Summary

The sample of gizzard shad, Dorosoma cepedianum (Le Sueur), used for this study consisted of 7, 477 fish from Elephant Butte Lake, New Mexico. They were taken between June 1, 1964, and December 31, 1970.

Locality of this study, along with findings in the literature, allows extension of the described range of gizzard shad. Extension of standard descriptions of range of the species includes a broad strip along the western boundary encompassing the Great Plains of Wyoming and Colorado and westward to the Continental Divide in New Mexico and north-central Mexico.

Published opinions of the role of gizzard shad in community ecology of fishes vary with characteristics of the waters in which studies have been made. Value of the gizzard shad as a link in the food chain of game fishes is not disputed, at least when the shad is small.

With a high reproductive potential and rapid rate of growth, gizzard shad tend to overpopulate many waters to the detriment of other fish populations. This is true in warm, shallow lakes with mud bottoms, excessive turbidity, and few predators.

The gizzard shad is highly esteemed as a forage fish in fluctuating impoundments which contain deep and relatively clear water, have abrupt shorelines, support little or no littoral vegetation, adequate plankton, sparse benthic flora and fauna, and contain sufficient predators to crop young-of-the-year shad. This is essentially a description of Elephant Butte Lake, except that predation is inadequate to prevent stunting.

Age and growth determinations were made from scales by use of the Lee Method (corrected direct-proportion). Mean total lengths, annual increments of growth, and grand mean lengths and increments were determined for each age group at time of annulus formation. Growth rates of shad in Elephant Butte Lake have increased substantially since 1965-66 but are still slower than in most other waters studied. Fastest growth reported was from western Lake Erie and Lake Newnan, Florida.

Empirical mean length-weight relationships were calculated by use of the LeCren Method. Sexual dimorphism did not occur in terms of length or weight. Grand mean weights were calculated to conform to grand mean lengths at time of annulus formation.

Time required for gizzard shad from different areas to attain a weight of 100 grams (3.5 ozs) varied from less than one year to five years. Time required for shad to attain a weight of 100 grams (3.5 ozs) in Elephant Butte Lake was longer than in any other water compared. However, fish in this study attained this weight one year sooner (four years) than did the fish in Patterson's study five years earlier.

Condition or relative robustness of gizzard shad was determined by use of the Hile Method. It is expressed as an index or coefficient. Coefficients of condition were determined for 10 mm length groups, for fish taken during each month, and for fish in each age group.

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Coefficients of condition of gizzard shad in Elephant Butte Lake were lower than those in 10 other waters from which comparisons were available. Comparison of condition by intervals of length and by age groups reveals that condition undergoes little change with increase in length or age. Monthly condition values revealed seasonal trends which appeared to be associated with changes in gonad development and spawning. Mean annual condition varies erratically from trends in age and growth, length-weight relationship, and population changes shown by catch per unit of effort. The mean coefficient of condition of 0.867 for the six-year period is the lowest which has been reported.

Length-frequencies were established in 10 mm intervals of total length. Overlap of age groups in length-frequency peaks add to cumulative evidence that this method may not be used as an indicator of age unless validated for a specific population.

In the study, gizzard shad spawned in Elephant Butte Lake from early May through late June at temperatures ranging from 17.8° to 23.9°C (64° to 75°F). A second spawn may occur in late summer. Shad spawned mostly in shallow water but were observed spawning at the surface where water was 50 feet (15 m) deep. While spawning, one female was attended by one to several males. All fish participating in the spawning process swam on their sides, and males would periodically bump the female with their snouts. Occasionally the fish would roll and tumble about each other.

Male shad matured in Age Groups II and III. Females matured in Age Groups HI and IV. Some fish of both sexes in older age groups were senile. Male shad were hyper-active during the spawning season. This resulted in post-spawning mortality and reduced longevity, in comparison with females.

Fecundity of shad was determined from a sample of 30 females collected during spring, 1970. Twenty-seven fish in Age Group III contained an average of 40,500 ova. Three fish in Age Group IV contained an average of 29,884 ova and one fish in Age Group VI contained 58,467 ova. Fecundity was low in comparison with shad from Lake Erie. A decline in fecundity with increase in size and age of fish was observed in both studies.

Studies of food habits of gizzard shad revealed that phytoplankton comprised 36.8 percent and zooplankton made up 31.2 percent of the number of food items. Unidentified organic residue and higher plant material comprised 28.4 percent and 3.6 percent, respectively. Phytoplankton was most abundant numerically and zooplankton comprised the grestest volume.

Sampling in Elephant Butte Lake revealed that gizzard shad occupied the littoral and limnetic zones of the lake most often from April through October. They moved into deep water and became relatively inactive in the fall as the water cooled to 14°C (57.2°F) and became active in spring when the temperature warmed to 14°C.

Gizzard shad were relatively free of parasites and diseases. An ectoparasitic copepod, <u>Argulus</u> Miller, was found on three fish. An acanthocephalan, <u>Gracilisentis</u> Van Cleave, was found in the intestine of one fish from the food habits sample. Common fungus or water-mold, Saprolegnia parasitica Coker, was observed on many specimens which showed evidence of external injury.

The sport fishery in Elephant Butte Lake is dependent upon gizzard shad as a source of forage. All major game fish populations, except flathead catfish, utilized shad as 69 to 94 percent of the number of food items. Flathead catfish took carp most frequently and contained shad as 16 percent of the number and 10 percent of the volume of food items.

Mass mortality of gizzard shad occurred in association with low temperature and extreme drawdown. Winter die-offs were observed in Caballo, Conchas, and Elephant Butte Lakes, in New Mexico, when water temperature fell below approximately 3.3°C (38°F). Summer die-offs were observed in Elephant Butte Lake in 1964, when water storage fell below 150,000 acre-feet (185.2 million m^3), and in 1968 and 1971 when storage was less than 100,000 acre-feet (123.5 million m^3). Mortality was attributed to a common coliform bacteria, Aerobacter aerogenes, producing nitrogen bubbles in the blood streams of fishes which were under severe stress from crowding.

Predation by introduced walleye and white bass populations has contributed to reduction of numbers of shad. Reduction of numbers has partially relieved stunting and growth rates have increased as intraspecific competition was reduced.

Gizzard shad in Elephant Butte Lake have greater value as forage to support game fish populations than they have for commercial fishing. Present abundance and continued stunting indicate that gizzard shad are still sufficiently numerious to support additional populations of game fishes.

Acknowledgments

The work reported here was conducted with funds granted by the New Mex[illegible] Department of Game and Fish through federal aid programs administered by the u. S. Fish and Wildlife Service and the National Marine Fisheries Service. Both state and federal support were essential for completion of the study.

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Assistance from commercial fisherman B. C. Sparkman and personnel of the New Mexico Department of Game and Fish is sincerely appreciated.

Contents

Life History and Ecology of the Gizzard Shad, Dorosoma cepedianum (Le Sueur) with Reference to Elephant Butte Lake

Douglas B. Jester, Assistant Professor of Wildlife Science
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Commercial Fisheries Project 6-11-R, Investigations of Commercial Fishery Potential of Rough Fish Species, was initiated at Elephant Butte Lake, in April, 1968. This followed four years of research under Project D-J F-22-R, Game Fish Reproduction and Rough Fish Problems in Elephant Butte Lake, New Mexico. Evaluations were made on effects of water-level fluctuation on game fish reproduction, status of "rough fish" populations, effects of commercial fishing, and introductions of predaceous species. These studies revealed that smallmouth buffalo, river carpsucker, and carp were major factors in suppression of game fish populations and that a dense population of stunted gizzard shad served as the most important source of forage for game fishes. Introduction of walleye and white bass was intended to enhance sport fishing by adding new species of game fishes to increase predation on rough and forage fishes.

Game fish increased from 16 percent of total weight of population samples during the first year to 48 percent of total weight during the third year. When it became apparent that game fish and rough fish biomasses were beginning to stabilize, emphasis was shifted to studies of rough fish populations to learn more about these species which were considered to be limiting the further expansion of game fish populations. With a change in emphasis from game fish to rough fish, the Dingell-Johnson project was terminated and replaced with the commercial fisheries project. Species to be studied, because of commercial fishery potential, were smallmouth buffalo, Ictiobus bubalus (Rafinesque); river carpsucker, Carpiodes carpio (Rafinesque); carp, Cyprinus carpio Linnaeus; and gizzard shad, Dorosoma cepedianum (Le Sueur).

The role of gizzard shad in the ecology of fish populations has been studied by many workers. Published opinions on status of the species vary greatly (Berry, 1955). Value of shad in the food chain of game fishes is not disputed, especially when the shad are small. On the other hand, with a high reproductive potential and rapid growth rate, gizzard shad tend to overpopulate many waters to the detriment of other fish populations (Madden, 1951; Berry, op. cit.; Lagler, 1956: Miller, 1960; and Bodola, 1965). Miller stated that this is especially true in warm, shallow lakes with mud bottoms, high turbidity, and relatively few predators, particularly when the species is not native to such waters. Conversely, the gizzard shad is highly esteemed as a forage fish in many waters. Waters which Miller described as ideal habitat for gizzard shad populations are similar to Elephant Butte Lake in physical and biological characteristics. He stated that this species is particularly valuable as a forage fish "in fluctuating impoundments which have deep and clear water, an abrupt shoreline, little or no littoral vegetation, adequate plankton (but a sparse benthic flora and fauna), and sufficient predatory fishes to crop young-of-the-year." This description fits Elephant Butte Lake, except that predation is inadequate to prevent stunting.

The goal in fisheries management is to create and maintain a sustained yield of sport and commercial fishes (Lagler, 1956). Knowledge of life histories of species is essential to sound management of fish populations. This report attempts to provide information for understanding the gizzard shad population as a basis for management of fishery resources in Elephant Butte Lake.

Classification

The gizzard shad is classified as follows (after Romer, 1955):

Phylum Chordata
- Subphylum Vertebrata
  - Superclass Pisces
    - Class Osteichthyes
      - Subclass Actinopterygii
        - Superorder Teleostei
          - Order Clupeiformes (after AFS, 1970)
            - Suborder Clupeoidei
              - Family Clupeidae
                - Genus Dorosoma
                  - _Dorosoma cepedianum_ (Le Sueur)

Taxonomy

Moore (in Blair et al., 1968) distinguishes Suborder Clupeoidei (tarpons, tenpounders, herrings, shads, and anchovies) from other Clupeiformes by absence of an adipose fin, a head devoid of scales, presence or absence of a lateral line, and a gular plate present if the lateral line occurs. Clupeidae (herrings and shad) are distinguished from other families of Clupeoidei by absence of the lateral line and the failure of the maxillae to reach beyond the middle of the eye. Genus _Dorosoma_ is differentiated from Genus _Alosa_ by a subterminal or inferior mouth with unequal jaws and a greatly elongated posterior dorsal fin ray. Two species of _Dorosoma_ occur in the United States. The following key separates these species:

Key to Species of _Dorosoma_

Anal fin speckled with melanophores, its rays 17-25. Young, less than 30 mm, with many melanophores along anal base _D petenense_

Anal fin immaculate, its rays 29-35. Young, less than 30 mm, with a few melanophores along anal base D cepedianum

Three additional species of Dorosoma occur in Mexico and Central America (Miller,1960).

It is not clear why Moore does not use the form and position of the mouth as a key character to separate threadfin shad, D. petenense, from gizzard shad, instead of using this character, among others, to separate Genus Dorosoma from Genus Alosa. This separation is erroneous because D. petenense has a terminal mouth rather than a sub-terminal mouth, and the ventral edge of the upper jaw is smooth. D. cepedianum has a subterminal mouth, and the ventral edge of the upper jaw is distinctly notched. These characters could be used better to distinguish threadfin shad from gizzard shad. They are readily discernible and were used by Miller (1960), who stated that resemblances between the two species are numerous and the differences few, the form and position of the mouth affording the most reliable means of distinction. Moore's key is used here because these two species are the only representatives of Dorosoma which are indigenous to, or have been introduced into, New Mexico waters.

A partial synonomy presented by Miller (1960) refers only to original descriptions of those forms now regarded to be conspecific with D. cepedianum. These include:

Megalops cepediana Le Sueur, 1818, Jour. Acad. Nat. Sci. Phila. , 1: 361-363 (original description; markets of Baltimore and Philadelphia, hence usually given as Chesapeake and Delaware Bays).

Clupea heterura Rafinesque, 1818, Amer. Month. Mag. , 1818: 354 (original description; Ohio River).

Dorosoma notata Rafinesque, 1820, Western Rev. and Misc. Mag. , 2: 172 (original description; falls of the Ohio River).

Chatoessus ellipticus Kirtland, 1838, Rept. Zool. Ohio, in Second Ann. Rept. Geol. Surv. Ohio, Columbus, 1838:169, 195 (nomen nudum, Ohio; same as Dorosoma notata). 1844, Boston Jour. Nat. Hist. , 4(2): 235-237, pl. 10, figure 1 (original description, comparisons, occurrence in Ohio, habits, mortality; Ohio River and its tributaries).

Chatoessus insociabilis Abbot, 1861, Proc. Acad. Nat. Sci. Phila. , 12 (1860): 365-366 (original description, habits; "sturgeon pond" 2 miles below Trenton, N.J.).

Megalops bimaculata Le Sueur, 1848, in Cuvier and Valenciennes, Hist. Nat. Poiss., 21: 104 (nomen nudum; synonymized with Chatoessus cepedianus by Valenciennes).

Dorosoma cepedianum exile Jordan and Gilbert, 1838, Proc. U. S. Natl. Mus., 5 (1882): 585 (original description, based on 2 specimens from Galveston, Tex.).

Miller states that insufficient data concerning certain variations in this species led to recognition of at least three nominal subspecies:

"D. c. cepedianum (Le Sueur), on the Atlantic slope southward and westward along the Gulf of Mexico; D. c. heterurum (Rafinesque), in the middle and upper parts of the Mississippi River System and the Great Lakes - St. Lawrence watershed; and D. c. exile Jordan and Gilbert, in coastal streams from Texas to northeastern Mexico."

He explains that the minor characteristics which were originally used to describe these subspecies cannot be used, and no subspecies are currently recognized.

Fishes of the Genus Dorosoma have been widely referred to as gizzard shads because of the gizzard-like, muscular stomach (Koster, 1957; Miller, 1960). A variety of vernacular names have been applied to D. cepedianum and, according to Miller, many are still in local use. Some of those commonly used are skipjack, hickory shad, mud shad, sawbelly, jack shad, and aucun. "Gizzard shad" is the common name adopted by the American Fisheries Society's committee on names of fishes to reflect the broadest current usage (AFS, 1970).

Description

Adult gizzard shad(figure 1) are deep-bodied, strongly compressed laterally, and the ventral edge of the body is formed into a saw-like ridge by a series of sharp, bony scutes. Young gizzard shad are slender, minnowlike, and nearly cylindrical (Miller 1960) (figure) 2). The elongated last dorsal fin ray, so prominent in adults, is absent from young individuals. Young gizzard shad attain adult characteristics in two to three months. A detailed morphological description of adults, based on specimens collected from scattered localities, is presented by Miller.

The body of the shad, in life, is silvery with an iridescence of blue, gold, and green. It is usually silvery-bluish over the back and upper parts and milky white on the abdomen. A round, dark spot behind the opercle is most prominent on the young and often absent on older fish. Six to eight horizontal, dark stripes along the upper sides are not present on many individuals. Absence of such lines has also been shown by other writers (plates in Hubbs and Lagler, 1949, and Blair et al., 1968). The head is devoid of scales, pigmented above, and silvery on the lower half. The fins have a dusky appearance, darker toward the outer edges.

External characteristics suggesting sexual dimorphism were not evident. This agrees with Miller (1960) who states that "no external characteristic will reliably distinguish the sexes." Bodola (1965) expressed the same conclusion but stated that "one might expect a shad that is relatively deep for its length to be a female." Vladykov (1959; from Bodola) stated that the males have darker fins than the females, but this was not evident in shad from either Lake Erie or Elephant Butte Lake. Moen (1959) sexed gizzard shad by examining the urogenital opening with a probe. Even with absence of dimorphic characteristics, the larger individuals collected from Elephant Butte Lake were expected to be females. This assumption arose from high frequency of occurrence of females among the larger fish collected. For example, in 1970, 75 percent of 228 fish, 260 mm (10 in.) long or longer, were females, indicating that they tend to live longer than males.

