Kraft. 1993. The relationship between growth and consumption: Comparisons across fish populations. Transactions of the American Fisheries Society. 122:814-821.

Kolander, T.D., and D.W. Willis. 1993. Proposed revisions of the standard weight equation for smallmouth bass. North American Journal of Fisheries Management. 13:398-400.

Murphy, B.R., and D.W. Willis. 1992. Comments: Proper distinction between relative weight and relative condition factor. North American Journal of Fisheries Management. 12:665-666.

Rach, J.J., and W.H. Gingerich. 1986. Distribution and accumulation in tissues of warmwater fishes. Transactions of the American Fisheries Society. 115:214-219.

Whitworth, W.R. 1989. Evaluation of largemouth bass growth estimates obtained from angler-collected scale samples. North American Journal of Fisheries Management. 9:116-119.

Diet

Barnhisel, D. R., and H. A. Harvey. Size-specific fish avoidance of the spined crustacean

Bythotrepes: Field support for laboratory predictions. Canadian Journal of Fisheries and Aquatic Sciences. 52:768-775.

Bergman, E., and L.A. Greenberg. 1994. Competition between a planktivore, a benthivore, and a species with ontogenetic diet shifts. Ecology. 75(5):1233-1245.

Davis, B.M., and T. N. Todd. 1998. Competition between larval lake herring (*Coregonus artedi*) and lake whitefish (*Coregonus clupeaformis*) for zooplankton. Canadian Journal of Fisheries and Aquatic Sciences. 55:1140-1148.

Englund, G., and D. Evander. 1999. Interactions between sculpins, net-spinning caddis larvae and midge larvae. Oikos. 85(1):117-126.

Fedoruk, A.N. 1966. Feeding relationship of walleye and smallmouth bass. Journal of the Fisheries Research Board of Canada. 23(6):941-943.

Guest, W.C., R.W. Drenner, S.T. Threlkeld, F.D. Marten, and J.D. Smith. 1990. Effects of gizzard shad on zooplankton and young of year white crappie production. Transactions of the American Fisheries Society. 119:529-536.

Hall, S.J., W.S.C. Gurney, H. Dobby, D.J. Basford, S.D. Heaney, and M.R. Robertson. 1995. Inferring feeding patterns from stomach contents data. Journal of Animal Ecology. 64(1):39-62.

Hartman, K.J., and D.W. Garton. 1992. Electrophoretic identification of partially digested prey of piscivorous fish. North American Journal of Fisheries Management. 12:260-263.

Hartleb, C.F., and J.R. Moring. 1995. An improved gastric lavage device for removing stomach contents from live fish. Fisheries Research. 24(3):261.

Hubert, W.A., R.D. Gipson, R.A. McDowell, and A.C. Stewart. 1994. Diet of Eagle Lake rainbow trout in Lake DeSmet, Wyoming. North American Journal of Fisheries Management. 14:457-459.

Kolok, A.S., and D.W. Rondorf. 1987. Effect of differential gastric evacuation and multispecies prey items on estimates of daily energy intake in juvenile chinook salmon. Environmental Biology of Fishes. 19(2):131-137.

Langeland, A., and T. Nost. 1995. Gill raker structure and selective predation on zooplankton by particulate feeding fish. Journal of Fish Biology. 47:719-732.

Marrero, C., and H. Lopez-Rojas. 1995. Quantitative evaluation of the point method for fish stomach contents analysis. Journal of Fish Biology. 47(5):914.

Mayer, C.M., and D.H. Wahl. 1997. The relationship between prey selectivity and growth and survival in a larval fish. Canadian Journal of Fisheries and Aquatic Sciences. 54:1504-1512.

Miranda, L.E. 1986. Removal of stomach contents from live largemouth bass using Hydrogen Peroxide. North American Journal of Fisheries Management. 6:285-286.

Ney, J.J. 1981. Forage-fish management in the U.S.: Evolution of forage-fish management in lakes and reservoirs. Transactions of the American Fisheries Society. 110:725-728.

Persson, L., J. Andersson, E. Wahlstrom, and P. Eklov. 1996. Size-specific interactions in lake systems: Predator gape limitation and prey growth rate and mortality. Ecology. 77(3):900-911.

Rand, P.S., B.F. Lantry, R. O'Gorman, R.W. Owens, and D.J. Stewart. 1994. Energy density and size pelagic prey fishes in Lake Ontario, 1978-1900: Implications for Salmonine energetics. Transactions of the American Fisheries Society. 123:519-534.

Rita, H., and E. Ranta. 1998. Group foraging, gain and the finder's advantage. Oikos. 82:515-521.

Scharf, F.S., J.A. Buckel, F. Juanes, and D.O. Conover. 1997. Estimating piscine prey size from partial remains: Testing for shifts in foraging mode by juvenile bluefish. Environmental Biology of Fishes. 49(3):377-388.

Singh-Renton, S., and P.J. Bromley. 1996. Effects of temperature, prey type and prey size on gastric evacuation in small cod and whiting. Journal of Fish Biology. 49(4):702-713.

Sterner, R.W. 1997. Modeling interactions of food quality and quantity in homeostatic consumers. Freshwater Biology. 38:473-481.

Stewart, D.J., J.F. Kitchell, and L.B. Crowder. 1981. Forage fishes and their salmonid predators in Lake Michigan. Transactions of the American Fisheries Society. 110:751-763.

Vigg, S., and C.C. Burley. 1991. Temperature-dependent maximum daily consumption of juvenile salmonids by northern squawfish (*Ptychocheilus oregonensis*) from the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences. 48: 2491-2498.

Wang, W.X., and N.S. Fisher. 1996. Assimilation of trace elements and carbon by mussel *Mytilus edulis*: Effects of food composition. Limnology and Oceanography. 41(2):197-207.

Weatherley, A.H., and H.S. Gill. 1983. Protein, lipid, water and caloric contents of immature rainbow trout, *Salmo gairdneri* Richardson, growing at different rates. Journal of Fish Biology. 23:653-673.

Wurtsbaugh, W.A., and G.E. Davis. 1977. Effects of fish size and ration level on the growth and food conversion efficiency of rainbow trout, *Salmo gairdneri* Richardson. Journal Fish Biology. 11:99-104.

Wydoski, R.S., and D.H. Bennett. 1981. Forage species in lakes and reservoirs of the western United States. Transactions of the American Fisheries Society. 110: 764-771.

Yule, D.L., and C. Luecke. 1993. Lake trout consumption and recent changes in the fish assemblage of Flaming Gorge Reservoir. Transactions of the American Fisheries Society. 122:1058-1069.

Electrofishing

Bardygula-Nonn, L.G., R. Nonn, and J. Savitz. 1995. Influence of pulsed direct current electrofishing on mortality and injuries among four Centrarchid species. North American Journal of Fisheries Management. 15:799-803.

Barrett, J.C., and G.D. Grossman. 1988. Effects of direct current electrofishing on the mottled sculpin. North American Journal of Fisheries Management. 8:112-116.

Bowen, Z.H., and M.C. Freeman. 1998. Sampling effort and estimates of species richness based on prepositioned area elecrofisher samples. North American Journal of Fisheries Management. 18:144-153.

Burkhardt, R.W., and S. Gutreuter. 1995. Improving electrofishing catch consistency by standardizing power. North American Journal of Fisheries Management. 15: 375-381.

Buynak, G.L., and B. Mitchell. 1993. Electrofishing catch per effort as a predictor of largemouth bass abundance and angler catch in Taylorsville Lake, Kentucky. North American Journal of Fisheries Management. 13:630-633.

Fisher, W.L., and M.E. Brown. 1993. A prepositioned aerial electrofishing apparatus for sampling stream habitats. North American Journal of Fisheries Management. 13: 807-816.

Fowles, C.R. 1974. Effects of electric fishing on the invertebrate fauna of a New

Zealand stream. New Zealand Journal of Marine and Freshwater Research. 9(1):35-43.

Hardin, S., and L.L. Connor. 1992. Variability of electrofishing crew efficiency and sampling requirements for estimating reliable catch rates. North American Journal of Fisheries Management. 12:612-617.

Hill, T.D., and D.W. Willis. 1994. Influence of water conductivity on pulsed AC and pulsed DC electrofishing catch rates for largemouth bass. North American Journal of Fisheries Management. 14:202-207.

Kershner, M.W., and E.A. Marschall. 1998. Allocating sampling effort to equalize precision of electrofishing catch per unit effort. North American Journal of Fisheries Management. 18:822-831.

Lyons, J. 1992. The length of stream to sample with a towed electrofishing unit when fish species richness is estimated. North American Journal of Fisheries Management. 12:198-203.

McInerny, M.C., and D.J. Degan. 1993. Electrofishing catch rates as an index of largemouth bass population density in two large reservoirs. North American Journal of Fisheries Management. 13:223-228.

Mesa, M.G., and C.B. Schreck. 1989. Electrofishing mark-recapture and depletion methodologies evoke behavioral and physiological changes in cutthroat trout. Transactions of the American Fisheries Society. 118:664-658.

Pugh, L.L., and H.L. Schramm Jr. 1998. Comparison of electrofishing and hoopnetting in lotic habitats of the lower Mississippi River. North American Journal of Fisheries Management. 18:649-656.

Schneider, J.C. 1992. Field evaluations of 230-v AC electrofishing on mortality and growth of warmwater and coolwater fish. North American Journal of Fisheries Management. 12:253-256.

Spencer, S.L. 1967. Internal injuries of largemouth bass and bluegills caused by electricity. The Progressive Fish-Culturist. 168-170.

Thompson, P.D., and F.J. Rahel. 1996. Evaluation of depletion-removal electrofishing of brook trout in small Rocky Mountain streams. North American Journal of Fisheries Management. 16:332-339.

Twedt, D.J., W.C. Guest, and B.W. Farquhar. 1992. Selective dipnetting of largemouth bass during electrofishing. North American Journal of Fisheries Management. 12:609-611.

Fish Keys

Robins, C.R. 1991. Common and Scientific Names of Fishes from the United States and Canada, 5th edition. American Fisheries Society Special Publication 20. Bethesda, Maryland.

Simpson, J. and R. Wallace. 1982. Fishes of Idaho, 2nd Edition. University of Idaho Press. Moscow, Idaho.

