EFFECTS OF PUMPED STORAGE PROJECT OPERATIONS ON THE SPAWNING SUCCESS OF CENTRARCHID FISHES IN LEESVILLE LAKE, VIRGINIA

by

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INTRODUCTION

Pumped storage projects are an economical means of producing large amounts of electrical power from relatively small water supplies by recycling the water through the turbines. Pumped storage electrical power projects in the United States are becoming an important part of many power networks as a means of producing peaking power. Prior to pumped storage projects, peak power demands were met by run-of-the-river hydroelectric facilities and older less efficient fossil fueled steamplants (Hauck and Edson 1973). The concept of producing peak power by pumped storage facilities originated in the early 20th century in Germany (Estes 1971); however, pumped storage power generation was not considered feasible in the United States until development of a turbine that could also be reversed to pump water from the lower to the upper reservoir. Since then, pumped storage projects have become increasingly common. Currently, there are 22 pumped storage projects in operation in the United States, ten more under construction and 21 projects in the planning stages (Hauck and Edson 1973). More than 1,000 potential pumped storage project sites have been identified by power companies in the United States.

Three general types of pumped storage projects are recognized (Reynolds 1966).

1. Pumped storage in combination with conventional hydroelectric production employing two reservoirs on a large river.
2. Pure pumped storage utilizing two reservoirs with negligible inflow.
3. Pumped storage with water diversion facilities for irrigation purposes or low flow augmentation.

Recently, a fourth type of pumped storage project employing a single dam on a large river has been constructed. In this type of project, the river below the dam serves the same function as the lower reservoir in a combination pumped storage project.

The operations of all pumped storage projects are similar. Water stored in the upper reservoir is used for power generation. All turbines can be used to produce electrical power during peak electrical demand periods, generally in the morning and evening hours. The water used for power generation gradually fills the lower reservoir and lowers the water level of the upper reservoir. During low power demand periods, when excess electrical power is available from base power production facilities the reversible turbines are used to pump water from the lower to the upper reservoir. Consequently, the upper reservoir is refilled while the lower reservoir is drawn down. Pumping usually occurs each night and to a major extent on weekends when overall power consumption is reduced. The volume of water pumped to the upper reservoir at night usually does not equal the amount of water used for power generation during the day. As the weekend approaches the lower reservoir gradually fills to near maximum capacity. Then on the weekend, the water storage in the upper reservoir is returned to capacity by water pumped from the lower reservoir. Thus the lower reservoir reaches its lowest water level of the week late Sunday or early Monday in preparation for the week's power demands.

The Appalachian Power Company's Smith Mountain pumped storage project in southcentral Virginia was the first combined project completed in the United States. Two main stream reservoirs were impounded; an upper lake formed by Smith Mountain Dam and immediately downstream, Leesville Lake formed by Leesville Dam. The Smith Mountain project has been fully operational since 1965 and has served as a data base for prediction of physical and chemical parameters for other pumped storage projects (Reynolds 1966, Chen and Orlob 1972). Detailed descriptions of the engineering aspects and operations of the Smith Mountain Project are given by Reynolds (1966) and Estes (1971).

Normal power production operations at the Smith Mountain Power Plant result in water level fluctuations of less than 1 m in Smith Mountain Lake and some minor localized temperature changes near Smith Mountain Dam (Simmons and Neff 1969). However in Leesville Lake, weekly water level fluctuations of as much as 4 m often occur during spring and summer. Maximum fluctuations coincide with occasional daily fluctuations to 3.5 m. The frequency and magnitude of water level fluctuations in Leesville Lake depend on the degree of peak electrical power demands and amount of rainfall within the watershed.

Water temperatures fluctuate daily in upper Leesville Lake as a result of the generating and pumping operations of the turbines at Smith Mountain Dam. Estes and Cumming (1969) indicated water temperatures may fluctuate as much as 13.9 C, in upper Leesville Lake near Smith Mountain Dam, when generating operations followed pumping from Leesville to Smith Mountain Lake. During pumping and generating operations at the Smith Mountain Power Plant, water exchanges between Leesville and Smith Mountain Lake also create flow reversals and high water velocities in the upper portion of Leesville Lake.

Most centrarchid fishes spawn in shallow, relatively stable environments of lakes and ponds when water temperatures reach favorable levels. Centrarchid fishes in pumped storage reservoirs, however, are subjected to water level fluctuations, rapid temperature changes and flow reversals with concomitant high water velocities during the spawning season. Fluctuating water levels have been shown to adversely affect the spawning success of centrarchid fishes by causing nest abandonment, resulting in indirect mortality from siltation, hypoxia, and predation and by exposing nests to desiccation (Anonymous 1975, Kimsey 1957, Parsons 1957, Patriarche 1952). Decreasing water temperatures have also been shown to reduce spawning success of centrarchid fishes by also causing nest abandonment (Emig 1965, Bennett 1965, Neves 1975) or direct temperature related mortality to eggs and fry (Kelly 1968, Makamura 1971).

Members of the Centrarchidae family are generally associated with lacustrine systems, consequently, little data are available regarding the effects of flow reversals and/or high water velocities on spawning of centrarchid fishes. Available data suggest that centrarchid fishes avoid moving waters for spawning. Surber (1943) reported that smallmouth bass (Micropterus dolomieui) spawning nests in lotic systems were located in areas of little perceptible current, even though smallmouth bass commonly inhabit streams and rivers. Breder (1936) found that sunfish (Lepomis sp.) nests in some New York streams were confined to areas sheltered from the current. These studies strongly suggest that the physical conditions in pumped storage reservoirs of fluctuating water levels and temperatures and flow reversals with high water velocities could significantly affect the spawning success of centrarchid fishes.

The few studies that have examined the spawning of centrarchid fishes in pumped storage reservoirs indicate that successful spawning of centrarchids does occur. Baren (1971) in a pond simulation of the proposed Yards Creek Pumped Storage Project reported that centrarchid fishes successfully spawned when exposed to about 1 m water level fluctuations during the spawning season. Fluctuations to about 1.7 m exposed some nests although production of juvenile centrarchids in ponds subjected to water level fluctuations was similar to production in a control pond. Based on the occurrence of year class frequency in rotenone cove samples, Estes (1971) concluded that spawning of largemouth bass (M. salmoides) and bluegill (L. macrochirus) had occurred in Leesville Lake since 1965 when full power operations commenced. He concluded that little adverse effect on spawning of centrarchid fishes in Leesville Lake could be attributed to power production operations from the Smith Mountain Power Plant. However, Estes suggested that most of the reproduction of centrarchid fishes occurred in the lower warmer section of Leesville Lake.

Due to the paucity of specific data on spawning success of centrarchid fishes in pumped storage reservoirs, this study was designed with the following objectives:

(1) to determine the spawning season for largemouth bass and sunfish (Lepomis sp.) in Leesville Lake;

(2) to determine water temperature regimes, dissolved oxygen concentrations, water level fluctuations and water velocities at spawning sites during the spawning season for centrarchid fishes in Leesville Lake;

(3) to document the vertical and horizontal distribution of

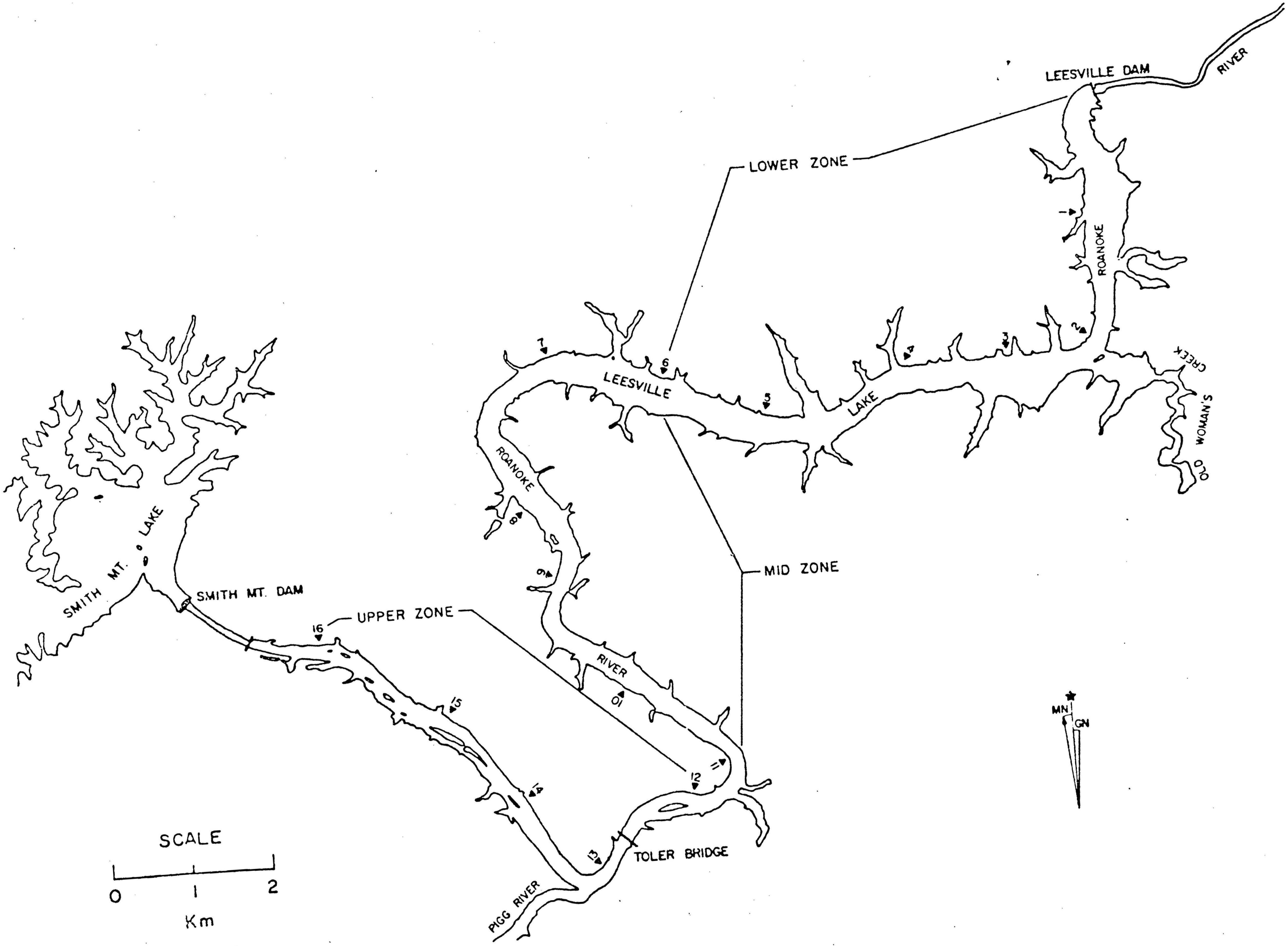
centrarchid spawning nests, and relate the location of spawning sites with extant physical conditions in Leesville Lake during the spawning season; and

(4) to quantify spawning success for bluegill and develop a mathematical computer implemented model to predict the probability of spawning success of centrarchid fishes in Leesville Lake.

STUDY AREA

Leesville Lake, a 1376 ha reservoir, located in Campbell, Bedford, and Pittsylvania counties, Virginia, is approximately 26 km long (Fig. 1). Markers placed along the shoreline for navigational aides were used as station markers. Water temperature data collected by Estes (1971) suggested that three discrete reservoir zones existed in Leesville Lake; a lower zone from the forebay area of Leesville Dam to navigational Marker 6 (8.8 km), a mid-reservoir mixing zone of about 7.9 km from Marker 6 to Marker 11, and an upper reservoir zone of 9.2 km from Marker 11 to Smith Mountain Dam (Fig. 1). The lower reservoir zone is the widest (about 800 m) and deepest (maximum 30 m) portion of Leesville Lake and has the greatest number of coves. The lake in the mid-reservoir zone is narrower (about 500 m wide), shallower (22 m deep), and has several small coves. The upper reservoir zone, about 300 m wide and 18 m deep resembles a large river. Few small coves occur in the upper zone and the largest tributary, the Pigg River, enters near Marker 13. Bottom growths of Potamogeton crispus are localized in the upper reservoir zone. Macrophytes were not observed in any other areas of Leesville Lake.

Fig. 1. Leesville Lake, the lower impoundment of the Smith Mountain Pumped Storage Project in southcentral Virginia. Numbers indicate navigational markers positioned along the shoreline used as station markers.


LEESVILLE DAM
RIVER
LOWER ZONE
ROANOKE
CREEK
OLD WOMAN'S
LEESVILLE
LAKE
ROANOKE
RIVER
MID ZONE
SMITH MT. LAKE
SMITH MT. DAM
UPPER ZONE
TOLER BRIDGE
PIGG RIVER
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
SCALE
0
1
2
Km
MN
GN

METHODS

Limnological

Water temperature (C) and dissolved oxygen (mg/l) profiles were measured using a Precision Scientific Company oxygen analyzer and thermistor at even numbered markers in the median of the lake. Temperature and oxygen measurements were taken from surface to bottom at 0.6 m depth intervals, generally at semimonthly intervals from May through August 1972, 1973, and 1974. The oxygen probe was calibrated using the Azide modification of the Winkler method of the Hach Kit (nearest 0.2 mg/l) prior to taking dissolved oxygen profiles. Some dissolved oxygen measurements were taken by the modified Winkler method using a Hach Kit during 1974.

Ryan thermographs were used to obtain continuous temperature recordings at selected locations along the main Leesville Lake and coves from May through August 1973 and 1974. Thermographs were positioned from 1.0 to 1.5 m below minimum pool level (182.9 m). Temperatures were recorded (C) on continuous recording tapes. Weekly temperature means and ranges were calculated from mean daily temperatures and are presented graphically.

Water temperatures at the Smith Mountain Dam tailrace and hourly water elevations of Leesville Lake were obtained from records maintained by Appalachian Power Company. Weekly mean temperatures were calculated from hourly temperature records during periods of power generation from May through August 1972, 1973, and 1974. Daily ranges of water elevations were also collected for the same time period during generating and pumping operations.

Water transparency measurements (cm) using a secchi disk were made in the lower, mid, and upper reservoir zones from May through August 1972, 1973, and 1974 (except May 1972). Readings were taken at the same stations as those used for water temperature and dissolved oxygen analysis. Mean monthly water transparency measurements for each reservoir zone were calculated from measurements taken at stations within a respective lake zone.

Surface water velocities during generating and pumping operations were measured about 0.5 and 1 m from the shoreline when Leesville Lake was near minimum pool level with a Gurley current meter and the float method using an orange (Chow 1964). Distances used to time the float averaged 50 m. The float method was used only when boating activities were absent and air movement was negligible.

Fish Collecting and Processing

Fish collections for gonadal development studies were made by electrofishing from a boat along the shoreline at night. Collections were made in each of the three reservoir zones from May through September 1972, and May through August 1974. Reference collections of fish gonadal development were made in April 1972 and 1974 in the lower reservoir zone. The reservoir zone sampled first on a sampling night was randomly selected, however, due to the proximity of a launching ramp between mid and upper reservoir zones, collections in these areas were made in sequence. A 15 min "current on" fishing effort was generally used in each zone. Occasionally, 20 min sampling efforts were used in all zones when few fish were collected during the first 15 minutes. All centrarchids captured were placed in plastic bags and iced for transport.

At the laboratory, fishes were kept iced until dissected (within 12 hours). Total length (mm) and weight (g) were measured, gonads were excised, and stage of maturity assessed by a modification of Ricker (1968): Stage I-Immature; Stage II-Developing; Stage III-Gravid and Spawning; Stage IV-Spent. Gonads were weighed to the nearest mg and gonad weights expressed as a percent of body weight for all adult fish. This value is the gonosomatic index (GSI) of Kaya and Hasler (1972). GSIs were compared between fish from each reservoir zone. The nonparametric Kruskal-Wallis test was used because of heterogeneous variances of GSIs. Median values of GSIs for fish from the three reservoir zones were compared by multiple comparisons based on Kruskal-Wallis rank sums when significance was determined (Hollander and Wolfe 1973).

Natural Reproduction

Artificial Spawning Substrates

Artificial spawning substrates were positioned in suspected spawning areas of each reservoir zone to check on spawning success. Spawning substrates were placed in a continuous mat from 1 m below maximum to 2 to 3 m below minimum water level elevation. Four rolls of rubberized hogs hair matting, 15.5 m x 0.6 m x 5.2 cm, were extended along the lake bottom perpendicular to the shoreline in each zone and anchored with stones. Five artificial concrete nests with a 26 cm diameter and a 3 cm depression interconnected by nylon line were positioned at about 3 to 4 m intervals depending on the gradient of the shoreline parallel to the matting. Three artificial nests were located above minimum pool level and two were located below this level. A total of 20 nests were placed, 5 at each of 4 suspected spawning sites, in each reservoir zone. Site selection for the positioning of artificial spawning substrates was based on reduced water velocities, hard bottom substrates, and general inaccessibility to the public.

Artificial spawning substrates were checked for signs of spawning by divers (trained fisheries scientists) at three day intervals early in the spawning season and at weekly intervals during the remainder of the spawning season. An underwater light to aid visual inspection of the spawning substrates was occasionally used when turbidity reduced visibility. Spawning nests and portions of matting above the extant water level were checked by a trained observer from the shoreline. Presence of a centrarchid fish on a cleaned area of the artificial spawning substrate defending a territory with or without eggs was included in calculating an index of the depth of spawning. Spawning activities were recorded relative to depth and extant water elevations.

Natural Spawning Areas

Other shoreline areas of the main lake and coves were systematically checked from the shoreline to about 3 m below minimum pool elevation by trained divers to document the occurrence of natural spawning. Occasionally shoreline areas were checked for spawning sites from a boat. These observations were only made when water elevations were low (182.9 m) and visibility was good (>2 m). Polaroid glasses were used to reduce surface glare. All spawning nests located were examined. Condition of natural spawning nests was recorded as inactive (nests silted), active (without silt), active with eggs and/or fry, and active with dead fry or eggs. Depth of nest construction was determined by measuring the elevation of spawning nests relative to the extant water level and by comparison with hourly water elevation records.

Spawning areas for largemouth bass were determined by locating spawning nests or collections of broods of bass fingerlings similar to procedures used by Kramer (1961). Samples of fingerlings were collected by dip net, preserved in formalin and measured in the laboratory to the nearest 0.1 m by vernier calipers. Estimates of the spawning dates were made by comparing size of specimens with size of known age fry.

Spawning Success

Field Samples

Estimates of spawning success of bluegill were made by sampling natural bluegill nests containing eggs or recently hatched non-motile fry, and by laboratory incubation tests under controlled constant temperature conditions. Bluegill larvae from natural nests were siphoned using a glass tube 1.25 cm inner diameter. This method of collection is similar to methods used to collect bass fry from natural nests by Kramer (1961) and Surber (1943). Fry captured were placed in a 3 l capacity jar containing 5 percent formalin. The nesting substrate was then stirred with the end of the glass tube to maximize collection efficiency. After several siphon samples were consecutively unsuccessful in collecting more fry, the nesting substrate was scooped into the sample jar with the fry. Spawning nest samples were processed in the laboratory by screening samples with a number 30 sieve of 600 mu. All material passing through the sieve was examined microscopically for the presence of eggs or fry. Small amounts of material retained in the sieve were distributed on a white pan sectioned with dark lines. The bottom of the pan was covered with about 3 mm of water and examined for fry and eggs under an illuminated magnifying glass. Bluegill fry, and dead eggs (determined by their opaque appearance and were usually covered by fungus) were counted in all sections of the pan. Spawning success estimates were determined from the ratio of the numbers of viable fry and eggs to the total number of fry and eggs.

Ages of sunfish fry from natural nest samples were determined by comparing their lengths with lengths of known age specimens from temperature controlled laboratory hatching tests. Total lengths of random samples of fry were measured by an ocular micrometer to the nearest 0.01 mm.

Controlled Temperature Tests

A second method of estimating spawning success was made in the laboratory by hatching bluegill eggs over a range of constant water temperatures. Gravid bluegills were collected from two local farm ponds and from Smith Mountain and Leesville Lakes by seining and trapping. The fish were transported to the laboratory and artificially spawned in a stainless steel pan following methods employed by Banner and Van Arman (1973). Eggs and milt were carefully stirred together using a feather. The fertilized eggs were allowed to water harden for about 2 hr. Test lots of one hundred eggs were then placed into glass hatching jars containing dechlorinated water at room temperature (24 C).

Naturally spawned and fertilized eggs were also used for hatching success estimates. Eggs from bluegill or largemouth bass nests were removed with the spawning substrate and placed in 1 l jars with lake water. Most naturally spawned and fertilized eggs were collected at Smith Mountain and Leesville Lakes. Jars with eggs were immediately placed into a cooler. Water temperatures were slowly decreased with ice to about 18 C to retard egg development, and transported to the laboratory. Viable eggs were counted while attached to the spawning substrate and placed in glass hatching containers. Seven replicate lots of about 100 eggs each were used from each nest. In order to minimize handling, substrates containing a few more or a few less than 100 eggs were occasionally used. The average test lot size was 105 eggs.

A total of 13 hatching success tests using artificially and naturally spawned and fertilized bluegill eggs were conducted at each of the test temperatures of 16, 18, 20, 22, 24, 26, and 28 C. Two hatching success tests were run at each test temperature of 16, 20, 24, and 26 C using naturally spawned largemouth bass eggs. Hatching jars were placed into constant temperature water baths with air stones to prevent hypoxia. Temperature variation in water baths was generally less than 0.5 C. Checks on the rate of hatching and water temperatures were made three times daily. Initial attempts to remove single dead eggs were abandoned to reduce handling, consequently, only groups of dead eggs were removed. Once hatching was completed, the percentage hatching success was determined by counting individual larvae removed with an eye dropper. Estimates of hatching success were made from the ratio of fry to the total number of eggs in each container and expressed as a percentage relative to the maximum percentage success of hatching for a single test lot of eggs following Banner and Van Arman (1973).

A Friedman's test, the nonparametric analog of the two-way analysis of variance, was used to determine treatment effects of hatching temperatures. Multiple comparisons based on the rank sums for each treatment were used to isolate temperature effects on egg success.

Exposure to Air Tests

Since some nests are occasionally exposed to air during periodic water cycling operations, tests to determine tolerance of bluegill and largemouth bass eggs to exposure to air were conducted using two methods; laboratory controlled exposure to air during night and daytime hours, and observing hatching eggs naturally exposed by drawdown in Leesville Lake. Naturally spawned and fertilized eggs for laboratory exposure tests were collected and transported in a manner similar to the eggs used for temperature tests as described above. In the laboratory, about 100 eggs attached to spawning substrates were counted and placed in concrete nests. Natural nest materials such as wet leaves were used as a test substrate for unattached eggs. A slight amount of water was sprayed on each nest depression and eggs to simulate natural drawdowns in Leesville. Concrete nests were placed in sun or shade for time periods of 30 min to 10 hr. Two initial air exposure tests using largemouth bass eggs were also conducted in dark indoor chambers at 22 C for 2 and 4 hr exposures. Following these controlled exposure times, spawning substrates with attached eggs were transferred from the concrete nests to 3.8 l capacity hatching jars. Tests at each exposure time were replicated. Jars were placed in temperature controlled water baths at about 26 C for bluegill (Banner and Van Arman 1973), and 20 C for bass eggs (Badenhuizen 1969), the reported optimum incubation temperatures.