Fig. 1. Adult gizzard shad from Elephant Butte Lake

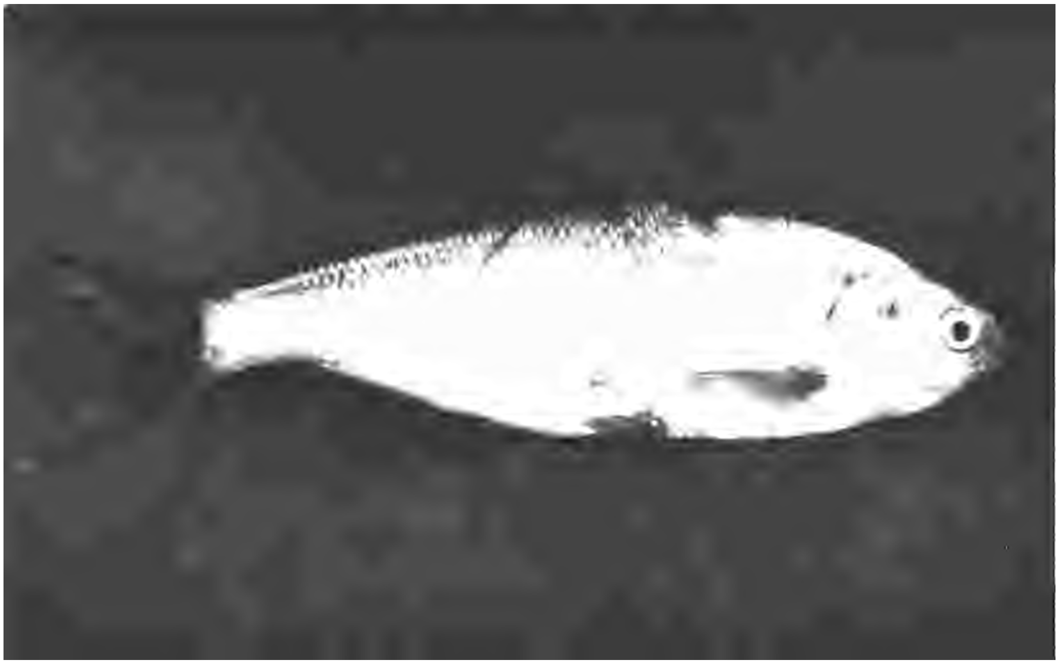
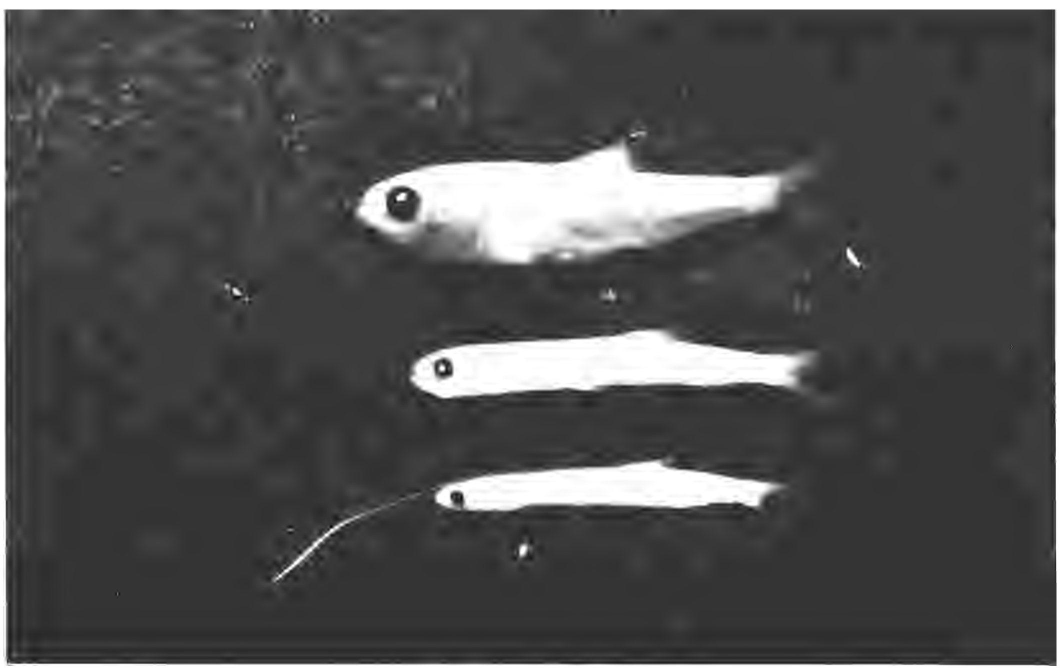


Fig. 2. Juvenile gizzard shad from Elephant Butte Lake



Range

Moore (in Blair et al., 1968) and Miller (1960) described the range of gizzard shad as central Minnesota, southeastern South Dakota, the Great Lakes drainage and extreme southern New York, and southward through the Mississippi River system and along the Atlantic slope to the Gulf Coast of the United States and to the basin of the Rio Panuco in northeastern Mexico. This should be corrected to include the Rio Grande drainage in north-central Mexico (Chihuahua), New Mexico drainages east of the Continental Divide (Koster, 1957), eastern Colorado (Beckman, 1952), and eastern Wyoming (Baxter and Simon, 1970). These sources, along with this report and Jester's report (1962) on the South Canadian drainage, should suffice to modify the western boundary so that the range of D. cepedianum may be described as the Great Lakes to southeastern South Dakota, southwestward across the Great Plains of Wyoming and Colorado to the Continental Divide in New Mexico and north-central Mexico, eastward to the Gulf of Mexico, and through the Mississippi and Great Lakes drainages to the Atlantic coast as far north as southern New York.

The species extended its range after the advent of manmade canals. It entered Lake Michigan by moving through the Chicago River Canal and its occurrence at the northern end of Cayuga Lake, N. Y., has been plausibly credited to its movement there from Lake Erie by way of the Erie Canal (Miller, 1960).

Temperature apparently plays an important role in controlling the establishment of gizzard shad populations in new waters. According to Miller (1957), gizzard shad forge northward during a series of warm years and then become almost eliminated from these waters during cold years. In addition, temperature undoubtedly serves as a control on established populations. Large dieoffs during the winter, which occur in Lake Erie (Bodola, 1965) and several reservoirs in New Mexico, may prevent the species from suppressing other fish populations as they did in Black Hawk Lake, Iowa (Madden, 1951).

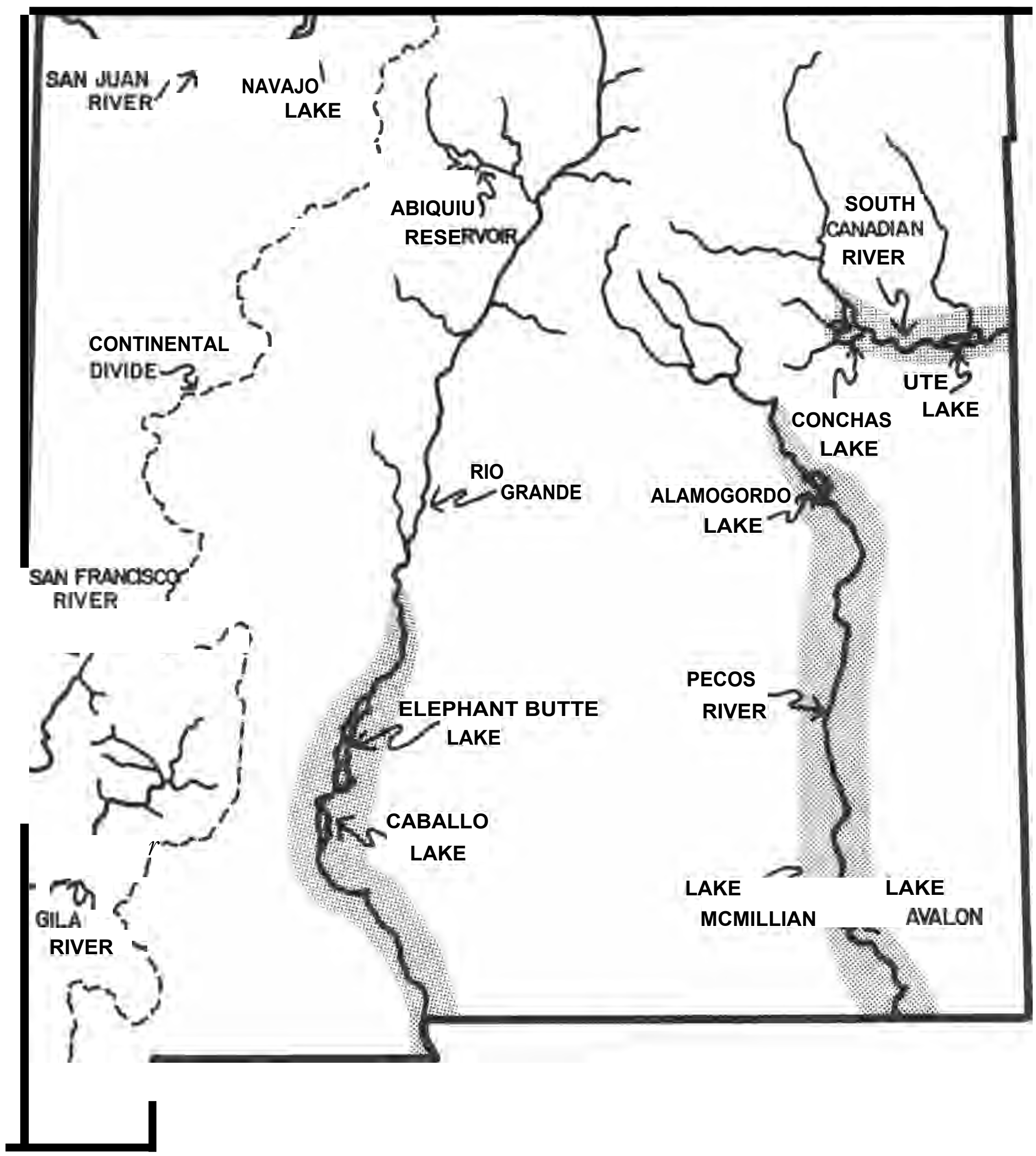
Local Distribution

Gizzard shad, New Mexico's only native representative of the Clupeidae, is endemic to waters east of the Continental Divide (figure 3), including the Rio Grande in central and southern New Mexico; the Pecos River in eastern New Mexico, a tributary to the Rio Grande in west Texas; and the South Canadian River in northeastern New Mexico, an eventual tributary to the Mississippi via the Arkansas.

Present distribution of the species within the state is closely related to impoundments on the rivers listed above. Gizzard shad are abundant in Elephant Butte, Caballo, Alamogordo, McMillan, Avalon, Conchas, and Ute reservoirs.

Thermal tolerance may once have been a factor in determining the range of this species in New Mexico, but intermittent flow upstream and downstream from reservoirs currently controls range and distribution. Koster (W.J., Univ. of New Mexico,

Fig. 3. Distribution of gizzard shad in drainages and reservoirs in New Mexico



personal communication) stated that original ranges of most native and introduced fishes have been reduced by a drying trend during the past century. It is possible that gizzard shad would be absent from the state if reservoirs had not been impounded.

Gizzard shad were introduced successfully into Alamogordo Reservoir in the spring of 1963 (Little, 1964). Their absence at time of impoundment coincided with drought conditions. Annual precipitation on the upper Pecos watershed was approximately three inches below normal during three years prior to completion of the dam (U. S. Dept. of Commerce, 1952). It is probable that the river was dry at the dam site at time of impoundment. Under these conditions, gizzard shad would not have survived upstream from Lake Avalon. The dam prevented upstream migration into Alamogordo Reservoir, although movement of gizzard shad to the stilling basin below the dam was verified by Little (R. G., N. M. Dept. of Game and Fish, personal communication). It seems reasonable that, if shad became established upon introduction, they would have become established at the time of impoundment, if they had been present.

Threadfin shad were stocked in Alamogordo Reservoir three years prior to introduction of gizzard shad. This fish, not indigenous to New Mexico, was brought from Arizona in May, 1960 (Little, 1961). Threadfin shad are not as large as gizzard shad and are considered to be a better forage fish. They failed to become established, although spawning success was verified the first year. Failure to become established was attributed to low water temperatures during the winter of 1960-61 (Little, R. G., personal communication). Threadfin shad were also introduced into the lower Pecos drainage near Carlsbad and into Caballo Reservoir on the Rio Grande (Regan, 1961). They persisted near Carlsbad for at least five years, but their presence has not been verified since 1965 (Little, R. G., personal communication). None have been collected from Caballo Reservoir or the Rio Grande since 1960. It is possible that both populations died out and the species does not exist in the state. It is safer, however, to be aware of the possibility that they may still be present.

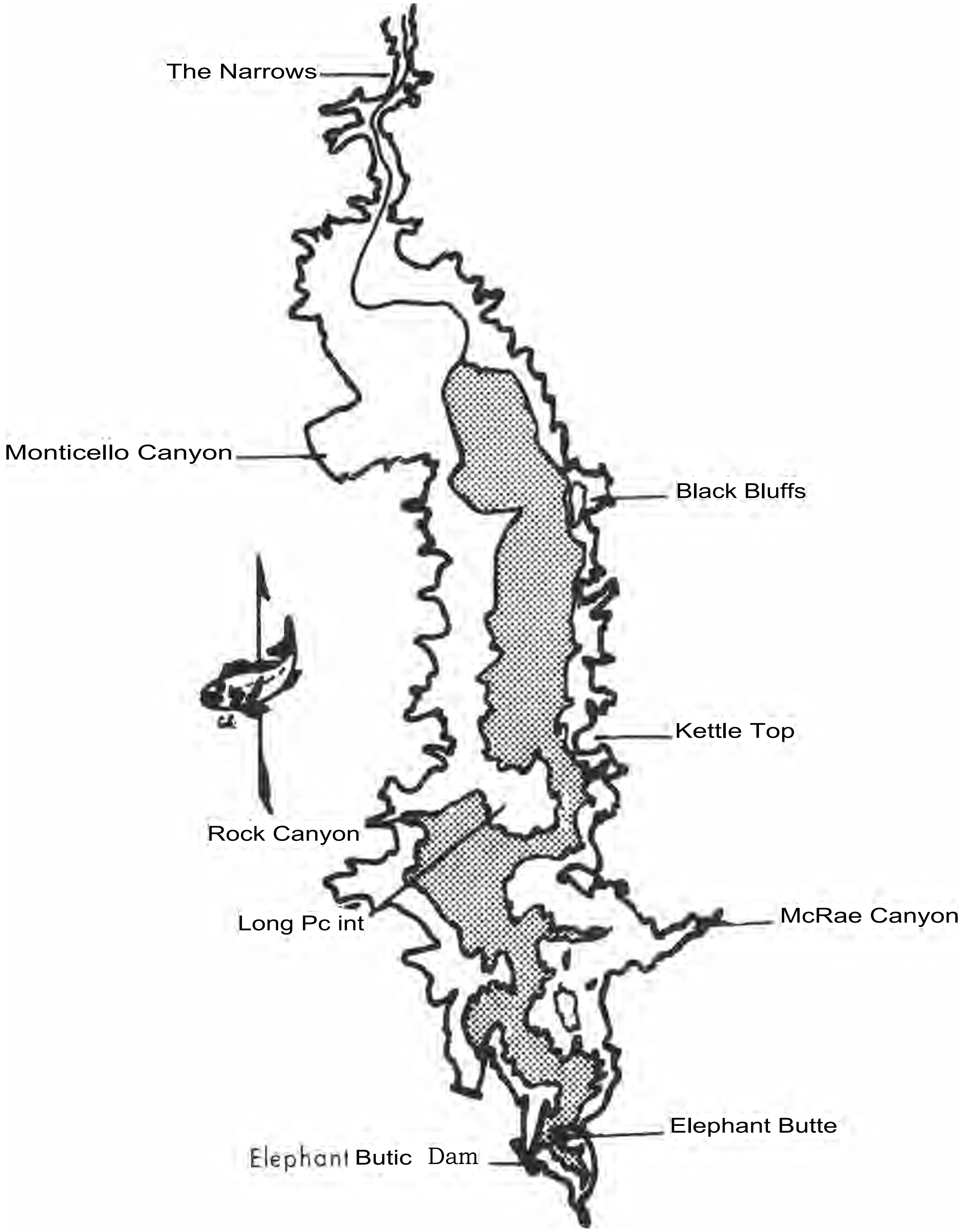
Occurrence of gizzard shad upstream from Elephant Butte Lake is not extensive. Presently, the range probably terminates in the vicinity of Socorro, 80 miles upstream, because diversion dams limit migration, and presence of fish upstream from the lake is dependent upon intermittent river flow. The only known record of gizzard shad north of Socorro is a single specimen collected in 1949 from Beach Pond, near Belen, 150 miles upstream from Elephant Butte Lake (Koster, W. J., personal communication). This small impoundment lies adjacent to the river channel.

Elephant Butte Lake

Elephant Butte Lake is a mainstream reservoir on the Rio Grande, five miles (8 km) northeast of Truth or Consequences, Sierra County, in south-central New Mexico (figure 4). It is operated by the U. S. Bureau of Reclamation.

First impounded in 1915, the lake is the oldest reservoir in New Mexico and one of the oldest in the United States. It is the second largest impoundment in the state, having a potential storage capacity of 2,150,000 acre-feet (2,654.3 million m^3) with a surface area of approximately 40,000 acres (16,327 ha). Original capacity of the reservoir has been reduced approximately 500,000 acre-feet (617.3 million m^3). Water storage is typically less than 700,000 acre-feet (864.2 million m^3) and is characterized by extreme fluctuations resulting from seasonal inflow and drawdown for irrigation pur-

Fig. 4. Map of Elephant Butte Lake, showing shoreline at maximum storage capacity and approximate shoreline at average storage volume during this study.



poses. Volume of stored water varied between 246,000 and 600,000 acre-feet (303.7 and 740.7 million m^3) during the course of this study.

The lake was impounded primarily for storage of water for irrigation in the lower Rio Grande Valley of southern New Mexico, extreme west Texas, and north-central Chihuahua, Mexico. Additional assets include power generation, sport fishing, and other water-oriented recreation. Maximum storage occurred only once, in 1942.

Elevation of Elephant Butte Lake is approximately 4,500 feet (1,646 m) MSL. In general, the surrounding country consists of low rolling hills, interspersed by numerous canyons. Mean annual rainfall is about eight inches (20 cm) (U. S. Dept. of Commerce, 1970). Vegetation is typical of that described by Merriam as indicative of the Lower Sonoran Life Zone (Bailey, 1913). Extensive stands of saltcedar, Tamarix pentandra Pall., and a few Rio Grande cottonwoods, Populus wislizeni (S. Watts.) Sarg. , are present along the shore. Fluctuating water levels (figure 5) prevent permanent establishment of rooted littoral flora. Occasionally, temporary stability allows establishment of large, ephemeral stands of cattail, Typha latifolia, on the silt delta at the mouth of the Rio Grande.