Wydoski, R.S., and R.R. Whitney. 1979. Inland Fishes of Washington. University of Washington Press. Seattle and London.

Fisheries Management

Bain, M.B. 1987. Structured decision-making in Fisheries Management: Trout fishing regulations on the Au Sable River, Michigan. North American Journal of Fisheries Management. 7:475-481.

Begon, M., J.L. Harper, and C.R. Townsend. 1986. Ecology, Individuals, Populations, and Communities. Sinauer Associates, Inc. Sunderland, Massachusetts.

Carlander, K.D. Handbook of Freshwater Fishery Biology, Volume Three. Iowa State University Press. Ames, Iowa.

Chadwick, P.A. Jr., B.J. Davies, T.K. Flowers, J.M. Walton, and W. Wirt. 1985. Moses Lake fish population analysis. Peninsula College, Port Angeles.

Duff, R.L. 1976. A year's survey of the Lake Moses fishery. Washington Department of Game.

Eads, R., T. Sibley, R. Ponce, and V. Peterson. 1991. Economic impact and environmental assessment of the decline of fishing, Moses Lake and Potholes Reservoir. Big Bend Economic Development Council. Ephrata, Washington.

Everhart W.H., and W.D. Youngs. 1981. Principles of Fishery Science, Second Edition. Cornell University Press. Ithaca, New York.

Fletcher, D., M. Hallock, and K. Perry. 1990. 1987, 1988, 1989, and 1990 Warmwater fishing contests in Washington, 4 Volumes. Washington Department of Wildlife.

Groves, K.E. 1951. Fishes of Moses Lake Washington. Walla Walla College, College Place.

Hall, G.E., and M.J. Van Den Avyle. 1986. Reservoir Fisheries Management, Strategies for the 80's. A National Symposium on Managing Reservoir Fishery Resources. American Fisheries Society. Bethesda, Maryland.

Fisheries Management (Cont.)

Jackson, S.Y. 1985. 1983 Moses Lake creel census. Washington Department of Game.

Minnesota Department of Natural Resources, United States Fish and Wildlife Service, and University of Minnesota. 2000. The 62nd Midwest Fish and Wildlife Conference, Abstracts. Minneapolis, Minnesota.

Mueller. K.W. 1998. 1997 Lake Tapps Survey: The warmwater fish community of a reservoir managed for hydropower. Washington Department of Fish and Wildlife.

Mueller. K.W., and M.R. Downen. 1997. Lacamas Lake Survey: The warmwater fish community of a highly eutrophic lowland lake. Washington Department of Fish and Wildlife Technical Report: FPT99-03.

Phillips, L., and M. Divens. 2000. 1998 warmwater fisheries survey of Clear Lake, Spokane County, Washington. Washington Department of Fish and Wildlife Report: FPT 00-24.

Walton, James M., and Will Wirt. 1989. Fish population assessment for four Eastern Washington Lakes. Peninsula College, Port Angeles.

WDFW. 2000. Bull trout and dolly varden management plan. Washington Department of Fish and Wildlife Report: 704.

Wootton, R.J. 1990. Ecology of Teleost Fishes. Chapman and Hall, New York, New York.

Zook, William. 1977. Fisheries Management Annual Report. Washington Department of Game.

Habitat

Beauchamp, D.A., E.R. Byrons, and W.A. Wurtsbaugh. 1994. Summer habitat use by littoral-zone fishes in Lake Tahoe and the effects of shoreline structures. North American Journal of Fisheries Management. 14:385-394.

Bowen, Z.H., M.C. Freeman, K.D. Bovee. 1998. Evaluation of generalized habitat criteria for assessing impacts of altered flow regimes on warmwater fishes. Transactions of the American Fisheries Society. 127:455-468.

Fish, P.A., and J. Savitz. 1983. Variations in home ranges of largemouth bass, yellow perch, bluegills and pumpkinseeds in an Illinois Lake. Transactions of the American Fisheries Society. 112:147-153.

Gent, R., J. Pitlo, Jr., and T. Boland. 1995. Largemouth bass response to habitat and water quality rehabilitation in a backwater of the upper Mississippi River. North American Journal of Fisheries Management. 15:784-793.

Gresswell, R.E. 1991. Use of antimycin for removal of brook trout from a tributary of Yellowstone Lake. North American Journal of Fisheries Management. 11:83-90.

Iowa Department of Natural Resources. 1998. Federal aid to fish restoration completion report small impoundment investigations. Project No. F-160-R.

Johnson, D.L., and W.E. Lynch Jr. 1988. White crappie and bluegill use of artificial structures constructed of evergreen trees, brush, and stakes. Appendix I of Evaluation of Fish Management Techniques. Final Report. Project F-57-R Study 10.

Johnson, D.L., and W.E. Lynch Jr. 1992. Panfish use of and angler success at evergreen tree, brush, and stake-bed structures. North American Journal of Fisheries Management. 12:222-229.

Killgore, K.J., R.P. Morgan II, and N.B. Rybicki. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River. North American Journal of Fisheries Management. 9:101-111.

King, J.R., B.J. Shutter, and A.P. Zimmerman. 1999. Empirical links between thermal habitat, fish growth, and climate change. Transactions of the American Fisheries Society. 128:656-665.

Miranda, L.E., and L.L. Pugh. 1997. Relationship between vegetation coverage and abundance, size, and diet of juvenile largemouth bass during winter. North American Journal of Fisheries Management. 17:601-610.

Radomski, P.J., T. J. Goeman, and P.D. Spencer. 1995. The effects of chemical control of submerged vegetation of the fish community of a small Minnesota Centrarchid lake. Minnesota Department of Natural Resources, Division of Fish and Wildlife Investigational Report: 442.

Sinclair, A.R.E., and R.P. Pech. 1996. Density dependence, stochasticity, compensation and predator regulation. Oikos. 75:164-173.

Tiffan, K.F., and E.P. Bergersen. 1996. Performance of antimycin in high-gradient streams. North American Journal of Fisheries Management. 16:465-468.

Tonn, W.M., I.J. Holopainen, and A.P. Cynthia. 1994. Density-dependent effects and the regulation of crucian carp populations in single-species ponds. Ecology. 73(3):824-834.

Zorn, T.G., and P.W. Seelbach. 1995. The relation between habitat availability and the short-term carrying capacity of a stream reach for smallmouth bass. North American Journal of Fisheries Management. 15:773-783.

Largemouth bass

Bennett, D.H., D.R. Hatch, and M.D. Liter. Managing largemouth bass in the Northwest: A game of recruitment, protection, and patience. Forest, Wildlife, and Range Experiment Station Publication, University of Idaho. 569:313-322.

Bettoli, P.W., M.J. Maceina, R.L. Noble, and R.K. Betsill. 1992. Piscivory in largemouth bass as a function of aquatic vegetation abundance. North American Journal of Fisheries Management. 12:509-516.

Boxrucker, J. 1987. Largemouth bass influence on size structure of crappie populations in small Oklahoma impoundments. North American Journal of Fisheries Management. 7:273-278.

Buck, D.H., and M.L. Hooe. 1986. Comparative growth of northern largemouth bass and F1 Hybrid largemouth bass through three growing seasons. Transactions of the American Fisheries Society. 115:286-304.

Carmichael, G.J., J.R. Tomasso, B.A. Simco, and K.B. Davis. 1984. Characterization and alleviation of stress associated with hauling largemouth bass. Transactions of the American Fisheries Society. 113:778-785.

Copeland, J.R., and R.L. Noble. 1994. Movements by young-of-the-year and yearling largemouth bass and their implications for supplemental stocking. North American Journal of Fisheries Management. 14:119-124.

Coble, D.W. 1992. Predicting population density of largemouth bass from electrofishing catch per unit effort. North American Journal of Fisheries Management. 12:650-652.

Coutant, C.C., and D.L. De Angelis. 1983. Comparative temperature-dependent growth rates of largemouth and smallmouth bass fry. Transactions of the American Fisheries Society. 112:416-423.

Dunham, R.A., C.J. Turner, and W.C. Reeves. 1992. Introgression of the Florida largemouth bass genome into native populations in Alabama public lakes. North American Journal of Fisheries Management. 12:494-498.

Ebbers, M.A. 1987. Vital statistics of a largemouth bass population in Minnesota from electrofishing and angler-supplied data. North American Journal of Fisheries Management. 7:252-259.

Fullerton, A.H., J.E. Garvey, R.A. Wright, and R.A. Stein. 2000. Overwinter growth and survival of largemouth bass: Interactions among size, food, origin, and winter severity. Transactions of the American Fisheries Society. 129:1-12.

Goodgame, L.S., and L.E. Miranda. 1993. Early growth and survival of age-0 largemouth bass relation to parental size and swim-up time. Transactions of the American Fisheries Society. 122:131-138.

Green, D.M. 1993. Evaluation of experimental angling regulations for bass. Final Report New York Federal Aid Project FA-5-R, Study VII, Job 101.

Guy, C.S., and D.W. Willis. 1991. Evaluation of largemouth bass-yellow perch communities in small South Dakota impoundments. North American Journal of Fisheries Management. 11:43-49.

Hodgson, J.R., and M.J. Kinsella. 1995. Small mammals in the diet of largemouth bass, revisited. Journal of Freshwater Ecology. 10(4):433-435.

Howick, G.L., and W.J. O'Brien. 1983. Piscivorous feeding behavior of largemouth bass: An experimental analysis. Transactions of the American Fisheries Society. 112:508-516.

Jackson, J.R., and R.L. Noble. 1995. Selectivity of sampling methods for juvenile largemouth bass in assessments of recruitment processes. North American Journal of Fisheries Management. 15:408-418.

Lange, T.R., H.E. Royals, and L.L. Connor. 1993. Influence of water chemistry on mercury concentrations in largemouth bass from Florida lakes. Transactions of the American Fisheries Society. 122:74-84.

Lee, D.P. 1992. Gas bladder deflation of depressurized largemouth bass. North

American Journal of Fisheries Management. 12:662-664.

Maceina, M.J. 1995. Estimating harvestable largemouth bass abundance in a reservoir with and electrofishing catch depletion technique. North American Journal of Fisheries Management. 15:103-109.