Tests to evaluate tolerance of naturally spawned bluegill eggs to air exposure were conducted at Leesville Lake during June 1975. Bluegill eggs were taken from nests at measured elevations on Monday morning as Leesville began filling above the level of nest construction and placed in 1 l jars with lake water. Eggs from each of two nests were collected at elevations of 183.0, 183.2, 183.5, and 183.8 m (600.5, 601, 602, 603 ft, respectively). Jars were placed in coolers to maintain constant lake temperatures and transported to the laboratory. Approximately 100 eggs adhering to spawning substrates were counted, placed into hatching jars and hatched at about 26 C. Replicate tests were conducted per nest when numbers of eggs permitted.

Length of exposure of naturally spawned eggs at Leesville was determined from water elevation records maintained by the Appalachian Power Company. The relationship between the length of exposure to air and hatching success of bluegill eggs was evaluated using regression procedures.

Fry Development

Embryo development studies were conducted to determine length of time that bluegill and largemouth bass fry are in the nest at various temperature conditions. Ten to 15 recently hatched fry were released into 3.8 l capacity jars. These jars were placed in constant temperature water baths at 16, 18, 20, 22, 24, 26, and 28 C.

Observations on the ability of the fry to swim freely in the water column were made three times daily. Development to the free swimming or fingerling stage was considered complete when fish were able to leave the bottom, swim freely, and maintain their position in the water column as defined by Kramer (1961) and Toetz (1966). Three tests were conducted at 22, 26, and 28 C and five each at 16, 18, 20, and 24 C. Total length of time in the nest was the sum of the length of the hatching period obtained from laboratory hatching tests and from the literature, plus the mean length of the pre-fingerling period. Estimates of the total length of time that bluegill and bass fry would be confined to the nest was used in a model as an estimate of the minimum time period that nests would have to be covered by water to prevent drying.

Predictive Model of Centrarchid Fish Spawning Success

Mathematical Model

A mathematical computer implemented model, SUCCESS, was developed to predict the probability of spawning success of centrarchid fishes in Leesville Lake. The following model was evaluated by SUCCESS:

$$P_S = \sum_{I=1}^{K} \sum_{J=1}^{L} \sum_{Q=1}^{H} \left[TIW_Q \cdot DW_I \cdot TW_J \cdot (P_E \cdot P_F \cdot P_N) \right]$$

where: P_S = Predicted probability of net spawning success.

K = Number of depths available for spawning from maximum pool level to the lowest elevation of spawning nest construction.

H = Estimated number of hours in the spawning period.

L = Number of temperature regimes in the Lake.

TIW_Q = Time weighting factor for changes in modes of spawning activity.

DW_I = Depth weighting factor based on the elevation of nest construction.

TW_J = Temperature weighting of the area of the reservoir encompassed by the respective water temperature.

P_E = Probability of an egg surviving exposure and hatching.

P_F = Probability of successful fry development to the free-swimming stage with respect to water level fluctuations.

P_N = Probability of successful hatching at a given water temperature.

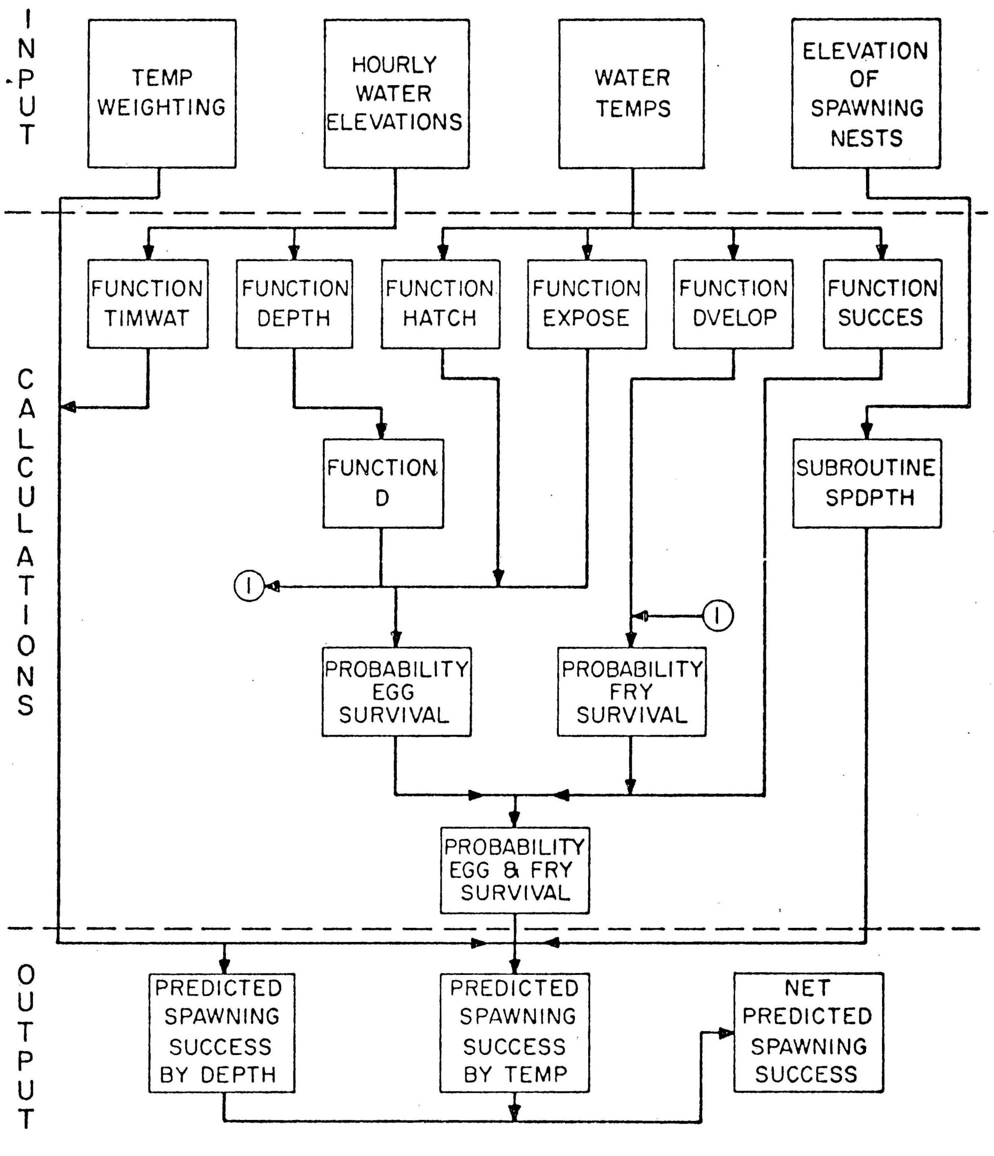
The model to predict spawning success in Leesville Lake was evaluated using data from laboratory and field tests for bluegill. Prediction of spawning success of other centrarchid fishes can also be made if appropriate data are supplied.

Model Input - Calculations - Output

Hourly water elevations, water temperature regimes for respective areas of the lake, and the frequency distribution of the elevation of spawning nest construction are used as input data for SUCCESS (Fig. 2). Calculations of the time weighting factor, hatching and developmental times, hatching success following exposure, hatching success as a function of water temperature, and the probability of nest construction at various elevations are performed in subprograms. These subprograms are called at appropriate time by the main program and the probability of egg and fry survival are calculated for a given time, elevation of spawning, and water temperature. These probabilities of egg and fry survival are calculated for each temperature and the range of elevations of spawning nest construction.

Output from SUCCESS includes the probability of spawning at a specific elevation based on the frequency distribution of spawning nest construction; predicted probabilities of spawning success at each water temperature regime and each elevation are printed out in matrix form with the appropriate weighting factors for depths and water temperatures. Predicted net survival of eggs and fry are printed by temperature and depth and a predicted net estimate of spawning success.

Fig. 2. Flowchart of SUCCESS, a computer program to predict spawning success of centrarchid fishes in pumped storage reservoirs.


INPUT
TEMP WEIGHTING
HOURLY WATER ELEVATIONS
WATER TEMPS
ELEVATION OF SPAWNING NESTS
CALCULATIONS
FUNCTION TIMWAT
FUNCTION DEPTH
FUNCTION HATCH
FUNCTION EXPOSE
FUNCTION DVELOP
FUNCTION SUCCES
FUNCTION D
SUBROUTINE SPDPTH
1
1
PROBABILITY EGG SURVIVAL
PROBABILITY FRY SURVIVAL
PROBABILITY EGG & FRY SURVIVAL
OUTPUT
PREDICTED SPAWNING SUCCESS BY DEPTH
PREDICTED SPAWNING SUCCESS BY TEMP
NET PREDICTED SPAWNING SUCCESS

SUCCESS was developed and evaluated on an IBM/370 computer. The computer program is written in Fortran IV and can be run on a WATFIV compiler. Execution times vary with the number of water temperature regimes and number of days of hourly water elevations. Approximately 116 min execution time is necessary for running seven temperatures and 92 days of hourly water elevations. Storage requirements are about 150 K bytes.

Main and Subprograms

SUCCESS was written with eight subprograms to maximize the generality of the program and increase its predictive utility for other fishes and pumped storage systems. A printout of the main program and subprograms are shown in Appendix Table I.

Functions of Subprograms

The following are the functions of the eight subprograms employed in SUCCESS:

Function DEPTH is used in SUCCESS to convert the days of hourly water elevations into a continuous variable from the first to last hour. This variable is then returned to the main program.

Function D provides the main program with a hypothetical elevation of spawning activity from maximum pool elevation to the lowest elevation where natural spawning occurred.

Function HATCH evaluates the length of the hatching period of eggs spawned at various water temperatures. Hatch returns a single value of the hatching period to the main program when called.

Function DVELOP calculates and returns to the main program the estimated length of the fry developmental period based on the input temperatures.

Function SUCCES evaluates the mean probability of hatching success for a respective water temperature. This value is P_N in the model.

Function EXPOSE is called by the main program to calculate the mean probability of survival of an egg exposed to air as a function of the hours of exposure.

Function TIMWAT provides flexibility in the program and permits uneven weighting of the time of spawning. Two peaks in the bluegill spawning period were included in SUCCESS. These peaks were found to occur in Leesville Lake during mid-June and mid-July. Similar data has been reported by Bennett (1962) for other impoundments.

Subroutine SPDPTH reads in the elevation and respective numbers of spawning nests and calculates the probabilities of nest construction at each elevation. SPDPTH probabilities are used as depth weighting factors in the main program.

Assumptions of SUCCESS

Several assumptions had to be made in the development of SUCCESS due to the paucity of data in certain areas. These assumptions were as follows:

1. Hatching rates in exposed nests are similar to the rates of hatching at the various temperatures of water that was inundating the nests. Interactions of the effects of elevated temperatures and hypoxia average so that the rates of egg development in exposed and inundated nests are similar.
2. Natural mortality exclusive of direct exposure related mortality is not increased.

3. Hatching success of eggs exposed to air at various stages of development would be similar.
4. Impact of multiple exposures on exposed eggs would be the product of the impacts at various water temperature regimes.
5. The frequency of spawning at night and during the day was the same.
6. Spawning at a particular water elevation would commence when nests were inundated by at least 30 cm of water.

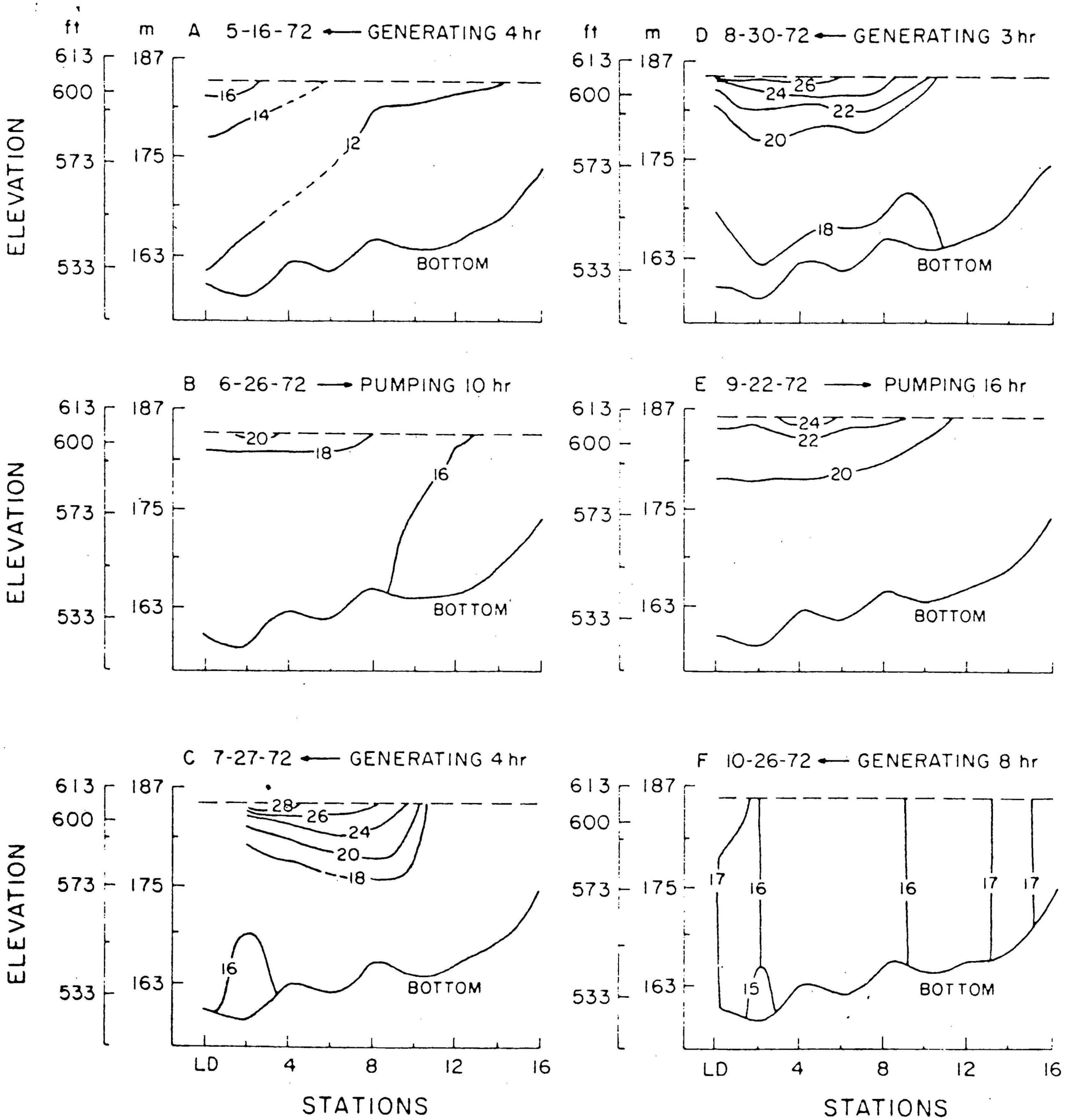
RESULTS

Water Temperature Regimes

Project operations at Smith Mountain Dam affect the distribution of water temperatures throughout Leesville Lake although the greatest effects of project operations occur from station 8 upstream to Smith Mountain Dam. Lake waters from Leesville Dam to station 8 were thermally stratified from mid-May until October when fall mixing occurred (Fig. 3). During pumping operations, Leesville Lake from station 8 to station 16 was occasionally stratified (Figs. 3, 4, 5, and 6), but stratification tended to break down during the generating cycle. Waters with the highest surface temperatures were found from Leesville Dam to station 6, while lowest surface water temperatures generally occurred from station 12 to Smith Mountain Dam. Water temperatures in the deeper strata of lower Leesville Lake were similar to surface water temperatures in the upper reservoir zone. Water temperature regimes from station 16 to Smith Mountain Dam were similar at all depths. Water temperature patterns in the spring and summer of 1972, 1973, and 1974 were generally similar except that water temperatures were slightly warmer during May 1973 and 1974 than May 1972 (Figs. 3, 4, and 5).

Pumping operations at Smith Mountain Dam tend to draw warmer surface waters from the lower reservoir zone into the mid and upper reservoir zones although the depth of the warmer strata generally decreased upstream to Smith Mountain Dam (Fig. 6). Extended periods of pumping which commonly occur on the weekends also draw water from the cooler strata from mid Leesville Lake that mixes with warmer surface waters at station 16. The lake from station 16 to Smith Mountain Dam was generally homothermous after extended periods of pumping.

Fig. 3. Monthly water temperature isopleths from May through October 1972 plotted against extant water elevations from Leesville Dam to navigational marker 16 in Leesville Lake, Virginia. Date of sampling and extant phase and duration of operations are also presented.



A 5-16-72 ← GENERATING 4 hr
B 6-26-72 → PUMPING 10 hr
C 7-27-72 ← GENERATING 4 hr
D 8-30-72 ← GENERATING 3 hr
E 9-22-72 → PUMPING 16 hr
F 10-26-72 ← GENERATING 8 hr
ft
m
613
600
573
533
187
175
163
ELEVATION
BOTTOM
LD
4
8
12
16
STATIONS

Fig. 4. Monthly water temperature isotherms from May through August 1973 plotted against extant water elevations with the duration and phase of operation also indicated at the time of sampling from Leesville Lake, Virginia.

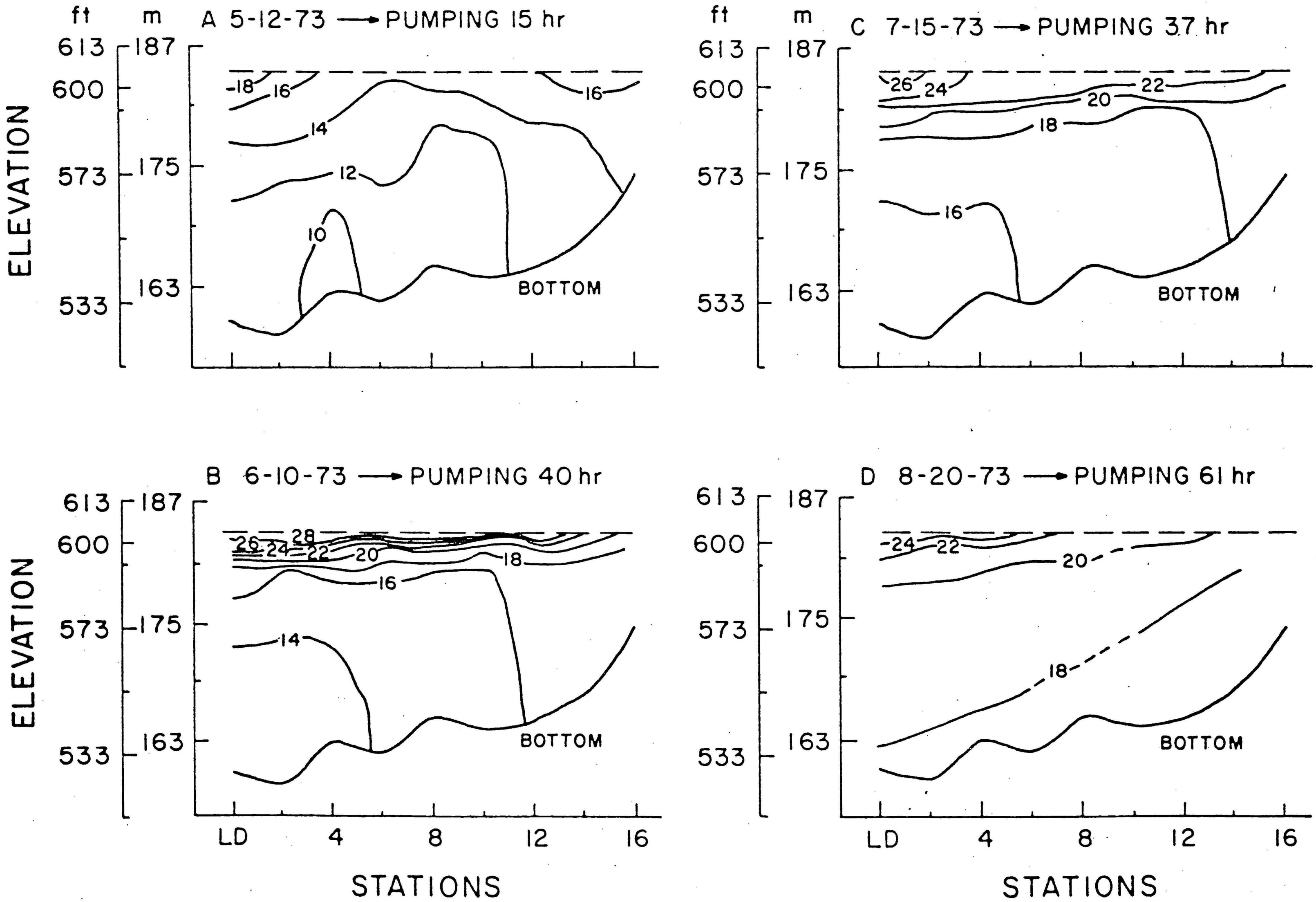

A 5-12-73 → PUMPING 15 hr
B 6-10-73 → PUMPING 40 hr
C 7-15-73 → PUMPING 37 hr
D 8-20-73 → PUMPING 61 hr
ft
m
613
600
573
533
187
175
163
ELEVATION
BOTTOM
LD
4
8
12
16
STATIONS

Fig. 5. Monthly water temperature isotherms for May, July, and August 1974 plotted against extant water levels with the duration and phase of operation also indicated at the time of sampling for Leesville Lake, Virginia.