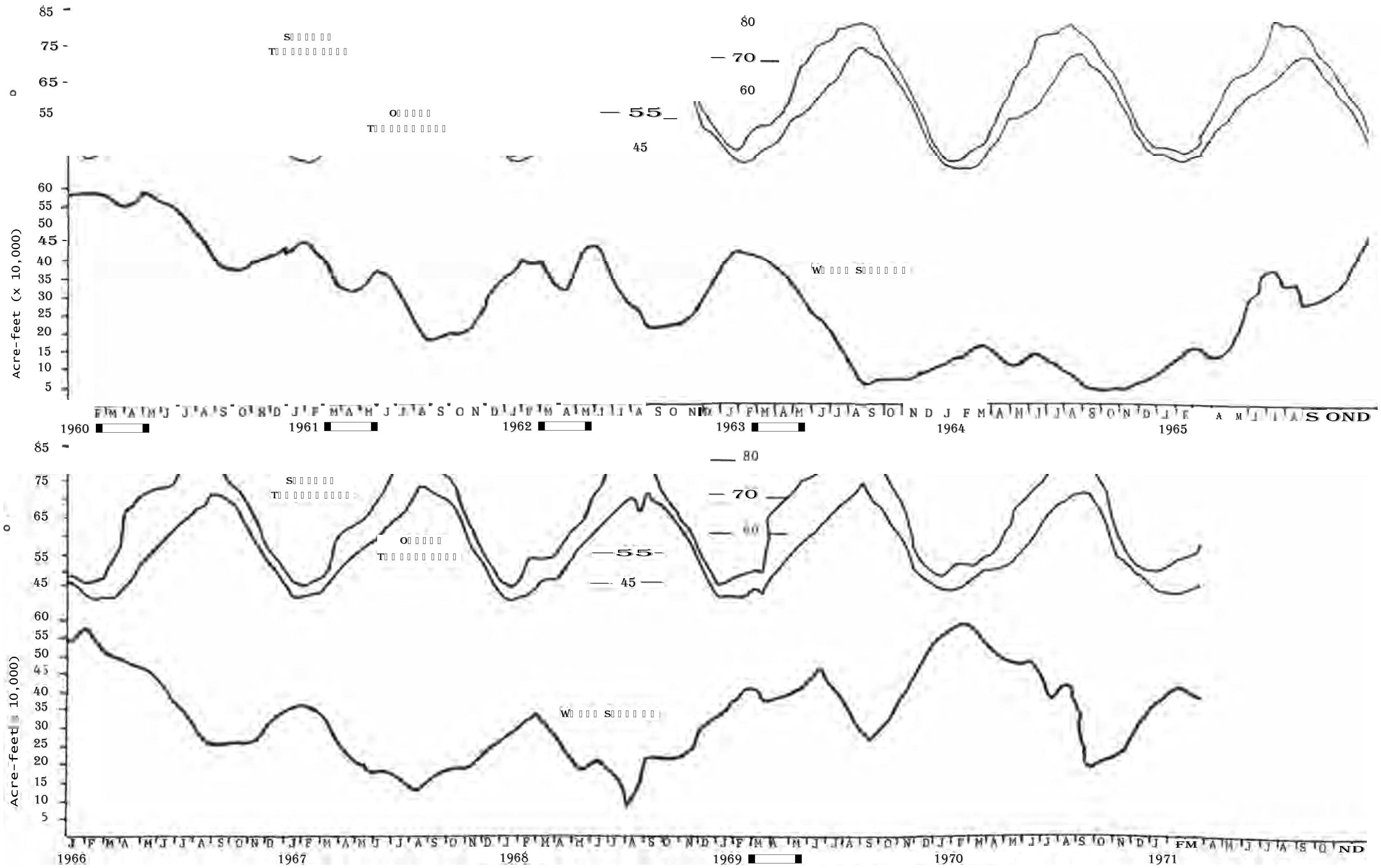
Elephant Butte Lake is morphometrically oligotrophic. According to Hutchinson and Löffler (1956), it is essentially dimictic. These classifications apply generally but are somewhat modified as density-current phenomena prevent formation of a true thermocline (Jester, 1971a). Temperature gradients occur during all seasons of the year, although there is uniformity from surface to bottom during fall and spring overturns. Moody et al. (1969) state that the fall overturn begins in late September to early October and summer gradients form in April and May. Annual mean surface temperature is approximately 15.6 C (60°F)(figure 5)(Jensen and Jester, 1970).

Bottom types vary greatly throughout the lake with the upstream third of the basin consisting of fine silt deposited during periods of inflow. Silt has also been carried by density currents and deposited along the length of the river channel to the dam. Substratum in the downstream portions of the lake, excluding the main channel, consists of boulder-strewn rocky slopes, sheer rock walls, rocky benches, and sand and gravel shoals. Extensive stands of terrestrial vegetation are frequently inundated by rising water. Maximum depths during this study ranged from approximately 30 feet (9 m) in the upstream one-third of the lake to 85 feet (26 m) near the dam.

Water chemistry is relatively stable. Dissolved oxygen ranges from approximately 5.5 to 8.5 mg/1, methyl orange alkalinity from 100 to 150 mg/1, total (versenate) hardness from 175 to 225 mg/1, and sulfates vary from approximately 150 to 250 mg/1 (Jester, 1971a). Phosphates range up to 1.5 mg/1, nitrate nitrogen up to 0.9 mg/1 (Johnson and Kidd, 1970), and pH ranges from 7.5 to 9.2, usually near 8.3.

Plankton and benthos are usually sparse. Low production of bottom organisms is attributed to depth, nature of bottom material, and frequent deposition of silt. Chironomidae (bloodworms), Oligochaeta (aquatic earthworms), and Chaoborinae (midges, Culicidae), are the most numerous organisms, in that order. A crawfish, Orconectes causeyi Jester, is periodically abundant. Analysis of plankton samples col-

Fig. 5. S E B R 1960-1970



lected during 1970 revealed a mean standing crop of 4.62 ml of net plankton/m^3 of water. Zooplankton comprised 96 percent of the number of plankton organisms collected. Sparsity of plankton in Elephant Butte Lake has been a subject of great interest for many years. No reliable conclusion has been reached about actual factors involved. Physical and chemical aspects of this problem are currently under investigation by Johnson and Kidd (University of New Mexico).

The authors of this research report, Jester and Jensen, believe that biological factors, especially gizzard shad, should be considered along with physical and chemical parameters, as a possible cause of sparse standing crops of plankton. They hypothesize that stunted, hungry gizzard shad are sufficiently numerous in Elephant Butte Lake to utilize plankton at such a rapid rate that dense standing crops do not accumulate. They cite abundance of nutrients, sparse plankton crop shown above, high density and heavy biomass of shad, (indicated in this study and in Jester, 1971b), and high density and heavy biomass of predacious fishes as the basis for this hypothesis.

A checklist of fishes known to occur in Elephant Butte Lake contains 27 species representing six orders and 10 families (table 1). From April, 1970, through March, 1971, gizzard shad comprised 71.2 percent of the number and 23.6 percent of the weight of fish collected in experimental gill nets. These data show that the gizzard shad population constitutes a major portion of the fish fauna and that these fish are an important factor in the trophic ecology of the fish community.

Methods and Materials

Fish populations were sampled primarily with nylon experimental gill nets. These nets are 125 feet (38.1 m) long by 10 feet (3 m) deep and contain five 25-foot (7.6 m) panels of progressive mesh sizes ranging from two to six inches (5.1 to 15.2 cm), stretch measure.

Jester (1971b) devised catch per net-unit as a method for analysis of catch per unit of sampling effort. A net-unit consists of a 25 by 10-foot (7.6 by 3 m) panel of one size mesh, set for 24 consecutive hours. Catch per net-unit of a species consists of mean number or weight of that species caught per net-unit, in net-units in which the species is taken. Twenty-five feet (7.6 m) of net was selected to conform to lengths of mesh sizes in experimental gill nets. A period of 24 hours was selected to allow for variations in diurnal activity of fishes. Homogeneity in sampling is provided by using these nets as standard collecting gear, thus presenting a representation of population structure and relative strength of year classes.

Tow nets, seines, spot rotenone samples, and electrofishing were used to supplement data collected in gill nets. These data were not included in analysis of catch rates or relative density and biomass.

A sample of 390 gizzard shad, collected between April and August, 1970, was used for age-growth studies. Fish were measured to the nearest mm, total length, and the nearest gram. Large scale samples were collected because of the high incidence of re-

Table 1. Check-list of fishes known to occur in Elephant Butte Lake, New Mexico. Those marked with an asterisk (*) are rarely taken. Common and scientific names after A.F.S. (1970).

Family Clupeidae - shad	
Gizzard shad	Dorosoma cepedianum (Le Sueur)
Family Salmonidae - trout	
*Rainbow trout	Salmo gairdneri Richardson
*Brown trout	Salmo trutta Linnaeus
Family Esocidae - pikes	
Northern pike	Esox lucius Linnaeus
Family Catostomidae - suckers	
River carpsucker	Carpiodes carpio (Rafinesque)
*White sucker	Catostomus commersoni (Lacepede)
Smallmouth buffalo	Ictiobus bubalus (Rafinesque)
Family Cyprinidae - carp and minnows	
*Goldfish	Carassius auratus (Linnaeus)
Carp	Cyprinus carpio Linnaeus
*Red shiner	Notropis lutrensis (Baird and Girard)
*Fathead minnow	Pimephales promelas Rafinesque
Family Ictaluridae - catfish	
*Blue catfish	Ictalurus furcatus (Le Sueur)
*Black bullhead	Ictalurus melas (Rafinesque)
*Yellow bullhead	Ictalurus natalis (Le Sueur)
Channel catfish	Ictalurus punctatus (Rafinesque)
Flathead catfish	Pylodictis olivaris (Rafinesque)
Family Poeciliidae - livebearers	
*Mosquitofish	Gambusia affinis (Baird and Girard)
Family Percichthyidae - temperate basses	
White bass	Morone chrysops (Rafinesque)
Family Centrarchidae - sunfish	
Warmouth	Lepomis gulosus (Cuvier)
Green sunfish	Lepomis cyanellus Rafinesque
Bluegill	Lepomis macrochirus Rafinesque
Longear sunfish	Lepomis megalotis (Rafinesque)
Largemouth bass	Micropterus salmoides (Lacepede)
White crappie	Pomoxis annularis Rafinesque
Black crappie	Pomoxis nigromaculatus(Le Sueur)
Family Percidae - perch	
*Yellow perch	Perca flavescens (Mitchill)
Walleye	Stizostedium vitreum (Mitchill)

placement scales found by Patterson[1]. Patterson's report is used throughout this paper for comparison of recent age-growth phenomena with those which occurred in 1965-66.

[1] Patterson, R. R., 1968. Age and growth of gizzard shad in Elephant Butte Lake. Typewritten research paper, New Mexico State University.

The scale method, described by Lagler (1956) was employed in age-growth studies. Scales were cleaned, soaked, wet-mounted between two microscope slides, and examined on a Van-Oosten-Deason-Jobes (1934) scale projector under 50 magnifications. The Lee (1920) Method (corrected direct-proportion) was used to calculate mean total lengths of fish when annuli were formed.

Length-weight relationships were calculated by use of the LeCren (1951) Method, from three annual samples taken during 1965-66, 1967-68, and 1969-70. Empirical mean lengths and weights of 10 mm length groups were used to calculate corrected weights for each length group.

Condition (expression of relative robustness or plumpness) was determined from monthly samples for 7,030 gizzard shad taken during a six-year period from January, 1965, through December, 1970. Condition of a fish may be expressed as a coefficient by which the cube of the length is multiplied to equal weight. This coefficient, represented by "K" in the formula $W=KL^3$, is known as coefficient of condition.

Length-frequencies were determined for 7,477 gizzard shad in 10 mm length-groups for a six-year period, 1965 through 1970. Numbers in length groups are presented as percentages of the total sample during a particular year.

Field observations and laboratory analysis of ovaries were used to obtain data on reproduction. Fecundity was determined by use of the weight method described by Eschmeyer (1950). Sections of ovaries were weighed to the nearest one-thousandth of a gram **on a Mettler precision electronic balance.**

Benthos was sampled with a six-inch by six-inch (15.2 cm by 15.2 cm) Ekman dredge and organisms were sorted from bottom material by washing through a series of progressively smaller screen meshes. Organisms were identified to various taxonomic groups.

Plankton samples were collected with a standard plankton net (11.2 cm mouth and bucket with No. 40 silk bolting cloth) and analyzed both quantitatively and qualitatively. Samples were concentrated by centrifuge to determine volume. Quantities were determined by use of the method described by Welch (1948). Qualitative analysis was made to determine frequency of occurrence and relative numerical abundance of organisms. Samples were diluted to 25 ml to reduce concentration of organisms and standardize volumes of samples. One ml of sample was transferred by pipette to a Sedgewick-Rafter counting cell for microscopic examination.

Gizzard shad collected for food habit studies were taken from experimental gill nets and by electrofishing. Stomach contents were examined qualitatively by use of the technique described for plankton. Quantities were determined by count.

Age *and Growth*

Age-growth, length-weight, and condition studies are essential in understanding life histories of fishes. Determining age structure of a population sample will reveal strength and weakness in year classes and population trends for a given species of fish (Sanchez, 1970). Length-weight relationship and condition express the relative well-being of a population. These data can be used to determine suitability of the environment, status of populations, and facilitate judgment in proposing management practices for species.

Age-growth

A sample of 390 gizzard shad was collected between April and August, 1970, for age-growth studies. Scale samples were taken from an area just below the origin of the dorsal fin. Because of the deciduous nature of gizzard shad scales, one or both sides were often devoid of scales in the "key" area. Samples were taken from the left side when possible and from the right side otherwise. When scales were absent from the appropriate area on both sides, the fish was discarded. Descriptions of the scales of gizzard shad are given by Lagler and Applegate (1942), Berry (1955), and Bodola (1965), and are not repeated here.

The scale method, described by Lagler (1956), was used. Lagler and Applegate (op. cit.), Lagler and Van Meter (1951), Bodola (op. cit.), Jester (1962), and Patterson[2] demonstrated validity of annuli as year-marks on scales of gizzard shad. Annuli were recognized by use of criteria described by Lagler (op. cit.), e. g., crowding, crossing over, and discontinuity of circuli, singly or in combination. Annuli were identified on one scale and confirmed by comparison with one or more additional scales. False annuli were recognized by proximity to true annuli and by incomplete formation. Scales were measured from the center of focus along the anteriomedian radius to each annulus and the scale margin. Twenty-six scale samples were found to be unreadable and were discarded, leaving 364 fish for use in age-growth determinations.

Relationship between body lengths and anterior scale radii was calculated to determine whether growth of gizzard shad scales was proportional to growth of the body (figure 6). Close correlation was found ($r = 0.983$). These data demonstrated a linear relationship, indicating that they were subject to analysis by the linear regression formula $X = a + bY$. Values of L and S were substituted for X and Y respectively. This placed L (body length) on the ordinate and S (length of scales) on the abscissae. Thus, the following formula was used: $I = a + bS$, when

L = mean total length of group
S = mean anterior scale radius of group
a = empirical constant (L - intercept)
b = empirical constant (slope of the line).

Empirical constants "a" and "b" were determined as follows:

$$b = \frac{\Sigma LS - \frac{\Sigma LS}{N}}{(\Sigma S)^2}$$, when N = number of data groups, and

$$a = \bar{L} - b\bar{S} \; .$$

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[2] Ibid.

Fig. 6. Body-scale relationship of 364 gizzard shad from Elephant Butte Lake, 1970

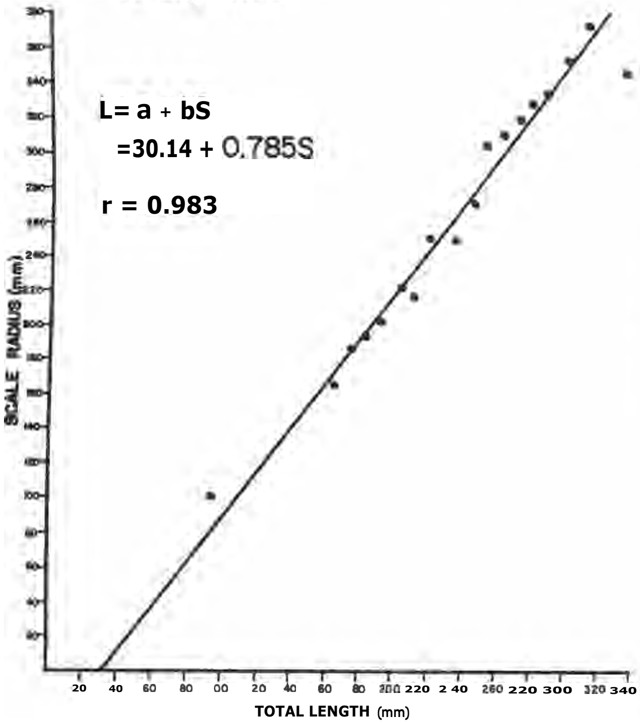
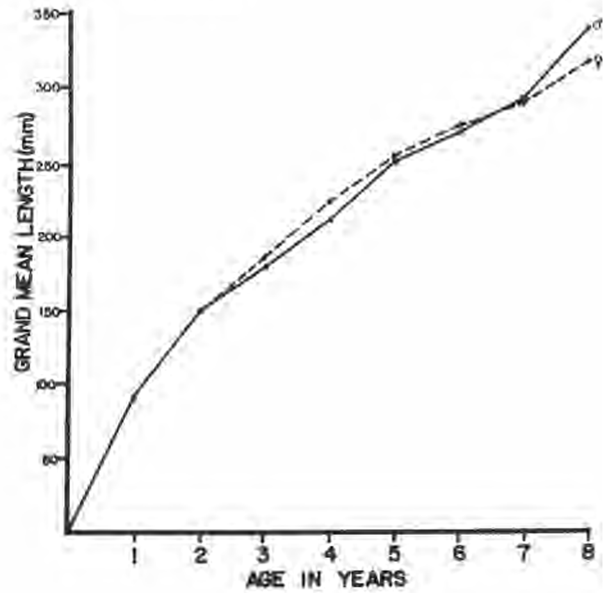


Fig. 7. Growth curves of gizzard shad from Elephant Butte Lake, 1970, representing 212 males and 151 females



"a" is a correction factor for use with a direct proportion formula for determining length of fish at time of annulus formation. Each plot was corrected by calculation of mean total length (L) and a regression line was plotted by connecting the calculated lengths. Coefficient of correlation between empirical grouped data and the regression line was determined by use of a standard formula (Mendenhall, 1963). Linear relationship with close correlation demonstrates proportional increase in body lengths and scale lengths. This relationship allows use of the Lee (1920) Method (corrected direct-proportion) to calculate mean total lengths of fish at annulus formation.