Maceina, M.J., and P.W. Bettoli. 1998. Variation in largemouth bass recruitment in four mainstream impoundments of the Tennessee River. North American Journal of Fisheries Management. 18:998-1003.

Maceina, M.J., and S.J. Rider. 1993. Use of catch-depletion method to estimate population density of age-0 largemouth bass in submersed vegetation. North American Journal of Fisheries Management. 13:847-851.

Meals, K.O., and L.E. Miranda. 1994. Size-related mortality of tournament-caught largemouth bass. North American Journal of Fisheries Management. 14:460-463.

Miller, S.J., and T. Storck. 1984. Temporal spawning distribution of largemouth bass and young-of-year growth, determined from daily otolith rings. Transactions of the American Fisheries Society. 113:571-578.

Miranda, L.E., and W.D. Hubbard. 1994. Winter survival of age-0 largemouth bass relative to size, predators and shelter. North American Journal of Fisheries Management. 14:790-796.

Miranda, L.E., and W.D. Hubbard. 1994. Length dependent winter survival and lipid composition of age-0 largemouth bass in Bay Springs Reservoir, Mississippi. Transactions of the American Fisheries Society. 123:80-87.

Quinn, S.P. 1989. Recapture rates of voluntarily released largemouth bass. North American Journal of Fisheries Management. 9:86-91.

Raibley, P.T., T.M. O'Hara, K.S. Irons, K.D. Blodgett, and R.E. Sparks. 1997. Notes: Largemouth bass size distributions under varying annual hydrological regimes in the Illinois River. Transactions of the American Fisheries Society. 126:850-856.

Rosenblum, P.M., T.M. Brandt, K.B. Mayes, and P. Hutson. 1994. Annual cycles of growth and reproduction in hatchery-reared Florida largemouth bass, *Micropterus salmoides floridanus,* raised on forage or pelleted diets. Journal of Fish Biology. 44:1045-1059.

Savino, J.F., and R.A. Stein. 1982. Predator-prey interaction between largemouth bass and bluegills as influenced by simulated, submersed vegetation. Transactions of the American Fisheries Society. 111(3):255-266.

Steeger, T.M., J.M. Grizzle, K.Weathers, and M. Newman. 1994. Bacterial diseases and mortality of angler-caught largemouth bass released after tournaments on Walter F. George Reservoir, Alabama-Georgia. North American Journal of Fisheries Management. 14:435-441.

Timmons, T.J., and W.L. Shelton. 1981. Early growth and mortality of largemouth bass in West Point Reservoir, Alabama-Georgia. Transactions of the American Fisheries Society. 110:489-494.

Van Horn, S.L., W.R. Chapman, R.I. Jones, and F.T. McBride. 1986. Effect of creel and minimum size regulations on largemouth bass in North Carolina waters. Federal Aid in Fish Restoration Project F-23-R.

Modeling and Statistical Analysis

Bannerot, S.P., and C.B. Austin. 1983. Using frequency distributions of catch per unit effort to measure fish-stock abundance. Transactions of the American Fisheries Society. 112:608-617.

Bartell, S.M., J.E. Breck, R.H. Gardner, and A.L. Brenkert. 1986. Individual parameter perturbation and error analysis of fish bioenergetics models. Canadian Journal of Fisheries and Aquatic Sciences. 43:160-168.

Beamesderfer, R.C., and B.C. Rieman. 1988. Size selectivity and bias in estimates of population statistics of smallmouth bass, walleye, and northern squawfish in a Columbia River reservoir. North American Journal of Fisheries Management. 8:505-510.

Beauchamp, D.A., D.J. Stewart, and G.L. Thomas. 1989. Corroboration of a bioenergetics model for sockeye salmon. Transactions of the American Fisheries Society. 118:597-607.

Brandt, S.B., D.M. Mason, and E.V. Patrick. 1992. Spatially-explicit models of fish growth rate. Fisheries. 17(2):23-34.

Brandt, S.B., and K.J. Hartman. 1993. Innovative approaches with bioenergetics models: Future applications to fish ecology and management. Transactions of the American Fisheries Society. 122:731-735.

Chen, Y., and J.E. Paloheimo. Robust regression approach to estimating fish mortality rates with a cohort-based model. Transactions of the American Fishery Society. 123:508-518.

Cyr, H., and R.H. Peters. 1996. Biomass-size spectra and the prediction of fish biomass in lakes. Canadian Journal of Fisheries and Aquatic Sciences. 53:994-1006.

Cyterski, M.J., and G.R. Spangler. Development and utilization of a population growth history of Red Lake walleye, *Stizostedion vitreum*. Environmental Biology of fishes. 46:45-59.

Dean, J., and G. Wright. 1992. Black bass length limits by design: A graphic approach. North American Journal of Fisheries Management. 12:538-547.

Edmodson, W.T. 1993. Experiments and quasi-experiments in limnology. Bulletin of Marine Science. 53(1):65-83.

Ellner, S., and P. Turchin. 1995. Chaos in a noisy world: New methods and evidence from time-series analysis. The American Naturalist. 145(3):343-369.

Engstrom-Heg, R. 1986. Interaction of area with catchability indices used in analyzing inland recreational fisheries. Transactions of the American Fisheries Society. 115:818-822.

Goodyear, C.P., and S.W. Christensen. 1984. Bias-elimination in fish population models with stochastic variation in survival of the young. Transactions of the American Fisheries Society. 113:627-632.

Goyke, A.P., and S.B. Brandt. 1993. Spatial models of Salmonine growth rates in Lake Ontario. Transactions of the American Fisheries Society. 122:870-883.

Hansen, M.J., D. Boisclair, S.B. Brandt, S.W. Hewett, J.F. Kitchell, M.C. Lucas, and J.J. Ney. 1993. Applications of bioenergetics models to fish ecology and management: Where do we go from here? Transactions of the American Fisheries Society. 122:1019-1030.

Hartman, K.J., and S.B. Brandt. 1995. Estimating energy density of fish. Transactions of the American Fisheries Society. 124:347-355.

Hartman, K.J., and S.B. Brandt. 1995. Predatory demand and impact of striped bass, bluefish, and weakfish in the Chesapeake Bay: Applications of bioenergetics models. Canadian Journal of Fisheries and Aquatic Sciences. 52:1667-1687.

Hightower, J.E., and R.J. Gilbert. 1984. Using the Jolly-Seber model to estimate population size, mortality, and recruitment for a reservoir fish population. Transactions of the American Fisheries Society. 115:633-641.

Hurlbert, S.H. 1984. Pseudo-replication and the design of ecological field experiments. Ecological Monographs. 54(2):187-211.

Isely, J.J, and J.R. Tomasso. Estimating fish abundance in a large reservoir by Mark-Recapture. North American Journal of Fisheries Management. 18:269-273.

Jensen, A.L. 1984. Logistic surplus-production model with explicit terms for growth, mortality, and recruitment. Transactions of the American Fisheries Society. 113: 617-626.

Johnson, B.L. 1995. Applying computer simulation models as learning tools in fishery management. North American Journal of Fisheries Management. 15:736-747.

Johnston, R.J. 1980. Multivariate Statistical Analysis in Geography. Longman Scientific and Technical. New York, New York.

Kimura, D.K. 1988. Analyzing relative abundance indices with log-linear models. North American Journal of Fisheries Management. 8:175-180.

Lorensen, K. 1996. A simple von Bertalanffy model for density-dependent growth in extensive aquaculture, with an application to common carp (*Cyprinus carpio*). Aquaculture. 142:191-205.

Maceina, M.J. 1997. Simple application of using residuals from catch-curve regressions to assess year-class strength in fish. Fisheries Research. 32:115-121.

Maceina, M.J., P.W. Bettoli, S.D. Finely, and V.J. Di Cenzo. 1998. Analysis of the sauger fishery with simulated effects of a minimum size limit in the Tennessee River of Alabama. North American Journal of Fisheries Management. 18:66-75.

Maceina, M.J., O. Ozen, M.S. Allen, and S.M. Smith. 1998. Use of equilibrium yield models to evaluate length limits for crappies in Weiss Lake, Alabama. North American Journal of Fisheries Management. 18:854-863.

Marwitz, T.D., and W.A. Hubert. 1995. Trends in relative stock density indices of walleye populations in Wyoming reservoirs. Journal of Freshwater Ecology 10(2):177-181.

Mason, D.M., and E.V. Patick. 1993. A model for the space-time dependence of feeding for pelagic fish populations. Transactions of the American Fisheries Society. 122:884-901.

Mason, D.M., and S.B. Brandt. 1996. Effects of spatial scale and foraging efficiency on the predictions made by spatially-explicit models of fish growth rate potential. Environmental Biology of Fishes. 45:283-298.

Mason, M.M., A. Goyke, and S.B. Brandt. 1994. A spatially explicit bioenergetics measure of habitat quality for adult Salmonines: Comparison between Lakes Michigan and Ontario. Canadian Journal of Fisheries and Aquatic Sciences. 52: 1572-1583.

Ney, J.J. 1993. Bioenergetics modeling today: Growing pains on the cutting edge.

Transactions of the American Fisheries Society. 122:736-748.

Otis, D.L., K.P. Burham, G.C. White, and D.R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs. 62:1-135.

Palmer, M.W. 1993. Putting things in even better order: The advantages of canonical correspondence analysis. Ecology. 74(8):2215-2230.

Pollock, K.H. 1982. A capture-recapture design robust to unequal probability of capture. Journal of Wildlife Management. 46(3):752-756.

Pollock, K.H., J.D. Nichols, C. Brownie, and J.E. Hines. 1989. Statistical inference for capture-recapture experiments. Wildlife Monographs. 107:1-97.

Porch, C.E., and W.W. Fox Jr. 1990. Simulating the dynamic trends of fisheries regulated by small daily bag limits. Transactions of the American Fisheries Society. 119:836-849.

Rand, P.S., D.J. Stewart, P.W. Seelbach, M.L. Jones, and L.R. Wedge. 1993. Modeling steelhead population energetics in Lakes Michigan and Ontario. Transactions of the American Fisheries Society. 122:977-1001.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada, Bulletin 191.

Robson, D.S., and H.A. Reiger. 1964. Sample size in Petersen Mark-Recapture experiments. Transactions of the American Fisheries Society. 93(3):215-226.