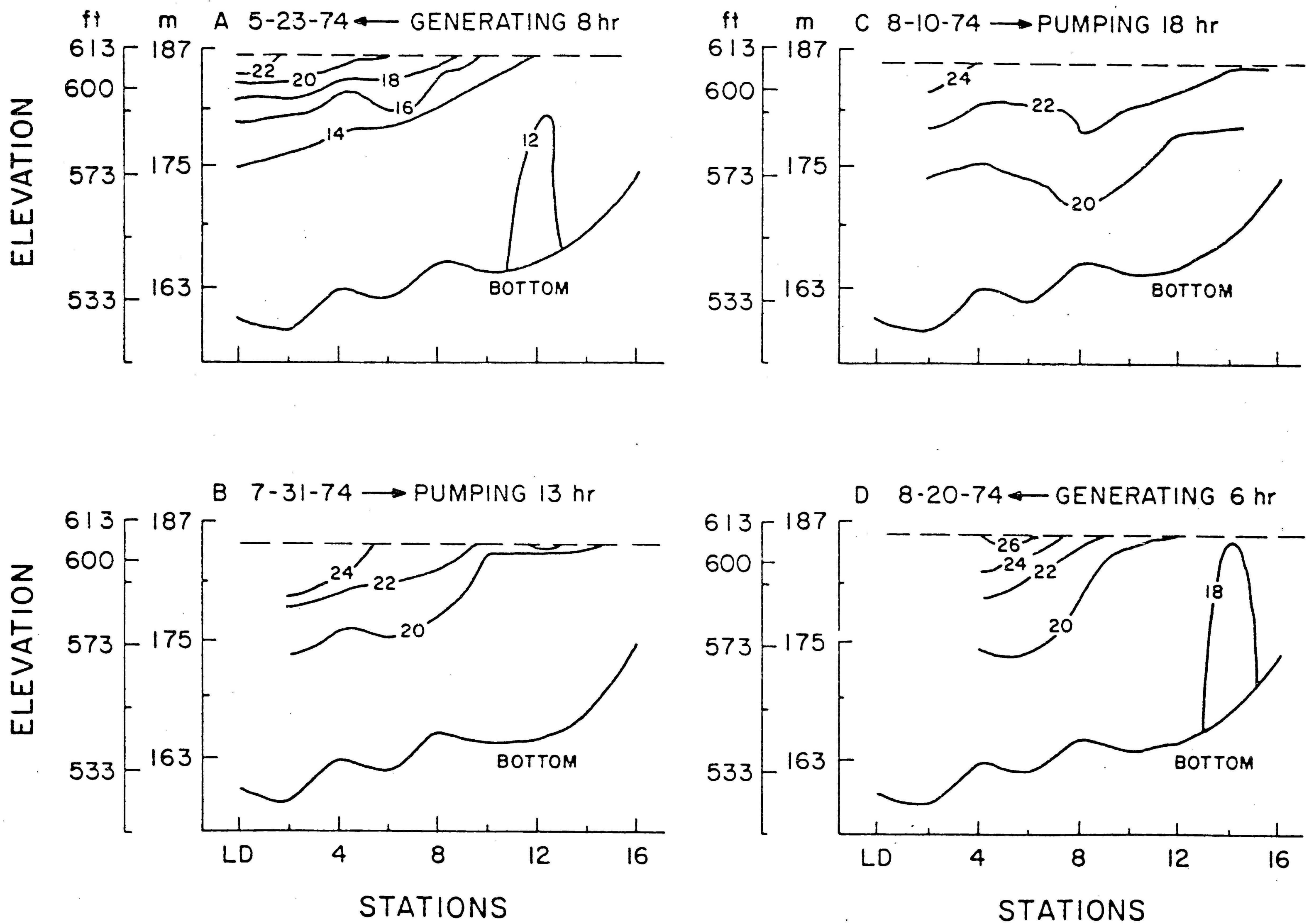
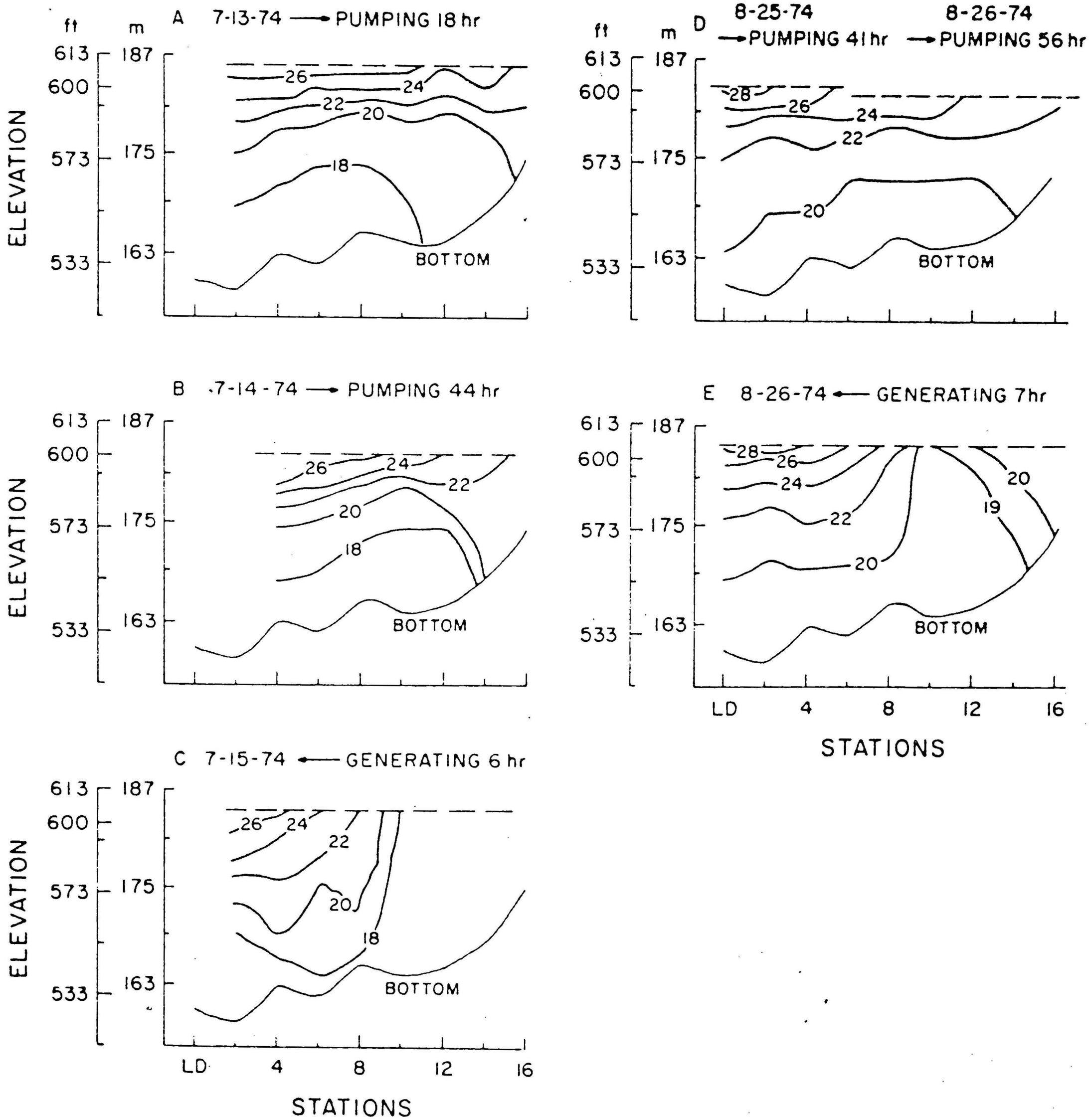

A 5-23-74 ← GENERATING 8 hr
B 7-31-74 → PUMPING 13 hr
C 8-10-74 → PUMPING 18 hr
D 8-20-74 ← GENERATING 6 hr
ft
m
613
600
573
533
187
175
163
ELEVATION
BOTTOM
LD
4
8
12
16
STATIONS
22
20
18
16
14
12
24
26

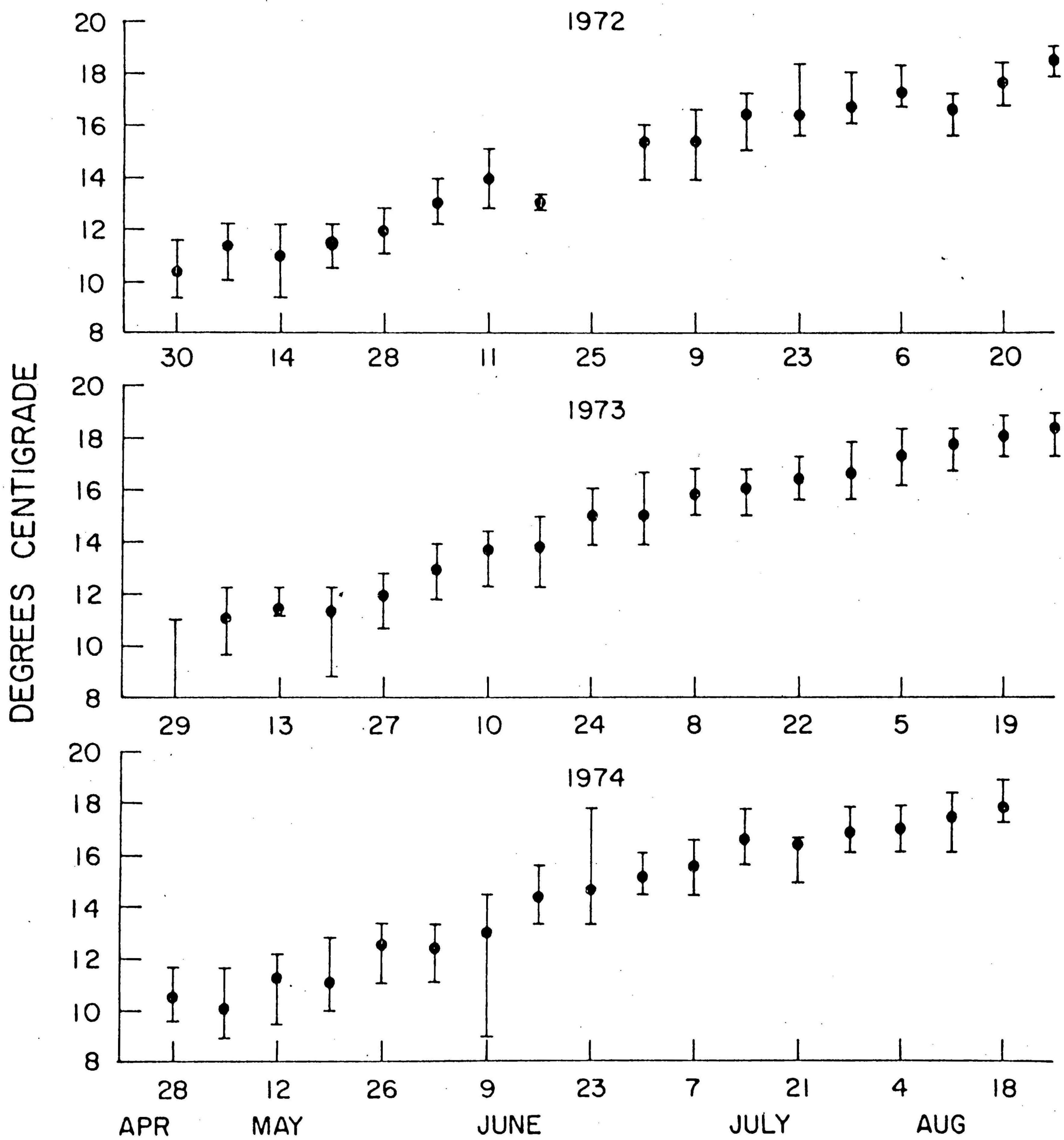
Fig. 6. Effects of pumping and generating at the Smith Mountain Dam power plant on water temperature distribution in Leesville Lake, Virginia.


A 7-13-74 → PUMPING 18 hr
B 7-14-74 → PUMPING 44 hr
C 7-15-74 ← GENERATING 6 hr
D 8-25-74 → PUMPING 41 hr 8-26-74 → PUMPING 56 hr
E 8-26-74 ← GENERATING 7 hr
ft
m
613
600
573
533
187
175
163
ELEVATION
28
26
24
22
20
19
18
BOTTOM
LD
4
8
12
16
STATIONS

Generating operations at Smith Mountain Dam caused a rapid decrease in water temperatures throughout the water column from Smith Mountain Dam to station 10 (Figs. 3, 5, and 6). Surface water temperatures often dropped 10 C from the time pumping operations ceased to a short time after generating operations commenced. Water entering upper Leesville from Smith Mountain Lake during generating averaged less than 18 C from May through August 1972, 1973, and 1974 (Fig. 7). Temperature of water entering Leesville during generation gradually increased from early May until mid-July after which further warming of waters was slight. Temperatures of entering water were found to vary about 3 C per day. Generating operations at Smith Mountain Dam tends to push the warmer surface waters of lower Leesville Lake in the direction of Leesville Dam whereas the upper reservoir from station 10 to station 16 becomes nearly homothermous (Figs. 3, 5, and 6). Cooler waters from Smith Mountain Lake entering Leesville during power generation did not appear to flow beneath the surface in a well defined density layer in either mid or lower Leesville Lake (Figs. 6C and 6E).

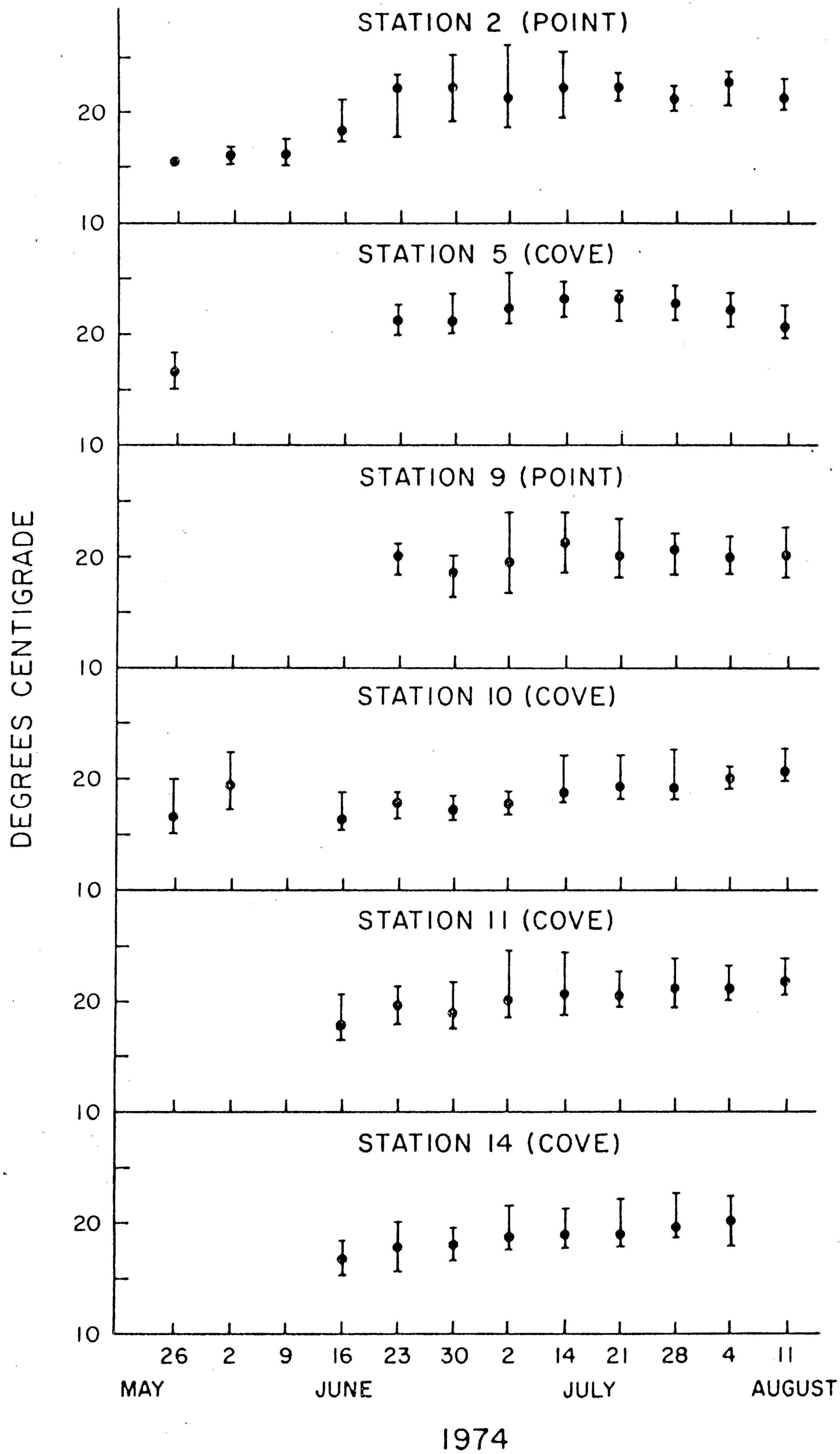
Summer water temperature differences between the lower, mid, and upper reservoir zones were clearly demonstrated by thermograph records in 1974 (Fig. 8). Water temperatures at stations 10 and 14 during 1973 were similar to water temperatures for the same period during 1974. Water temperatures recorded at about 182 m elevation at stations 2 and 5 consistently averaged above 20 C from the week starting 23 June through the spawning season. Water temperatures at stations 9 and 10, however, usually averaged below 20 C for the same period. Water temperatures near station 14 were generally below 20 C from June through August 1974.

Fig. 7. Weekly mean water temperatures and ranges of water entering Leesville Lake, Virginia during generating operations at the Smith Mountain Dam power plant for 1972, 1973, and 1974.



1972
20
18
16
14
12
10
8
30
14
28
11
25
9
23
6
20
DEGREES CENTIGRADE
1973
29
13
27
10
24
8
22
5
19
1974
28
12
26
9
23
7
21
4
18
APR
MAY
JUNE
JULY
AUG

Fig. 8. Weekly mean water temperatures and ranges for 1974 recorded at about 182 m elevation (598 ft) in Leesville Lake, Virginia. Stations 2 and 5 were in the lower reservoir zone, stations 9, 10, and 11 were in the mid, and station 14 was in the upper reservoir zone.


STATION 2 (POINT)
STATION 5 (COVE)
STATION 9 (POINT)
STATION 10 (COVE)
STATION 11 (COVE)
STATION 14 (COVE)
DEGREES CENTIGRADE
10
20
26
2
9
16
23
30
2
14
21
28
4
11
MAY
JUNE
JULY
AUGUST
1974

Although station 11 (cove) was nearer to Smith Mountain Dam than stations 10 (cove) and 9 (point), water temperatures were consistently higher than either station 9 or 10.

The greatest range in daily water temperatures occurred on the points in Leesville Lake. Water temperatures about 1 m below minimum pool level in coves were also slightly warmer than temperatures recorded on points in the lower and mid reservoir zones.

Dissolved Oxygen Concentrations

Project operations at the Smith Mountain Dam power plant have similar effects on the distribution of dissolved oxygen as on water temperatures. Subsurface water from Smith Mountain Lake entering Leesville varied in dissolved oxygen concentrations from 2 to 6 mg/l in July, August, and September (Figs. 9 and 10). These waters entering Leesville Lake during periods of generation at Smith Mountain Dam push the water with highest dissolved oxygen concentrations back to the lower reservoir zone. Pumping operations at Smith Mountain Dam drew the surface waters from lower Leesville with the highest concentrations of dissolved oxygen toward upper Leesville Lake.

Dissolved oxygen concentrations in Leesville Lake varied between stations but were generally similar between years (Figs. 9 and 10). Highest concentrations of dissolved oxygen generally occurred in lower Leesville Lake. Greater than 6 mg/l dissolved oxygen was found throughout the water column in Leesville from May until mid July 1973 and late August 1972 when oxygen concentrations rapidly decreased in the deeper strata. Water with less than 4 mg/l dissolved oxygen occurred in late August and September 1972 at minimum pool level and in deeper strata

Fig. 9. Monthly dissolved oxygen (mg/l) isopleths for Leesville Lake, Virginia from June through October 1972. Time of sampling, duration, and phase of project operations are also presented.

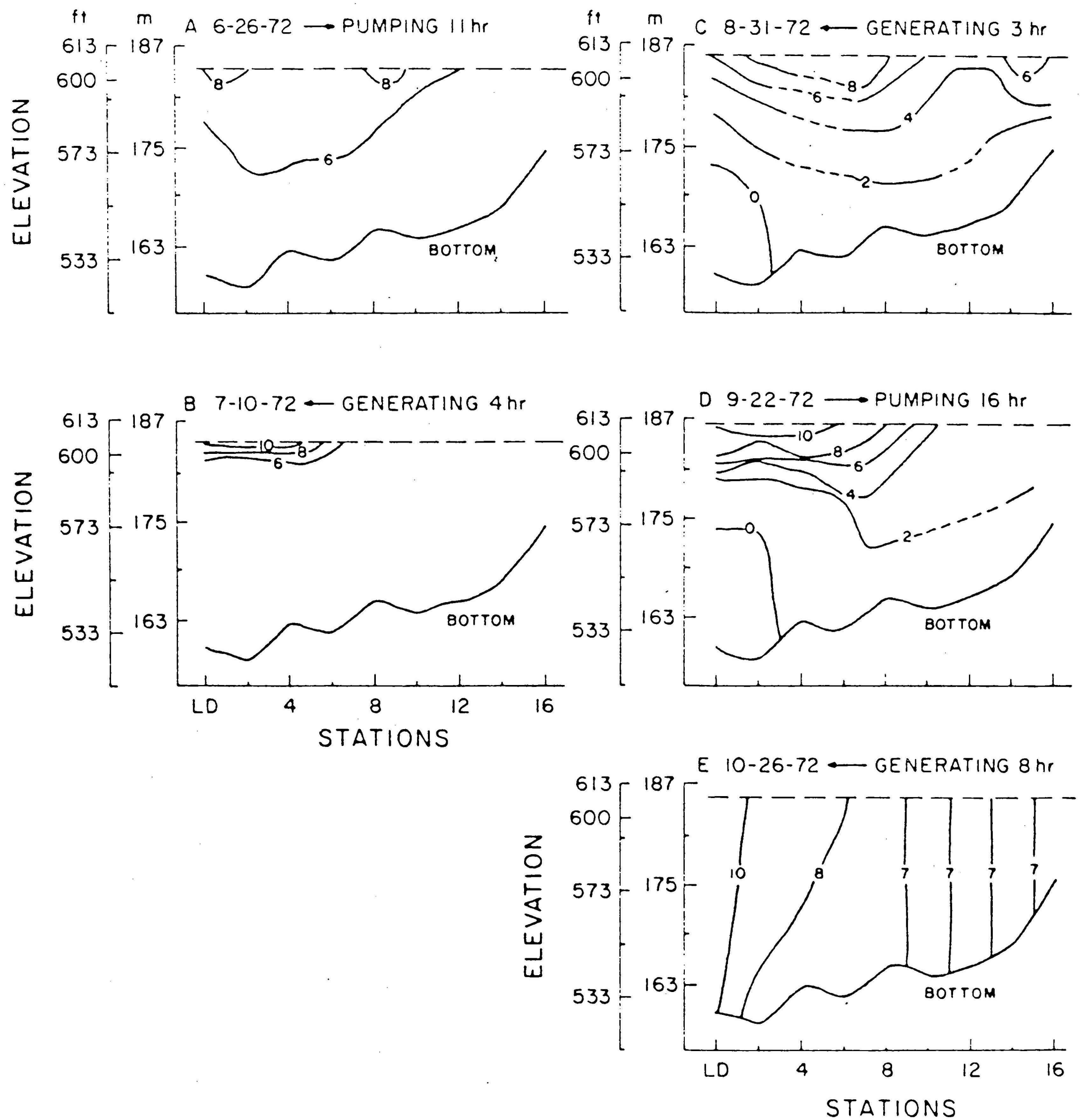
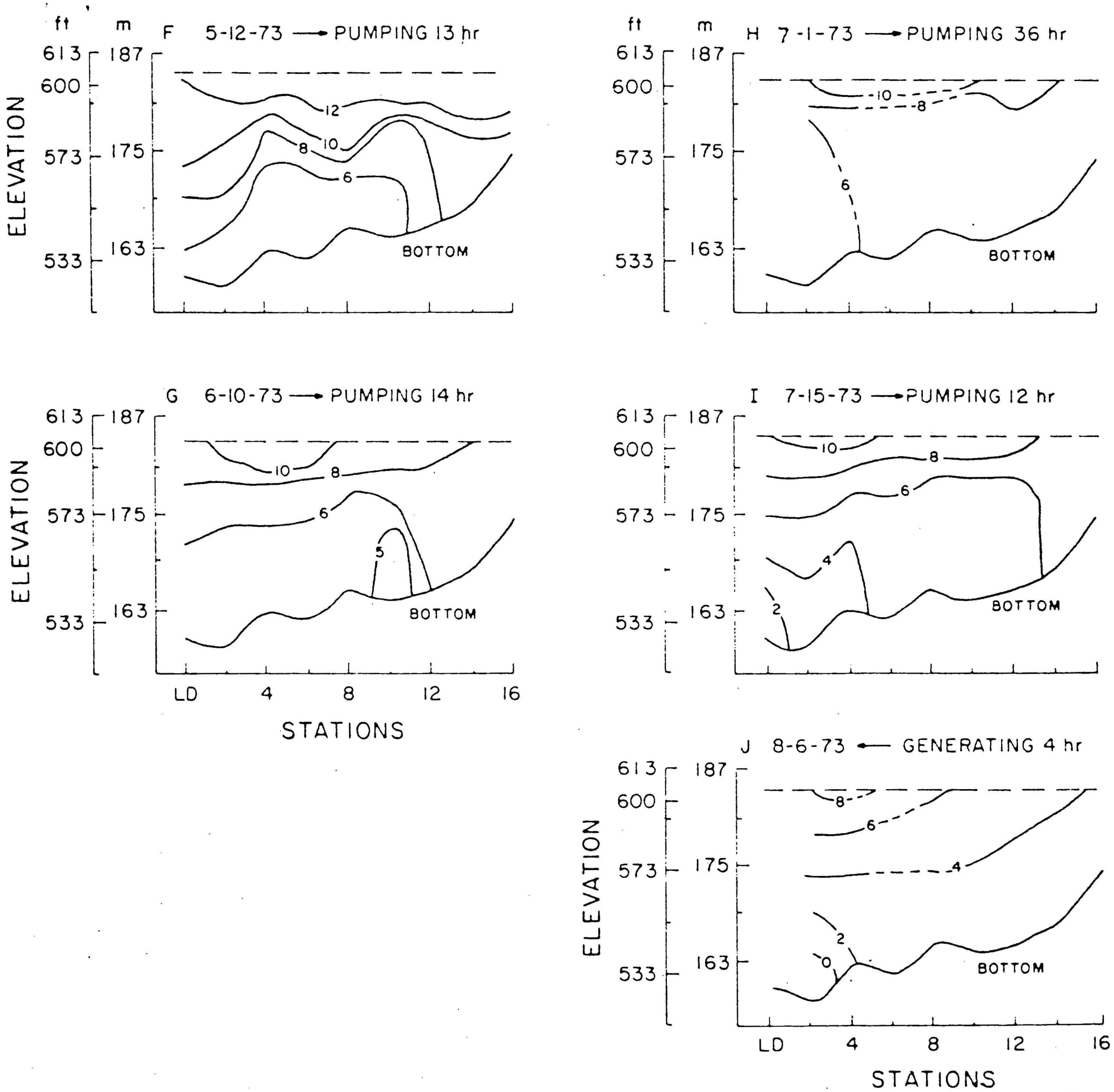

ft
m
A 6-26-72 → PUMPING 11 hr
B 7-10-72 ← GENERATING 4 hr
C 8-31-72 ← GENERATING 3 hr
D 9-22-72 → PUMPING 16 hr
E 10-26-72 ← GENERATING 8 hr
613
600
573
533
187
175
163
ELEVATION
BOTTOM
LD
4
8
12
16
STATIONS

Fig. 10. Dissolved oxygen (mg/l) isopleths for Leesville Lake, Virginia for May, June, July, and August 1973. Time of sampling, duration, and phase of project operations are also presented.