Fish were grouped by age for calculations of mean lengths at formation of annuli. The basic direct-proportion formula is:

$$\frac{Ln}{Sn} \quad \frac{Lt}{St}$$

When the formula is corrected by addition of empirical "a", it becomes:

$$Ln - \frac{Sn(Lt - a)}{St} + a$$, when:

Ln = length of fish at any annulus
Sn = scale radius at corresponding annulus
Lt = length of fish at capture
St = length of scale at capture
a = L-intercept (correction factor) derived from body scale regression.

The calculated body scale regression is represented by: L = 30.14 + 0.785S (see figure 6). These data reveal a straight-line relationship and demonstrate that scale-length increases proportionally with body-length.

Calculated mean lengths and grand mean lengths of fish in each age group at time of annulus formation are shown for 212 males, 151 females, and a total sample of 364 gizzard shad (table 2). Eight age groups are represented, with Age Group III comprising 53 percent of the total sample. The rapid decline of fish in Age Groups IV through

Table 2. Age-growth of 364 gizzard shad from Elephant Butte Lake, 1970. Lengths in mm and weights in grams.

Year Class	Sex	N	Mean Total Length at Formation of Annulus -- I	II	III	IV	V	VI	VII	VIII
			I	II	III	IV	V	VI	VII	VIII
1969	♂	0								
	♀	0								
	♂ ♀	1	95.0							
1968		62	101.9	166.6						
		11	101.4	166.8						
	♂	73	101.8	166.7						
1967		112	89.3	141.9	178.1					
		81	90.2	143.5	179.6					
		193	89.7	142.6	178.7					
1966		24	91.1	140.6	175.2	200.5				
		18	89.3	142.1	177.8	201.3				
	♂ ♀	42	90.3	141.2	176.3	200.8				
1965		6	96.3	162.7	201.4	226.7	248.5			
		14	96.5	161.2	205.8	233.8	252.8			
	e 2	20	96.4	161.7	204.5	231.7	251.5			
1964	♂	5	108.3	163.8	207.0	235.0	252.5	267.2		
		14	108.1	174.3	215.2	241.1	260.4	274.2		
	♂ ♀	19	108.2	171.5	213.0	239.5	258.3	272.4		
1963	♂	2	95.2	149.2	175.6	206.8	231.2	253.9	271.1	
		11	109.9	155.9	190.2	220.1	247.9	270.2	288.1	
	d	13	107.6	154.9	188.0	218.1	245.3	267.7	285.5	
1962		1	128.3	222.9	279.1	296.1	311.2	323.7	332.7	338.0
		2	101.6	147.9	192.4	226.7	263.5	288.6	305.8	316.7
	♂	3	110.5	172.9	221.3	249.8	279.4	300.3	314.8	323.8
Numbers:	d		212	212	150	38	14	8	3	1
	♀		151	151	140	59	41	27	13	2
	d ♀		364	363	290	97	55	35	16	3
Grand mean: Lengths	♂		94.1	150.5	180.2	212.0	251.9	270.9	291.6	338
	♀		94.7	150.5	186.6	222.8	254.6	273.6	290.8	316.7
	♂ 2		94.4	150.5	183.3	218.6	253.9	273.0	291.0	323.8
Increments	d		94.1	56.4	29.7	31.8	39.9	19.0	20.7	46.4
	♀		94.7	55.8	36.1	36.2	31.8	19.0	17.2	25.9
	♂ ♀		94.4	56.1	32.8	35.3	35.3	19.1	18.0	32.8
Weights			7.5	30.2	51.9	84.5	141.7	176.3	219.9	342.6
			7.5	30.2	57.6	98.1	146.4	181.6	218.1	281.8
	♂ ♀		7.5	30.2	54.6	92.6	145.1	180.4	218.6	301.2
Increments	e		7.5	22.8	21.7	32.6	57.2	34.6	43.6	122.7
			7.5	22.7	27.4	40.5	48.3	35.2	36.5	63.7
	♂ ♀		7.5	22.7	24.4	38.0	52.5	35.3	38.2	82.6

VIII indicate a high mortality rate after age three. The high incidence of males in Age Groups II and III probably is not indicative of actual sex ratios in these age groups. Males become hyper-active during spawning season, when a large portion of the sample was collected. The small number of fish in Age Groups I and II is a result of limitations of mesh sizes in experimental gill nets for catching young shad. This study, then, represents the portion of the population which had reached nettable size, approximately 160 mm (6.3 in) total length or Age Group II.

Separate age determinations for males and females reveal insignificant differences in grand mean lengths at time of annulus formation and grand mean increments of growth. Growth curves representing 212 males and 151 females are shown in figure 7. Growth rates do not show dimorphism in terms of length, nor does sexual dimorphism occur in terms of grand mean weights (see table 2). These calculations were made on the basis of length-weight relationship and will be discussed in that section.

Grand mean increments show that growth of gizzard shad in Elephant Butte Lake is most rapid during their first year of life. Growth rates decrease during the second year and, with two exceptions, show a general decline in the older age groups. Rate of growth has increased since November, 1965, and September, 1966 (215 specimens reported by Patterson[3]). The body-scale regression calculated for Patterson's sample was: L = 36.673 + 0.0883S, with a coefficient of correlation of 0.930(figure 8). Grand mean lengths and weights are shown in table 3. Comparison of grand mean lengths and grand mean increments of growth from both studies are shown in table 4. Differences in grand mean lengths show that gizzard shad in Elephant Butte Lake have achieved a faster growth rate since Patterson's study. This change is demonstrated in figure 9. This trend can be explained as a result of increased predation on the shad

[3]Ibid.

Fig. 8. Body-scale relationship of 215 gizzard shad from Elephant Butte Lake, 1965-66

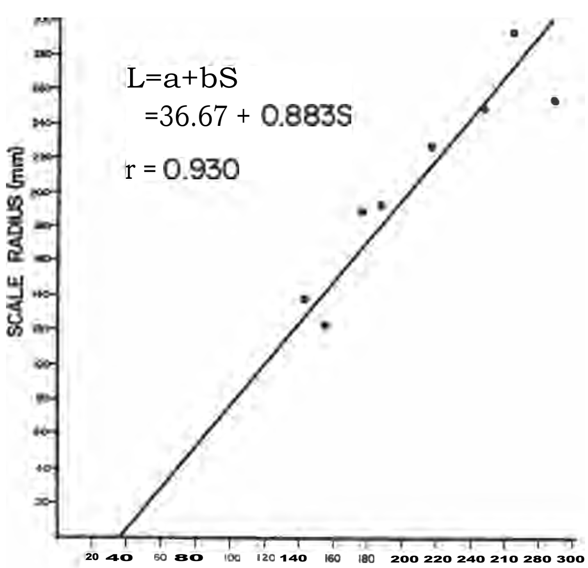


Fig. 9. Comparison of growth rates of gizzard shad in Elephant Butte Lake, 1365-66 and 1970

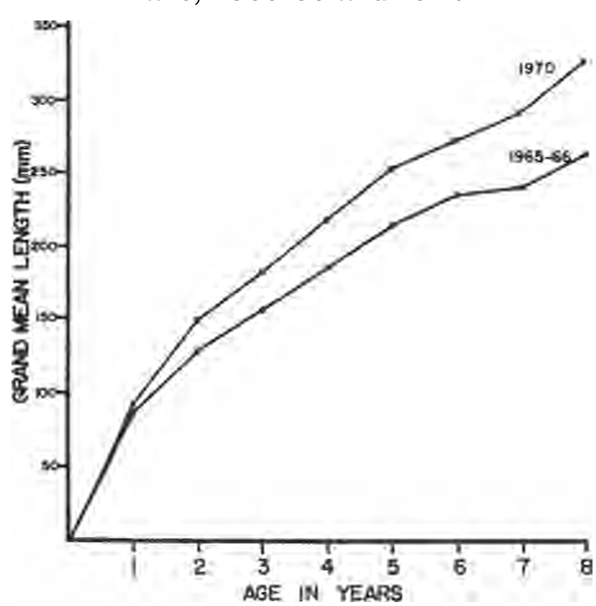


Table 3. Age-growth of 215 gizzard shad from Elephant Butte Lake, 1965-66. Lengths in mm and weights in grams.

	Mean Total Length at Formation of Annulus --							
N	I	II	III	IV	V	VI	VII	VIII
0								
52	83.4	123.7						
113	87.2	129.5	158.9					
34	86.0	128.4	159.1	182.0				
6	85.9	134.5	163.6	188.5	210.1			
5	82.7	124.4	165.3	200.9	222.6	242.6		
4	84.1	128.7	156.5	181.6	205.8	221.6	235.5	
1	88.8	126.8	169.4	188.4	221.6	235.8	250.0	259.5
Numbers	215	215	163	50	16	10	5	1
Grand mean								
Lengths	85.9	127.9	156.0	184.8	213.7	233.5	238.4	259.5
Increments	85.9	42.0	28.1	28.8	28.9	19.8	4.9	21.1
Weights	4.4	16.2	30.9	53.6	85.9	114.6	122.7	161.7
Increments	4.4	11.8	14.7	22.7	32.3	28.7	8.1	39.0

Table 4. Grand mean lengths, grand mean increments, and differences in lengths for 579 gizzard shad from Elephant Butte Lake, 1965-66, and 1970. Shown in mm.

	Grand Mean Lengths and Increments at Formation of Annulus --							
Study	I	II	III	IV	V	VI	VII	VIII
Patterson, (1965-66 data)								
Lengths	85.9	127.9	156.0	184.8	213.7	233.5	238.4	259.5
Increments	85.9	42.0	28.1	28.8	28.9	19.8	4.9	21.1
Jester and Jensen, (new data)								
Lengths	94.4	150.5	183.3	218.6	253.9	273.0	291.0	323.8
Increments	94.4	56.1	32.8	35.3	35.3	19.1	18.0	32.8
Difference								
Lengths	8.5	22.6	27.3	33.8	40.2	39.5	52.6	64.2
Increments	8.5	14.1	4.7	6.5	6.4	-0.7	13.1	11.7

population by introduced, predatory game-fishes. As an increased proportion of the shad population was cropped by game fishes, intraspecific competition for food resources by shad was reduced, thus allowing an increase in growth rate. Changes in catch per unit of effort and length-weight relationship support this explanation. These data are discussed in appropriate sections.

Lee's phenomenon (Lagler, 1956), which may be stated as "slower growing fishes tend to live longer," did not occur in fishes used for this study or in Patterson's sample. Conversely, faster growing fishes lived longer. Eight-year-old fishes in both samples (see tables 2 and 3) had faster growth rates than other age groups in both samples. This is also noted in Age Groups VI and VII in the 1970 sample. Thus, those fishes which grew fastest composed the older age groups. These faster growth rates are demonstrated in Age Group VIII of both samples (figure 9). Patterson found that gizzard shad are subject to heavy predation until they reach a length of approximately 130 mm, and moderate predation up to 200 mm. Fishes which grow faster are subject to predation for a shorter period of time than slower growing fishes. This may be a factor in faster-growing gizzard shad in Elephant Butte Lake attaining the greatest age.

Current growth rates of gizzard shad in Elephant Butte Lake are much slower than those reported for nine other waters (table 5 and figure 10). Growth rate in Lake

Table 5. Grand mean lengths and increments of gizzard shad at time of annulus formation. Upper line is lengths and lower line is increments for each water. Shown in mm.

Locality (Author and date)	Grand Mean Lengths and Increments at Formation of Annulus -- I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Elephant Butte Lake, N.M.	94.4	150.5	183.3	218.6	253.9	273.0	291.0	323.8			
(Jester and Jensen, new data)	94.4	56.1	32.8	35.3	35.3	19.0	18.0	32.8			
Elephant Butte Lake, N.M.	85.9	127.9	156.0	184.8	213.7	233.5	238.4	259.5			
(Patterson, 1968)	85.9	42.0	30.2	24.5	23.0	17.7	14.0	9.5			
Conchas Lake, N. M.	75.8	153.8	225.0	284.3	320.0	342.5	360.3	370.8	378.5	386.5	411.5
(Jester, 1962)	75.8	78.0	71.2	59.3	35.7	22.5	17.8	10.5	7.7	8.0	25.0
Grand Lake, Okla.	100.0	202.5	260.0	317.5	350.0	382.5	395.0				
(Jenkins, 1953)	100.0	102.5	57.5	57.5	32.5	32.5	12.5				
Tenkiller Reservoir, Okla.	140.0	237.5	350.0	385.0	422.5	422.5					
(Hall and Jenkins, 1953)	140.0	97.5	112.5	35.0	37.5	0					
Fort Gibson Reservoir, Okla.	142.5	257.5	325.0								
(Jenkins, 1953)	142.5	115.0	67.5								
Spike Lake, Okla.	160.0	225.0	305.0								
(Hall, 1951)	160.0	65.0	80.0								
Poteau River, Okla.	197.5	227.5	310.0	330.0	357.5						
(Hall, 1951)	197.5	30.0	82.5	20.0	27.5						
Lake Erie	258.7	365.8	402.6	429.3	467.4	428.4					
(Bodola, 1965)	258.7	107.1	36.8	26.7	38.1	-39.0					
Foots Pond, Ind.	190.0	247.5	265.0	282.5	347.5						
(Lagler and Applegate, 1942)	190.0	57.5	17.5	17.5	65.0						
Grassy Pond, Ind.	192.5	227.5	257.5	282.5	295.0						
(Lagler and Applegate, 1942)	192.5	35.0	30.0	25.0	12.5						
Crab Orchard Lake,	100.8	136.1	167.1	170.1	162.5						
(Lewis, 1953)	100.8	35.3	31.0	3.0	-7.6						
Beaver Dam Lake, Ill.	240.0	277.5	330.0	375.0							
(Lagler and Van Meter, 1951)	240.0	37.5	52.5	45.0							
Lake Wappapello, Mo.	102.5	170.0	207.5	230.0	245.0	257.5	272.5	292.5	300.0	292.5	
(Patriarche, 1953)	102.5	67.5	37.5	22.5	15.0	12.5	15.0	20.0	7.5	-7.5	
Herrington Lake, Ky.	109.5	196.0	259.0	311.0	334.3						
(Turner, 1953)	109.5	86.5	63.0	53.0	23.3						
Lake Newnan, Fla.	253.6	316.7	338.2								
(Berry, 1955)	253.6	62.0	22.6								

Fig. 10. Growth curves of gizzard shad

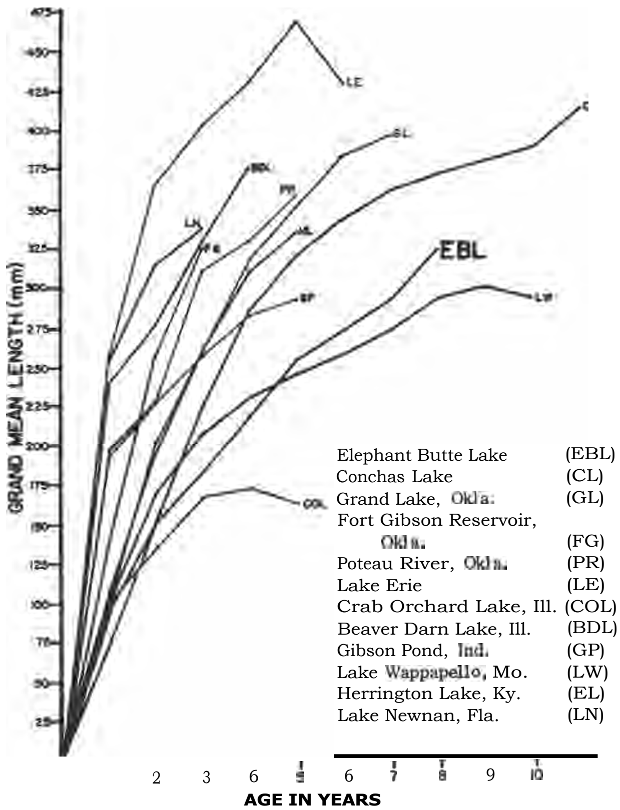
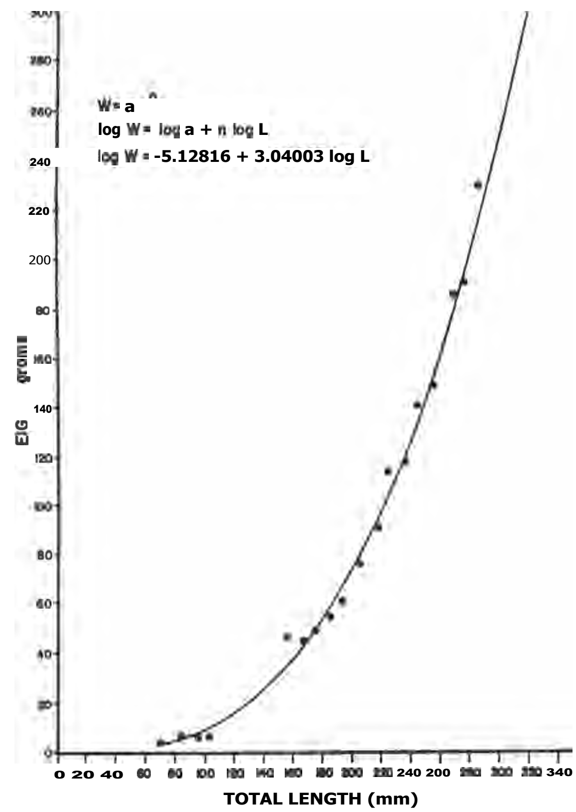


Fig. 11. Length-weight relationship of 718 gizzard shad at time of capture from Elephant Butte Lake, 1965-66



Wappapello, Missouri, was faster into the fourth year and slower thereafter (Patriarche, 1953), while at Conchas Lake, growth was slower through the second year and considerably faster thereafter, (Jester, 1962). Although faster than growth in Elephant Butte and Conchas Lakes during the first year, growth of gizzard shad in Crab Orchard Lake, Illinois, was slowest for all waters reported (Lewis, 1953). Gizzard shad from Elephant Butte Lake, Conchas Lake, and Lake Wappapello are represented by older age groups than those from any other water reported.