Rose, K.A., E.S. Rutherford, D.S. McDermont, J.L. Forney, and E.L. Mills. 1999. Individual-based model of yellow perch and walleye populations in Oneida Lake. Ecological Monographs. 69(2):127-154.

Steel, R.G.D., and J.H. Torrie. 1960. Principles and Procedures of Statistics with Special Reference to the Biological Sciences. McGraw-Hill Book Company, Inc. New York.

Trebitz, A., S. Carpenter, P. Cunningham, B. Johnson, R. Lillie, D. Marshall, T. Martin, R. Narf, T. Pellett, S. Stewart, C. Storlie, and J. Unmuth. 1997. A model of bluegill- largemouth interactions in relation to aquatic vegetation and its management. Ecological Modeling. 94:139-156.

Trudel, M., and D. Boisclair. 1994. Seasonal consumption by dace (*Phoniness egos* x *P. neogaeus*): A comparison between field and bioenergetic model estimates. Canadian Journal of Fisheries and Aquatic Sciences. 51:2558-2567.

Vaughan, D.S., and M.L. Burton. 1994. Estimation of Von Bertalanffy growth parameters in the presence of size-selective morality: A simulated example with red grouper. Transactions of the American Fisheries Society. 123(1):1-8.

Walters, C.J., and J.R. Post. 1993. Density-dependent growth and competitive asymmetries in size-structured fish populations: A theoretical model and recommendations for field experiments. Transactions of the American Fisheries Society. 122:34-45.

Willis, D.W. 1987. Use of gill-net data to provide a recruitment index for walleyes. North American Journal of Fisheries Management. 7:591-592.

Xiao, Y. 1994. Growth models with corrections for the retardative effects of tagging. Canadian Journal of Fisheries and Aquatic Sciences. 51:263-267.

Zar, J.H. 1996. Biostatistical Analysis, 3rd Edition. Prentice Hall. Upper Saddle River, New Jersey.

Pollution

Boreman, J. 1997. Methods for comparing the impacts of pollution and fishing on fish populations. Transactions of the American Fisheries Society. 126:506-513.

Fausch, K.D., J. Lyons, J.R. Karr, and P.L. Angermeier. 1990. Fish communities as indicators of environmental degradation. American Fisheries Society Symposium. 8:123-144.

Fjeldsa, J., and J.C. Lovett. 1997. Biodiversity and environmental stability. Biodiversity and Conservation. 6:315-323.

Griswold, B.L., Section Editor. 1997. Special Section. Fisheries and Pollution: A conference overview. Transactions of the American Fisheries Society. 126:504-505.

Lipton, D.W., and I.E. Strand. 1997. Economic effects of pollution in fish habitats. Transactions of the American Fisheries Society. 126:514-518.

Plourde, Y., M. Lucotte, and P. Pichet. 1997. Contribution of suspended particulate matter and zooplankton to MeHg contamination of the food chain in mid-northern Quebec (Canada) reservoirs. Canadian Journal of Fisheries and Aquatic Sciences. 54:821-831.

Rotenone

Gilderhus, P.A., J.L. Allen, and V.K. Dawson. 1986. Persistence of rotenone in ponds at different temperatures. North American Journal of Fisheries Management. 6: 129-130.

Johnson, B.M., R.A. Stein, and R.F. Carline. 1988. Use of a quadrat rotenone technique and bioenergetics modeling to evaluate prey availability to stocked piscivores. Transactions of the American Fisheries Society. 117:127-141.

Sampling Techniques

Fago, D. 1998. Comparison of littoral fish assemblages sampled with a mini-fyke net or with a combination of electrofishing and small-mesh seine in Wisconsin lakes. North American Journal of Fisheries Management. 18:731-738.

Fletcher, D., S. Bonar, B. Bolding, A. Bradbury, and S. Zeylmaker. 1993. Analyzing warm water fish populations in Washington state: Warmwater fish survey manual. Washington Department Wildlife Technical Report.

Graham, R.J. 1992. Visually estimating fish density at artificial structures in Lake Anna, Virginia. North American Journal of Fisheries Management. 12:204-212.

Groves, P.A., and A.P. Garcia. 1998. Two carriers used to suspend an underwater video camera from a boat. North American Journal of Fisheries Management. 18:1004-1007.

Henderson, B.A., and S.J. Nepszy. 1992. Comparison of catches in mono and multifilament gill nets in Lake Erie. North American Journal of Fisheries Management. 12:618-624.

Holland, R.S., and E.J. Peters. 1992. Differential catch by hoop nets of three mesh sizes in the Lower Platte River. North American Journal of Fisheries Management. 12:237-243.

King, T.A., J.C. Williams, W.D. Davies, and W.L. Shelton. 1981. Fixed versus random sampling of fishes in a large reservoir. Transactions of the American Fisheries Society. 110:563-568.

Kissick, L.A. 1993. Comparison of traps lighted by photochemicals or electric bulbs for sampling warmwater populations of young fish. North American Journal of Fisheries Management. 13:864-867.

Krueger, K.L., W.A. Hubert, and R.M. Price. 1998. Tandem-set fyke nets for sampling benthic fishes in lakes. North American Journal of Fisheries Management. 18: 154-160.

Metzer, R.J., and P.L. Shafland. 1986. Use of detonating cord for sampling fish. North American Journal of Fisheries Management. 6:113-118.

Minns, C.K., and D.A. Hurley. 1988. Effects of net length and set time on fish catches in gill nets. North American Journal of Fisheries Management. 8:216-223.

Murphy, Brian R., David W. Willis, editors. 1996. Fisheries Techniques, 2nd Edition. American Fisheries Society, Bethesda, Maryland.

Paller, M.H. 1995. Relationships among number of fish species sampled, reach length surveyed, and sampling effort in South Carolina coastal plain streams. North American Journal of Fisheries Management. 15:110-120.

Peterson, J.T., and C.F. Rabeni. 1995. Optimizing sampling effort for sampling warmwater stream fish communities. North American Journal of Fisheries Management. 15:528-541.

Sammons, S.M., and P.W. Bettoli. 1998. Larval sampling as a fisheries management tool: Early detection of year-class strength. North American Journal of Fisheries Management. 18:137-143.

Spangler, G.R., and J.J. Collins. 1992. Lake Huron fish community structure based on gill-net catches corrected for selectivity and encounter probability. North American Journal of Fisheries Management. 12:585-597.

Wiley, R.W. 1984. A review of sodium cyanide for use in sampling stream fishes. North American Journal of Fisheries Management. 4:249-256.

Smallmouth bass

Barrett, P.J., and O.E. Maughan. 1994. Habitat preferences of introduced smallmouth bass in a central Arizona stream. North American Journal of Fisheries Management. 14:112-118.

Bevelhimer, M.S. 1996. Relative importance of temperature, food, and physical structure to habitat choice by smallmouth bass in laboratory experiments. Transactions of the American Fisheries Society. 125:274-283.

Clapp, D.F., and R.D. Clark Jr. 1989. Hooking mortality of smallmouth bass caught on live minnows and artificial spinners. North American Journal of Fisheries Management. 9:81-85.

Cole, M.B., and J.R. Moring. 1997. Relation of adult size to movements and distribution of smallmouth bass in a central Maine lake. Transactions of the American Fisheries Society. 126:815-821.

Hoff, M.H. 1995. Comparisons of the effects of 10-inch, 8- inch and non-minimum length limits on the smallmouth bass population and the fishery in Nebish Lake, Wisconsin. North American Journal of Fisheries Management. 15:95-102.

Kieffer, J.D., M.R. Kurbacke, F.J.S. Phelan, D.P. Philipp, and B.L. Tufts. 1995. Effects of catch-and-release angling on nesting male smallmouth bass. Transactions of the American Fisheries Society. 124:70-76.

Lyons, J. 1997. Influence of winter starvation on the distribution of smallmouth bass among Wisconsin streams: A bioenergetics modeling assessment. Transactions of the American Fisheries Society. 126:157-162.

Mesa, M.G., S.D. Duke, and D.L. Ward. 1990. Spatial and temporal variation in proportional stock density and relative weight of smallmouth bass in a reservoir. Journal of Freshwater Ecology. 5(3):323-339.

Roell, M.J., and D.J. Orth. 1993. Trophic basis of production of stream dwelling smallmouth bass, rock bass and flathead catfish in relation to invertebrate bait harvest. Transactions of the American Fisheries Society. 122:46-62.

Ross, L.M, J. Savitz, and G. Funk. 1995. Comparison of diets of smallmouth bass (*Micropterus dolomieui*) collected by sport fishing and by electrofishing. Journal of Freshwater Ecology. 10(4):393-398.

Sabo, M.J., and D.J. Orth. 1997. Absence of size-selective mortality among larval smallmouth bass in a Virginia stream. Transactions of the American Fisheries Society. 125:920-924.

Slipke, J.W., M.J. Maceina, V.H. Travnichek, and K.C. Weathers. 1998. Effects of a 356-mm maximum length limit on the population characteristics and sport fishery of smallmouth bass in the shoals reach of the Tennessee River, Alabama. North American Journal of Fisheries Management. 18:76-84.

Walters, J.P, and J.R. Wilson. 1996. Intraspecific habitat segregation by smallmouth bass in the Buffalo River, Arkansas. Transactions of the American Fisheries Society. 125:284-290

Weathers, K.C., and M.B. Bain. 1992. Smallmouth bass in the shoals reach of the Tennessee River: Population characteristics and sport fishery. North American Journal of Fisheries Management. 12:528-537.

Weigman, D.D., J.R. Baylis, and M.H. Hoff. 1997. Male fitness, body size, and timing of reproduction in smallmouth bass, *Micropterus dolomieui*. Ecology. 78(1):111-128.

Tagging

Bernard, D.R., R.P. Marchall, and J.E. Clark. 1988. Planning programs to estimate salmon harvest with coded wire tags. Canadian Journal of Fisheries and Aquatic Sciences. 55:1983-1995.

Dorazio, R.M., K.A. Hattala, C.B. McCollugh, and J.E. Skjeveland. 1994. Tag recovery estimates of migration of striped bass from spawning areas of the Chesapeake Bay. Transactions of the American Fisheries Society. 123:950-963.