F 5-12-73 → PUMPING 13 hr
G 6-10-73 → PUMPING 14 hr
H 7-1-73 → PUMPING 36 hr
I 7-15-73 → PUMPING 12 hr
J 8-6-73 ← GENERATING 4 hr
ft
m
613
600
573
533
187
175
163
ELEVATION
BOTTOM
LD
4
8
12
16
STATIONS

(Fig. 9C), however, oxygen concentrations from May to August in the upper 6 m of the water column were generally above 6 mg/l. Dissolved oxygen concentrations in the deeper strata were replenished in October during reservoir mixing.

Water Level Fluctuations

Maximum water level fluctuations of 4 m from 186.8 to 182.9 m elevation (613 to 600 ft) occurred in Leesville Lake during May, June, July, and August 1972, 1973, and 1974. These fluctuations and the percentage of time at each level are shown in Figure 11. Operating schedules were similar to those described earlier; minimum pool level was usually attained early Monday morning whereas maximum pool level occurred on Thursday or Friday night during the spawning season. Maximum daily water level fluctuation was about 3.5 m. Annual differences in the frequency of water level fluctuations were slight and the percentage of time at various water levels between 1972, 1973, and 1974 were similar. Water levels from 186.2 to 186.7 m occurred the highest proportion of time from May through August.

Water Transparency

Secchi disk readings in Leesville Lake ranged from 20 to 356 cm and were usually similar between reservoir zones. Transparencies from May through August were generally lower in 1972 than 1973 and 1974 (Table 1). Water transparencies in each reservoir zone were related to the magnitude and phase of project operations and boating activities. Leesville Lake was generally clearer at higher water levels on the weekdays than on weekends when water levels were low and the majority of boating occurred. Observations made in the lower zone indicated low water transparencies

Fig. 11. Range of daily water elevations from 1 May through 31 August 1972, 1973, and 1974 for Leesville Lake, Virginia. Numbers at right indicate the percentage of time during the period represented at a respective water elevation.

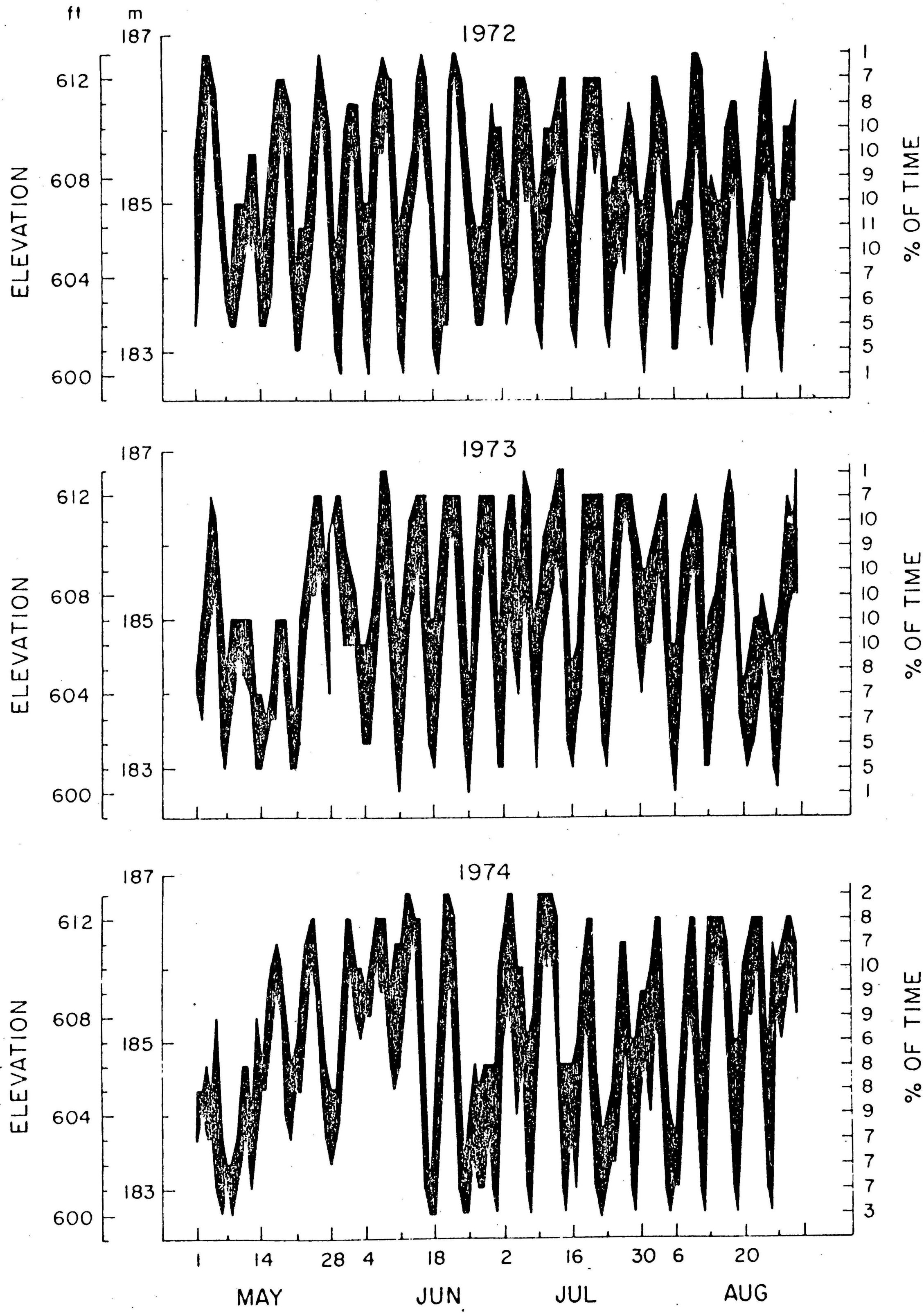

ft
m
1972
1973
1974
ELEVATION
% OF TIME
187
185
183
612
608
604
600
1 7 8 10 10 9 10 11 10 7 6 5 5 1
1 7 10 9 10 10 10 10 8 7 7 5 5 1
2 8 7 10 9 9 6 8 8 9 7 7 7 3
1
14
28
4
18
2
16
30
6
20
MAY
JUN
JUL
AUG

Table 1. Mean water transparencies (cm), ranges, and number of readings from the lower (LR), mid (MR), and upper (UR) reservoir zones in Leesville Lake, Virginia as determined by Secchi disk readings.

	May	June	July	August
1972				
LR		43(38-51)(3)	88(51-130)(5)	170(160-175)(4)
MR		69(61-76)(2)	76(30-108)(6)	111(91-142)(7)
UR		199(112-275)(3)	102(46-150)(7)	80(46-102)(3)
1973				
LR	80(53-96)(5)	146(91-168)(5)	148(63-198)(6)	133(107-160)(6)
MR	79(61-96)(2)	154(137-183)(4)	147(89-183)(4)	73(28-104)(3)
UR	80(61-91)(4)	116(39-256)(3)	88(39-168)(7)	63(20-122)(5)
1974				
LR	128(113-160)(4)	131(66-193)(7)	162(51-234)(39)	164(51-356)(42)
MR	134(113-155)(2)	128(99-165)(14)	144(66-208)(61)	134(56-218)(62)
UR	224(218-229)(2)	122(122)(4)	123(69-180)(19)	120(61-180)(17)

in this section of Leesville Lake were generally caused by high levels of boating activities and to a lesser extent from project operations. Water in some larger coves in the lower lake was turbid throughout the week. Observations made in the mid and upper reservoir zones indicated water transparencies were largely related to project operations. Pumping at Smith Mountain Dam drew the turbid water from the Pigg River to upper Leesville whereas generating operations pushed these turbid waters to mid Leesville.

Flow Reversals and Water Velocities

Water velocities in Leesville Lake were higher during power generating operations at Smith Mountain Dam than during pumping operations. Water velocities were highest in upper Leesville and proportionally lower with increasing distance from Smith Mountain Dam (Table 2). Water velocities during generating and pumping operations were about three to five times higher along the center of Leesville Lake than along the shoreline. Water movement exceeding 0.1 m/sec occurred along the shoreline during generating operations as far as 16 km from Smith Mountain Dam whereas equivalent surface velocities during pumping operations occurred only about 5 km below Smith Mountain Dam.

The following linear models were developed to predict surface water velocities along the shoreline at selected locations in Leesville Lake:

Generating - $V_G = 0.7228 - 0.5149\ (\mathrm{LOG}_{10}\ D_K)$ $R^2 = 0.953$

Pumping - $V_P = 0.2062 - 0.1436\ (\mathrm{LOG}_{10}\ D_K)$ $R^2 = 0.970$

where:

V = surface water velocity along the shoreline in m/sec.

D_K = distance (km) from Smith Mountain Dam.

Table 2. Measured and estimated maximum water velocities (m/sec) about 1 m from the shoreline in Leesville Lake, Virginia. Estimated water velocities are made from the models given in the text.

	Velocity-			
Station no.	Generation- Measured	Estimated	Pumping- Measured	Estimated
16	0.56	0.58	0.16	0.17
14	0.43	0.36	0.11	0.10
12	0.21	0.25	0.08	0.07
10	0.15	0.19	--	0.06
8	0.12	0.14	0.05	0.04
6	0.06	0.09	--	0.03
4	--	0.05	--	0.02
2	0.06	0.02	0.02	0.01

Relative Abundance of Centrarchid Fishes

Numbers of centrarchid fishes collected varied between years and reservoir zones. Abundance of centrarchid fishes from May through August as assessed by catch per unit of effort data along the shoreline were highest in the lower reservoir zone and lowest in the upper zone (Table 3). Although electroshocking collecting efforts for 1972 and 1974 were similar, significantly greater numbers of centrarchid fishes (X^2 = 674.2, 7 df) were collected per unit effort in 1972.

The following centrarchid fishes collected in decreasing order of abundance were: bluegill, redbreast sunfish (L. auritus), largemouth bass, and pumpkinseed sunfish (L. gibbosus). A few smallmouth bass (M. dolomieui) and crappies (Pomoxis annularis and P. nigromaculatus) were also collected in Leesville Lake. Bluegill comprised about 85 percent of the total number of centrarchid fishes collected during 1972 and 1974. Largemouth bass (1974) and bluegill were collected in significantly higher numbers from the lower lake zone than from either of the other zones. Significantly more pumpkinseed sunfish were collected from upper Leesville than from mid and lower lake zones for 1972 and 1974. Proportionately more redbreast sunfish were collected from the upper and lower zones of Leesville in 1972, however in 1974, highest numbers of redbreast sunfish were collected from mid Leesville Lake.

Lengths, weights, and body condition of fishes used for reproductive development studies from Leesville Lake are shown in Appendix Tables II, III, IV, V, and VI. Variations in sizes of adult fish were similar between monthly samples and reservoir zones.

Table 3. Numbers and percentage abundance of centrarchid fishes collected by nighttime electrofishing in Leesville Lake, Virginia. Chi square values and significance levels are shown for $P \leq 0.01$ (**) and $P \leq 0.05$ (*). Demarcation of reservoir zones in Leesville Lake is indicated in the text.

Species		1972- Lower	Mid	Upper	X^2	1974- Lower	Mid	Upper	X^2
Largemouth bass		39	23	26	4.93	17	4	0	22.6**
	Percent	44.3	26.1	29.5	5.62	81	19.0	0	107.7**
Bluegill		786	417	330	229.4**	212	122	122	35.5**
	Percent	51.3	27.2	21.5	15.01**	46.5	26.8	26.8	7.76**
Redbreast Sunfish		54	20	59	20.3**	13	27	6	14.9**
	Percent	40.6	15.0	44.4	15.33**	28.3	58.7	13.0	32.47**
Pumpkinseed		1	11	31	32.6**	--	2	19	31.1**
	Percent	2.3	25.6	72.1	75.7**	0	9.5	90.5	148.4**
Totals	Numbers	880	471	446		242	155	147	
	Percent	49.0	26.2	24.8		44.5	28.5	27.0	

Reproductive Development

Largemouth Bass

Fifty-eight male and 145 female bass collected from April through September were examined for reproductive development (includes data collected by Estes 1971). Some largemouth bass were in spawning condition in May, June, July, and September (Table 4). Gonads of 50 percent of the males examined and 12 percent of the female bass were spent by late May indicating that spawning of largemouth bass is probably initiated in mid-May and continues into July. Several bass examined on June 30, 1975 had abraded fins and reddened genital pores indicating recent spawning. Although Estes (1971) suggested that bass may spawn in September, I did not collect any bass with ripe or enlarged gonads in August or September. Since the majority of the bass were collected from lower Leesville Lake, statistical comparison of GSIs between reservoir zones was not made.

Bluegill

One hundred and seventy-nine mature male and 295 mature female bluegills from Leesville Lake were examined for reproductive condition during 1972 and 1974 (Tables 5 and 6). About equal numbers of mature male and female bluegill were collected in the lower, mid, and upper reservoir zones. Smallest sizes of sexually mature male and female bluegill were 62 and 75 mm (total length), respectively (Appendix Tables II and III). However some fish at equivalent lengths or slightly larger were considered immature because of small undeveloped gonads.

Sex, month, year, and reservoir zones interact to affect the size of bluegill gonads during the spawning season in Leesville Lake.

Table 4. Stage of maturity of gonads of largemouth bass (<u>Micropterus salmoides</u>) collected from Leesville Lake, Virginia during 1971, 1972, 1974, and 1975. Number of males/females is presented for each category.

Month	Enlarged	Stage of maturity- Ripe	Spent	Totals
April	3/2			3/2
May	6/11*	3/33*	8/6	17/50
June	3/6*	3/30*	7/1	13/37
July	/7*	1/9*	19/19*	20/35
August			4/8*	4/8
September		/2*	1/11*	1/13

*Data from Estes (1971) included.

Table 5. Numbers of male bluegill (Lepomis macrochirus) collected from the lower, mid, and upper reservoir zones in Leesville Lake, Virginia, that were sexually immature (Imm) and mature (Mat) during 1972 and 1974.

	Reservoir zone-					
	Lower-		Mid-		Upper-	
	Imm	Mat	Imm	Mat	Imm	Mat
1972						
April	6	9				
May	12	5	11	4	2	2
June	5	13	12	10	18	13
July	22	26	2	10	11	5
August	2	2			2	3
September	13	7	6	1	6	—
Totals 1972	50	62	31	25	39	23
1974						
April	6	11				
May	4	2	6	9	8	4
June	8	8	10		22	
July		8	16	11	12	1
August	3	9	4	5	—	1
Totals 1974	21	38	36	25	42	6

Table 6. Numbers of female bluegill (Lepomis macrochirus) collected from lower, mid, and upper Leesville Lake, Virginia that were sexually immature (Imm) and mature (Mat) during 1972 and 1974.

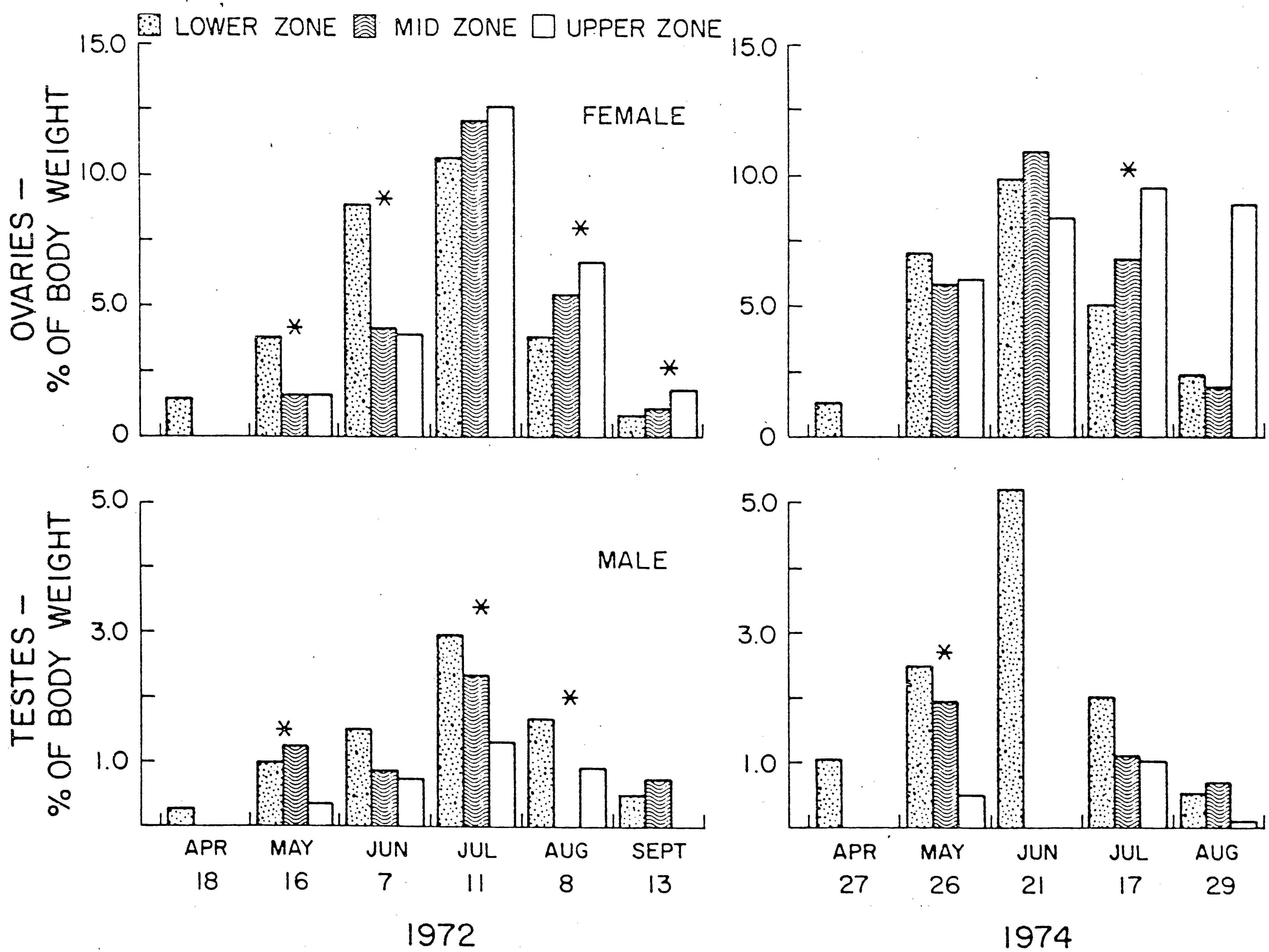
	Reservoir zone-					
	Lower-		Mid-		Upper-	
	Imm	Mat	Imm	Mat	Imm	Mat
1972						
April	2	10				
May	3	12	2	11	3	13
June	3	13	4	17	4	9
July	4	29		17	4	18
August	3	14	3	9	6	5
September	4	8	6	4	2	10
Totals 1972	19	86	15	58	19	55
1974						
April		4				
May	4	5		11		5
June	5	11	1	6	2	7
July	4	14	3	17	5	11
August	3	3	3	1	1	1
Totals 1974	16	37	7	35	8	24

Preliminary reference collections of bluegills in April 1972 and 1974 indicated that gonadal recrudescence had begun by the time of sampling although gonads were small (Fig. 12) and in an enlarged, prespawning condition (Fig. 13). GSIs for males and females in the April 1972 and 1974 collections were similar in size; later in the spawning season, GSIs for females were more than two times greater than that for males. Bluegill gonads nearly doubled in size between the April to May collections. All mature bluegill in the May 1972 collections were in the enlarged prespawning condition, however in May 1974, some bluegill were in spawning condition in all reservoir zones. In 1972, female bluegill gonadal maturation and the presence of fish in spawning condition occurred earliest in the warmer lower zone of the lake and later in the mid and upper reservoir zones. A similar trend in earlier female gonadal maturation in the lower zone occurred again in 1974, but with greater overlap in time between zones. Gonadal maturation rates between reservoir zones for 1972 and 1974 were more similar in male than female bluegill. The greatest numbers of mature bluegill throughout Leesville Lake generally occurred in June with the exception of 1974 when females from the upper zone matured in greatest numbers in July. Collections in August 1972 and 1974 indicated that most fish had spawned. Bluegill in the September 1972 collections were spent except for one ripe female from the upper zone.