Length-weight Relationship

The LeCren Method (1951) was employed to calculate empirical mean length-weight relationships for three annual samples of gizzard shad collected during alternate years from 1965-66 through 1969-70. The total sample consisted of 2, 256 fish collected as follows: 1965-66, 718 fish; 1967-68, 130 fish; 1969-70, 1,408 fish. Fish were grouped into 10 mm intervals of length, ranging from 70 to 330 mm for which mean lengths and weights were determined. Empirical mean lengths and weights for each length group were plotted, and each sample exhibited an exponential relationship. This relationship is expressed by the formula: $W = aL$, when

Fig. 12. Length-weight relationship of 130 gizzard shad at time of capture from Elephant Butte Lake, 1967-68

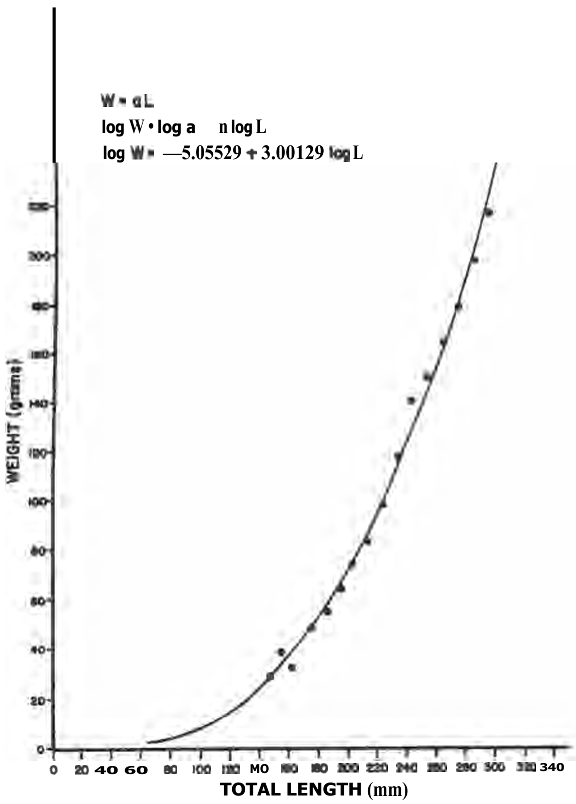
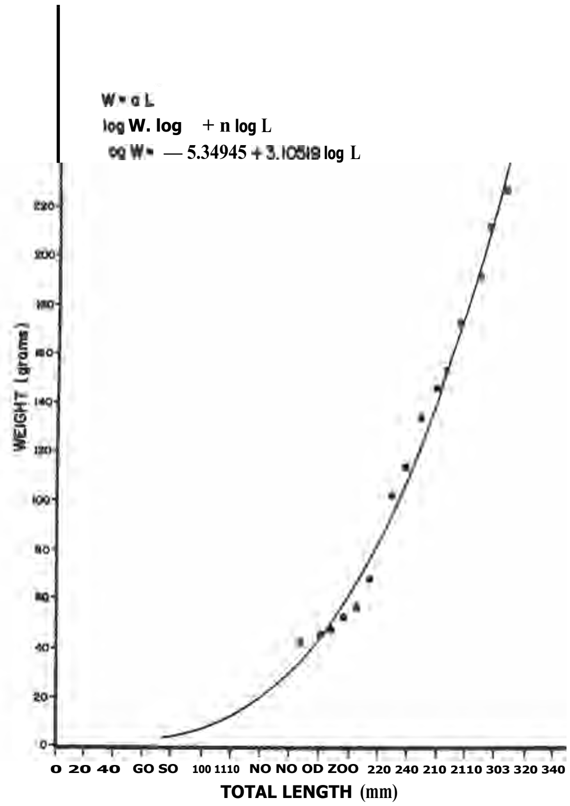


Fig. 13. Length-weight relationship of 1408 gizzard shad at time of capture from Elephant Butte Lake, 1969-70



W = mean weight in grams of each length group at capture
L = mean total length of groups in millimeters
a = empirical constant
n = empirical exponent or logarithm.

Empirical constants, log a and n, were determined as follows:

$$\log a = \frac{\Sigma \log W \cdot \Sigma (\log L)^2 - \Sigma \log L \cdot \Sigma (\log L \cdot \log W)}{N \cdot \Sigma (\log L)^2 - (\Sigma \log L)^2}$$

$$n = \frac{\Sigma \log W - (N \cdot \log a)}{\Sigma \log L} \quad \text{when:}$$

N = number of length groups.

Log a and n were substitued in the logarithmic form of the equation:

$$\log W = \log a + n \log L \quad ,$$

and corrected weights were determined for each length group. When plotted, corrected weights smooth the curve used to express length-weight relationship.

Intervals of length, numbers of fish, mean lengths and weights, corresponding logarithms, and calculated weights are shown in tables 6, 7, and 8. Mean lengths, weights, and corrected weights are presented graphically to demonstrate exponential relationships and variation of mean weights from empirical mean weights of samples (figures 11-13).

Table 6.—Calculated mean length-weight relationships of 718 gizzard shad at time of capture from Elephant Butte Lake, 1965-66.—Lengths in mm and weights in grams.

Interval of Length	N	$\bar{L}$	log $\bar{L}$	$\bar{W}$	log W	log $\bar{L}$ log W	log $\bar{L}^2$	Calculated* log W	Calculated* $\bar{W}$
70- 79	1	72.0	1.85733	4.0	0.60206	1.11822	3.44967	0.51880	3.2
80- 89	2	84.5	1.92686	6.5	0.81291	1.56636	3.71279	0.72955	5.4
90- 99	1	96.0	1.98227	7.0	0.84510	1.67522	3.92939	0.89800	7.9
100-109	1	103.0	2.01284	6.0	0.77815	1.56629	4.05152	0.99093	9.8
150-159	3	157.3	2.19673	47.7	1.67852	3.68726	4.82562	1.54997	35.4
160-169	18	167.4	2.22376	44.9	1.65225	3.67421	4.94511	1.63214	42.9
170-179	204	176.1	2.24576	49.2	1.69197	3.79976	5.04344	1.69902	50.0
180-189	241	185.0	2.26717	54.9	1.73957	3.94390	5.14006	1.76411	58.1
190-199	134	193.5	2.28668	61.4	1.78817	4.08897	5.22891	1.82342	66.6
200-209	31	204.3	2.31027	76.7	1.88480	4.35440	5.33735	1.89511	78.6
210-219	12	216.8	2.33606	90.8	1.95809	4.57422	5.45718	1.97353	94.1
220-229	12	225.2	2.35257	114.3	2.05805	4.84171	5.53459	2.02372	105.6
230-239	11	235.9	2.37273	118.1	2.07225	5.91689	5.62985	2.08501	121.6
240-249	15	246.5	2.39182	141.2	2.14983	5.14201	5.72080	2.14305	139.0
250-259	13	255.3	2.40705	148.5	2.17173	5.22746	5.79389	2.18934	154.6
260-269	10	266.9	2.42635	185.5	2.26834	5.50379	5.88717	2.24802	177.0
270-279	5	276.4	2.44154	191.2	2.28149	5.57035	5.96112	2.29420	196.9
280-289	4	286.0	2.45637	230.8	2.36324	5.80499	6.03375	2.33928	218.4
Groups	18		40.49416		30.79652	71.05600	91.68221		

*Calculated with formula $W = aL^n$, when

$$\log W = \log a + n \log L$$
$$= -5.12816 + 3.04003 \log L$$

Table 7. Calculated mean length-weight relationships of 130 gizzard shad at time of capture from Elephant Butte Lake, 1967-68. Lengths in mm and weights in grams.

Interval of Length	N	$\bar{L}$	log $\bar{L}$	$\bar{W}$	log $\bar{W}$	log $\bar{L}$ log $\bar{W}$	log $\bar{L}^2$	Calculated* logW	Calculated* $\bar{W}$
160-169	2	167.5	2.22401	43.5	1.63849	3.64402	4.94622	1.55652	36.0
170-179	4	178.3	2.25115	46.0	1.66276	3.74312	5.06768	1.64080	43.7
180-189	20	187.6	2.27323	48.3	1.68935	3.82801	5.16758	1.70936	51.2
190-199	43	196.4	2.29314	52.2	1.71767	3.93886	5.25849	1.77119	59.1
200-209	26	205.9	2.31366	57.5	1.75967	4.07128	5.35302	1.83490	68.4
210-219	6	215.7	2.33385	68.3	1.83442	4.28126	5.44686	1.89760	79.0
220-229	2	229.0	2.35984	102.0	2.00860	4.73998	5.56884	1.97830	95.1
230-239	1	239.0	2.37840	114.0	2.05690	4.89213	5.65679	2.03593	108.6
240-249	1	249.0	2.39620	134.0	2.12710	5.09696	5.74177	2.09121	123.4
250-259	2	259.0	2.41330	146.0	2.16435	5.22323	5.82402	2.11431	139.4
260-269	2	266.0	2.42488	154.0	2.18752	5.30447	5.88004	2.18026	151.4
270-279	6	275.8	2.44059	173.3	2.22880	5.46399	5.95648	2.22905	169.5
280-289	5	287.6	2.45879	192.4	2.28421	5.61639	6.04565	2.28556	193.0
290-299	6	295.3	2.47026	211.8	2.32593	5.74565	6.10219	2.32118	209.5
300-309	4	305.8	2.48544	226.0	2.35411	5.85100	6.17741	2.36831	233.5
Groups	15		35.51674		30.03988	71.44034	84.19303		

*Calculated with formula $W = aL^n$, when

$$\log W = \log a + n \log L$$
$$= -5.34945 + 3.10519 \log L$$

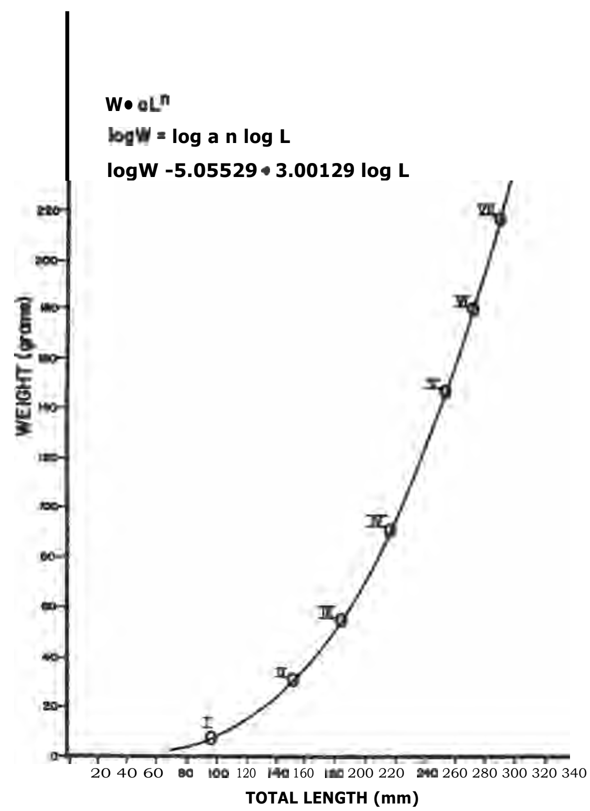
Table . calculated mean length-weight relationships of 1,408 gizzard shad at time of capture from Elephant Butte Lake, 1969-70. Lengths in mm and weights in grams.

Interval of Length	N	$\bar{L}$	logt	$\bar{W}$	log W	log $\bar{L}$ log W	log $\bar{L}^2$	Calculated* log $\bar{W}$	Calculated* $\bar{W}$
140-149	3	147.3	2.16820	29.3	1.46687	3.18047	4.70109	1.45211	28.3
150-159	6	155.8	2.19257	38.3	1.58320	3.47128	4.80736	1.52525	33.5
160-169	3	163.7	2.21405	32.3	1.50920	3.34144	4.90202	1.58971	38.9
170-179	57	176.1	2.24576	49.2	1.69197	3.79976	5.04344	1.68488	48.4
180-189	359	184.9	2.26694	55.9	1.74741	3.96127	5.13902	1.74845	56.0
190-199	507	194.2	2.28825	64.3	1.80821	4.13764	5.23609	1.81241	64.9
200-209	207	203.2	2.30792	74.3	1.87099	4.31810	5.32650	1.87144	74.4
210-219	35	213.7	2.32980	83.3	1.92065	4.47473	5.42797	1.93711	86.5
220-229	13	224.9	2.35199	99.5	1.99782	4.69885	5.53186	2.00371	100.9
230-239	16	235.4	2.37181	117.9	2.07151	4.91323	5.62549	2.06320	115.7
240-249	28	245.5	2.39005	140.6	2.14799	5.13380	5.71234	2.11794	131.2
250-259	39	255.4	2.40722	150.7	2.17181	5.24319	5.79471	2.16947	147.7
260-269	39	264.8	2.42292	164.8	2.21696	5.37152	5.87054	2.21659	164.7
270-279	33	274.4	2.43838	179.6	2.25431	5.49686	5.94570	2.26300	183.2
280-289	26	283.9	2.45317	198.0	2.29667	5.63412	6.01804	2.30738	202.9
290-299	14	293.6	2.46766	217.9	2.33816	5.77003	6.08935	2.35087	224.3
300-309	12	303.8	2.48259	246.3	2.39146	5.93702	6.16325	2.39568	248.7
310-319	6	315.7	2.49927	287.5	2.45864	6.14481	6.24635	2.44574	279.1
320-329	4	323.8	2.51028	294.5	2.46909	6.19811	6.30151	2.47879	301.2
330-339	1	338.0	2.52892	354.0	2.54900	6.44622	6.39544	2.53473	342.6
Groups	20		47.33775		40.96832	97.67244	112.27804		

*Calculated with formula $W = aL^n$, when

$$\log W = \log a + n \log L$$
$$= -5.05529 + 3.00129 \log L$$

Fig. 14. Length-weight relationship of 1408 gizzard shad, at time of annulus formation, in Elephant Butte Lake, 1969-70



Empirical constants, log a and n, for each sample were applied to grand mean lengths at time of annulus formation to calculate grand mean weights at time annuli were formed (see table 2). Grand mean increments of weight are shown in the same context. According to these data, differences in weight between the sexes are insignificant, and sexual dimorphism does not exist. Calculated grand mean length-weight relationships at time of annulus formation are shown (figure 14).

Jester (1971a) compared the number of years required in different localities for river carpsucker to attain a weight of 800 grams (28.2 ozs). This type of comparison for gizzard shad is included here. Ages at which gizzard shad attain 100 grams (3.5 ozs) are shown with authors and localities:

Lagler and Van Meter (1951), Beaver Dam Lake, Ill.	<1 year
Berry (1955), Lake Newnan, Fla.	<1 year
Bodola (1965), Lake Erie	<1 year
Lagler and Applegate (1942), Foots Pond, Ind.	1 year
Turner (1953), Herrington Lake, Ky.	2 years
Jester (1962), Conchas Lake, N.M.	3 years
Patterson[4], Elephant Butte Lake, N.M.	5 years
Jester and Jensen, (new data), Elephant Butte Lake, N.M.	4 years

Comparison of grand mean weights at time of annulus formation from Patterson's study and current data are shown in table 9. These data support the conclusion that a change in growth rate of gizzard shad in Elephant Butte Lake has occurred. Differences in grand mean weights show a continuous increase through successive age groups, as did grand mean lengths, except in Age Group VI.

The largest gizzard shad reported in the literature was recorded from Ohio (Trautman, 1957). It was 520 mm (20.5 in.) long and weighed 1,257 grams (44 ozs). Miller states that these fish do not commonly grow longer than 330-355 mm (13-14 in. The largest specimen collected during this study was an eight-year-old male which was 338 mm (13.3 in.) long and weighed 354 grams (12.5 ozs).

Condition

A standard method for expressing relative plumpness or robustness of fishes was established by Hile (1936). It is based upon the Cube Law which states that weight of an animal is a function of the cube of the length. Condition may be expressed as a coefficient, represented by "K" in the formula $W = KL^n$, by which the cube of the length must be multiplied to equal weight of fish. Values of K derived with this formula usually fall in the fifth or sixth decimal place. A factor is applied to raise the coefficient to a value near unity for easier comprehension. Purpose is to present condition in a standard form for comparison between length groups, age groups, sexes, and populations. The final formula used here for determination of coefficient of condition is:

$$K_{TL} = \frac{W \cdot 10^5}{L^3}, \text{ when:}$$

[4] thid.

Table 9. Grandmean weights, grandmean increments of weight, and differences in weights and increments, of gizzard shad from Elephant Butte Lake. Samples compared were taken in 1965-66 and 1970. Shown in grams.

	Grand Mean Weights and Increments at Formation of Annulus --							
Study	I	II	III	IV	V	VI	VII	VIII
Patterson (1965-66 data)								
Weights	4.4	16.2	30.9	53.6	85.9	114.6	122.7	161.7
Increments	4.4	11.8	14.7	22.7	32.3	28.7	8.1	39.0
Jester and Jensen, (new data)								
Weights	7.5	30.2	54.6	92.6	145.1	180.4	218.6	301.2
Increments	7.5	22.7	24.4	38.0	52.5	35.3	38.2	82.6
Difference								
Weights	3.1	14.0	23.7	39.0	59.2	65.8	95.9	139.5
Increments	3.1	10.9	9.7	15.3	20.2	6.6	30.1	43.6

W = weight of fish in grams
L = total length of fish in millimeters.

Subscript TL indicates that condition is calculated from total lengths of fish rather than standard length (SL) or fork length (FL).

Condition values have been used by Cooper and Benson (1951) and more-recent workers to indicate suitability of environments for particular species by comparison with indices from other localities and regional averages and to measure the effects of environmental improvement.