Heupel, M.R., C.A. Simpfendorfer, and M.B. Bennett. 1998. Analysis of tissue responses to fin tagging in Australian carcharhinids. Journal of Fish Biology. 52: 610-620.

Myers, R.A., and J.M. Hoenig. 1997. Direct estimates of gear selectivity from multiple tagging experiments. Canadian Journal of Fisheries and Aquatic Sciences. 54:1-9.

Niva, T. 1995. Retention of visible implant tags by juvenile brown trout. Journal of Fish Biology. 46:997-1002.

Smith, C. 1994. Fish tags for observing free-ranging rattlesnakes. Herpetological Review. 25(2):58.

Xiao, Y. 1996. A general model for estimating tag-specific shedding rates and tag interactions from exact or pooled times at liberty for a double tagging experiment. Canadian Journal of Fisheries and Aquatic Sciences. 53:1852-1861.

Xiao, Y. 1996. A framework for evaluating experimental designs for estimating rates of fish movement from tag recoveries. Canadian Journal of Fisheries and Aquatic Sciences. 53:1272-1280.

Walleye

Anderson, C.S. 1998. Partitioning total size selectivity of gill nets for walleye (*Stizostedion vitreum*) into encounter, contact and retention components. Canadian Journal of Fisheries and Aquatic Sciences. 55:1854-1863.

Baccante, D.A., and D.M. Reid. 1988. Fecundity changes in two exploited walleye populations. North American Journal of Fisheries Management. 8:199-209.

Beamesderfer, R.C., and B.C. Rieman. 1991. Abundance and distribution of northern squawfish, walleyes and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society. 120:439-447.

Beard, T.D. Jr., S.W. Hewett, Q. Yang, R.M. King, and S.J. Gilbert. Prediction of angler catch rates based on walleye population density. North American Journal of Fisheries Management. 17:621-627.

Billington, N., R.J. Barrette, and P.D.N. Hebert. 1995. Management implications of mitochondrial DNA variation in walleye stocks. North American Journal of Fisheries Management. 12:276-284.

Billington, N., and R.M. Strange. 1995. Notes. Mitochondrial DNA analysis confirms the existence of a genetically divergent walleye population in northeastern Mississippi. Transactions of the American Fisheries Society. 124:770-776.

Bolding, B., S.A. Bonar, and M. Divens. 1998. Walleye diet in a shallow impoundment: Relative importance of pumpkinseed sunfish and yellow perch. Journal of Freshwater Ecology. 13(1):9-14.

Bryan, S.D., T.D. Hill, S.T. Lynott, and W.G. Duffy. 1995. The influence of changing water levels and temperatures on the food habits of walleye in Lake Oahe, South Dakota. Journal of Freshwater Ecology. 10(1):1-10.

Bulkowski, L., and J.W. Meade. 1983. Changes in phototaxis during early development of walleye. Transactions of the American Fisheries Society. 112:445-447.

Copeland, T., and R.F. Carline. 1998. Overwinter survival and lipid content of walleye fingerlings. North American Journal of Fisheries Management. 18:383-390.

Corbett, B.W., and P.M. Powers. 1986. Spawning and larva drift of sympatric walleyes and white suckers in an Ontario stream. Transactions of the American Fisheries Society. 115:41-46.

Craig, J.F., J.A. Babaluk, S.G. Stevenson, and P.C. Williams. 1995. Variation in growth and reproduction of walleye (*Stizostedion vitreum*) in three Manitoba lakes. Canadian Journal of Zoology. 73:367-372.

Ebbers, M.A., P.J. Colby, and C.A. Lewis. 1988. Walleye-Sauger Bibliography. Minnesota Department of Natural Resources. St. Paul, Minnesota.

Erickson, C.M. 1983. Age determination of Manitoban walleye using otoliths, dorsal spines, and scales. North American Journal of Fisheries Management. 3:176-181.

Fletcher, D.H. 1987. Hooking mortality of walleyes captured in Porcupine Bay, Washington. North American Journal of Fisheries Management. 7:594-596.

Franzin, W.G., and S.M. Harbicht. 1992. Tests of drift samplers for estimating abundance of recently hatched walleye larvae in small rivers. North American Journal of Fisheries Management. 12:396-405.

Hansen, J.H., M.D. Staggs, and M.H. Hoff. 1991. Derivation of safety factors for setting harvest quotas on adult walleyes from past estimates of abundance. Transactions of the American Fisheries Society. 120:620-628.

Hartman, K.J., and F.J. Margraf. 1992. Effects of prey and predator abundances on prey consumption and growth of walleyes in western Lake Erie. Transactions of the American Fisheries Society. 121:245-260.

Hauber, A.B. 1983. Two methods for evaluating fingerling walleye stocking success and natural year class densities in Seven Island Lake, Wisconsin, 1977-1981. North American Journal of Fisheries Management. 3:152-155.

Henderson, B.A., J.L. Wong, and S.J. Nepszy. 1996. Reproduction of walleye in Lake Erie: Allocation of energy. Canadian Journal of Fisheries and Aquatic Sciences. 53:127-133.

Hulsman, P.F., P.M. Powles, and J.M. Gunn. 1983. Mortality of walleye eggs and rainbow trout yolk-sac larvae in low pH waters of the LaCloche Mountain Area, Ontario. Transactions of the American Fisheries Society. 112:680-688.

Isbell, G.L., and M.R. Rawson. 1989. Relations of gill-net catches of walleyes and angler catch rates in Ohio waters of western Lake Erie. North American Journal of Fisheries Management. 9:41-46.

Jennings, M.J., and D.P. Philipp. 1992. Use of allozyme markers to evaluate walleye stocking success. North American Journal of Fisheries Management. 12:285-290.

Jennings, M.J., J.E. Claussen, and D.P. Philipp. 1996. Evidence for heritable preferences for spawning habitat between two walleye populations. Transactions of the American Fisheries Society. 125:978-982.

Johnson, B.L., D.L. Smith, and R.F. Carline. 1988. Habitat preferences, survival, growth, foods and harvests of walleyes and walleye X sauger hybrids. North American Journal of Fisheries Management. 8:292-304.

Johnson, B.M., C. Luecke, R.S. Stewart, M.D. Staggs, S.J. Gilbert, and J.F. Kitchell. 1992. Forecasting effects of harvest regulations and stocking of walleyes on prey fish communities in Lake Mendota, Wisconsin. North American Journal of Fisheries Management. 12:797-807.

Johnson, J.M. 1999. Modeling Walleye Year-Class Strength from Age-0 Catch Rates in Northern Wisconsin Lakes. Thesis. University of Wisconsin, College of Natural Resources. Stevens Point, Wisconsin.

Johnston, T.A., and J.A. Mathias. 1993. Mortality of first-feeding postlarval walleye (*Stizostedion vitreum*) in culture ponds. Canadian Journal of Fisheries and Aquatic Sciences. 50:1835-1843.

Johnston, T.A., and J.A. Mathias. 1994. Feeding ecology of walleye, *Stizostedion vitreum*, larvae: Effects of body size, zooplankton abundance, and zooplankton community composition. Canadian Journal of Fisheries and Aquatic Sciences. 51:2077-2089.

Johnston, T.A., and J.A. Mathias. 1996. Maintenance food requirements and response to short-term food deprivation of walleye larvae. Transactions of the North American Fisheries Society. 125:211-223.

Johnston, T.A., and J.A. Mathias. 1996. Gut evacuation and absorption efficiency of walleye larvae. Journal of Fish Biology. 49(3):375-389.

Jones, M.S., J.P. Goettl Jr., and S.A. Flickinger. 1994. Changes in walleye food habits and growth following a rainbow smelt introduction. North American Journal of Fisheries Management. 14:409-414.

Jude, D.J. 1992. Evidence for natural reproduction by stocked walleyes in the Saginaw River tributary system, Michigan. North American Journal of Fisheries Management. 12:386-395.

Kallemeyn, L.W. 1987. Correlations of regulated lake levels and climatic factors with abundance of young of year walleye and yellow perch in four lakes in Voyageurs National Park. North American Journal of Fisheries Management. 7:513-521.

Kallemeyn, L.W. 1989. Loss of carlin tags from walleyes. North American Journal of Fisheries Management. 9:112-115.

Kershner, M.W., D.M. Schael, R.L. Knight, R.A. Stein, and E.A. Marschall. 1999. Modeling sources of variation for growth and predatory demand of Lake Erie walleye (*Stizostedion vitreum*), 1986-1995. Canadian Journal of Fisheries and Aquatic Sciences. 56:527-538.

Knight, R.L., F.J. Margraf, and R.F. Carline. Piscivory by walleye and yellow perch in western Lake Erie. Transaction of the American Fisheries Society. 113:667-693.

Knight, R.L., and B. Vondracek. 1993. Changes in prey fish populations in western Lake Erie, 1969-88, as related to walleye, *Stizostedion vitreum*, predation. Canadian Journal of Fisheries and Aquatic Sciences. 50:1289-1298.

Kocovsky, P.M. 1999. Dynamics and feeding ecology of the unexploited walleye population of Pymatuning Sanctuary, Pennsylvania, 1997-1998. M.S. Thesis. Pennsylvania State University, The Graduate School College of Agricultural Sciences.

Koppelman, J. B., K.P. Sullivan, and P.J. Jeffries Jr. 1992. Survival of three sizes of genetically marked walleyes stocked into two Missouri impoundments. North American Journal of Fisheries Management. 12:291-298.

LaJeone, L.J., T.W. Bowzer, and D.L. Bergerhouse. 1992. Supplemental stocking of fingerling walleyes in the upper Mississippi River. North American Journal of Fisheries Management. 12:307-312.

Leis, A.L., and M.G. Fox. 1996. Feeding growth and habitat associations of young-of-year walleye (*Stizostedion vitreum*) in a river affected by a mine tailings spill. Canadian Journal of Fisheries and Aquatic Sciences. 53:2408-2417.

Li J., Y. Cohen, D.H. Schupp, I.R. Adelman. 1996. Effects of walleye stocking on population abundance and fish size. North American Journal of Fisheries Management. 16:830-839.