Redbreast Sunfish

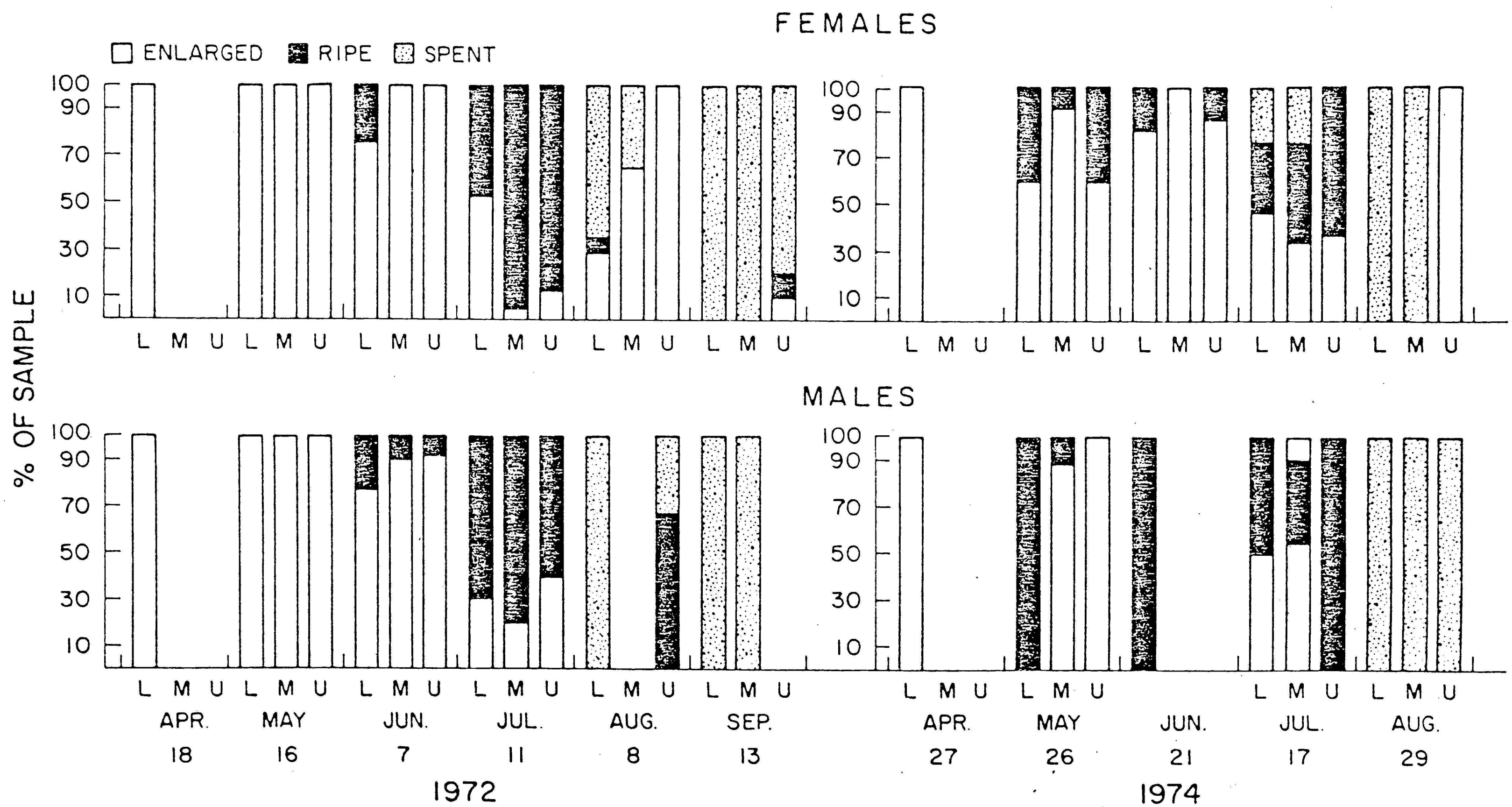
Gonadal development of redbreast sunfish in Leesville Lake during 1972 and 1974 was similar to that of bluegill (Table 7). Based on the stage of maturity information, the spawning period of redbreast sunfish

Fig. 12. Mean gonosomatic indices (GSI) of bluegill (Lepomis macrochirus) collected from the lower, mid, and upper reservoir zones of Leesville Lake, Virginia during 1972 and 1974. Significance at $P \leq 0.05$ is indicated (*). Significant differences in mean GSIs were as follows: Female: May and June 1972 - lower vs. mid and upper; August 1972 - lower vs. upper; September 1972 - mid vs. upper; July 1974 - lower vs. mid and upper and mid vs. upper. Male: May and July 1972 - mid vs. upper; May 1974 - lower vs. upper.



LOWER ZONE
MID ZONE
UPPER ZONE
FEMALE
OVARIES – % OF BODY WEIGHT
15.0
10.0
5.0
0
MALE
TESTES – % OF BODY WEIGHT
5.0
3.0
1.0
APR 18
MAY 16
JUN 7
JUL 11
AUG 8
SEPT 13
1972
APR 27
MAY 26
JUN 21
JUL 17
AUG 29
1974

Fig. 13. Percentage of bluegill (Lepomis macrochirus) gonads in the enlarged, ripe, or spent reproductive condition collected from Leesville Lake, Virginia.



FEMALES
ENLARGED
RIPE
SPENT
MALES
% OF SAMPLE
100
90
70
50
30
10
L M U L M U L M U L M U L M U L M U
L M U L M U L M U L M U L M U
APR. 18
MAY 16
JUN. 7
JUL. 11
AUG. 8
SEP. 13
1972
APR. 27
MAY 26
JUN. 21
JUL. 17
AUG. 29
1974

Table 7. Stage of maturity of gonads from redbreast sunfish (*Lepomis auritus*) collected from Leesville Lake, Virginia during 1972 and 1974. The number of males/females in each class is shown.

Month	Stage of maturity- Enlarged	Ripe	Spent	Totals
April	/3			/3
May	2/15	/2		2/17
June	3/1	/1		3/2
July	2/2	2/21	8/5	12/28
August	/1	/5	5/10	5/16
September			12/19	12/19

probably extended from mid-May to August in Leesville with a peak in spawning activity in July. Some fish collected in July samples were spent. The small numbers of redbreast sunfish collected throughout Leesville Lake precluded meaningful comparisons of gonadal maturation between reservoir zones and years.

Pumpkinseed

Pumpkinseed sunfish in Leesville Lake appear to reach a peak in spawning condition in July although ripe fish were also collected in May and June samples (Table 8). Pumpkinseed with spent gonads were first collected in July. Since about 80 percent of all pumpkinseed collected in Leesville Lake were from the upper reservoir zone (Table 4), these data probably represent the spawning period for that portion of the lake. Low numbers of pumpkinseed collected from lower and mid Leesville Lake prevented within-lake comparisons of the reproductive cycle.

Natural Reproduction

Spawning Substrates

Use of artificial spawning substrates in Leesville Lake by centrarchid fishes was negligible. No definite signs of nest cleaning or spawning behavior were observed. A few locations on the artificial spawning mats appeared to have been cleaned presumably by spawning fishes. However, since no eggs or other signs such as male sunfish manifesting territorial behavior were observed, no spawning data were available from the artificial substrate tests.

Largemouth Bass

Evidence of natural reproduction by largemouth bass in Leesville Lake was ascertained by two methods; locating spawning nests, and observing

Table 8. Stage of maturity of gonads from pumpkinseed (*Lepomis gibbosus*) from Leesville Lake, Virginia during 1972 and 1974. The number of males/females in each class is shown.

Month	Enlarged	Stage of maturity- Ripe	Spent	Totals
May	1/1	/1		1/2
June	9/5	/6		9/6
July	1/1	14/13	6/2	21/16
August			6/1	6/1
September			4/5	4/5

and collecting individuals from broods of fingerling bass (fingerling stage is defined and used here following Kramer 1961; fingerling stage is attained when the fish leave the spawning nest and actively swim and feed near the surface) protected by male bass. Nine largemouth bass nests similar to spawning nests described by Reighard (1906) and Breder (1936) were found in Leesville Lake at the following elevations: 6 at 182.9 m (600 ft), 1 at 182.3 m (598 ft), and 2 at 182.0 m (597 ft). These nests were located in coves from station 6 to station 7 and along the shoreline of the main lake near station 6. The bass nests were found in early June 1974, but were considered inactive since they were slightly silted and no broods of fingerlings were observed near the nests. However in early June 1975, largemouth bass fingerlings were located in the area of bass nest construction observed in July 1974.

Broods of largemouth bass fingerlings ranging in size from 8 to 35 mm were observed and collected with dip nets in eight locations in Leesville Lake (Table 9). All broods of bass fingerlings were located in coves although about equal effort was made to observe and collect bass fingerlings in suitable areas in the main lake. Trained divers were unable to locate spawning nests in areas where fingerlings were collected. No broods of bass fingerlings were observed or collected in any coves from station 12 to Smith Mountain Dam. Broods of bass fingerlings were dispersed by the end of June 1974.

Bluegill

I located 2,001 sunfish spawning nests in Leesville Lake from 12 June to 31 August 1974. Spawning nests were observed from about 1.2 m below maximum pool elevation (185.6 m or 609 ft) to about 1.5 m below

Table 9. Means and ranges of total lengths of fingerling largemouth bass (*Micropterus salmoides*) collected by dip net from Leesville Lake, Virginia during 1974.

Nearest station	Date	Mean (mm)	Size range (mm)	Est. brood size*
10	6-17	19.4	15.8-22.2	1,000
10	6-24	9.1	8.2-12.1	1,000
11	6-24	21.3	8.6-30.0	1,500
10	6-24	12.3	9.4-18.6	500
5	6-30	26.2	9.0-34.7	100
7	7-1	19.7	18.4-22.2	1,000
8	7-1	18.4	15.3-21.2	100
7	7-1	28.8		2,000

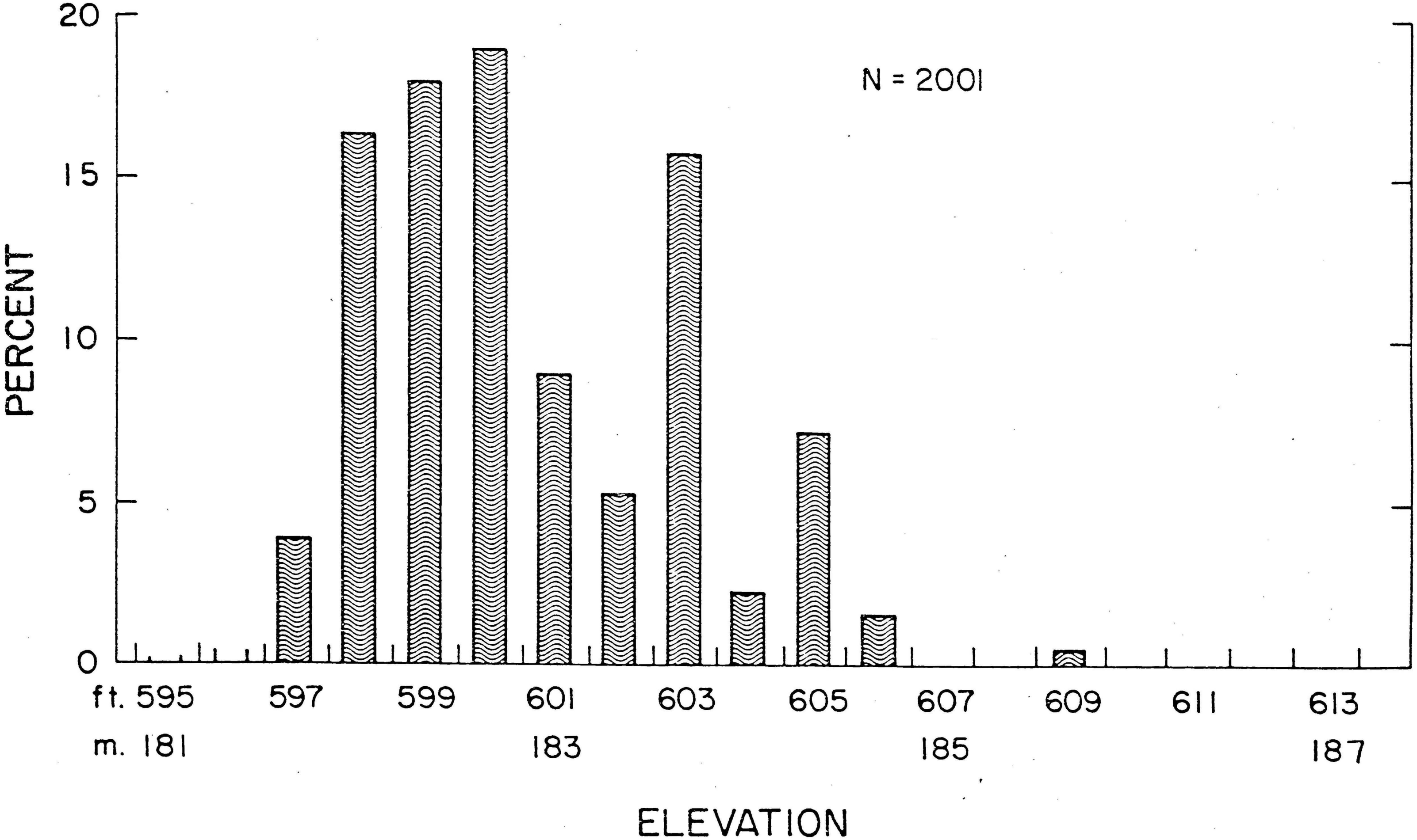
*Brood sizes were estimated by the method employed by Brouha (1974).

minimum pool elevation (181.4 m or 585 ft) with a weighted mean depth of spawning at minimum pool elevation (182.9 m or 600 ft) (Fig. 14). Of all the sunfish spawning nests located, 19 percent were at minimum pool level which was also the peak nesting depth in Leesville Lake. Other peaks in the nesting depths were about 1 m above and 0.3 and 0.6 m below minimum water level. Nearly 40 percent of all sunfish nests in Leesville Lake were located between 0.3 and 1.5 m below minimum pool elevation (182.6 to 181.4 m); these nests were consequently not exposed to air. However, spawning nests at minimum pool level were exposed on Sunday night and Monday morning when lowest water levels occurred. Although some spawning nests that were active (not heavily silted) were found to 185.6 m elevation in Leesville Lake, eggs, and fry were found only in nests constructed at 2 m below maximum pool elevation and below (184.4 or 605 ft).

The hypothesis that the elevation of sunfish spawning nest construction decreased from the inception of spawning to the end of the spawning season was formulated. A linear model was used to test this hypothesis. The null hypothesis could not be rejected (Ho : B = 0, t = -0.24) indicating that the weighted mean elevation of spawning did not change through the spawning season. These results were supported by observations in Leesville during May and June 1975. Spawning nest construction and egg deposition in June 1975 occurred with similar depth distribution as observed in 1974 at the same time in Leesville Lake.

Most nests were constructed on decomposing leaves and sticks although some nests were constructed on gravel and hardpan substrates. Nests constructed at or above minimum pool elevation were exposed on the weekends;

Fig. 14. Distribution of sunfish (Lepomis sp.) spawning nests throughout the water column in Leesville Lake, Virginia. Nests were located June through August, 1974. No eggs or fry were found in spawning nests located above 184.4 m (605 ft) elevation.


N = 2001
PERCENT
20
15
10
5
0
ft. 595
597
599
601
603
605
607
609
611
613
m. 181
183
185
187
ELEVATION

retention of water in these nests depended upon the nesting substrate. Nests constructed over hardpan substrates generally retained water from the time water levels dropped below the elevation of nest construction to the time when water levels rose to recover the nests. About 2.5 percent of the nests located at or above 183.2 m (601 ft) elevation retained water during drawdown and filling periods. Water temperatures in nests retaining water not shaded from the sun rapidly increased and occasionally exceeded 32 C. Survival of eggs and fry in these nests did not appear to be adversely affected by the conditions created by elevated water temperatures.

A few spawning areas were located near spring seeps. As water levels in the lake dropped below the level of higher nest construction, eggs and fry were usually covered by water from these springs. Since some springs were cold, fry and eggs were subjected to cold temperature shock. Water temperatures in these nests were occasionally 10 C lower than the ambient lake water temperature. Dead fry were observed in some nests covered by spring water.

Location of Spawning Areas

Greater than 85 percent of the sunfish spawning nests were found in coves in Leesville Lake. Most coves from station 1 to station 11 contained spawning nests whereas less than 1 percent (20) of all spawning nests were located in the upper reservoir zone. Of the few nests located in the upper zone, most were in a cove near station 15. Some early nest construction was observed in a cove near station 14, but no eggs or fry were observed in any nests in upper Leesville. With the exception of these coves, no spawning nests were located along the shoreline from station 11 to Smith Mountain Dam.

The greatest number of spawning nests was located in the mid reservoir zone. About 66 percent (1321) of all sunfish nests were found in coves while 5 percent (100) were located along the shorelines of the main lake. Spawning nests along the main shoreline of the lake in the mid zone were generally found on the downstream or Leesville Dam side of rocks, stumps, etc., similar to the location of sunfish spawning nests in New York trout streams (Breder 1936).

Fewer spawning nests were located in the lower reservoir zone than in mid Leesville. About 18 percent (360) of all sunfish nests were located in coves in lower Leesville whereas about 10 percent (200) were found along the shorelines of the main lake in this zone. In contrast, nests along the shoreline of the main lake where water velocities were much reduced appeared to be less sheltered from the water velocities than those nests in mid Leesville.

A disproportionate amount of diving effort was expended in some of the three reservoir zones in order to maintain constant efficiency in locating spawning nests. High turbidities (secchi disk readings $<$ 10 cm) localized along the shorelines and high turbidities and cold waters in upper Leesville Lake reduced the available time when observations could be effectively made in lower and upper Leesville Lake. Diving efforts for each zone were as follows: 43 man-hours (lower); 76 man-hours (mid); and 23.5 man-hours (upper). Because of this disproportionate amount of diving effort in the three zones, the number of nests located in each zone was expressed as a number per unit diving effort. The resulting proportion of nests per zone was corrected by multiplying a constant that was used to make the relative proportions of nests sum to one.

Based on these calculations for a constant unit of diving effort, 40 percent of the nests occurred in lower Leesville Lake, 57 percent in mid, and 3 percent from the upper zone. The corrected estimate of distribution of spawning nests in each zone was then used to predict spawning success of bluegill in the entire reservoir.

Spawning Activity of Sunfish

The length of the sunfish spawning period in Leesville Lake was ascertained through field observations made in 1974 and 1975. Active spawning nests were found from 12 June 1974 to 11 August 1974. Only nests found in the lower and mid reservoir zones contained eggs or fry during this period. During 1975, checks of known spawning areas revealed that spawning had begun in lower Leesville Lake by 8 June.

Spawning nests free of silt were found in the mid reservoir zone to station 9 by 8 June 1975 although eggs were not present in any of these nests observed. Bluegill eggs were first observed in nests from lower Leesville to station 10, two weeks later. Nests were not found from stations 10 to 11 by the end of June 1975, although spawning sites had been active at these locations in July and August 1974.

Low Water Temperatures and Flow Reversals

The upper reservoir zone is characterized by having low water temperatures during most of the week and flow reversals with high water velocities (Figs. 3, 4, 5, 6, and Table 2). Little spawning activity was detected in the upper reservoir zone throughout the study period. A stepwise regression model was used to isolate the apparently deleterious effects of water velocities during generating and pumping operations and low water temperatures on the distribution of spawning nests along the shoreline of the main lake in upper Leesville. In order to predict water temperatures at selected locations in Leesville Lake during the spawning season, the following linear model based on mean daily water temperatures from thermograph recordings was developed:

$$T_C = 9.592 + 0.0428 (N_D) + 0.1527 (D_K) \quad R^2 = 0.77$$

where:

T_C = Water temperature (C) at about 182.0 m level.

N_D = Number of days after 1 January to make days of the year a continuous variable.

D_K = Distance in kilometers (km) to a selected location in Leesville Lake from Smith Mountain Dam.

The stepwise regression model that was found to best describe the distribution of spawning nests was:

$$C_L = 11.437 - 42.54 (V_G) + 0.4479 (T_C) \quad R^2 = 0.825$$

where:

C_L = Square root (+1) of the cumulative number of sunfish nests along the shoreline of Leesville Lake.

V_G = Surface water velocity (m/sec) during generation.

T_C = Mean water temperature (C) at about 182.0 m level.

The model indicated that water velocity during generating operations was the most significant variable in the model ($\alpha = 0.0002$, $R^2 = 0.724$) although water temperatures were also considered significant in affecting spawning nest distribution ($\alpha = 0.027$, $R^2 = 0.236$). The effects of water velocity during pumping operations were deemed nonsignificant ($F = 1.221$, 13 df, $\alpha = 0.295$).

Spawning Success

Bluegill Fry Counts from Spawning Nests

The number of viable fry and eggs from a single nest were highly variable and ranged from 2,100 to 11,500 (Table 10). Hatching success estimates based on the ratio of viable eggs and fry to the total number of fry and eggs ranged from 79 to 99 percent. Total lengths of fry from nests ranged from 3.6 to 5.25 mm with a mean length of 4.20 mm. These fry ranged in age from 16 to 192 hr based on data from Morgan (1951) and my fry developmental tests under controlled water temperatures. Wide ranges in total lengths of fry from a single nest suggest multiple spawnings in a nest (Table 10). Numbers of sunfish fry collected from nests located at 183.8 m, 1 m above minimum pool, were within the range of numbers of fry collected below minimum pool level. Based on counts of the numbers of fry and percentage hatching in a nest, spawning success was higher in lower Leesville than in mid Leesville Lake although only one nest was sampled in the lower lake.

Controlled Temperature Hatching and Development Studies

Largemouth Bass Eggs

Largemouth bass eggs were hatched at constant temperatures of 16, 20, 24, and 26 C. Estimates of hatching success for largemouth bass eggs were generally similar between test temperatures of 20, 24, and 26 C. At 20, 24, and 26 C, estimates of mean hatching success based on one replicate were 89, 78, and 92 percent, respectively. Bass eggs incubated at 16 C started to hatch but died before hatching was completed.

Length of the fry developmental period for largemouth bass was inversely related to water temperature. At 20, 24, and 26 C, estimated

Table 10. Numbers, total lengths (mm), and estimates of hatching success of sunfish fry counted from individual spawning nests located in coves of Leesville Lake, Virginia in 1974.

Date	Nearest station	Elevation m (ft)	No. fry	Percent success	Length- Mean	Length- Range	Est. mean age (hr)
7-15	9	183.8 (603)	5,170	*	3.95	3.55-4.62	50
8-4	2	182.3 (598)	11,547	99.2	4.19	3.93-4.44	66
8-4	7	182.3	3,167	78.8	4.25	3.99-4.46	70
8-4	7	182.3	2,146	96.1	4.17	3.93-4.32	62
8-4	7	182.3	2,416	94.5	3.77	3.61-4.31	34
8-5	10	182.6 (599)	2,431	93.5	4.25	3.83-4.56	70
8-5	10	182.6	4,431	97.6	4.33	3.86-4.87	76
8-11	7	182.3	4,879	96.3	4.72	3.99-5.25	138
	Means		4,522	93.7			
	Range		2,146-11,547	78.8-99.2			

*Count based on fry siphoned from nest.

lengths of fry developmental periods based on a single test at each temperature were 192, 120, and 96 hr, respectively.