Because condition differs with age, sex, and season, K values were calculated monthly, by 10 mm length groups, and by sex, when these data were available. Sex data were not available for most fish collected prior to 1969.

Coefficients of condition (K_{TL}) were determined for 7,031 gizzard shad collected during a six-year period, from January 1965, through December 1970.

Comparison of monthly K values (figure 15) for 1,710 male and 1,072 female gizzard shad taken from Elephant Butte Lake during 1970, show females to have slightly higher condition values during most months but with no consistent trend. Higher values for females during April through July probably result from ovarian development during April and May and weight loss in males because of hyper-activity during the spawning season. The abrupt decline in condition for both sexes in June is a result of spawning activities and spent gonads. Weighted mean condition values for the 1970 sample revealed a K factor of 0.853 for females and 0.842 for males. These data demonstrate that sexual dimorphism does not occur in terms of condition. Monthly differences are probably related to development of gonads and loss of body weight from spawning activities.

Coefficients of condition for 2,836 gizzard shad collected during 1970 are shown by 10 mm intervals of length (figure 16). Comparison shows that, in general, condition of gizzard shad in Elephant Butte Lake is higher in lengths ranging from 230-279 mm (9-11 in.), with one exception. This is more obvious when condition is compared in 50 mm (2 in.) intervals of length (table 10).

Condition values of age groups were determined from mean length and weight of all fish in each age group (figure 17). Highest value is in Age Group IV and lowest in Age Group I.

Fig. 15. Comparison of monthly coefficients of condition (K_{TL}) for 1710 male and 1072 female gizzard shad from Elephant Butte Lake, January through Dec December, 1970

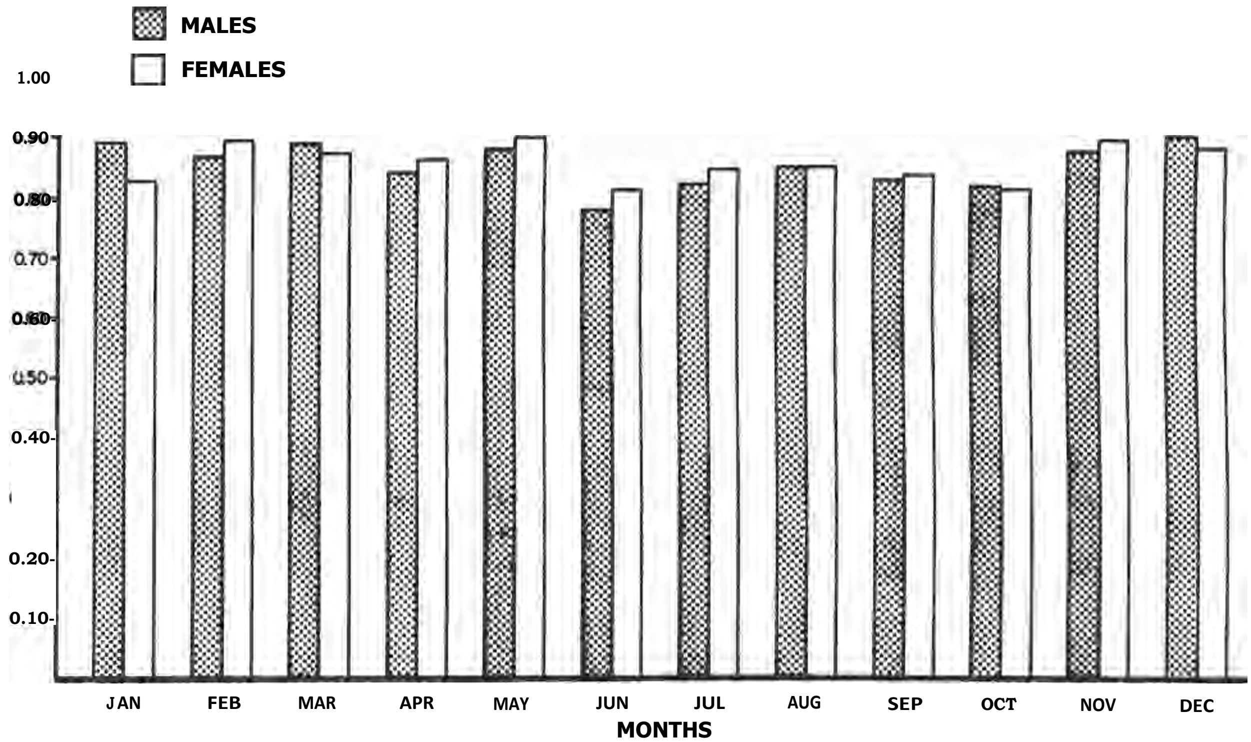


Fig. 16. Comparison of coefficients of condition (K_{TL}) of 2836 gizzard shad in 10 mm length groups, from Elephant Butte Lake, 1970

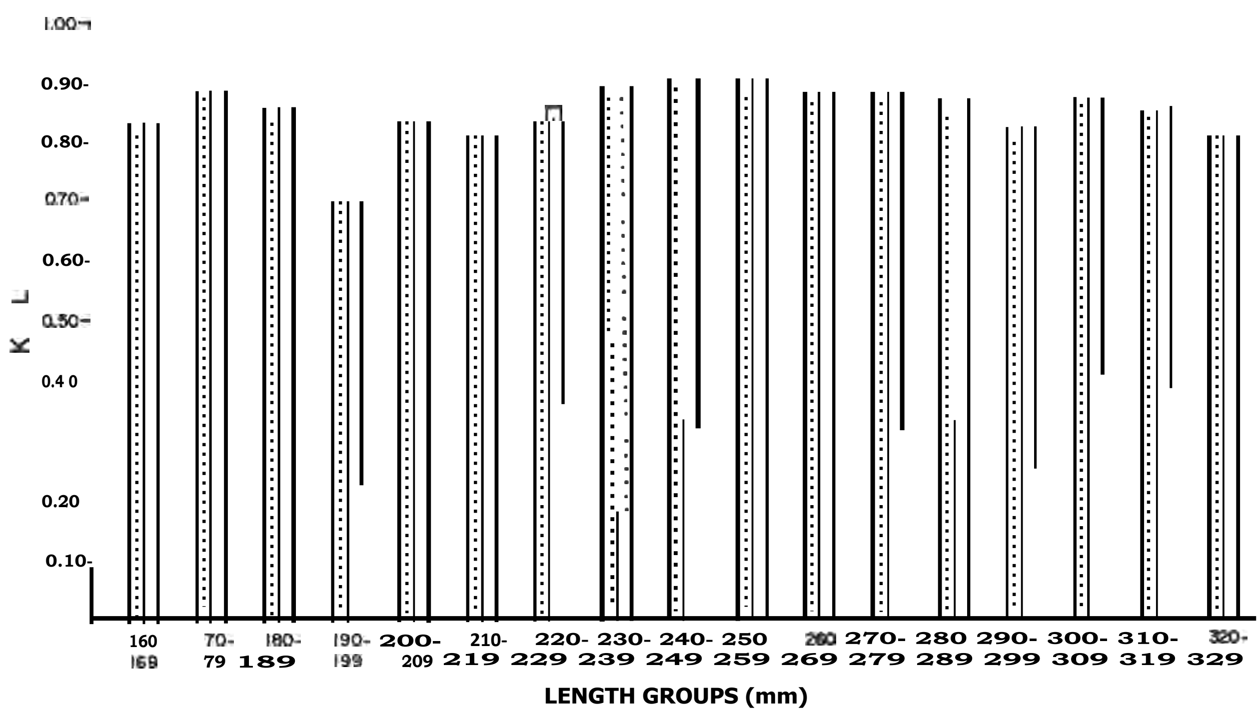


Fig. 17. Coefficients of condition of 364 gizzard shad by age group from Elephant Butte Lake, 1970

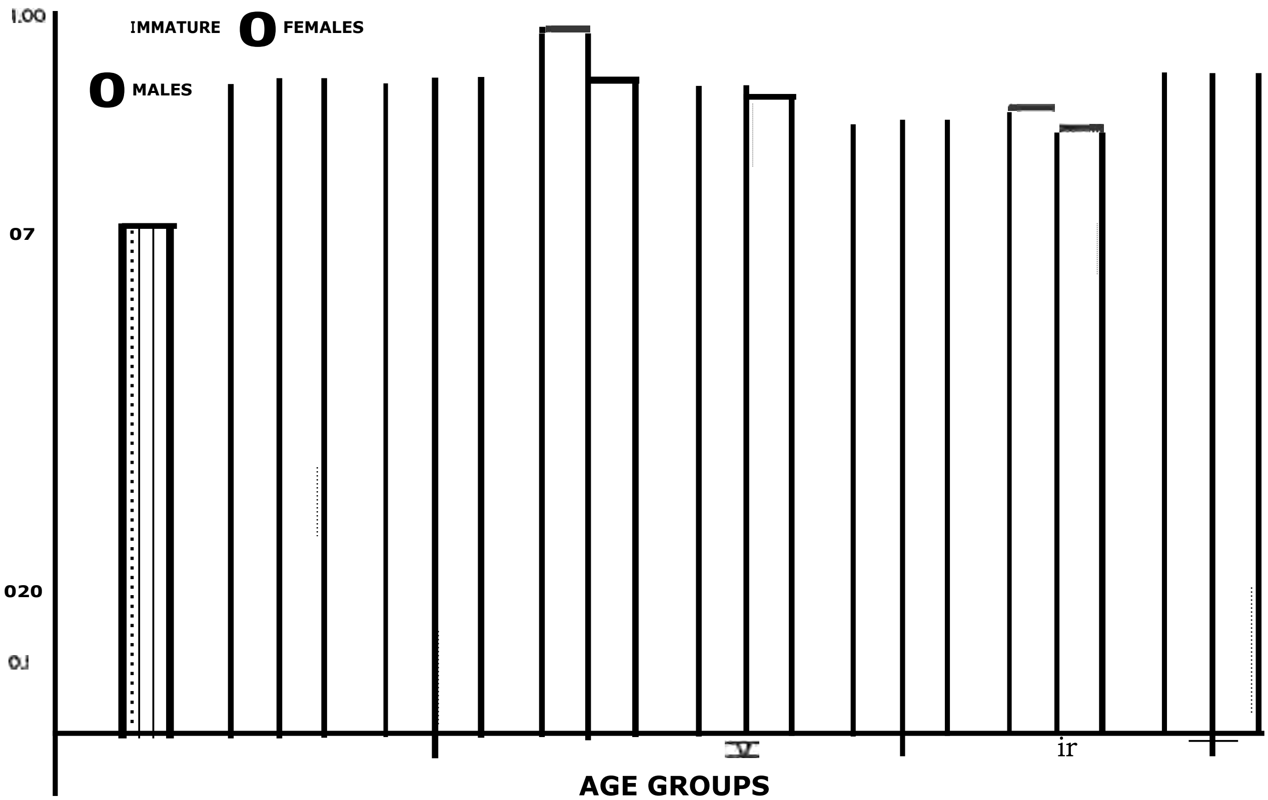


Table 10. Comparison of coefficients of condition of gizzard shad in 50 mm length groups by sex and all fish from Elephant Butte Lake, 1970.

Intervals of Length	Males N	Males K	Females N	Females K	Total N	Total K
160-209	1,513	0.84	716	0.86	2,266	0.84
210-259	141	0.86	183	0.88	333	0.87
260-309	55	0.86	168	0.87	227	0.87
3104	1	0.92	5	0.81	11	0.85

Grand mean coefficient of condition for the six-year collection of gizzard shad is 0.867. Condition was highest in 1965 (0.965) and lowest in 1967 (0.814) (figure 18). These data demonstrate that annual condition is erratic and does not conform to trends in growth rates, length-weight relationship, and population changes shown by changes in catch per unit of effort. Grand mean value of 0.867 is lower than that of shad from all other waters compared (Jester, 1962; Hancock;[5] Jackson, 1957; Shields, 1957; Jenkins, 1949; Bodola, 1965; Starrett and Fritz, 1965; Lagler and Applegate, 1942; Turner, 1953; and Berry, 1955) (figure 19).

[5]Hancock, H. M., 1955. Age and growth of some of the principal fishes in Canton Reservoir, Oklahoma, 1951, with particular emphasis on the white crappie. Oklahoma Fish & Game Coun. Proj. Rept. , Pt. 2. Mimeographed.

Fig. 18. Annual mean coefficients of condition (K_{TL}) of 7031 gizzard shad from Elephant Butte Lake, January, 1965 through December, 1970

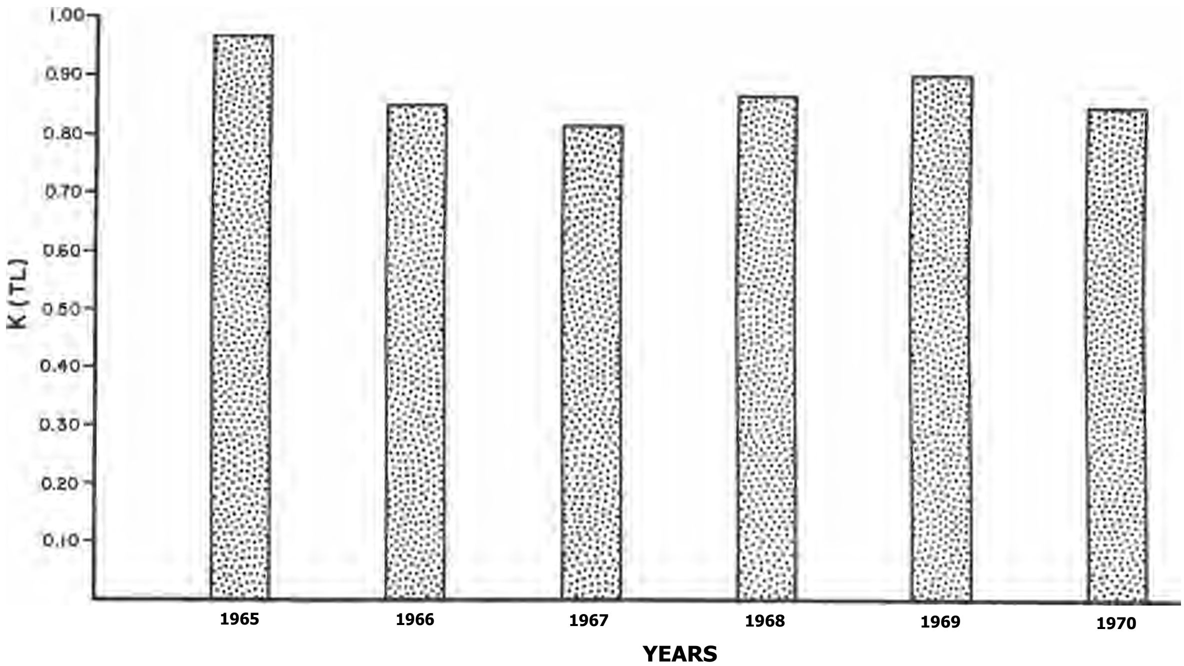
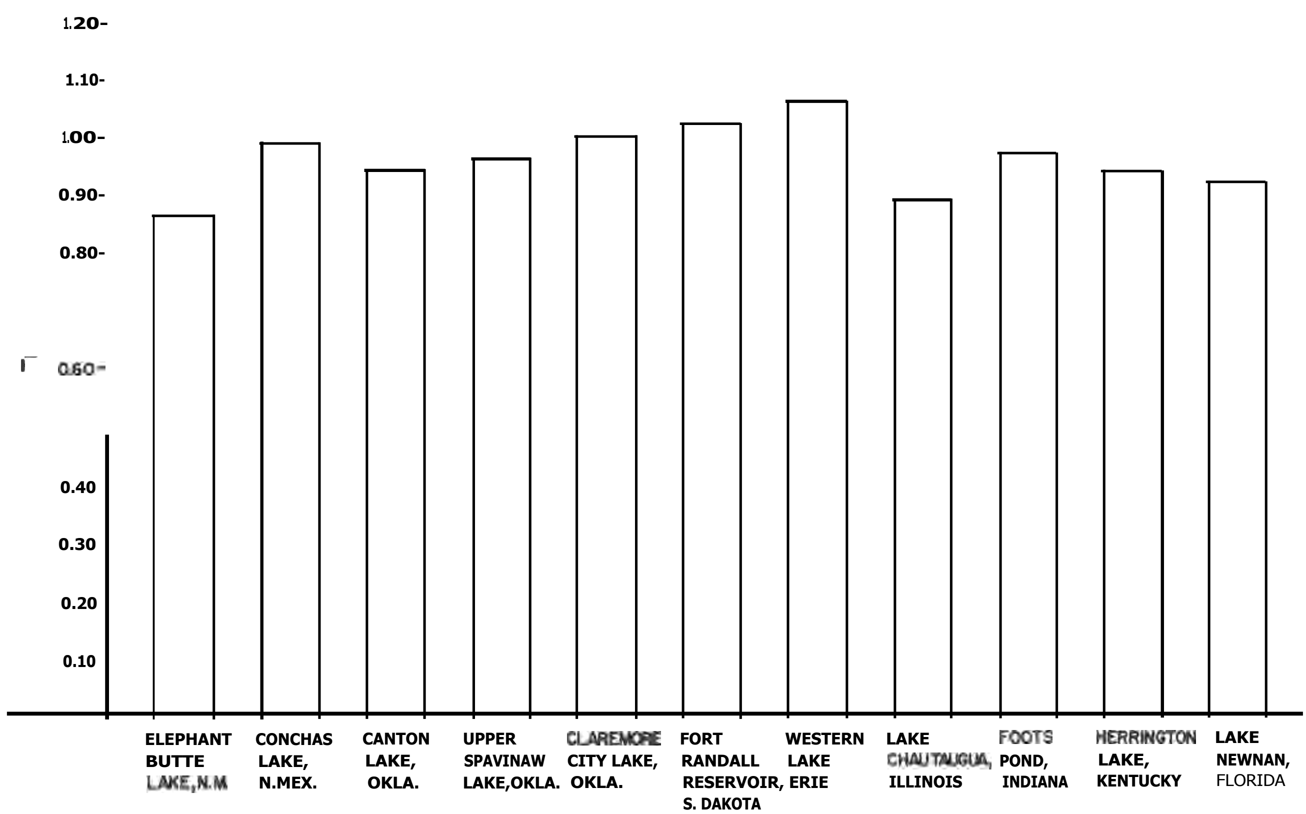


Fig. 19. Comparison of coefficients of condition (KTL) of gizzard shad from Elephant Butte Lake and 10 other waters



Length-Frequency

According to Lagler (1956), Petersen (1891) stated that length-frequency may be used as an age-growth study method. He summarized work of subsequent researchers (including **Hile,** 1941) to conclude that length-frequency is largely limited to estimation of mean lengths in younger age groups prior to the end of the second or third growing season, thus implying that length-frequency peaks in smaller length groups conform to length-frequency peaks of younger age groups (Jester, 1971a). Jester concluded that coincidence of length-frequency peaks of length groups and age groups in river carpsucker was weak evidence for validating the scale method because of overlap of lengths of fish among age groups and by erratic frequencies of fish in certain length groups.