Li, J., Y. Cohen, D.H. Schupp, and I.R. Adelman. 1996. Effects of walleye stocking on year-class strength. North American Journal of Fisheries Management. 16:840-850.

Li, S., and J.A. Mathias. 1982. Causes of high mortality among cultured walleyes. Transactions of the American Fisheries Society. 111:710-721.

Madenjian, C.P., J.T. Tyson, R.L. Knight, M.W. Kershner, and M.J. Hansen. 1996. First-year growth, recruitment and maturity of walleyes in western Lake Erie. Transactions of the American Fisheries Society. 125(6):821-830.

Margenau, T.L., S.T. Schram, and W.H. Blust. 1988. Notes: Lymphocystis in a walleye population. Transactions of the American Fisheries Society. 117:308-310.

Mathias, J.A., and S. Li. 1982. Feeding habits of walleye larvae and juveniles: Comparative laboratory and field studies. Transactions of the American Fisheries Society. 111:722-735.

Mathias, J.A., W.G. Franzin, J.F. Craig, J.A. Babluk, and J.F. Flannagan. 1992. Evaluation of stocking walleye to enhance a commercial fishery in a large, Canadian prairie lake. North American Journal of Fisheries Management. 12:299-306.

Mc Williams, R.H., and J.G. Larscheid. 1992. Assessment of walleye fry and fingerling stocking in the Okoboji Lakes, Iowa. North American Journal of Fisheries Management. 12:329-335.

Mitro, M.G., and D.L. Parrish. 1997. Temporal and spatial abundance of larval walleyes in two tributaries of Lake Champlain. Transactions of the American Fisheries Society. 126:273-287.

Mitzner, L. 1992. Evaluation of walleye fingerling and fry stocking in Rathbun Lake, Iowa. North American Journal of Fisheries Management. 12:321-328.

Mosindy, T.E., W.T. Momot, P.J. Colby. 1987. Impact of angling on the production and yield of mature walleyes and northern pike in a small boreal lake in Ontario. North American Journal of Fisheries Management. 7:493-501.

Muncy, R.J., and A.P. D'Silva. 1981. Marking walleye eggs and fry. Transactions of the American Fisheries Society. 110:300-305.

Munn, M.D., and T.M. Short. 1997. Spatial heterogeneity of mercury bioaccumulation by walleye in Franklin D. Roosevelt Lake and the upper Columbia River, Washington. Transactions of the American Fisheries Society. 126:477-487.

Murphy, B.R., L.A. Nielsen, and B.J. Turner. 1983. Use of genetic tags to evaluate stocking success for reservoir walleyes. Transactions of the American Fisheries Society. 112:457-463.

Muth, K.M., and D.R. Wolfert. 1986. Changes in growth and maturity of walleyes associated with stock rehabilitation in western Lake Erie, 1964-1983. North American Journal of Fisheries Management. 6:168-175.

Nate, N.A. 1999. Predicting walleye (*Stizostedion vitreum*) Presence, Reproduction, and Abundance in Northern Wisconsin Lakes. Thesis. University of Wisconsin. College of Natural Resources. Stevens Point, Wisconsin.

Nate, N.A., M.A. Bozek, M.J. Hansen, and S.W. Hewett. 2000. Variation in walleye abundance with lake size and recruitment source. North American Journal of Fisheries Management. 20:119-126.

Newman, S.P., and M.H. Hoff. 1998. Estimates of loss rates of jaw tags on walleyes. North American Journal of Fisheries Management. 18:202-205.

Nielsen, L.A. 1980. Effect of walleye (*Stizostedion vitreum vitreum*) predation on juvenile mortality and recruitment of yellow perch (*Perca flavescens*) in Oneida Lake, New York. Canadian Journal of Fisheries and Aquatic Sciences. 37:11-19.

Paragamian, V.L. 1989. Seasonal habitat use by walleye in a warmwater river system as determined by radiotelemetry. North American Journal of Fisheries Management. 9:392-401.

Paragamian, V.L., and R. Kingery. 1992. A comparison of walleye fry and fingerling stockings in three rivers in Iowa. North American Journal of Fisheries Management. 12:313-320.

Parrish, D.L., B. Vondracek, and W.J. Eckmayer. 1994. Accuracy and precision of daily age estimates for walleyes from Ohio hatcheries and Lake Erie. Transactions of the American Fisheries Society. 123:601-605.

Payer, R.D., R.B. Pierce, and D.L. Pereira. 1989. Hooking mortality of walleyes caught on live and artificial baits. North American Journal of Fisheries Management. 9: 188-192.

Peterson, M.S., and J.P. Key. 1992. Evaluation of hand-tagging juvenile walleyes with binary-coded wire microtags. North American Journal of Fisheries Management. 12:814-818.

Pitlo, J. Jr. 1989. Walleye spawning habitat in Pool 13 of the upper Mississippi River. North American Journal of Fisheries Management. 9:303-308

Porath, M.T., and E.J. Peters. 1997. Walleye prey selection in Lake McConaughy, Nebraska: A comparison between stomach content analysis and feeding experiments. Journal of Freshwater Ecology. 12(4):511-520.

Porath, M.T., and E.J. Peters. 1997. Use of walleye relative weights (W*r*) to assess prey availability. North American Journal of Fisheries Management. 17:628-637.

Riley, L.M., and R.F. Carline, 1982. Evaluation of scale shape for the identification of walleye stocks from western Lake Erie. Transactions of the American Fisheries Society. 111:736-741.

Ritchie, B.J., and P. J. Colby. 1988. Even-odd year differences in walleye year-class strength related to mayfly production. North American Journal of Fisheries Management. 8:210-215.

Schaefer, W.F. 1989. Hooking mortality of walleyes in a northeastern Ontario lake. North American Journal of Fisheries Management. 9:193-194.

Schlagenhaft, T.W., and B.R. Murphy. 1985. Habitat use and overlap between adult largemouth bass and walleye in a west Texas reservoir. North American Journal of Fisheries Management. 5:465-470.

Serns, S.L. 1982. Influence of various factors on density and growth of age-0 walleyes in Escanaba Lake, Wisconsin, 1958-1980. Transactions of the American Fisheries Society. 111:299-306.

Serns, S.L. 1986. Cohort analysis as an indication of walleye year-class strength in Escanaba Lake, Wisconsin, 1956-1974. Transactions of the American Fisheries Society. 115:849-852.

Serns, S.L., and J.J. Kempinger. 1981. Relationships of angler exploitation to the size age and sex of walleyes in Escanaba Lake, Wisconsin. Transaction of the American Fisheries Society. 110:216-220.

Slipke, J.W. 1997. Food habits of walleye in Shadhill Reservoir, South Dakota. Journal of Freshwater Ecology. 12(1):11-17.

Smith, I.R., A.F. Johnson, D. MacLennan, and H. Manson. 1992. Chemical contaminants, lymphocytis, and dermal sarcoma in walleyes spawning in the Thames River, Ontario. Transactions of the American Fisheries Society. 121: 608-616.

Vandenbyllaardt, L., F.J. Ward, C.R. Brakevelt, and D.B. McIntyre. 1991. Relationships between turbidity, piscivory and development of the retina in juvenile walleyes. Transactions of the American Fisheries Society. 120:382-390.

Wahl, D.H., L.M. Einfalt, and M.L. Hooe. 1995. Effect of experience with piscivory on foraging behavior and growth of walleyes. Transactions of the American Fisheries Society. 124:756-763.

Wiener, J.G., R.E. Martini, T.B. Sheffy, and G.E. Glass. 1990. Factors influencing mercury concentrations in walleyes in northern Wisconsin lakes. Transactions of the American Fisheries Society. 119:862-870.

Willis, D.W., and J.L. Stephen. 1987. Relationships between storage ratio and population density, natural recruitment and stocking success of walleye in Kansas reservoirs. North American Journal of Fisheries Management. 7:270-282.

Zhang, Z., E. Kim, and D. Martineau. 1999. Functional characterization of a piscine retroviral promoter. Journal of General Virology. 80:3065-3072.

Water Quality

Bain, Richard C. Jr., Consulting Engineer, and Moses Lake Irrigation District. 1985. Moses Lake Clean Lake Project Stage 2 Report. Moses Lake Irrigation and Rehabilitation District.

Bain, Richard C. Jr., Consulting Engineer, and Moses Lake Irrigation District. 1987. Moses Lake Clean Lake Project Final Stage 3 Report. Moses Lake Irrigation and Rehabilitation District.

Bain, Richard C. Jr., Consulting Engineer. 1990. Moses Lake Clean Lake Project Irrigation Water Management Final Report. Moses Lake Irrigation and Rehabilitation District.

Bain, Richard C. Jr. 1993. Moses Lake Area Water quality Monitoring Report (1991-1992 Water Year). Moses Lake Irrigation and Rehabilitation District.

Bain, Richard C. Jr. 1998. Moses Lake Area Water quality Monitoring Report (1997 Water Year). Moses Lake Irrigation and Rehabilitation District.

Boyd, C.E. 1990. Water Quality in Ponds for Aquaculture. Birmingham Publishing Co. Birmingham, Alabama. 482 pp.

Brown and Caldwell. 1984. Moses Lake Clean Lake Project Phase 1 Report. Moses Lake Irrigation and Rehabilitation District.

Brown and Caldwell. 1977. Moses Lake Clean Lake Project Pilot study. Moses Lake Irrigation and Rehabilitation District.

Bush, Ronald M., and E.B. Welch. Plankton Associations and Related Factors in a Hypereutrophic Lake. University of Washington Civil Engineering. Seattle.

Campbell, P. 1994. Phosphorous budgets and stoichiometry during the open-water season in two unmanipulated lakes in the experimental lakes area, northwestern Ontario. Canadian Journal of Fisheries and Aquatic Sciences. 51:2739-2755.

Carmichael, G.J., J.R. Tomasso, B.A. Simco, and K.B. Davis. 1984. Confinement and water quality-induced stress in largemouth bass. Transactions of the American Fisheries Society. 113:767-777.

Carlson, K.L, and E.B. Welch. 1983. Evaluation of Moses Lake Dilution: Phase II. Water Resources Series Technical Report No. 80. University of Washington Department of Civil Engineering Environmental Engineering and Science.