<u>Bluegill Eggs</u>

Laboratory tests of hatching success of bluegill eggs at constant water temperatures were highly variable. Variability was especially pronounced at lower temperatures (Table 11). Hatching success for all artificially spawned eggs was significantly lower than that for naturally spawned eggs. Due to the extreme variability in artificially spawned eggs, results of hatching success estimates at the various test temperatures in Table 11 are based on naturally fertilized eggs. Estimates of hatching success ranged from 0 to 100 percent. Average hatching success increased as hatching temperatures were increased from 16 to 28 C. The variability of hatching success also decreased as hatching temperatures increased.

Length of the hatching period was determined from artificially spawned and fertilized eggs since the exact time of naturally spawned eggs could not be determined. The length of hatching and fry developmental periods was inversely related to water temperatures (Fig. 15). Hatching times for the few artificially spawned and fertilized eggs that successfully hatched were similar to those reported by Makamura (1971), Morgan (1951), and Meyer (1970). Hatching times at 16 C were determined by extrapolation of the following model because little data are available on the length of the hatching period at this temperature:

$$L_H = 4.739 - 2.27\ (T_C) \quad R^2 = 0.958$$

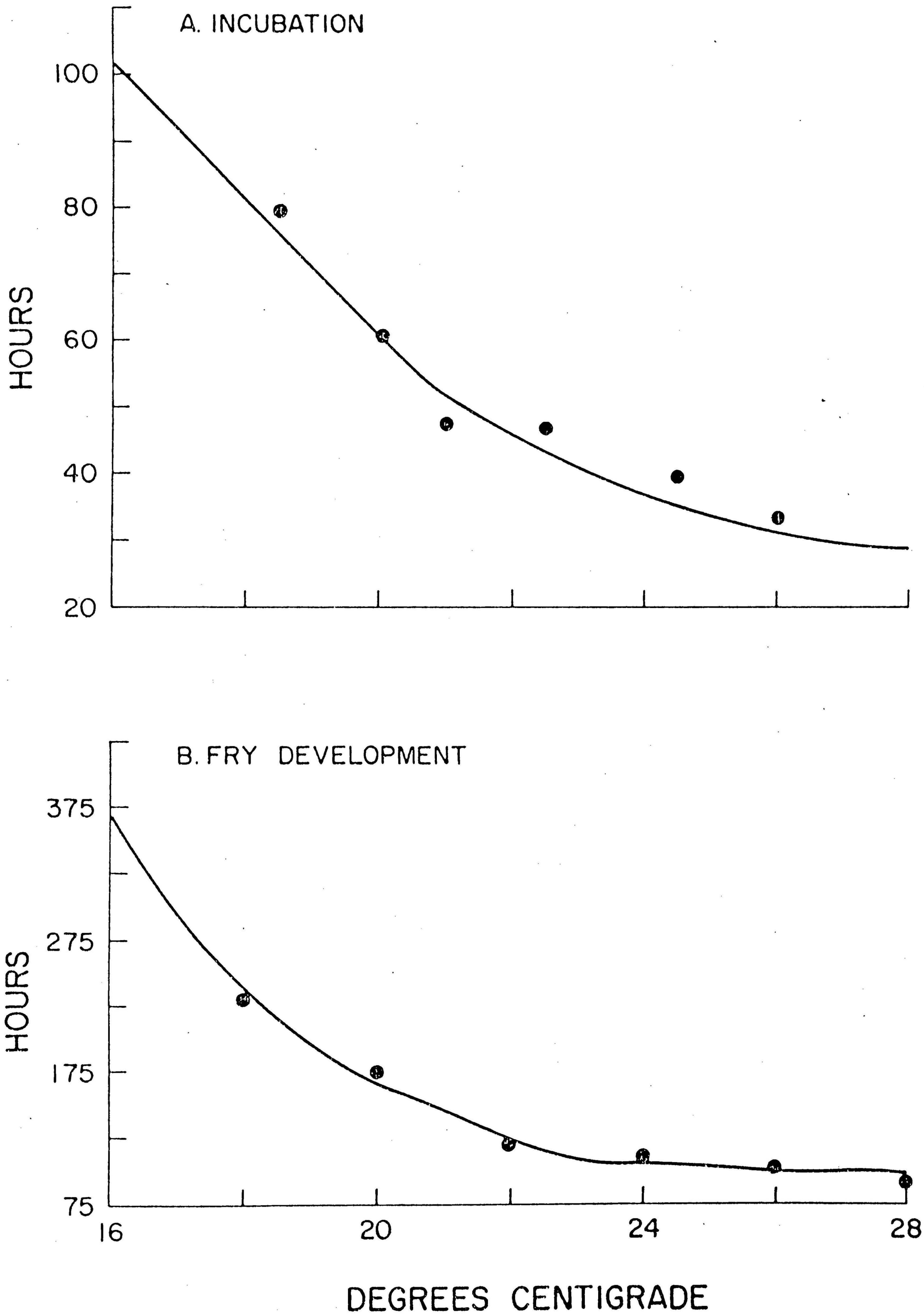
where:

$L_H = \log_{10}$ hatching period (hr).

Table 11. Relative percentage hatching success of bluegill (*Lepomis macrochirus*) eggs incubated in a laboratory at constant water temperatures. All eggs were collected from nests at either Smith Mountain or Leesville Lake, Virginia during 1975.

Temperature C						
16	18	20	22	24	26	28
100.0	59.0	11.8	8.64	56.2	96.6	84.6
0.0	86.6	29.5	100.0	89.3	98.1	98.8
29.2	15.2	5.6	77.2	59.4	71.6	100.0
0.0	77.2	4.5	63.6	75.1	88.7	100.0
62.8	54.8	100.0	100.0	68.8	98.2	80.2
63.7	35.2	59.8	77.9	85.6	97.7	100.0
77.5	94.6	61.4	100.0	78.0	93.8	98.6
10.7	68.6	86.8	71.8	61.7	100.0	59.7
20.0	50.0	98.0	78.7	71.9	59.3	100.0
1.3	34.8	25.0	8.0	100.0	96.4	86.1
Mean						
36.5	57.6	48.2	68.4	74.6	90.0	90.8
S.D.						
36.6	24.9	37.8	34.1	14.0	13.6	13.3

Fig. 15. Relationship between lengths of hatching (A) and fry developmental (B) periods as a function of water temperature in bluegill (*Lepomis macrochirus*).


A. INCUBATION
100
80
60
40
20
HOURS
B. FRY DEVELOPMENT
375
275
175
75
HOURS
16
20
24
28
DEGREES CENTIGRADE

$T_C = \log_{10}$ incubation temperature (C).

A similar inverse relationship for the length of the fry developmental period to the swim-up stage at various temperatures from 16 to 28 C was found (Fig. 15). The following model best described the relationship between fry development and water temperatures:

$$L_D = 5.545 - 2.516\ (T_C)\quad R^2 = 0.943$$

where:

$L_D = \log_{10}$ fry developmental period (hr).

$T_C = \log_{10}$ of water temperatures (C).

The sum of hatching and fry developmental periods represent the total average number of hours that bluegill spawning nests would have to be covered for successful reproduction. These times and respective water temperatures are as follows:

28 C - 120 hr; 26 C - 138 hr; 24 C - 152 hr; 22 C - 170 hr;

20 C - 237 hr; 18 C - 308 hr; and 16 C - 476 hr.

Exposure of nests at anytime during this time period would reduce the average success of bluegill spawning.

Exposure of Eggs

Eggs spawned by centrarchid fishes above minimum pool level would be exposed to the air for various lengths of time. Little data are available to indicate whether centrarchid fish eggs can successfully tolerate exposure to air without causing complete mortality.

Largemouth Bass

Largemouth bass eggs were found to be relatively tolerant of exposure to air during daylight and nighttime laboratory tests. Exposure to air during nighttime for 7 hr and in the shade during the day for 3 hr reduced hatching success about 13 percent from the controls (Table 12). Results of a Wilcoxon nonparametric test indicated that hatching success of bass eggs were significantly ($\alpha = 0.05$) reduced by 10 hr exposures to air from that of the controls. Hatching success for 2 and 4 hr exposures at room temperature in the dark was significantly lower than 10 hr exposures to outside air in the shade. Exposure of bass eggs to direct sunlight for 1 hr reduced hatching success about 50 percent.

Bluegill

Naturally spawned and fertilized bluegill eggs were more tolerant of exposure to air than largemouth bass eggs (Table 13). Exposure of bluegill eggs to outside air in the shade for as long as 9 hr did not significantly alter their hatchability ($H_0 : B = 0$, $\alpha = 0.40$, 9 df) from that of control lots.

Bluegill eggs exposed in natural nests for 23 hr averaged 6.6 percent hatchability (Table 14). Estimates of hatching success by test lot at various exposure times were generally similar with the exception of one lot of eggs exposed for 4 hr that exhibited about 20 percent reduction in hatchability. The relationship between hatching success and exposure times was:

$$S_E = 77.964 - 2.52 \ (H_E) \quad R^2 = 0.599$$

where:

S_E = Estimate of hatching success (percent).

H_E = Exposure time (hr).

Ninety-five percent confidence intervals on B the regression coefficient were $\pm$ 1.181.

Table 12. Average hatching success (%) of largemouth bass (*Micropterus salmoides*) eggs following exposure to air in artificial nests during daylight and nighttime hours.* Following exposure, eggs were held at 20 C until hatched.

Exposure- Length (*hr*)	Condition	Mean hatching success	No. of tests
0 (Control)	-	87	2
1/2	Sun	73	2
1	Sun	11	2
2	Dark (Lab)**	44	2
4	Dark (Lab)**	48	2
10	Shade***	74	4

*Air temperatures during exposure ranged 18.5 to 20.0 C.
**Room temperature at 24 C with about 60% humidity.
***Outside exposure of 7 hr night and 3 hr shade.

Table 13. Average hatching success (%) of bluegill (Lepomis macrochirus) eggs following exposure to air in artificial nests during night and daytime hours.* Following exposure, eggs were incubated in the laboratory at about 26 C until hatched.

Exposure- Length (hr)	Condition	Mean hatching success	No. of tests
0 (Control)	-	90	12
1	Shade	89	4
2	Shade	78	2
9	Shade**	91	2

*Outside air temperature ranged 17.8 to 20.0 C.
**Exposure of 7 hr night and 2 hr daylight.

Table 14. Mean hatching success (%) of bluegill eggs (*Lepomis macrochirus*) following exposure to air during daylight* and night-time hours in natural spawning nests at Leesville Lake, Virginia. Following exposure, eggs were incubated in the laboratory at about 26 C until hatched.

Exposure length (hr)	Exposure condition	Mean hatching success	No. of tests
0	None	89.8	12
1/2	Day**	75.3	1
4	Day	65.5	2
4	Night & Day	49.5	7
11	Night & Day	64.9	3
14	Night & Day	38.3	4
17	Night & Day	51.4	2
22	Night & Day	15.5	2
23	Night & Day	6.6	3

*Day exposures were in direct sun with little clouds.
**Exposures made in artificial nests.

Nest Desertion Behavior

Bluegill

A few observations were made on male bluegill defending spawning nests while water levels receded below the level of nest construction. Male bluegills tended to remain on the nest defending the eggs and fry from predation until water elevations dropped to about 3 cm above the perimeter of the nest. Males at this time left the nest and preyed on eggs in neighboring nests. If another male advanced to prey on eggs in their nest, however, the defending male would drive off the intruder and return to eating eggs from deserted nests. Male bluegill protecting nests with eggs remained on nests at shallower water levels than those defending nests without eggs.

Some observations were made to determine if males returned to their nests when water levels increased to again cover the nests. Reduced water transparencies during generation made observations difficult. It was determined, however, that at least some male bluegill immediately returned to nests with eggs and appeared to resume their defensive position over the nest. However without tagging fish, it was difficult to distinguish between males homing to and defending their own nests from those preying on the eggs of other nests.

Computer Implemented Model

Prediction of bluegill spawning success was accomplished through the use of SUCCESS at seven water temperatures, 16, 18, 20, 22, 24, 26, and 28 C. Predicted estimates of spawning success based on water elevations for 1974 are shown in Table 15. Estimates based on water temperatures from 16 to 28 C are shown in Appendix Table VII. Results of SUCCESS

Table 15. Mean estimated probabilities of bluegill (Lepomis macrochirus) spawning success for Leesville Lake during 1974 as a function of depth and location predicted by SUCCESS, a computer implemented model. Spawning success estimates for the various reservoir zones are based on the following water temperatures (C): 26 (lower); 21 (mid); and 18 (upper). Depth weighting factors, used to calculate net spawning success, are not shown but were obtained from the vertical distribution of spawning nests (Fig. 14).

Depth (m)	Reservoir zone- Lower	Mid	Upper
186.8 to 185.6	0.000	0.000	0.000
185.3	0.000	0.000	0.000
185.0	0.002	0.000	0.000
184.7	0.005	0.000	0.000
184.4	0.019	0.000	0.000
184.1	0.046	0.009	0.001
183.8	0.076	0.001	0.001
183.5	0.095	0.012	0.001
183.2	0.131	0.017	0.001
182.9	0.253	0.030	0.002
182.6	0.847	0.629	0.484
182.3	0.847	0.629	0.484
182.0	0.847	0.629	0.484
181.7	0.847	0.629	0.484
181.4	0.847	0.629	0.484
Net success by zone	0.407	0.250	0.188

indicated that water level fluctuations would affect bluegill spawning success most severely at lower water temperatures. Predicted estimates of spawning success at water temperatures commonly occurring in the mid and upper reservoir zones at and above minimum water level (182.9 or 600 ft) were less than 5 percent. Estimates of spawning success throughout the water column for the mid and upper zones ranged from 19 to 25 percent. The occurrence of higher water temperatures in lower Leesville would insure from 12 to 38 percent spawning success in eggs in nests at and to 1 m above minimum pool level. Estimates of spawning success throughout the water column for lower Leesville Lake averaged 41 percent and ranged from 33 to 50 percent.

Using average estimates of spawning success for lower (28, 26, and 24 C), mid (22 and 20 C), and upper (18 C) Leesville Lake (Table 15), and the estimated horizontal distribution of spawning sites in these zones, an estimated 31 percent spawning success for bluegill would occur in the entire reservoir.

DISCUSSION

The relative success of centrarchid fishes that spawn in unstable aquatic environments has been of concern to fisheries managers for many years. The basis for this concern is that centrarchid fishes are generally found in the relatively stable environments of lakes and ponds; these physical conditions are a direct antithesis to the physical conditions in pumped storage reservoirs having rapid temperature changes, fluctuating water levels, and flow reversals with high water velocities. Prior to this study, little data on the effects of pumped storage project operations on spawning success of centrarchid fishes were available.

Results of this study support the conclusion made by Estes (1971) that largemouth bass and bluegill are successfully spawning in Leesville Lake although fish are subjected to adverse physical conditions during the spawning season. My data however, strongly indicate that project operations at the Smith Mountain Dam power plant does affect the success of centrarchid fish spawning in the mid and upper reservoir zones and to a lesser extent in lower Leesville Lake. Although most of my data were collected on bluegill, these data also probably apply to largemouth bass in Leesville Lake.

Results of a stepwise regression model indicated that water velocity during generating operations at Smith Mountain Dam had the greatest negative effect on the distribution of spawning nests along the shoreline in the main lake of Leesville. Water velocities during pumping operations along the shoreline were about 30 percent lower than those occurring during generation in upper Leesville and were subsequently deemed non-significant. Shoreline surface velocities in upper Leesville Lake were similar to those in some rivers and streams. In upper Leesville, water velocities during generating operations were within the recommended range of water velocities for reproduction of some Oregon salmonids (Smith 1973). However, centrarchid fishes appeared to attempt to compensate for moving waters by spawning on the downstream side of obstructions. In mid Leesville Lake along the shoreline, Lepomis sp. also spawned in areas sheltered from the current; i.e., the downstream side of rocks or boulders. Spawning nests that could be adversely affected by the current, by the location in the main channel along the shoreline in mid Leesville, were solitary and widely scattered as was also observed by Breder (1936). Nests in colonies were found only in the coves in mid Leesville Lake. In contrast, nests in colonies were found along the shoreline of the main lake from station 8 to station 1. Water velocities were negligible at these locations. Sunfish eggs and fry were observed in nests both in coves and along the main lakeshore from station 8 to station 1 whereas nests containing eggs and fry were found only in coves from station 8 to station 11. No spawning nests were located along the shoreline of the main lake in the upper reservoir zone. This distribution presumably was the result of avoidance of high water velocities.

The greatest occurrence of spawning nests in Leesville Lake was in the mid reservoir zone (57 percent) followed by the lower zone (40 percent), and the upper zone (3 percent). These percentages are based on a constant unit of diving effort as explained in the Results section.

Solitary spawning nests located along the shoreline from station 8 to station 11 may have been spawning nests of pumpkinseed. Pumpkinseed were more common in this area of the lake than any other portion (Table

3), and are reported to spawn at lower water temperatures than bluegill (Clark and Keenleyside 1967). Breder (1936) also, indicated that pumpkinseed are more commonly found in moving waters than bluegill. Consequently, habitat in the upper and upper-mid reservoir zones may be more suitable to pumpkinseed than to bluegill. Spawning success may be one reason for the apparent high abundance of pumpkinseeds in upper Leesville Lake.

Low water temperatures affect the timing of spawning, rate of hatching and development, and the relative spawning success of centrarchid fishes in Leesville Lake. Low water temperatures in the spring during the period of gonadal development can apparently delay the timing of centrarchid fish spawning. Dissections of bluegill from lower, mid, and upper Leesville Lake demonstrated that delayed gonadal development and delayed spawning may indeed occur in Leesville Lake. Delayed gonadal development was observed in bluegill from mid and upper Leesville Lake during 1972 and to a lesser extent in 1974 (Fig. 12). Higher general water temperatures from May throughout the spawning season in 1974 were probably the reason for rates of gonadal maturation being more similar throughout Leesville Lake during 1974 than in 1972.

Water temperatures in lower Leesville Lake were found to be slightly lower than water temperatures reported for Smith Mountain Lake by Simmons and Neff (1969). Consequently, the timing of spawning of centrarchid fishes in Leesville may be delayed and extended relative to Smith Mountain Lake fishes. Spawning of largemouth bass in Smith Mountain Lake generally commenced around the first part of May and continued for about 4 to 6 weeks. Largemouth bass examined for reproductive condition at the Smith Mountain Lake Fishing Contest held the first weekend of May were nearly ripe and ready to spawn. In Leesville Lake, however, spawning of largemouth bass apparently occurs from mid-May into July, about 2 weeks later than the incipience of spawning at Smith Mountain Lake. These observations generally support Estes' (1971) hypothesis that spawning of largemouth bass in Leesville Lake was slightly later than that of largemouth bass in other lakes in the same geographical area.

Delayed spawning of bluegill in Leesville Lake was suggested by Estes (1971) and observed in this study. Underwater observations made at Smith Mountain Lake in 1975 indicated that bluegill were spawning in the later part of May with peak spawning probably occurring around the middle of June (personal communication - Eric D. Prince). In Leesville, studies at spawning sites indicated that spawning began in lower Leesville the first week of June 1975 and may not actually occur from station 10 to Smith Mountain Dam until the last of June or first of July.

Water temperatures are sufficiently low in upper Leesville to inhibit centrarchid fish spawning. Water temperatures were generally lower in upper Leesville Lake during 1972 than 1973 and 1974 (Figs. 3, 4, and 5). Lowest water temperatures during the 1972 centrarchid fish spawning season in upper Leesville were occasionally around 16 C. However, water temperatures at 17 C appear to be near the minimum temperature that will initiate bluegill spawning activities. The initiation of spawning of bluegill was observed in the mid reservoir zone in Leesville in June 1974 when water temperatures averaged about 17 C. Clark and Keenleyside (1967) found bluegill spawning at 17 and 23 C in two ponds in Canada. Stevenson, Momot, and Svoboda (1969) found the majority of bluegill spawning activity in Ohio at 26 C although some natural spawning was initiated at 17 C. Other authors have reported slightly higher temperatures for bluegill spawning. Breder (1936) suggested that most bluegill in New York spawn at 24 C. Mraz and Cooper (1957) indicated that bluegill initiate spawning activities in Pennsylvania at about 21 C. Morgan (1951) reported that the range of water temperatures suitable for bluegill spawning in Buckeye Lake, Ohio was 19.4 to 30.6 C. My observations and these studies suggest that summer water temperatures in upper Leesville at 16 C may inhibit natural spawning of bluegill.

Gonadal maturation and spawning of some largemouth bass in Leesville may be delayed until fall by low water temperatures. Estes (1971) suggested that fall spawning of largemouth bass may occur in Leesville Lake. Fall spawnings of bass were also suggested by Stevens (1970). Also, Brauhn, Holz, and Anderson (1972) reported that largemouth bass held at 17 C spawned in August after being transferred to ponds ranging in water temperature from 23 to 31 C. Since water temperatures of 16 and 17 C occurred in upper Leesville during this study, gonadal maturation and spawning by largemouth bass may in some cases be delayed similar to that of bass held at 17 C by Brauhn, Holz, and Anderson. However, no data were collected that support this hypothesis.

Low water temperatures were also found to affect the hatching success of bluegill. Although bluegill probably do not spawn at 16 C, naturally spawned and fertilized eggs were found to successfully hatch at 16 C. Hatching success was, however, significantly reduced at 16 C and highly variable. Variability in hatching success of naturally spawned bluegill eggs at 16 C is probably related to the stage of embryo development. Variability in tests of hatching success was about 40 percent higher at temperatures of 16, 18, 20, and 22 C than at 24, 26, and 28 C. Other studies have found similar variation in evaluating temperature effects on hatching in bluegill. Banner and Van Arman (1973) evaluated the effects of various hatching temperatures from 18 to 38 C. Eggs were artificially fertilized from bluegill collected in Florida and hatched using methods similar to those employed in this study. Comparison of their results with mine indicate differences in the lower temperature requirements for hatching, possibly due to racial differences between spawning stocks. Eggs hatched in this study were from more northerly bluegill stocks which apparently have lower temperature tolerances for hatching. For example, Banner and Van Arman's results indicated zero hatching success at 18 and less than 5 percent hatchability at 20 C compared to 58 and 48 percent, respectively, found in this study. Their average estimates of hatching success from 22 to 28 C were similar to mean hatching success estimates at the same temperatures in this study. Variation in hatchability was high in both studies although Banner and Van Arman's mean estimates were based on one replicate while mine were based on nine replicates. Results of hatching success of bluegill eggs from Minnesota at 23 C (Hokanson and Smith 1971) were generally higher than my estimates of hatchability at either 22 or 24 C. The estimates of hatching success by these authors were similar to my results at 26 and 28 C. Differences in hatching success may again be due in part to racial differences for increased tolerance to lower temperatures during hatching.