Length-frequency of gizzard shad was established in 10 mm intervals of total length. Length-frequency of 364 shad collected for age-growth studies suggests possibility of three or four age groups (figure 20). However, examination of age groups which fall

Fig. 20. Length-frequency of 364 gizzard shad from Elephant Butte Lake, 1970, showing overlap of age groups into different length groups. Frequency is expressed as percent of each length group in the sample.

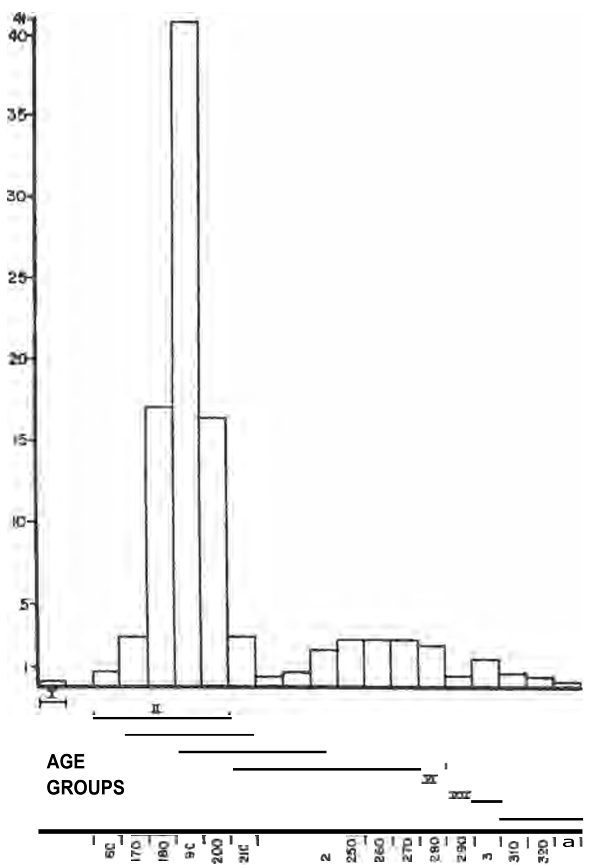


Fig. 21. Length frequencies of 7157 gizzard shad collected in gill nets from Elephant Butte Lake, 1965-1970. Expressed as percent of each length group during individual years.

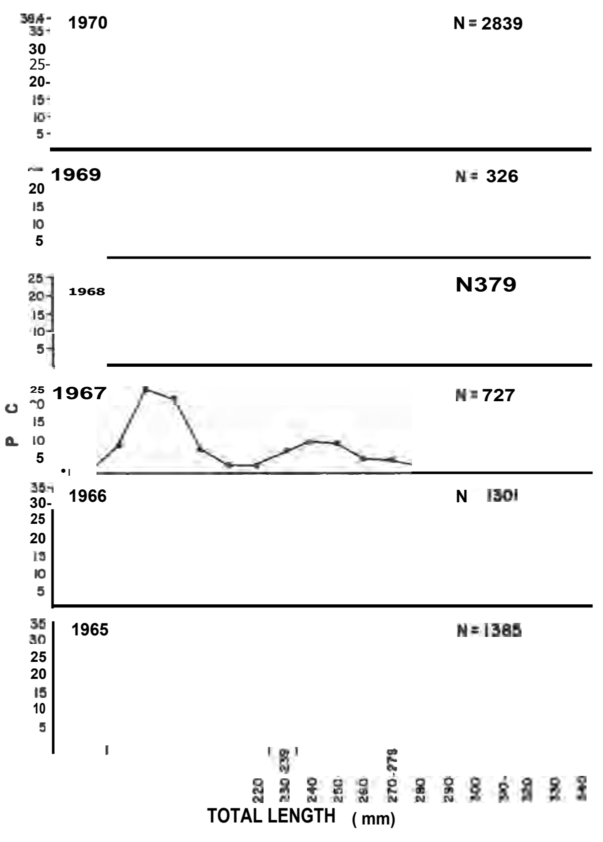


Table 11. Length-frequency by age group of 364 gizzard shad from Elephant Butte Lake, 1970.

Interval of Total Length	Number in Age Group --								Total
				IV	V	VI	VII	VIII	
90	1								1
160		3							3
170		9	2						11
180		41	22						63
190		19	124	6					149
200		1	42	17					60
210			3	7	1				11
220				2					2
230				3					3
240				3	5				8
250				3	7				10
260				1	4	4	1		10
270						7	3		10
280					3	5	1		9
290							2		2
300						3	3		6
310							2	1	3
320							1	1	2
330								1	1
Totals	1	73	193	42	20	19	13	3	364
Percent	0.3	20.1	53.0	11.5	5.5	5.2	3.6	0.8	100.0
Year Class	1969	1968	1967	1966	1965	1964	1963	1962	

within frequency peaks reveals that such interpretation is erroneous. The dominant peak results from overlap of Age Groups II-IV while the second peak results from overlap of Age Groups IV-VII (table 11). These data add to cumulative evidence that length-frequency may not be used as an indicator of age unless it is validated for a specific population.

Annual length-frequencies for six years, 1965-70, indicate occurrence of strong year classes during alternate years (figure 21). From 1965 to 1966, emphasis in frequency shifted from 180 mm to 190 mm (7.1 to 7.5 in.). This trend is evident each two years throughout the collection period. Also evident during alternate years is the loss of fish in intervals of 190 and 200 mm (7.5 and 7.9 in.) and recruitment of fish in intervals of 170 and 180 mm (6.7 and 7.1 in.).

Reproduction

A study of reproduction was made to determine spawning season, areas, behavior, sexual maturity, sex ratio, and fecundity of gizzard shad in Elephant Butte Lake. All data pertaining to reproduction were collected during 1970.

Spawning Season

Spawning season is dependent upon water temperature and occurs at different times from year to year. Miller (1960) states that most populations of gizzard shad spawn during April, May, and June at temperatures ranging from 50° to 70°F (10° to

(21.1°C). He emphasizes that these fish usually spawn on a rising temperature although, on one occasion, Trautman (1957) found them spawning on a falling temperature in Buckeye Lake, Ohio. Bodola (1965) found shad spawning on a rising temperature in western Lake Erie where they were spawning in great numbers at 67°F (19.4°C). When water temperatures dropped slightly to 65° and 65.5°F (18.3 to 18.6°C), the numbers of shad spawning on gravel bars decreased. Bodola (op. cit.) concluded that water temperature during development of the eggs is probably more important in determining the time of spawning than is the water temperature immediately preceding the spawning period. Langlois (1954) observed gizzard shad spawning at 64°F (17.8°C) on May 29 in North Reservoir, Akron, Ohio. In Norris Reservoir, Tennessee, Dendy (1946) observed shad spawning between May 18 and June 8, 1943, when surface temperatures varied from 73.5° to 81.7°F (23.1° to 27.6°C). In 1944 most of the spawning took place between May 15 and June 1 in a temperature range of 78° to 84°F (25.6° to 28. 9°C). Peak of spawning activity in Lake Newnan, Florida, occurred around April 1 (Berry, 1955). At Conchas Lake, Jester (1962) observed that shad began to spawn in early May, reached a peak in mid-May, and declined until mid-June when spawning ceased. Temperature varied from 65° to 75°F (18.3° to 23.9°C) and was 70°F (21. 1°C) at the peak of spawning activity. In 1970, spawning of gizzard shad in Elephant Butte Lake was first observed on May 7. Temperature was 17.8 C (64°F). Peak spawning occurred from May 15 through May 22 in a temperature range from 18. 9° to 20.0°C (66°-68°F). Spawning continued through late June when the temperature was 23.9 C(75°F).

As noted in the section on condition, there is a gradual but erratic increase in condition values from November through May and a pronounced decline in condition during June following spawning in May (see figure 15). Increase and decline of condition values in both sexes from July through October is indicative of a second but less pronounced spawning period. Ovaries examined before spawning in May and during July-October lends additional support to this possibility. Females which were releasing ova were collected through August 27 while males with free-flowing milt were observed only through July 21. Many of the ovaries collected prior to and during the spawning period in May contained ova which appeared to be ripe. In a distinct layer near the outer edge of the ovary, the ova were mature or were being released when the fish was collected. Mean diameter of mature ova was approximately one mm. Ova in inner layers ranged from 0.5 mm to 0.75 mm in diameter and were immature. Increase in condition values during July and August paralleled development of the remaining ova, with the decline during September and October probably reflecting the spawning of remaining ova. By early fall, nearly all ovaries examined were flaccid, verifying that ova had been spawned or resorbed. Low incidence of observed resorption suggests that spwaning probably occurred. No actual observations of spawning activities were made during the late summer period, nor did documentation confirm that this had occurred elsewhere. The data only suggest that a second spawn may have occurred in Elephant Butte Lake.

Spawning Areas

Langlois (1954) observed gizzard shad spawning along the shore at depths of 6 to 12 inches (15 to 30 cm) in North Reservoir, Akron, Ohio. Bodola (1965) located a spawning site in western Lake Erie, on a sandy, gravel-covered bar at depths of two to four feet (0.6 to 1.2 m). In Conchas Lake, Jester (1962) observed the largest spawning concentrations on shallow silt beds ranging from one to six feet (0.3 to 1.8 m) in depth, with most fish at depths less than three feet (one m).

Gizzard shad in Elephant Butte Lake spawn in areas where depth ranges from a few inches to 40 and 50 feet (12 and 15 m). Greatest concentrations were observed in shallow coves in water depths varying from one to five feet (0.3 to 1.6 m). Considerable numbers of these fish were observed spawning along the shore line in 6 to 12 inches (15.2 to 30.5 cm) of water. The most detailed observations of spawning activity were made in unoccuppied, covered boat docks located at the Elephant Butte Boat Company marina. Spawning shad were concentrated in these areas where the water-depth was approximately 50 feet (15 m). Ova were very adhesive. Some sank to the bottom while others floated and adhered to submerged and floating objects. Numerous ova were observed sticking to the marina, boathouses, and inundated vegetation.

Spawning Behavior

Spawning activity begins when a group of males and females, swimming near the surface, begin to roll and tumble about each other in a mass, the eggs and sperm being ejected during this activity (Miller, 1960). Langlois (1954) reported that a female was flanked on each side by a male while gizzard shad were spawning in North Reservoir, Akron, Ohio.

Large concentrations of spawning gizzard shad were observed in Elephant Butte Lake during May, 1970. Fish were so numerous at times, and activity so erratic, that specific patterns of behavior were not detectable. Behavior patterns, at other times, were evident and consistent (figure 22). One fish, assumed to be a female, was followed by one to eight other fish, probably males. The males would periodically bump the female with their snouts. Whether this action was intentional or merely incidental is not known, although it appeared to be quite deliberate. All fish were swimming on their sides. Occasionally the group of fish would begin to roll and tumble in a manner similar to that described above. Fish participating in spawning activities were collected with dip nets. Several groups were captured and inspection revealed that only one fish in each group was a female. These data show that there is an unbalanced sex ratio during the spawning process.

Sexual Maturity

Examination of gonads and determination of age revealed that gizzard shad in Elephant Butte Lake become sexually mature at two and three years of age. Bodola (1965) collected a few precocious males and females in Age Group I from western Lake Erie. He found a few immature individuals in Age Group III.

Male gizzard shad in Elephant Butte Lake began to mature in Age Group II, and all were mature in Age Group IV. Females were mature in Age Groups III and IV. Many

Fig. 22. Spawning behavior of gizzard shad in Elephant Butte Lake, 1970. Upper left - Male approaching female to bump abdomen. Upper right - Males and females rolling and tumbling about each other. Lower - Female and 3 males swimming on sides.

of the older females and a few of the older males were sexually inactive, with the gonads in a state of degeneration, suggesting senility. Gonads in some fish had degenerated to the point that sex could not be determined.

Sex Ratio

Sex ratios were determined for gizzard shad collected during each month in 1970 (table 12). April, May, and June are noteworthy because of the preponderance of males (74.9 percent). As noted above, male gizzard shad in Elephant Butte Lake become hyper-active during the spawning season. This activity results in an imbalanced sex ratio in samples, favoring males. Although females were collected most frequently during seven months, they comprised only 38.5 percent of the annual sample. The high percentage of females in January probably is a result of sampling error, resulting from the small number of fish in the sample.

Table 12. **Monthly sex ratios for 1,712 male and 1,073 female gizzard shad from Elephant Butte Lake, 1970**

	Percent of Total Catch During Months of --												Twelve-Month
Sex	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
Males													
	23.5	43.3	54.3	66.8	76.8	75.4	56.5	39.6	47.6	49.6	48.0	40.7	61.5
N	4	29	25	129	552	370	178	78	110	136	35	66	
Females													
	76.5	56.7	45.7	33.2	23.2	24.6	43.5	60.4	52.4	50.4	52.0	59.3	38.5
N	13	38	21	64	167	121	137	119	121	138	38	96	

Table 13. **Change in sex ratio of gizzard shad from Elephant Butte Lake, as they increase in size.**

Intervals	Males		Females		Total	
of Length	Number	Percent	Number	Percent	Number	Percent
160-209	1,514	67.9	716	32.1	2,230	100.0
210-259	141	43.1	186	56.9	327	100.0
260-309	55	24.9	166	75.1	221	100.0
310+	2	28.6	5	71.4	7	100.0
Totals	1,712		1,073		2,785	

Because males are excessively active, and probably participate in numerous spawns, their energy requirements for continual gamete production and harassment of females must be tremendous. This is probably why the condition of males declined nearly as much as it did in females after initial spawning in May and June (-0.085 for males and -0.090 for females). Perhaps this results in spawning mortalities and a shorter life expectancy for males, as indicated by the progressively changing sex ratio in larger fish (table 13). This is also evident from the number of males and females in each age group in the age-growth study (see table 2). Berry (1955) attributed a sudden decline of shad in older age groups following the spawning season to a post-spawning die-off in Lake Newnan, Florida. Evidence suggesting a similar occurrence in Elephant Butte Lake was observed during the spawning season. Several dead gizzard shad were collected in areas where spawning was taking place. Determination of sex of these fish revealed that all were males. Because dead shad were not observed prior to or following the spawning season, these data suggest that mortality resulted from spawning activity.

Fecundity

Fecundity of female gizzard shad was determined from a sample of 30 fish taken during spring, 1970, just prior to spawning.

Number of ova in each ovary was determined by the weight method described by Eschmeyer (1950). Because variations in ovary size from individual fish were observed, each ovary was analyzed and the number of ova in each was combined to indicate the number of ova per fish. Ovaries were divided into thirds and each section weighed to the nearest one-thousandth of a gram. Ova in one gram from each section were counted to determine number of ova per gram. These data were expanded to number per section, and all data from each ovary were combined to equal number of ova per fish.

Determination of ages of fish examined for fecundity revealed that the sample was represented by three age groups (table 14). Age Group III contained 26 fish. These fish contained ova ranging in number from 28,545 to 70,874 and a mean number of 40,500. Three fish in Age Group IV contained an average of 29,884 ova and one fish in Age Group VI contained 58,467 ova. These findings are low compared with shad from Lake Erie. Bodola (1965) found ova production to be lowest in precocious individuals in Age Group I, highest in Age Group II, and a decling fecundity from Age Group II through Age Group VI. Mean number of ova per female in the sample was 298,545. These data give additional evidence of the stunted condition of gizzard shad in Elephant Butte Lake.

Multiple regression analyses of fecundity in relation to length, weight, and age are shown in figures 23-25. Data for plotting regression lines were calculated on the IBM System/360 computer. Standard formula for expressing multiple linear regression is:

$Y = a + b_1X_1 + b2X_2 + b_3X_3$, which is expressed as:
$F = a + b_1L + b2W + b_3A$, when
= fecundity
a = intercept
b_1, b_2, b3 = coefficients of L, W, A
= total length of fish in millimeters
= weight of fish in grams
A = age of fish in years.

Calculated regressions were negative in all cases, indicating a declining fecundity with increase in size and age of fish. This is the same trend which Bodola (op.cit.) found in gizzard shad from Lake Erie. Correlations between length, weight, age, fecundity, and combinations of these parameters are shown in table 15.

Correlations are low when considered separately. Age and fecundity show the highest correlation at r = 0.267. Combinations of parameters raise correlations significantly. Closest correlation is between length, weight, and fecundity (0.863) while correlation of all parameters combined is only slightly lower at 0.830.

Table 14. Fecundity of 30 gizzard shad from Elephant Butte Lake, 1970.

				Ova per Female	
Age	N	TL	Weight	Mean	Range
III	26	172-208	52-89	40,500	28,545-70,874
IV	3	205-210	73-85	29,884	27,815-31,396
V	--	--	--	--	--
VI	1	270	187	58,467	

Table 15. Coefficients of correlation expressing relationships between length, weight, age, fecundity, and combinations of these parameters.