Chow-Fraser P., D.O. Trew, D. Findlay, and M. Stainton. 1994. A test of hypotheses to explain the sigmoidal relationship between total phosphorous and chlorophyll a concentrations in Canadian lakes. Canadian Journal of Fisheries and Aquatic Sciences. 51:2052-2065.

Embrey, S.S., and E.K. Block. 1995. Reconnaissance Investigation of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Columbia Basin Project, Washington, 1991-92. U. S. Geological Survey Water- Resources Investigations Report: 95-4007.

Fee, E. J. 1976. The vertical and seasonal distribution of chlorophyll in lakes of the experimental lakes area, northwestern Ontario: Implications for primary production estimates. Limnology and Oceanography. 21(6):767-782.

Fuiman, L.A. 1993. Water Quality and the Early Life Stages of Fishes. American Fisheries Society Symposium 14. Bethesda, Maryland.

Horne, A.J., and C.R. Goldman. 1994. Limnology, Second Edition. McGraw Hill, Inc. United States.

Jensen, H.S., and F. O. Andersen. 1992. Importance of temperature, nitrate and pH for phosphate release from aerobic sediments of four shallow, eutrophic lakes.

Limnology and Oceanography. 37(3):577-589.

Kellogg, R.L., and J.J. Gift. 1983. Relationship between optimum temperatures for growth and preferred temperatures for the young of four fish species. Transactions of the American Fisheries Society. 112:424-430.

Kreeger, D.A., C.E. Goulden, S.S. Kilham, S.G. Lynn, S. Datta, and S.J. Interland. 1997. Seasonal changes in the biochemistry of Lake Seston. Freshwater Biology. 38: 539-554.

Kushlan, J.A. 1981. Sampling characteristics of enclosure fish traps. Transactions of the American Fisheries Society. 110:557-562.

Mc Lellan, H.J. 2000. Limnological and Fisheries Evaluation of Rock Lake. Thesis. Eastern Washington University, Biology Department. Cheney, Washington.

Nurnberg, G.K. 1995. The anoxic factor, a quantitative measure of anoxia and fish species richness in central Ontario lakes. Transactions of the American Fisheries Society. 124:677-686.

Richardson, M.J., F.G. Whoriskey, and L.H. Roy. 1995. Turbidity generation and biological impacts of an exotic fish *Carassius auratus*, introduced into shallow seasonally anoxic ponds. Journal of Fish Biology. 47(4):576-585.

Scheller, R.M., V.M. Snarski, J.G. Eaton, and G.W. Oehlert. 1999. An analysis of the influence of annual thermal variables on the occurrence of fifteen warmwater fishes. Transactions of the American Fisheries Society. 128:257-264.

Schultz, E.J., M.V. Hoyer, and D.E. Canfield Jr. 1999. An index of biotic integrity: A test with limnological and fish data from sixty Florida lakes. Transactions of the American Fisheries Society. 128:564-577.

Shaw, R.D. and E.E. Prepas. 1990. Groundwater-Lake Interactions II: Nearshore seepage patterns and the contribution of ground water to lakes in central Alberta. Journal of Hydrology. 119:121-136.

Stauffer, R. E., and B. D. Wittchen. 1992. Hydrogeochemistry of Maine seepage lakes and related groundwaters. Journal of Hydrology. 138:559-581.

Stefan, H.G., X. Fang, D. Wright, J.G. Eaton and J.H. McCormick. 1995. Simulation of dissolved oxygen profiles in a transparent, dimictic lake. Limnology and Oceanography. 40(1):105-118.

Sylvester, R.O. and R.T. Oglesby. 1964. The Moses Lake Water Environment. University of Washington Civil Engineering. Seattle.

Townley, L.R., and M. R. Davidson. 1988. Definition of a capture zone for shallow water table lakes. Journal of Hydrology. 104:53-76.

WDOE. 1997. Water Quality Standards for Surface Waters of the State of Washington, Ecology edition. Washington Department of Ecology. Chapter 1273-201A WAC.

WDFW. 1993. Final- supplemental Environmental Impact Statement lake and stream rehabilitations-1992-1993. Report Number: 92-14.

Welch, E. B., J. Buckley, and R. M. Bush. 1971. Dilution as a Control for Nuisance Algal Blooms. University of Washington Civil Engineering. Seattle.

Welch, Eugene B., C.A Jones, and R.P Barbiero. 1989. Moses Lake Quality: Results of Dilution, Sewage Diversion and BMPs- 1977 through 1988. Water Resources Series Technical Report No. 118. University of Washington Department of Civil Engineering Environmental Engineering and Science.

Yellow Perch

Anderson, M.R., S.J. Fisher, and D.W. Willis. 1998. Relationship between larval and juvenile yellow perch abundance in eastern South Dakota glacial lakes. North American Journal of Fisheries Management. 18:989-991.

Bronte, C.R., J.H. Selgeby, and D. V. Swedberg. 1993. Dynamics of a yellow perch population in western Lake Superior. North American Journal of Fisheries Management. 13:511-523.

Fisher, S.J., C.R. Pyle, and D.W. Willis. 1999. Habitat use by age-0 yellow perch in two South Dakota glacial lakes. Ecology of Freshwater Fish. 8:85-93.

Hulsmann, S., and T. Mehner. 1997. Predation by underyearling perch (*Perca fluviatilis*) on a *Daphnia galeata* population in a short-term enclosure experiment. Freshwater Biology. 38:209-219.

Kraft, C.E., and B.L. Johnson. 1992. Fyke net and gill-net size selectivities for yellow perch in Green Bay, Lake Michigan. North American Journal of Fisheries Management. 12:230-236.

Mills, E.L., J.L. Confer, and R.C. Ready. 1984. Prey selection by young yellow perch: The influence of capture success, visual acuity, and prey choice. Transactions of the American Fisheries Society. 113:579-587.

Mills, E.L., and J.L. Forney. 1981. Energetics, food consumption and growth of young yellow perch in Oneida Lake, N.Y. Transactions of the American Fisheries Society. 110:479-488.

Mills, E.L., and J.L. Forney. 1983. Impact on *Daphnia pulex* of predation by young yellow perch in Oneida Lake, N.Y. Transactions of the American Fisheries Society. 112:154-161.

Parish, D.L., and F.J. Margraf. 1994. Spatial and temporal patterns of food use by white perch and yellow perch in Lake Erie. Journal of Freshwater Ecology. 6(1):28-35.

Post, J.R., and D.J. McQueen. Variability in first-year growth of yellow perch (*Perca flavescens*): Predictions from a simple model, observations and an experiment. Canadian Journal of Fisheries and Aquatic Sciences. 51:2501-2511.

Shroyer, S.M., and T.S. McComish. 1998. Forecasting abundance of quality-size yellow perch in Indiana water of Lake Michigan. North American Journal of Fisheries Management. 18:19-24.

Willis, D.W., C.S. Guy, and B.R. Murphy. 1991. Development and evaluation of a standard weight (W*s*) equation for yellow perch. North American Journal of Fisheries Management. 11:374-380.

Zooplankton

Achenbach, L., and W. Lampert. 1997. Effects of elevated temperatures on threshold food concentrations and the possible competitive abilities of differently sized cladoceran species. Oikos. 79:469-476.

Adrian, R., and R. Deneke. 1996. Possible impact of mild winters on zooplankton succession in eutrophic lakes of the Atlantic European area. Freshwater Biology. 36:757-770.

Arnott, S.E., J.J. Magnuson, and N.D. Yan. 1998. Crustacean zooplankton species richness: Single- and multiple- year estimates. Canadian Journal of Fisheries and Aquatic Sciences. 55:1573-1582.

Batzer, D.P. 1998. Trophic interactions among detritus, benthic midges, and predatory fish in a freshwater marsh. Ecology. 79(5):1689-8-1698.

Beklioglu, M., and B. Moss. 1995. The impact of pH on interactions among phytoplankton algae, zooplankton and perch (*Perca fluviatilis*) in a shallow fertile lake. Freshwater Biology. 33:497-509.

Boersma, M., and J. Vijverberg. 1994. Seasonal variations in the condition of two *Daphnia* species and their hybrid in a eutrophic lake: Evidence for food limitation. Journal of Plankton Research. 16(12):1793-1809.

Bremigan, M.T., and R.A. Stein. 1994. Gape-dependent Larval foraging and zooplankton size: Implication for fish recruitment across systems. Canadian Journal of Fisheries and Aquatic Sciences. 51: 913-922.

Bukaveckas, P., and W. Shaw. 1998. Phytoplankton responses to nutrient and grazer manipulations among northeastern lakes of varying pH. Canadian Journal of Fisheries and Aquatic Sciences. 55:958-966.

Carpenter, S.R., J.F. Kitchell, K.L. Cottingham, D.E. Schindler, D.L. Christensen, D.M. Post, and N. Voichick. 1996. Chlorophyll variability, nutrient input, and grazing: Evidence from whole-lake experiments. Ecology. 77(3):725-735.

Carrillo, P., I. Reche, and L. Cruz-Pizarro. 1996. Intraspecific stoichiometric variability and the ratio of nitrogen to phosphorus resupplied by zooplankton. Freshwater Biology. 36:363-374.

Chen, C.Y., and C.L. Folt. 1996. Consequences of fall warming for zooplankton overwintering success. Limnology and Oceanography. 41(5): 1077-1086.

Cyr, H. 1998. Cladoceran and copepod-dominated zooplankton communities graze at similar rates in low-productivity lakes. Canadian Journal of Fisheries and Aquatic Sciences. 55:414-422.

Cyr, H., J.A. Downing, and R.H. Peters. 1997. Density-body size relationships in local aquatic communities. Oikos. 79:333-346.

De Stasio, B.T. Jr. 1993. Diel vertical and horizontal migration by zooplankton: Population budgets and the diurnal deficit. Bulletin of Marine Sciences. 53(1): 44-64.

Elert, E. V. and C. J. Loose. 1996. Predator-induced diel vertical migration in *Daphnia*: Enrichment and preliminary chemical characterization of a kairomone exuded by fish. Journal of Chemical Ecology. 22(5):885-895.

Epp, G.T. 1996. Grazing on filamentous cyanobacteria by *Daphnia pulicaria*. Limnology and Oceanography. Notes. 41(3):560-567.