In addition to temperature related mortalities, low water temperatures can indirectly decrease spawning success of centrarchid fishes by increasing the length of the hatching and fry developmental periods. While in the nest, eggs and fry are highly vulnerable to various factors that may cause mortality such as predation, hypoxia, nest exposure, and siltation. Higher water temperatures increase the rate of development and shorten the egg and fry stages. Conversely, low water temperatures increase the time that eggs and fry are vulnerable to these various indirect mortality factors. These indirect mortality factors would consequently have greater effect on the spawning success of centrarchids in mid and upper Leesville Lake as the result of lower water temperatures in these areas. Kramer's (1961) data on survival of largemouth bass fry support this hypothesis; he found higher survival was directly correlated with higher water temperatures.

Daily as well as seasonal changes in water temperatures in mid and upper Leesville from pumping and generating operations may affect the time when spawning occurs. In mid and upper Leesville Lake, water temperatures at spawning depths generally increased on the weekends as the pumping operations at Smith Mountain Dam drew the warmer waters from lower Leesville to the upper reservoir zone. Spawning of bluegill has been correlated with rising water temperatures within the range of the spawning temperature requirements (Clark and Keenleyside 1967; Stevenson, Momot, and Svoboda 1969; Breder 1936). Consequently, it was thought that more spawning might occur on the weekends in the upper and mid reservoir zones of Leesville than during the week. Increased spawning activity on the weekends was not found in this study, however, and was consequently not incorporated into the model.

Rapid water temperature changes could cause additional stress on eggs and fry in mid and upper Leesville Lake. Estes and Cumming (1969) indicated that temperature changes of 13.9 C could occur in upper Leesville Lake when generating operations closely followed pumping at Smith Mountain Dam. I never observed these extreme temperature changes. However, rapid water temperature changes in the magnitude of 10 C were observed during this study. Mortality of bluegill eggs and fry was observed in natural spawning nests during July 1974 about 14 km from Smith Mountain Dam presumably resulting from rapid temperature drops during extensive periods of power generation.

The magnitude and frequency of water level fluctuations in Leesville Lake are much greater than normally occur in most reservoirs during the spawning season of centrarchid fishes. Most fisheries biologists generally regard centrarchid fishes as shallow water spawners. Consequently, water level fluctuations during the spawning season could severely affect spawning success. Depth of spawning of centrarchid fishes appears to be directly correlated with water transparency; depth of spawning usually increasing with increased transparency. Many reports suggest this phenomenon. Trautman (1957) reported spawning nests of smallmouth bass at 6.7 m in clear waters but he never found nests deeper than about 1 m in turbid waters. Most other reports in the literature indicate that spawning activity of most centrarchid fishes occur in the upper 2 m from the surface of the water. Everman and Clark (1920) reported an average spawning depth of largemouth bass to about 2 m. Other authors have reported shallower depths of spawning for largemouth bass. Kramer (1961) reported about 45 cm as an average spawning depth for largemouth bass. Clugston

(1966) reported bass spawning from 30 to 75 cm in depth. Kramer (1961) suggested that depth of spawning may be related to water level fluctuations although the fluctuations in water levels were only about 2.5 percent the magnitude of water level fluctuations in Leesville Lake. Spawning nests of largemouth bass in Leesville Lake were located at depths greater than 4 m relative to full pool. The depth of spawning is an apparent response to water level fluctuations in spite of generally turbid conditions.

Bluegill spawning in Leesville Lake also occurred at abnormally low levels relative to published reports. Morgan (1951) reported that bluegill spawning nests in an Ohio lake were located from 0.3 to 1.5 m below the surface. Breder (1936) indicated that most Lepomis sp. spawning nests in New York were from 0.3 to 0.6 m deep. The deepest known report of sunfish spawning was presented by Swingle and Smith (1950); bluegill spawning nests were found in water to 3.1 m where dense growths of aquatic weeds covered shallow shoreline areas. Less than 1 percent of the sunfish spawning nests in Leesville Lake were within the range of spawning depths reported by these authors. The remaining 99 percent of spawning nests in Leesville were at deeper depths.

Adjustment in spawning depth has obviously occurred in largemouth bass and bluegill in Leesville Lake. Depth of spawning regulated only by water transparency would be expected to occur at relatively shallow depths due to the moderately high turbidities. Depth of spawning by bass and sunfish in Leesville appears to more nearly follow Kramer's hypothesis that depth of spawning may be related to the magnitude of water level fluctuations. Also, there is quite likely an interaction between depth of spawning and availability of suitable spawning habitat. For example, a small peak in spawning at a depth of 183.8 m (603 ft) elevation (Fig. 14), in Leesville Lake was mainly associated with small tributary flood plains. These areas were generally flat and afforded gravel and sand substrate. These materials have been considered important in the selection of nesting sites by bluegill (Snow, Engisn, and Klingbiel 1970).

Spawning site selection in Leesville appears to be constant from year to year. Areas utilized by sunfish for spawning in 1974 were also utilized in 1975. Most nests were located from 1 m above to about 1 m below minimum pool level.

Spawning in Leesville Lake at abnormally deep levels is the first well documented occurrence of centrarchid fishes adjusting their depth of spawning to the existing water level fluctuations. Kramer (1961) reported largemouth bass adjusted their spawning depth to water level fluctuations, but the adjustments he reported were less than 15 cm. Baren (1971) reported that centrarchid fishes successfully spawned in ponds where water level fluctuations simulated proposed operations of the Yards Creek Pumped Storage Project, however, the mean depth of spawning was greater in a control pond with increased water transparencies.

Spawning success of largemouth bass may be enhanced in Leesville Lake by reduced water level fluctuations during a portion of the bass spawning season. The timing of spawning of largemouth bass in lower Leesville Lake occurs about the same time as the striped bass (Morone saxatilus) spawning run in the Roanoke (Staunton) River below Leesville Dam. During about a 20 day period in late May or early June, the Appalachian Power Company provides increased, regulated downstream discharges for spawning striped bass. During this time, water level fluctuations are reduced in Leesville Lake (Fig. 11). The reduced water level fluctuations increase the probability of successful spawning by largemouth bass by providing a more stable environment during the spawning season. Since hourly water elevations are input data for SUCCESS, higher estimates of spawning success would be predicted during this period of reduced water level fluctuations, providing the period of water level stabilization was of sufficient length to permit hatching and fry development.

Baren (1971) implied a possible tolerance of smallmouth bass eggs to exposure to air. Results from my exposure tests indicated that successful hatching can occur in largemouth bass and bluegill eggs after exposure to air, but with a decrease in hatchability. Survival of bluegill eggs exposed to air in the shade for 9 hr was similar to that of controls. Exposure times of as much as 23 hr during the day and nighttime at natural spawning nests in Leesville Lake did not result in 100 percent mortality of exposed eggs. Although many of the eggs appeared small and dehydrated following exposure, when placed in water, some of these eggs swelled, appeared normal, and hatched. These results suggest that under normal project operations on the weekends, some limited hatching success would occur in exposed nests. Current operation schedules at Leesville generally indicate, however, that spawning nests constructed at levels higher than about 1 m above minimum water level would receive more than 24 hr exposures and probably would suffer nearly 100 percent mortality. These data were used to develop the equation that described hatching success as a function of exposure time. This equation was incorporated into a subprogram called by SUCCESS to calculate hatching success based on various exposure times. The use of these data increase the ability of the model to mimic the real system.

Although some bluegill and largemouth bass egg lots were found to survive short-term exposure to air, secondary effects of exposure may also adversely affect survival. One of these important secondary effects is predation on unattended eggs and fry. Neves (1975) reported that nest attendance by a defending male smallmouth bass was mandatory to prevent total loss of eggs or fry to predation. Kelley (1968) indicated that survival of largemouth bass eggs from deserted nests ranged from 0 to 50 percent. Lydell (1904) reported that nest desertion in largemouth bass resulted in nearly complete loss of spawn. My underwater observations made in Smith Mountain and Leesville Lakes following removal of male sunfish indicated predation on eggs and fry by sunfish and carp (Cyprinus carpio) was rapid. However, my observations on two male bluegill suggest that some centrarchid fishes may indeed return to tend their nests as soon as water levels permit. My observations are also supported by those made by Baren (1971) in a pumped storage pond simulation study. He found that a smallmouth bass built its nest after a large drawdown, spawned after the second drawdown, and returned to the nest after each subsequent drawdown until hatching. Consequently, brief water drawdowns do not necessarily cause permanent desertion and some of the secondary effects of exposure to air may be minimal. The secondary effects of predation on exposed nests was not quantifiable and was consequently not incorporated into SUCCESS.

Results of SUCCESS indicate that low water temperatures and water level fluctuations in Leesville Lake interact to affect the distribution of spawning and survival of bluegill eggs and fry (Table 15 and Appendix Table VII). Predicted estimates of spawning success varied greatly at water temperatures from 16 to 28 C at, above, and below 182.9 m elevation (minimum water level). These estimates of spawning success indicate that survival of eggs and fry vary within a reservoir zone as a result of temperature differences between the upper and lower boundaries of the zone. For example, from station 8 to station 6 in the lower section of the mid reservoir zone, water temperatures are near 24 C during the spawning season. SUCCESS predicted that spawning success at this temperature would be as high as 12 percent at and above minimum water level. Estimates of 33 percent spawning success were made at water column temperatures of 24 C. In the upper section of the mid reservoir zone, water temperatures of 18 and 20 C commonly occurred during the spawning season. Estimates of spawning success at 18 and 20 C are less than 1 percent at and above minimum water level and from 19 to 22 percent throughout the water column. In contrast to the low water temperatures in mid and upper Leesville Lake, higher water temperatures in lower Leesville result in shorter hatching and developmental periods. The shorter time periods insure that a minimum of 12 percent spawning success (24 C) does occur at and above minimum pool level in lower Leesville Lake. For example, SUCCESS indicated that at 28 C, about 15 to 38 percent of the eggs spawned at minimum pool level to 183.3 m elevation (603 ft) would survive to become fingerlings. Predictions of spawning success throughout the water column at 28 C were about 50 percent. Therefore, higher predicted estimates of spawning success as a result of higher water temperatures in lower Leesville support the conclusion made by

Estes (1971) that "most (successful) spawning probably occurred in the lower portion of the reservoir."

The utility of SUCCESS is not limited to centrarchid fishes or other nest spawning fishes. To use SUCCESS for other species, one would only need to evaluate the mathematical relationships for the various subprograms. Also, SUCCESS could be directly used to predict spawning success of bluegill in other pumped storage reservoirs providing the necessary input data of temperature regimes, hourly elevations, and vertical distribution of spawning nests were available. SUCCESS was not used in this study to predict spawning success of largemouth bass. Data on the spatial distribution of spawning nests (9 were located) were deemed insufficient to permit a realistic estimate of spawning success of bass. Predicted estimates of spawning success of largemouth bass, however, probably follow a trend similar to that of spawning success of bluegill in Leesville.

Natural spawning success of largemouth bass and bluegill in Leesville Lake appears to be sufficient to maintain these stocks (Table 3) under present levels of exploitation. Currently, stock densities of bluegill are being maintained in the upper third of the lake by about 19 percent spawning success throughout the water column. No successful spawning occurs at and above minimum water level in the upper zone. Spawning success in mid Leesville is higher and ranges from 33 percent near station 6 to 19 percent near station 11.

These estimates of spawning success of bluegill (Table 15 and Appendix Table VII) and the relative abundance of centrarchid fishes (Table 3) suggest that conditions occurring in mid and upper Leesville Lake are indeed marginal for spawning of centrarchid fish stocks. Under present power plant operating conditions at Smith Mountain Dam, water entering Leesville from Smith Mountain Lake is too cold to support a good warmwater fishery and too low in dissolved oxygen to support a trout fishery. The problem of too low a temperature to support a good warmwater fishery could possibly be overcome by drawing warmer highly oxygenated waters from the surface of Smith Mountain Lake into Leesville. Elevated water temperature regimes in upper and mid Leesville Lake would increase the spawning success and growth of centrarchid fishes. However, the occurrence of high water velocities would probably restrict most spawning activity in upper and mid Leesville Lake to coves. Another possibility would be to develop a coldwater fishery in the upper reservoir zone. Water temperatures in upper Leesville Lake are well within the upper thermal limits of selected stocks of salmonid fishes. Although some salmonids were once stocked in Leesville, low dissolved oxygen levels measured in this study (Figs. 9 and 10) and reported by Estes (1971) suggest that insufficient oxygen concentrations probably precluded these fish from doing well. Consequently, dissolved oxygen levels would probably have to be increased in upper Leesville in order to develop a coldwater fishery. There are a number of ways of increasing the dissolved oxygen content of the water at dams. Once this adjustment has been implemented at Smith Mountain Dam, favorable physical and chemical conditions could conceivably occur for establishment of a coldwater fishery in upper Leesville Lake. Increased levels of dissolved oxygen in inflowing water from Smith Mountain Lake might also increase the oxygen concentrations sufficiently in the upper section of the mid reservoir zone to support selected salmonids. However, these effects would probably produce negligible changes in the physical and chemical conditions in the remaining portion of Leesville. Consequently, the increase in suitable habitat for salmonid fishes would probably only occur in the upper third to half of the reservoir.

Pumped storage power production is rapidly providing a significant portion of our electrical peak power base. A large part of the peak power demands of the future will probably be met by pumped storage generation. The future of pumped storage reservoirs for recreational development in the United States should be the combined responsibility of resource managers from industry, government, and academia with inputs from the public. Care must be taken during project development to maximize the potential of these impoundments for power generation, recreation, fish and wildlife, and aesthetic appearance and minimize potential environmental degradation. Based on the results of this study, at least some centrarchid fishes appear to adjust to the fluctuating conditions of pumped storage operations. Current restrictions on operations of some pumped storage reservoirs during the spawning seasons of some centrarchid fishes may be overly stringent. To properly maximize electrical power output and centrarchid fish spawning success from pumped storage reservoirs, the effects of each pumped storage system on the indigenous fishery resource should be individually evaluated. The overall recreational potential should be skillfully interwoven into pumped storage project operations schedules so that the resulting aquatic resource can be judiciously utilized.

SUMMARY

Physical conditions in Leesville Lake undergo continuous alteration as a result of pumped storage operations at the Smith Mountain Dam power plant. Fluctuating water levels and temperatures and high water velocities during periods of flow reversals occur during the spawning season of centrarchid fishes.

High water velocities restricted centrarchid fish spawning activity in the upper 14 km (marker 8 to Smith Mountain Dam) almost entirely to cove areas. The few centrarchid fishes that spawned outside of coves appeared to compensate for the high water velocities by spawning on the downstream side of obstructions along the shoreline in the main lake. Water velocities had negligible effects on the distribution of spawning activity in lower Leesville Lake.

Low water temperatures from the intrusion of subsurface Smith Mountain Lake waters into upper Leesville Lake delayed fish gonadal maturation throughout all of Leesville Lake about two weeks. Generally, the incipience of bluegill spawning in Leesville occurred earliest in the warmer lower zone, later in the mid zone, and last in the upper reservoir zone during 1972 and 1974.

Trained divers located 9 largemouth bass and 2001 sunfish spawning nests in Leesville Lake. All bass nests were located at or below minimum water level whereas more than 1760 sunfish nests (88 percent) were found from below to 1 m above minimum water level.

Bluegill embryo development studies, conducted under conditions of controlled water temperature and exposure to air, evaluated hatching success, tolerance to exposure to air, and rates of hatching and fry

development at various water temperatures extant in Leesville Lake during the spawning season. Average hatching success increased as incubation temperatures were increased over a temperature range of 16 to 28 C. The variability of hatching success decreased with increased water temperatures. Increased water temperatures geometrically decreased the time when eggs and fry were vulnerable to exposure to air; this interaction between water temperature and exposure to air resulted in higher survival of bluegill at and above minimum water level as temperatures increased. Bluegill eggs were also found to hatch following day and nighttime exposures to air; hatching success decreased linearly with increasing lengths of exposures to about 24 hr when 100 percent mortality would occur.

A computer implemented model, SUCCESS, was developed to predict spawning success of centrarchid fishes in pumped storage reservoirs. Field and laboratory studies on bluegill eggs and fry provided the necessary input data to estimate spawning success in Leesville Lake. The model estimated spawning success of bluegill would be highest in the lower reservoir zone, averaging about 41 percent throughout the water column. Spawning success could be as high as 38 percent at and above minimum water level. However, the occurrence of water temperatures at or below 22 C in mid and upper Leesville Lake would limit spawning success of bluegill at and above minimum water level to a maximum of 5 percent. Bluegill spawning success throughout the water column in mid and upper Leesville would attain a maximum of 27 percent. Based on the spatial distribution of sunfish spawning nests in Leesville Lake, spawning success throughout the water column for the entire reservoir would be near 31 percent. This prediction of spawning success of bluegill in Leesville Lake is also probably representative of spawning success for largemouth bass. However, based on the relative abundance of other sunfishes, redbreast sunfish and pumpkinseed may be more successful in spawning in the cooler mid and upper reservoir waters than in lower Leesville although insufficient data precluded estimating spawning success by the model. Although an estimated 31 percent spawning success appears low, densities of bluegill and largemouth bass stocks in Leesville Lake appear to be maintained by natural spawning success under current levels of exploitation.

CONCLUSIONS

1. Spawning seasons of largemouth bass and bluegill were delayed greater than two weeks in Leesville Lake by the intrusion of subsurface waters from Smith Mountain Lake. Therefore, the time of year when suitable spawning conditions exist in Leesville Lake are more than two weeks later than in other reservoirs in the same geographical area.
2. Horizontal distribution of sunfish spawning nests per unit diving effort was 40, 57, and 3 percent for lower, mid, and upper Leesville Lake, respectively. Therefore, the majority of sunfish spawning activity occurs in the mid and lower reservoir zones while little spawning activity occurs in upper Leesville.
3. Water velocities along the shoreline in the main lake, excluding coves, restrict about 95 percent of all spawning activity to cove areas from marker 8 to Smith Mountain Dam. Therefore, nearly all the spawning in the upper half of the reservoir occurs in cove areas.
4. Mean hatchability of bluegill eggs increased linearly at temperatures from 16 to 28 C. Highest hatching success occurred at 28 C and lowest at 16 C. Therefore, low water temperatures that commonly occur during the spawning season of bluegill in the mid and upper reservoir zones reduce hatchability whereas higher hatching success occurs in lower Leesville as a result of higher water temperatures.
5. Increased water temperatures geometrically decreased the hatching and fry developmental periods from 16 to 28 C. Therefore, higher water temperatures shorten the time that eggs and fry are vulnerable to exposure to air resulting in increased survival of bluegill under conditions of fluctuating water levels.

6. Hatching success of bluegill eggs exposed to air followed an inverse linear relationship; longer exposures to air resulted in decreased hatchability to about 24 hr when 100 percent mortality would occur. Therefore, all bluegill eggs that are exposed to air for up to 24 hr do not incur 100 percent exposure related mortality.
7. Spawning success of bluegill in upper Leesville Lake is near 19 percent throughout the water column. Survival at or above minimum water level is negligible. Therefore, low water temperatures and water level fluctuations interact to cause about 81 percent mortality of eggs and fry in upper Leesville.
8. Spawning success of bluegill averaged 25 percent and ranged from 19 to 33 percent in upstream to downstream areas throughout the water column in mid Leesville. Spawning success at or above minimum water level is near 5 percent. Therefore, water temperatures and water level fluctuations interact to cause about 75 percent mortality in bluegill eggs and fry throughout the water column and nearly 95 percent mortality at and above minimum water level in mid Leesville.
9. Spawning success of bluegill averaged 41 percent in lower Leesville Lake. The range was from 33 to 50 percent throughout the water column. Higher water temperatures in the lower reservoir zone increase survival at and above minimum water level to a maximum range of 12 to 38 percent which accounts in part for the higher predictions of spawning success. Therefore, survival of bluegill eggs and fry is nearly twice as high in the lower reservoir zone than in the other zones as a result of higher water temperatures.

10. Spawning success of bluegill for the entire reservoir based on the spatial distribution of spawning nests per zone averages about 31 percent. Therefore, 69 percent of all bluegill eggs and fry in the entire reservoir do not survive to the free-swimming fingerling stage.
11. Spawning success of bluegill and largemouth bass in Leesville Lake is sufficient to support the maintenance of stocks under current levels of exploitation.
12. Fishing pressure for bluegill in Leesville Lake is extremely light and fish are stunting. Therefore, exploitation of bluegill could probably be increased by about 30 to 40 percent in Leesville. This estimate of increased exploitation is approximate and is based on the abundance of bluegill in the reservoir.
13. Fishing pressure for largemouth bass in Leesville Lake is considered light. Therefore, exploitation of largemouth bass could probably be increased by about 15 to 25 percent. This estimate of increased exploitation is approximate and is based on the abundance of largemouth bass and fishing effort.
14. Adjustment in the depth of spawning in largemouth bass and bluegill stocks has occurred in Leesville Lake. Therefore, regulation of water levels in other pumped storage reservoirs during the spawning season for these centrarchids may not be necessary to maintain the stocks by natural spawning.
15. The interaction of water level fluctuations and low water temperatures and high water velocities adversely affect centrarchid fish spawning. Therefore, consideration must be given to the physical and chemical requirements of the fishery resource during development of future pumped storage projects.