Evans, M.S., M.T. Arts, and R.D. Robarts. 1996. Algal productivity, algal biomass, and zooplankton biomass in a phosphorous-rich, saline lake: Deviations from regression model predictions. Canadian Journal of Fisheries and Aquatic Sciences. 53:1048-1060.

France, R., N. Yan, P. Olesiuk, R. Nero, and P.A. Del Giorgios. 1995. Secondary analysis of relationships between pelagic invertebrate predators and phytoplankton abundance and water clarity. Freshwater Biology. 34:255-261.

Gessner, F. 1948. The vertical distribution of phytoplankton and the thermocline. Ecology. 29(2):386-389.

Ghan D., J.D. McPhail, and K.D. Hyatt. 1998. The temporal-spatial pattern of vertical migration by the freshwater copepod *Skistodiaptomus oregonensis* relative to predation risk. Canadian Journal of Fisheries and Aquatic Sciences. 55:1350-1363.

Giorgio, P.A.D., and J.M. Gasol. 1995. Biomass distribution in freshwater plankton communities. The America Naturalist. 146(1):135-152.

Green, J. 1956. Growth, size and reproduction in *Daphnia* (*Crustacea*: *Cladocera*). Proceedings of the Zoological Society of London. 126(Part 2):173-203.

Greene, C.H. 1990. A brief review and critique of zooplankton sampling methods: copepodology for the larval ecologist. Ophelia. 32(1-2):109-113.

Havens, K.E., T.L. East, and J.B. Beaver. 1996. Experimental studies of zooplankton-phytoplankton-nutrient interactions in a large subtropical lake (Lake Okeechobee, Florida U.S.A.). Freshwater Biology. 36:579-597.

Hebert, P.D.N., and T.L. Finston. 1997. A taxonomic reevaluation of North American *Daphnia* (*Crustacea*: *Cladocera*). The *D. catawba* complex. Canadian Journal of Zoology. 75:1254-1261.

Hessen, D.H., F. A. Bjorn, and T. Andersen. 1995. Replacement of herbivore zooplankton species along gradients of ecosystem productivity and fish predation pressure. Canadian Journal of Fisheries and Aquatic Sciences. 52:733-742.

Hu, S.S., and A.J. Tessier. 1995. Seasonal succession and the strength of intra and interspecific competition in a *Daphnia* assemblage. Ecology. 76(7):2278-2294.

Kerfoot, W.C. 1977. Competition in cladoceran communities: The cost of evolving defenses against copepod predation. Ecology. 58:303-313.

Kilham, S.S., D.A. Kreeger, C.E. Goulden, and S.G. Lynn. 1997. Effects of algal food quality on fecundity and population growth rates of *Daphnia*. Freshwater Biology. 38:639-647.

Kiorboe, T. 1989. Phytoplankton growth rate and nitrogen content: Implications for feeding and fecundity in a herbivorous copepod. Marine Ecology Progress Series. 55:229-234.

Kolar, C.S., and D.H. Wahl. 1998. Daphnid morphology deters fish predators. Oecologia. 116: 556-564.

Lauridsen, T.L. 1996. Avoidance by *Daphnia magna* of fish and macrophytes: Chemical cues and predator-mediated use of macrophyte habitat. Limnology and Oceanography. Notes. 41(4):794-798.

Limburg, K.E., M.L. Pace, D. Fischer, and K.K. Arend. 1997. Consumption, selectivity, and use of zooplankton by larval striped bass and white perch in a seasonally pulsed estuary. Transactions of the American Fisheries Society. 126:607-621.

Lin, W., P.X. Mang Dai, and J. Wang. 1997. Effects of silver carp density on zooplankton and water quality: Implications for eutrophic lakes in China. Journal of Freshwater Ecology. 12(3):437-444.

Lott, J.P., D.W. Willis, and D.O. Lucchehesi. 1998. Zooplankton structural indices as indicators of yellow perch population characteristics. The Prairie Naturalist. 30(2):111-121.

Lougheed, V.L., and P. Chow-Fraser. 1998. Factors that regulate the zooplankton community structure of a turbid, hypereutrophic Great Lakes wetland. Canadian Journal of Fisheries and Aquatic Sciences. 55:150-161.

Lougheed, V.L., B. Crosbie, and P. Chow-Fraser. 1998. Predictions on the effect of common carp (*Cyprinus carpio*) exclusion on water quality, zooplankton, and submergent macrophytes in a Great Lakes wetland. Canadian Journal of Fisheries and Aquatic Sciences. 55:1189-1197.

Luecke, C., and D. Brandt. 1993. Estimating the energy density of daphnid prey for use with rainbow trout bioenergetics models. Transactions of the American Fisheries Society. 122:386-389.

Lurling, M., and E. Van Donk. Life history consequences for *Daphnia pulex* feeding on nutrient limited phytoplankton. Freshwater Biology. 38:693-709.

Mazumder, A. 1994. Phosphorous-chlorophyll relationships under contrasting zooplankton community structure: Potential mechanisms. Canadian Journal of Fisheries and Aquatic Sciences. 55:150-161.

Megard, R.O, M.M. Kuns, M.C. Whiteside, and J.A. Downing. Spatial distributions of zooplankton during coastal upwelling in western Lake Superior. Limnology and Oceanography. 42(5):827-840.

Moloney, C.L., and M.J. Gibbons. 1996. Sampling and analysis of gut contents in relation to environmental variability and diel vertical migration by herbivorous zooplankton. Journal of Plankton Research. 18(9):1535-1556.

Moore, M.V., N.D. Yan, and T. Pawson. 1994. Omnivory of the larval phantom midge (*Chaoborus* spp.) and its potential significance for freshwater planktonic food webs. Canadian Journal of Zoology. 72:2055-2065.

Musaeva, E.I., and N.P. Nezlin. 1996. Comparison of various zooplankton sampling tools based on catches in the Bering Sea. Oceanology. 35(6):857-861.

Pace, M.L., and D. Value. 1994. The importance of *Daphnia* in determining mortality rates of protozoans and rotifers in lakes. Limnology and Oceanography. 39(5):
985-996.

Patalas, K., and A. Salki. 1993. Spatial variation of crustacean plankton in lakes of different size. Canadian Journal of Fisheries and Aquatic Sciences. 50:2626-2640.

Pijanowska, J. 1997. Alarm signals in *Daphnia*? Oecologia. 112:12-16.

Repka, S. 1998. Effects of food type on the life history of *Daphnia* clones from lakes differing in trophic state. II. *Daphnia cucullata* feeding on mixed diets. Freshwater Biology. 38:685-692.

Rodriguez, M.A., P. Magnan, and S. Lacasse. 1993. Fish species composition and lake abiotic variables in relation to the abundance and size structure of *Cladoceran* zooplankton. Canadian Journal of Fisheries and Aquatic Sciences. 50:638-647.

Rosen, R.A. 1981. Length-dry weight relationships of some freshwater zooplankton. Journal of Freshwater Ecology. 1(2):225-229.

Scheffer, M., S. Rinaldi, Y.A. Kuznetsov, and E. H. Van Nes. 1997. Seasonal dynamics of *Daphnia* and algae explained as a periodically forced predator-prey system. Oikos. 80:519-532.

Schindler, E.U., E.R. DeBruyn, E.J. Fee, and J.A. Shearer. 1994. Sensitivity of estimates of seasonal phytoplankton photosynthesis to sampling frequency. Canadian Journal of Fisheries and Aquatic Sciences. 51:2734-2738

Schriver, P., J. Bogestrand, E. Jeppesen, and M. Sondergaard. 1995. Impact of submerged macrophytes on fish-zooplankton-phytoplankton interactions: Large-scale enclosure experiments in a shallow eutrophic lake. Freshwater Biology. 33:255-270.

Shuter, B.J., and K.K. Ing. 1997. Factors affecting the production of zooplankton in lakes. Canadian Journal of Fisheries and Aquatic Sciences. 54:359-377.

Stemberger, R.S., and J. M. Lazorchak. 1994. Zooplankton assemblage response to disturbance gradients. Canadian Journal of Fisheries and Aquatic Sciences. 51: 2435-2447.

Stockwell, J.D., and O.E. Johannsson. 1997. Temperature-dependent allometric models to estimate zooplankton production in temperate freshwater lakes. Canadian Journal of Fisheries and Aquatic Sciences. 54:2350-2360.

Stockwell, J.D., K.L. Bonfantine, and B.M. Johnson. 1999. Kokanee foraging: A *Daphnia* in the stomach is worth two in the lake. Transactions of the American Fisheries Society. 128:169-174.

Tilzer, M.M. 1973. Diurnal periodicity in the phytoplankton assemblage of a high mountain lake. Limnology and Oceanography. 18(1):15-29.

Vanni, M.J., and G.D. Layne. 1997. Nutrient recycling and herbivory as mechanisms in the top-down effect of fish on algae in lakes. Ecology. 78(1):21-40.

Vanni, M.J., G.D. Layne, and S.E. Arnott. 1997. Top-down trophic interactions in lakes: Effects on nutrient dynamics. Ecology. 78(1):1-20.

Vezina, A.F. 1994. An inverse model analysis of planktonic food webs in experimental lakes. Canadian Journal of Fisheries and Aquatic Sciences. 51:2034-2044.

Vijverberg, J., D.F. Kalf, and M. Boersma. 1996. Decrease in *Daphnia* egg viability at elevated pH. Limnology and Oceanography. Notes. 41(4):789-794.

Westerlund, J.E., P.C. Jacobsen, H.K. Van Offelen, and J.K. Hirsch. 1998. Use of limnetic zooplankton sampling in assessments of fish community structure in Minnesota bass-panfish lakes. Minnesota Department of Natural Resources, Investigational Report 467.

Wright, D.I., W.J. O'Brien, and C. Luecke. 1983. A new estimate of zooplankton retention by gill rakers and its ecological significance. Transactions of the American Fisheries Society. 112:638-646.

Yan, N.D., W. Keller, K.M. Somers, T.W. Pawson, and R.E. Girard. 1996. Recovery of crustacean zooplankton communities from acid and metal contamination: Comparing manipulated and reference lakes. Canadian Journal of Fisheries and Aquatic Sciences. 53:1301-1327.