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APPENDIX

Appendix Table I. Program listing for SUCCESS, a model to predict spawning success of centrarchid fishes in pumped storage reservoirs.

```
C
C      ******************************************************************
C
C
C
C       VPIVPI   VP    VP     VPIV      VPIV      VPIVPIV    VPIVPI    VPIVPI
C      VPIVPIV   VP    VP    VPIVPI    VPIVPI     VPIVPIV   VPIVPIV   VPIVPIV
C      VP        VP    VP    VP    VP  VP    VP   VP        VP        VP
C      VP        VP    VP    VP        VP         VP        VP        VP
C       VPIVPI   VP    VP    VP        VP         VPIVPIV    VPIVPI    VPIVPI
C       VPIVPI   VP    VP    VP        VP         VPIVPIV    VPIVPI    VPIVPI
C           VP   VP    VP    VP        VP         VP              VP        VP
C           VP   VP    VP    VP    VP  VP    VP   VP              VP        VP
C      VPIVPIV   VPIVPIV     VPIVPI    VPIVPI     VPIVPIV   VPIVPIV   VPIVPIV
C      VPIVPI    VPIVPIV      VPIV      VPIV      VPIVPIV   VPIVPI    VPIVPI
C
C      PREDICTED  CENTRARCHID  FISH  SPAWNING  SUCCESS
C
C
C      ******************************************************************
C
       INTEGER DSUB,TSUB,TZERO,HOUR,START
       DIMENSION TEMP(30),CUMSRV(30,30),DPTHSM(30),TEMPWT(30),
      1 TEMPSM(30),DPTHWT(30)
       COMMON /AREA1/L,N,ID(130),IX(130,24)
       COMMON /AREA2/ CR(20)
C      L IS THE NUMBER OF TEMPERATURE REGIMES
       READ(5,200)L
  200  FORMAT(I3)
C      N IS THE NUMBER OF DAYS OF HOURLY WATER ELEVATIONS
       READ(5,112)N
C      READ IN NUMBER OF DAYS OF WATER LEVEL READINGS
```

```
  112 FORMAT(I3)
C       K IS THE NUMBER OF DEPTHS
        READ(5,1102)K
 1102 FORMAT(I3)
        DO 14 I=1,N
        READ(5,11)ID(I),(IX(I,J),J=1,24)
   11 FORMAT(I5,22I3,/,2I3)
C       READ HOURLY WATER LEVELS
   14 CONTINUE
        DO 19 II=1,L
        READ(5,110)TEMP(II),TEMPWT(II)
  110 FORMAT(F4.0,2X,F4.0)
   19 CONTINUE
C       PF IS THE PROBABILITY OF FRY SURVIVAL
C       PE IS THE PROBABILITY OF EGG SURVIVAL
        PF=0.0
        PE=0.0
        DO 70 DSUB=1,K
        TEXPOZ=1.
        NATLEV=D(DSUB)
C       NATLEV EQUALS THE LEVEL OF SPAWNING
        DO 60 TSUB=1,L
        T=TEMP(TSUB)
C       PN IS THE PROBABILITY OF NATURAL SURVIVAL AT A PARTICULAR TEMP
        PN=SUKCES(T)
C       DEVLOP IS THE LENGTH OF THE FRY DEVELOPMENTAL PERIOD
        NLOW=HATCH(T)+DVELOP(T)
        LAST=N*24-NLOW-1
C       CUMSRV IS THE ACCUMULATIVE SURVIVAL
        CUMSRV(TSUB,DSUB)=PN
        IF (TEXPOZ .EQ. 0.0)GO TO 60
        CUMSRV(TSUB,DSUB)=0.0
```

```
      IF (LAST .LT. 1) GO TO 60
      DO 10 TZERO=1,LAST
      NHATCH=TZERO+HATCH(T)
C     NDVLOP IS THE TOTAL LENGTH OF TIME IN THE NEST
      NDVLOP=NHATCH+DVELOP(T)
      IF (DEPTH(TZERO) .LE. NATLEV) GO TO 9
    1 IF (DEPTH(NHATCH) .GT. NATLEV) GO TO 5
      NHATCH=NHATCH+1
      NDVLOP=NDVLOP+1
      IF (NHATCH .GT. (LAST+HATCH(T)))GO TO 60
      GO TO 1
    5 PE=1.0
      FLAG=1
      LEXPOZ=0
      DO 20 HOUR=TZERO,NHATCH
      IF (DEPTH(HOUR) .GT. NATLEV) GO TO 30
      IF (FLAG .EQ. 0) GO TO 40
      LEXPOZ=0
      FLAG=0
   40 LEXPOZ=LEXPOZ+1
      GO TO 20
   30 IF (FLAG .EQ. 0)PE=PE*EXPOSE(LEXPOZ)
      TEXPOZ=TEXPOZ+LEXPOZ
C     LEXPOZ IS THE LENGTH OF THE EXPOSURE PERIOD
C     TEXPOZ IS THE TOTAL LENGTH OF THE EXPOSURE PERIOD
      FLAG=1
      LEXPOZ=0
   20 CONTINUE
      PE=1.0
      START=NHATCH+1
      DO 50 HOUR=START,NDVLOP
      IF (DEPTH(HOUR) .GT. NATLEV) GO TO 50
```

```
      PF=0.0
      GO TO 51
   50 CONTINUE
   51 SURV=PE*PF*PN
      CUMSRV(TSUB,DSUB)=CUMSRV(TSUB,DSUB)+TIMWAT(TZERO)*SURV
      GO TO 10
    9 TEXPOZ=TEXPOZ+1.
   10 CONTINUE
      TEXPOZ=TEXPOZ-1.
   60 CONTINUE
   70 CONTINUE
      DO 71I=1,K
      DPTHSM(I)=0.0
   71 CONTINUE
      DO 72 I=1,L
      TEMPSM(I)=0.0
   72 CONTINUE
      GRNDSM=0.0
      CALL SPDPTH(K)
      DO 80 DSUB=1,K
      DPTHWT(DSUB)=CR(DSUB)
      DO 80 TSUB=1,L
      DPTHSM(DSUB)=DPTHSM(DSUB)+CUMSRV(TSUB,DSUB)*TEMPWT(TSUB)
      TEMPSM(TSUB)=TEMPSM(TSUB)+CUMSRV(TSUB,DSUB)*DPTHWT(DSUB)
   80 GRNDSM=GRNDSM+CUMSRV(TSUB,DSUB)*TEMPWT(TSUB)*DPTHWT(DSUB)
      WRITE(6,1000)
      WRITE(6,2000)
      WRITE(6,3000)(TEMP(TSUB),TSUB=1,L)
      WRITE(6,2000)
      WRITE(6,4000)
      WRITE(6,5000)(TEMPWT(TSUB),TSUB=1,L)
      WRITE(6,6000)
```

```
      DO 90 DSUB=1,K
      A=D(DSUB)
      B=DPTHWT(DSUB)
      WRITE(6,7000)DPTHSM(DSUB),A,B,(CUMSRV(TSUB,DSUB),TSUB=1,L)
   90 WRITE(6,8000)
      WRITE(6,11000)
      WRITE(6,9000)
      WRITE(6,10000)GRNDSM,(TEMPSM(TSUB),TSUB=1,L)
      WRITE(6,12000)
 1000 FORMAT('1',15X,15X,1X,17X,'TEMPERATURE (C)')
 2000 FORMAT(' ',15X,15X,1X,77('-'))
 3000 FORMAT(' ',15X,15X,1X,7(3X,F5.2,3X))
 4000 FORMAT(' ',15X,08X,'WEIGHT',1X,7(11X),1X,'NET SURVIVAL')
5000  FORMAT(' ',T110,'BY DEPTH',T2,15X,8X,'FACTOR',4X,7(1X,G9.3,1X))
 6000 FORMAT(' ',15X,'DEPTHS',2X,85('-'))
7000  FORMAT(' ',T110,G9.3,T2,15X,F5.0,2X,8(1X,G9.3,1X))
 8000 FORMAT(' ')
 9000 FORMAT(' ',17X,'NET SURVIVAL',T114,'NET SPAWNING')
10000 FORMAT(' ',T110,G9.3,'SUCCESS',T2,16X,'BY TEMPERATURE',3X,7(1X,G9.
     13,1X))
11000 FORMAT(' ',15X,114('-'))
12000 FORMAT('1')
      STOP
      END
C     ************************************************************************
C     *****************************************************************
C     *****************************************************************
```

```
C
C     *******************************************************************
C     ****************************************************************************
      FUNCTION DEPTH(TIME)
      COMMON /AREA1/ SPACE(132),IX(130,24)
      REAL RTIME
      INTEGER DAYS,TIME
      RTIME=TIME
      DAYS=RTIME/24.0
      HOURS=TIME-DAYS*24
      HOURS=HOURS+1
      DAYS=DAYS+1
      DEPTH=IX(DAYS,HOURS)
      RETURN
      END
```

```
C
C     *****************************************************************
C     ************************************************************************
      FUNCTION D(DSUB)
      INTEGER DSUB
      D=614-DSUB
      RETURN
      END
```

```
C
C      *******************************************************************
C      ***************************************************************************
       FUNCTION HATCH(T)
       REAL M
       M=0.0
       M=4.739-(2.27*ALOG10(T))
       HATCH=10**M
       RETURN
       END
```

```
C
C      *******************************************************************
C      ***************************************************************************
       FUNCTION TIMWAT(TIME)
       INTEGER TIME
       RTIME=TIME
       F=0.194*(1.0/280.9*EXP(-(RTIME-336.0)**2/25088.0))
       G=0.306*(1.0/963.2*EXP(-(RTIME-1056.0)**2/294912.0))
       TIMWAT=(F+G)/0.9955269
       RETURN
       END
```

```
C
C     ****************************************************************
C     *******************************************************************
      SUBROUTINE SPDPTH(N)
      COMMON /AREA2/ CR(20)
      INTEGER W(30)
      DIMENSION NEST(20)
      DIMENSION NESTS(20),NF(30)
      NSUM=0
      ISUM=0
      NNUM=0
      WMEAN=0.0
      DO 19 I=1,N
      READ (5,102)W(I),NESTS(I)
  102 FORMAT (19(2I3))
      NSUM=NSUM + NESTS(I)
      ISUM=ISUM + (W(I)*NESTS(I))
      NNUM=NNUM + 1
      NF(NNUM)=W(I)
      NEST(NNUM)=NESTS(I)
   19 CONTINUE
      WMEAN=ISUM/NSUM
      DO 105 J=1,NNUM
      SN=NEST(J)
      CR(J)=SN/NSUM
  105 CONTINUE
      RETURN
      END
```

```
C
C     ****************************************************************
C     *************************************************************************
      FUNCTION DVELOP(T)
      S=0.0
      S=5.545-(2.516*ALOG10(T))
      DVELOP=10**S
      RETURN
      END
```

```
C
C      *****************************************************************
C      *************************************************************************
       FUNCTION SUKCES(T)
       S=0.0
       S=-33.332+4.541*T
       IF (S .LE. 0.0)S=0.0
       SUKCES=S/100.
       RETURN
       END
```

```
C
C      ********************************************************************************
C      *****************************************************************************************
       FUNCTION EXPOSE(LEXPOZ)
       S=0.0
       S=77.964-(2.52*LEXPOZ)
       EXPOSE=S/100
       IF(EXPOSE .LE. 0.0)EXPOSE=0.0
       RETURN
       END
```

Appendix Table II. Mean and ranges of body size and condition factors (K) of mature male bluegill (<u>Lepomis macrochirus</u>) dissected for determination of reproductive condition in Leesville Lake, Virginia.

1972	Low-Length mm	Weight g	K	Mid-Length mm	Weight g	K	Upper-Length mm	Weight g	K
APR	175	90	1.65						
	(146-192)	(47-123)	(1.51-1.86)						
MAY	123	42	1.69	128	40	1.5	159	72	1.56
	(72-175)	(7-95)	(1.53-1.87)	(97-174)	(13-96)	(1.26-1.82)	(134-184)	(32-112)	(1.33-1.80)
JUNE	151	64	1.69	142	58	1.59	173	107	1.98
	(83-180)	(8-100)	(1.40-1.97)	(62-181)	(2-109)	(0.84-1.92)	(156-210)	(66-210)	(1.70-2.27)
JULY	122	35	1.63	115	33	1.74	133	43	1.75
	(72-193)	(6-116)	(1.34-1.78)	(67-154)	(6-70)	(1.60-1.99)	(109-159)	(22-67)	(1.64-1.95)
AUG	106	20	1.63				157	73	1.76
	(102-111)	(16-24)	(1.51-1.75)				(128-181)	(34-101)	(1.62-1.95)
SEPT	103	20	1.61	86	9.0	1.41			
	(78-145)	(8-52)	(1.50-1.70)	(86-86)	(9.0-9.0)	(1.41-1.41)			
1974									
APR	142	54	1.56						
	(72-179)	(4-102)	(1.07-1.85)						
MAY	124	39	1.49	120	40	1.76	151	66	1.87
	(83-165)	(8-71)	(1.40-1.58)	(62-162)	(4.79)	(1.36-2.25)	(137-167)	(45-89)	(1.75-1.93)

Appendix Table II. Mean and ranges of body size and condition factors (K) of mature male bluegill (*Lepomis macrochirus*) dissected for determination of reproductive condition in Leesville Lake, Virginia. (continued).

1974	Low-Length mm	Weight g	K	Mid-Length mm	Weight g	K	Upper-Length mm	Weight g	K
JUNE	115 (68-150)	30 (5.60)	1.54 (1.38-1.78)						
JULY	131 (98-193)	41 (13-113)	1.49 (1.24-1.72)	132 (97-173)	41 (13-82)	1.65 (1.42-1.83)	187 (187-187)	125 (125-125)	1.91 (1.91-1.91)
AUG	132 (80-172)	44 (6-89)	1.46 (1.17-1.89)	121 (74-173)	34 (6-79)	1.5 (1.43-1.68)	132 (132-132)	34 (34-34)	1.48 (1.48-1.48)

Appendix Table III. Means and ranges of body size and condition factors (K) of mature female bluegill (<u>Lepomis macrochirus</u>) collected from Leesville Lake, Virginia.

1972	Low-Length mm	Weight g	K	Mid-Length mm	Weight g	K	Upper-Length mm	Weight g	K
APR	131	35	1.46						
	(106-160)	(17-64)	(1.33-1.60)						
MAY	122	29	1.51	121	30	1.57	132	44	1.74
	(92-150)	(12-52)	(1.33-1.71)	(93-149)	(11-64)	(1.37-1.93)	(100-183)	(15-110)	(1.40-3.27)
JUNE	124	31	1.57	119	27	1.46	150	69	1.86
	(108-167)	(21-73)	(1.27-1.85)	(97-168)	(12-74)	(1.26-1.58)	(102-189)	(19-130)	(1.78-1.99)
JULY	112	24	1.7	129	40	1.71	127	41	1.89
	(87-148)	(11-53)	(1.19-2.05)	(104-174)	(19-88)	(1.36-2.00)	(75-163)	(8-76)	(1.59-2.25)
AUG	106	19	1.55	113	24	1.59	126	33	1.64
	(83-128)	(9-36)	(1.28-1.75)	(94-158)	(14-62)	(1.31-1.80)	(114-132)	(24-38)	(1.5-1.7)
SEPT	115	24	1.50	94	12	1.47	131	39	1.7
	(95-131)	(14-36)	(1.36-1.63)	(92-100)	(10-15)	(1.28-1.62)	(106-148)	(21-38)	(1.57-1.79)
1974									
APR	124	28	1.34						
	(89-141)	(9-39)	(1.28-1.39)						
MAY	90	11	1.46	112	25	1.66	126	36	1.7
	(77-105)	(6-18)	(1.31-1.69)	(94-137)	(14-47)	(1.40-1.83)	(104-148)	(18-55)	(1.60-1.75)

Appendix Table III. Means and ranges of body size and condition factors (K) of mature female bluegill (*Lepomis macrochirus*) collected from Leesville Lake, Virginia. (continued).

1972	Low-Length mm	Weight g	K	Mid-Length mm	Weight g	K	Upper-Length mm	Weight g	K
JUNE	119 (93-196)	29 (8-111)	1.44 (1.26-1.75)	105 (87-127)	18 (9-36)	1.47 (1.36-1.76)	147 (102-201)	70 (14-151)	1.7 (1.32-1.95)
JULY	114 (94-131)	21 (11-33)	1.39 (1.12-1.60)	123 (103-167)	31 (15-71)	1.59 (1.29-2.20)	122 (90-144)	32 (10-55)	1.60 (1.37-1.84)
AUG	98 (88-111)	14 (10-18)	1.43 (1.32-1.52)	102 (102-102)	11 (11-11)	1.04 (1.04-1.04)	109 (109-109)	17 (17-17)	1.31 (1.31-1.31)

Appendix Table IV. Means and ranges of body size and condition factors (K) of mature largemouth bass (Micropterus salmoides) from Leesville Lake, Virginia.

	Male- Length mm	Weight g	K
APR	332 (262-391)	506 (246-779)	1.30 (1.22-1.37)
MAY	318 (260-441)	535 (213-1446)	1.45 (1.21-1.68)
JUNE	269 (269)	276 (276)	1.42 (1.42)
JULY	377 (253-470)	847 (203-1538)	1.49 (1.18-1.90)
AUG	310 (293-334)	420 (373-515)	1.40 (1.26-1.48)
SEPT	397 (397)	1113 (1113)	1.78 (1.78)

	Female- Length mm	Weight g	K
APR	386 (331-442)	1055 (523-1587)	1.64 (1.44-1.84)
MAY	351 (255-435)	794 (205-1521)	1.63 (1.24-2.22)
JUNE	419 (361-461)	1252 (724-1602)	1.63 (1.54-1.73)
JULY	425 (340-524)	1324 (529-1999)	1.65 (1.35-1.88)
AUG	357 (302-444)	815 (436-1531)	1.58 (1.27-1.75)

Appendix Table V. Means and ranges of body size and condition factors (K) of mature redbreast sunfish (Lepomis auritus) from Leesville Lake, Virginia.

	Male- Length mm	Weight g	K
MAY	152 (128-178)	62 (35-95)	1.70 (1.56-1.92)
JUNE	156 (118-177)	84 (29-116)	1.96 (1.76-2.20)
JULY	152 (115-182)	73 (27-127)	1.93 (1.75-2.16)
AUG	135 (90-173)	59 (11-108)	1.82 (1.49-2.12)
SEPT	134 (98-164)	48 (17-77)	1.88 (1.63-2.17)

	Female- Length mm	Weight g	K
APR	150 (142-154)	54 (41-61)	1.6 (1.43-1.70)
MAY	129 (100-158)	38 (19-62)	1.70 (1.44-1.96)
JUNE	82 (65-109)	10 (4-22)	1.63 (1.46-2.02)
JULY	130 (92-165)	45 (14-95)	1.84 (1.42-2.11)
AUG	126 (82-166)	38 (7-81)	1.67 (1.27-1.94)
SEPT	114 (78-160)	28 (8-76)	1.73 (1.48-1.91)

Appendix Table VI. Means and ranges of body size and condition factors (K) of mature pumpkinseed (Lepomis gibbosus) from Leesville Lake, Virginia.

	Male-Length mm	Weight g	K
MAY	149 (149)	70 (70)	2.12 (2.12)
JUNE	143 (127-164)	60 (44-84)	2.03 (1.83-2.24)
JULY	127 (80-214)	43 (11-152)	1.84 (1.41-2.54)
AUG	132 (92-163)	43 (13-79)	1.68 (1.51-1.87)
SEPT	117 (105-126)	29 (20-36)	1.75 (1.67-1.83)

	Female-Length mm	Weight g	K
MAY	126 (106-147)	46 (23-69)	2.05 (1.93-2.17)
JUNE	138 (106-176)	52 (18-83)	1.90 (.84-2.56)
JULY	131 (103-156)	44 (20-77)	1.88 (1.54-2.15)
AUG	128 (128)	35.0 (35.0)	1.67 (1.67)
SEPT	112 (91-129)	27 (13-40)	1.83 (1.67-2.10)

Appendix Table VII. Program output from SUCCESS, a computer implemented model to predict spawning success of centrarchid fishes in pumped storage reservoirs. Depth weighting factors are provided from data on the vertical distribution of sunfish spawning sites in Leesville Lake, Virginia. Temperature weighting factors were arbitrarily selected to incorporate all temperature regimes that were found to occur in Leesville during the sunfish spawning season. Estimated probabilities of spawning success less than 0.10 are indicated in scientific notation form; i.e., 0.952E-01 = 0.0952.

TEMPERATURE (C)

DEPTH	WEIGHT FACTOR	28.00	26.00	24.00	22.00	20.00	18.00	16.00	NET SURVIVAL BY DEPTH
		0.230	0.170	0.130	0.120	0.900E-01	0.600E-01	0.230	
613.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
612.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
611.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
610.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
609.	0.600E-02	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
608.	0.000	0.796E-03	0.000	0.000	0.000	0.000	0.000	0.000	0.159E-03
607.	0.000	0.774E-02	0.152E-02	0.560E-03	0.000	0.000	0.000	0.000	0.188E-02
606.	0.180E-01	0.252E-01	0.508E-02	0.172E-02	0.365E-03	0.000	0.000	0.000	0.617E-02
605.	0.720E-01	0.539E-01	0.194E-01	0.691E-02	0.559E-02	0.000	0.000	0.000	0.150E-01
604.	0.220E-01	0.841E-01	0.462E-01	0.254E-01	0.131-01	0.495E-02	0.861E-03	0.000	0.301E-01
603.	0.159	0.147	0.764E-01	0.360E-01	0.139E-01	0.531E-02	0.964E-03	0.000	0.493E-01
602.	0.540E-01	0.178	0.952E-01	0.458E-01	0.190E-01	0.569E-02	0.107E-02	0.000	0.605E-01
601.	0.925E-01	0.235	0.131	0.585E-01	0.285E-01	0.630E-02	0.125E-02	0.000	0.810E-01
600.	0.190	0.382	0.253	0.125	0.537E-01	0.720E-02	0.151E-02	0.000	0.143
599.	0.180	0.937	0.847	0.757	0.666	0.575	0.484	0.393	0.681
598.	0.165	0.937	0.847	0.757	0.666	0.575	0.484	0.393	0.681
597.	0.365E-01	0.937	0.847	0.757	0.666	0.575	0.484	0.393	0.681
596	0.350E-02	0.937	0.847	0.757	0.666	0.575	0.484	0.393	0.681
595.	0.100E-02	0.937	0.847	0.757	0.666	0.575	0.484	0.393	0.681
NET SURVIVAL TEMPERATURE		0.495	0.407	0.331	0.274	0.225	0.188	0.152	0.311 NET SPAWNING SUCCESS

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EFFECTS OF PUMPED STORAGE PROJECT OPERATIONS ON THE SPAWNING SUCCESS OF CENTRARCHID FISHES IN LEESVILLE LAKE, VIRGINIA

by

David H. Bennett

(ABSTRACT)

Research was initiated in the spring of 1972 to evaluate the effects of the Smith Mountain Pumped Storage Project on the spawning success of centrarchid fishes in the lower impoundment, Leesville Lake.

Hydroelectric power generation operations at the Smith Mountain Dam power plant create high water velocities with daily flow reversals, and water level and temperature fluctuations in Leesville Lake. Water levels in Leesville fluctuate as much as 3.5 m (11 ft) per day and 4 m (13 ft) per week during spawning periods of centrarchid fishes. In addition, daily intrusions of subsurface water from Smith Mountain Lake into Leesville Lake during periods of power generation average less than 20 C in temperature. At night and on weekends, surface waters from Leesville Lake are pumped back to Smith Mountain Lake. These project operations create three fluctuating, relatively unstable sections in Leesville Lake; a cool upper reservoir zone, a mid reservoir temperature mixing zone, and a warmer lower reservoir zone.

Centrarchid fishes were collected from the three reservoir zones in Leesville Lake and gonads were examined. Generally, gonadal maturation and the presence of fish in spawning condition occurred earliest in the warmer lower zone, later in the mid reservoir, and last in the cooler upper zone of Leesville Lake during 1972 and 1974.

During 1974, trained divers located and inspected 2010 centrarchid fish spawning nests in Leesville Lake. Based on a constant unit of diving effort, 40 percent of nests occurred in lower Leesville, 57 percent in mid, and about 3 percent in the upper reservoir zone. High water velocities restricted spawning activity in the mid and upper reservoir zones almost entirely to cove areas. Water velocities in lower Leesville had negligible effects on the distribution of spawning activity. A stepwise regression model indicated that water velocities during power generation at Smith Mountain Dam was the single most important factor affecting the distribution of spawning nests in the main lake.

Vertical distribution of centrarchid fish spawning nests suggested that adjustment to the spawning depth had occurred in response to the fluctuation in water levels. Nearly 40 percent of all spawning nests in Leesville Lake were located 0.3 to 1.5 m below minimum pool elevation or about 4.5 m below maximum pool level.

Laboratory and field studies were conducted to evaluate hatching success of bluegill (*Lepomis macrochirus*) eggs under controlled water temperatures and exposures to air. Average hatching success increased as hatching temperatures increased from 16 to 28 C. Hatching success of naturally spawned bluegill eggs exposed during night and daytime hours in natural spawning nests in Leesville Lake decreased with increased exposure to air.

SUCCESS, a computer implemented mathematical model using data generated in this study, indicated that the average spawning success of bluegill would be about two times higher in the lower zone than in upper Leesville Lake. Predicted estimates of spawning success of bluegill for the entire reservoir were about 31 percent. Based on the current levels of exploitation, natural spawning success of largemouth bass and bluegill in Leesville Lake appears adequate to maintain the densities of these centrarchid fish stocks.