	Parameters						
	L-F	W-F	A-F	L-W-F	L-A-F	W-A-F	L-W-A-F
Coefficient of Correlation	0.187	0.027	0.267	0.863	0.482	0.427	0.830
When	L = length		W = weight		A = age		F = fecundity

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= fecundity
a = intercept
$b_1, b_2, b3$ = coefficients of L, W, A
L = total length of fish in millimeters
= weight of fish in grams
A = age of fish in years.

Calculated regressions were negative in all cases, indicating a declining fecundity with increase in size and age of fish. This is the same trend which Bodola (op.cit.) found in gizzard shad from Lake Erie. Correlations between length, weight, age, fecundity, and combinations of these parameters are shown in table 15.

Correlations are low when considered separately. Age and fecundity show the closest correlation at r = 0.27. Combinations of parameters raise correlations substantially to r = 0.32 for a combination of length, weight, and fecundity and to r = 0.37 for length, weight, age, and fecundity. Thus, length, weight, and age affect fecundity with age having the greatest single effect.

Table 14. Fecundity of 30 gizzard shad from Elephant Butte Lake, 1970.

Age	N	TL	Weight	Ova per Female Mean	Ova per Female Range
III	26	172-208	52-89	40,500	28,545-70,874
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V	--	--	--	--	--
VI	1	270	187	58,467	

Table 15. Coefficients of correlation expressing relationships between length, weight, age, fecundity, and combinations of these parameters.

	Parameters						
	L-F	W-F	A-F	L-W-F	L-A-F	W-A-F	L-W-A-F
Coefficient of Correlation	0.19	0.03	0.27	0.32	0.27	0.28	0.37

When: L length W = weight A = age F = fecundity

Fig. 23. Relationship between fecundity and total length of 29 gizzard shad from Elephant Butte Lake, April, 1970

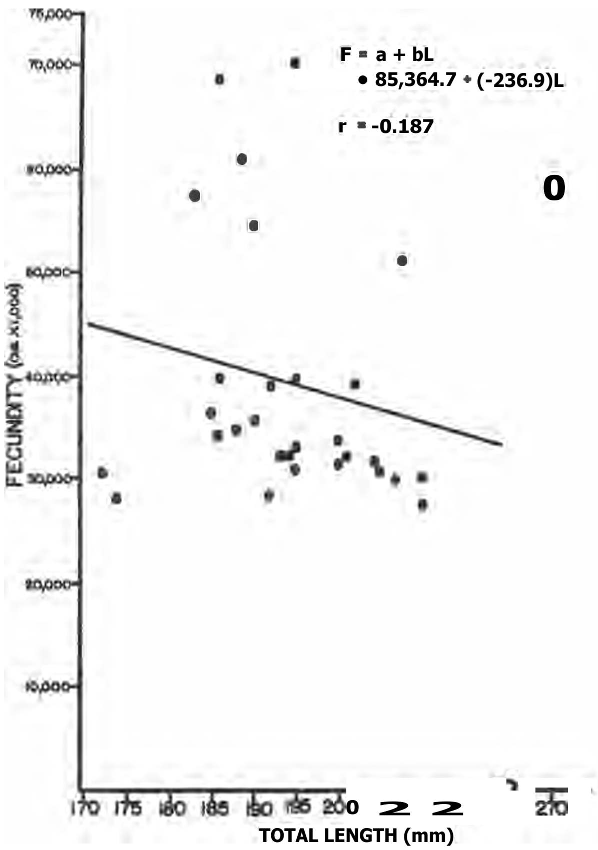


Fig. 24. Relationship between fecundity and weight of 29 gizzard shad from Elephant Butte Lake, April, 1970

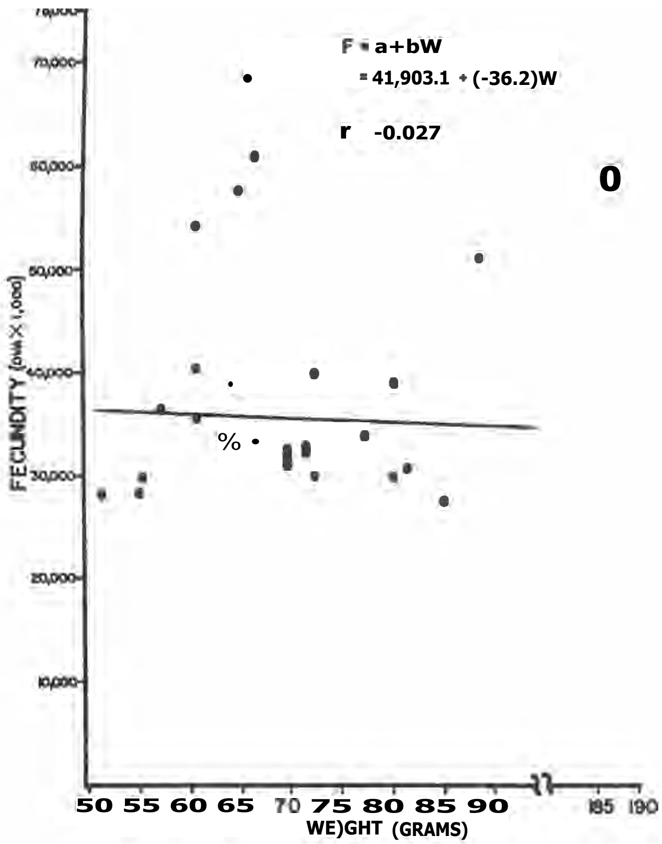


Figure 26 illustrates the consistent relationship between length and fecundity when compared in various ways. These data also show the declining fecundity expressed by the regression analysis. Conversely, the lone fish in length group 270 varies erratically from one analysis to the next.

Feeding and Food Habits

An important aspect in studying life history and ecology is investigation of food and feeding habits of fishes. Sanchez (1970) cited Harrison (1948) and Moen (1953) as stating that food and feeding relationships of fishes commonly dominate their ecological associations, and that an understanding of food-habit relationships is necessary for proper handling of fishery resources.

Feeding

The gizzard shad feeds by swimming through the water in an apparently-aimless manner with its mouth open (Tiffany, 1921a). The feeding apparatus of this species

Fig. 25. Relationship between fecundity and age of 29 gizzard shad from Elephant Butte Lake, April, 1970

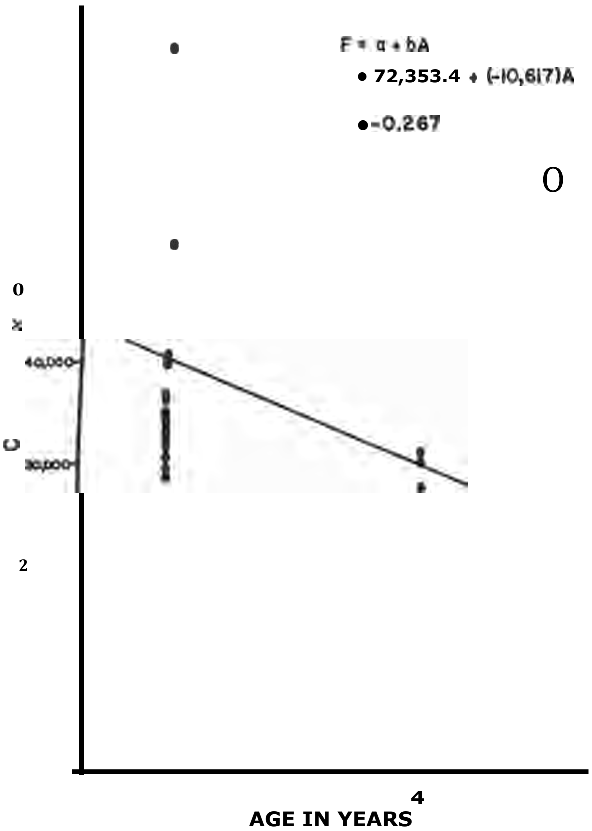
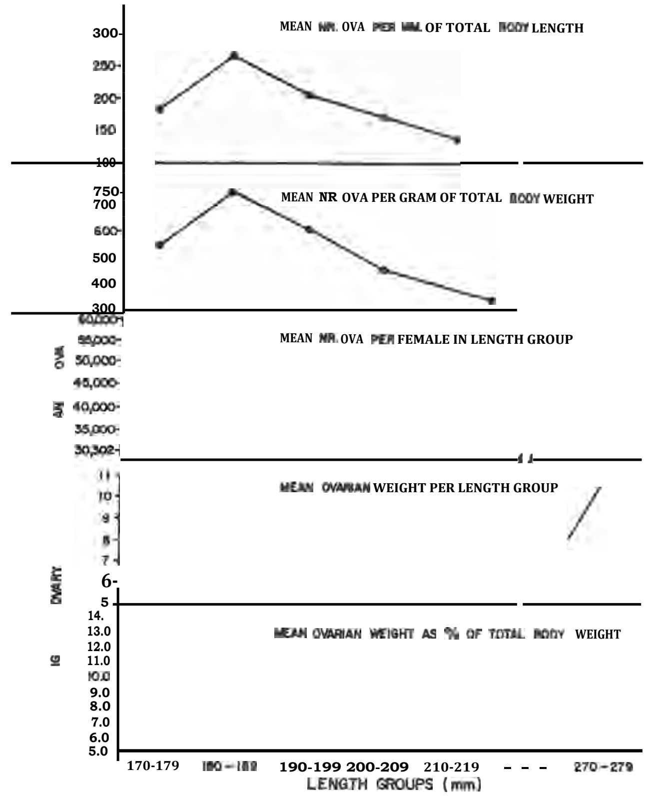


Fig. 26. Comparison of parameters of fecundity with total length of 30 gizzard shad from Elephant Butte Lake, April, 1970



was described by Lagler and Kraatz (1944) and Wier and Churchill (1945). The fine gill rakers on the gill arches, acting as a tiny sieve, allow the water to pass out through the gill slits as the fish swims along, while the planktonic organisms are retained and introduced into the alimentary canal (Tiffany, op. cit.). The great variation in the food consumed by the gizzard shad led Tiffany (1921b) to describe these fish as "living tow-nets."

Food

Food habits of gizzard shad were determined from 20 fish collected in October, 1970, and March, 1971. Qualitative analyses were made on contents of the entire digestive tract. Contents were examined microscopically in a Sedgewick-Rafter counting cell to determine relative numerical abundance of food items. All digestive tracts in the sample contained food items.

According to Forbes (1888), the shad is a "mudlover par excellence;" it swallows "large quantities of fine mud containing about 20 percent of minutely divided vegetable debris." Tiffany (1921b) was of the opinion that mud in the digestive tract was merely incidental--"so much unavoidable non-nutrient material that is ingested with actual food." Tiffany's studies on the food of shad indicate that the fish is almost entirely a vegetarian, except for a short time after hatching. This exception was emphasized by Warner (1940), who stated that an examination of the contents of the digestive tracts of larval and post-larval gizzard shad reveals that their food consists entirely of small animal plankton (cladocerans, copepods, and a few ostracods). Velasquez (1939) concluded that not all planktonic organisms ingested by gizzard shad were utilized as food. He found, after extensive culture experiments on the contents from shad digestive tracts, that some of the algae were viable, even from the terminal portion of the intestine.

Results of other studies indicate that a definitive statement concerning the food of gizzard shad should not be made. Ewers and Boesel (1936) recorded digestive tract contents as algae and debris, 85 percent; and Cladocera, 15 percent. Berry (1955) reported food items as algae, 7.9 percent; plant remains, 1.0 percent; Crustacea, 9.0 percent; Hydracarina, 0.1 percent; sand, 4.0 percent; and debris, 78.0 percent. Rice (1942; from Berry, op. cit.) found 75 percent crustacens, 10 percent insect larvae, and 15 percent diatoms. Two other studies cited by Berry give further evidence of the variety of the food of gizzard shad. Freeman and Huish[6] found chironomid larvae and mollusks (probably small snails) to be the main portion of the identifiable food, Reid (1949) found the contents of the digestive system to consist almost entirely of ostracods, copepods, and cladocerans, with phytoplankton in lesser quantity. Dendy (1946) found that, on occasion, the species was even cannibalistic, while Jester (1962) observed several large specimens (15 to 17 inches or 380 to 435 mm long) which were caught on hooks baited with small fathead minnows.

Bodola (1965) found that gizzard shad captured in open waters contained mostly free-floating phytoplankton; those captured among littoral vegetation had ingested Cladocera, Copepoda, Rotifera, and small aquatic insect larvae; and those collected in very turbid waters were filled largely with mud. Bodola's observations appear to explain the great variation in food items of gizzard shad when combined with Tiffany's (1921a) statement that shad feed by swimming through the water in an apparently aimless manner with their mouths open. Data included in this discussion indicate that the food ingested by gizzard shad is primarily incidental to its activities within the habitat. Bodola (1965) was of the opinion that these fish occasionally ingest small quantities of sand to aid in mastication of food material in the gizzard-like stomach, although he did not eliminate the possibility that it could have been accidentally taken along with food.

Food habits of shad in Elephant Butte Lake were analyzed in terms of frequency of occurrence and relative numerical abundance (table 16). Unidentified organic residue, Chlorophyta, Bosmina, and Diaptomus were the most numerous food items in digestive tracts. A total of 6,280 food items were counted in digestive tracts of the 20 fish. Phytoplankton comprised 36.8 percent of the total number, while zooplankton made up 31.2 percent, and unidentified organic residue and higher plant material comprised 28.4 percent and 3.6 percent of the sample, respectively.

[6]Freeman, B. 0„ and M. T. Huish, 1953. A summary of a fish population control investigation conducted in two Florida lakes. Florida Game & Freshwater Fish Comm., 109 pp. Mimeographed.

Table 16. Food items in digestive tracts of 20 gizzard shad from Elephant Butte Lake, October, 1970 and March, 1971.

Food Item	Frequency of Occurrence N	Frequency of Occurrence %	Relative Numerical Abundance N	Relative Numerical Abundance %
Phytoplankton:				
Chlorophyta	20	100.0	1,508	24.0
Chrysophyta	20	100.0	731	11.6
Cyanophyta	16	80.0	62	1.0
Unidentified	8	40.0	12	0.2
Zooplankton:				
Crustacea:				
Cladocera:				
Bosmina	18	90.0	819	13.0
Daphnia	16	80.0	290	4.6
Copepoda:				
Diaptomus	16	80.0	358	5.7
Cyclops	11	55.0	115	1.8
Nauplius	13	65.0	75	1.2
Invertebrate eggs	17	85.0	156	2.5
Unidentified	14	70.0	83	1.3
Rototaria	7	35.0	60	1.0
Protozoa	5	25.0	5	0.1
Higher plant material	18	90.0	223	3.6
Unidentified organic residue	20	100.0	1,783	28.4

Although phytoplankton was more abundant than zooplankton in terms of relative numerical abundance, zooplankton comprised the greater biomass. Of identifiable food items, zooplankton comprised the major portion of the diet of gizzard shad in Elephant Butte Lake. Of the 6,280 food items counted, 4,854 (77.3 percent) were observed in digestive tracts collected in October.

Data in this and other studies indicate that gizzard shad ingest a great variety of food items. The diversity from one location to another suggests that predominance of plant or animal material in the diet of gizzard shad is controlled by availability.

Habitat and Movements

Gizzard shad were collected over all types of substratum in Elephant Butte Lake, e.g., mud, sand and gravel, bedrock, and amoung inundated vegetation. They were taken most consistently over sand and gravel in shallow water. Distribution of these fishes was not affected by turbidity, but rather by clarity. Large numbers were collected in water where Secchi disc visibility was as low as six inches (15 cm). When visibility was near 60 inches (152 cm), the catch rate of gizzard shad was lower than in the more turbid water. They may have avoided the clearer water because increased visibility enhances predation by sight-feeding game fishes; or it is possible that they avoided nets which were more visible in clear water.

Sampling revealed that gizzard shad occupy chiefly the littoral and limnetic areas in Elephant Butte Lake. They were collected in shallow water during all months, although numbers caught from November through March were considerably smaller than catches during the other months. This is evident in monthly catch per net-unit and mean temperature data (table 17). Gizzard shad apparently move into deeper areas of the lake and cease activity almost entirely in the fall as the water temperature ap-

Table 17. Monthly catch per net-unit and mean temperature data from Elephant Butte Lake, 1970.

Item	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct	Nov.	Dec.
N per net-unit	1.6	1.9	1.3	6.9	17.1	16.8	12.1	15.1	24.5	18.8	3.2	5.7
Wpernet-unit (grams)	6.6	7.6	4.8	22.6	41.2	36.6	30.8	48.7	59.6	52.6	12.6	19.3
Mean temperature:												
°F	48.6	51.6	52.6	57.7	66.0	78.2	79.7	81.4	79.5	67.0	56.6	50.8
°C	9.2	10.9	11.4	14.3	18.9	22.9	26.5	27.4	26.4	19.4	13.7	10.4

Table 18. Change in activity of gizzard shad in Elephant Butte Lake, 1968-1970.

Date	N of Fish Caught	Feet of Net Set	N per 100 Feet of Net	Temperature °F	Temperature °C
11- 9-68	219	1,250	17.5	60	15.6
11-16-68	26	1,000	2.6	58	14.4
11- 7-69	74	500	14.8	60	15.6
11-13-69	31	750	4.1	58	14.4
10-31-70	286	500	57.2	58	14.4
11- 7-70	44	500	8.8	57	13.9

proaches 14°C (57.2°F) (tables 17 and 18). In 1970, they became active and returned to littoral areas in the spring as the water temperature warmed to 14°C (table 17).

Gizzard shad were caught from the surface to a depth of 108 feet (33 m) in Norris Reservoir, Tennessee (Dendy, 1945) and at depths of 70 and 80 feet (21 and 25 m) during the winter months at Conchas Lake, New Mexico (Jester, 1962). Shad in Elephant Butte Lake were collected in profundal net-sets to a depth of 52 feet and in nets set at a mid-depth of 23 feet in 52 feet of water.

Young-of-the-year gizzard shad in Elephant Butte Lake were first observed in schools on September 5, 1970, four months after the advent of spawning. According to Dendy (1946a), young-of-the-year gizzard shad in Norris Reservoir, Tennessee, travel in compact schools soon after hatching, but by fall most of the schools disperse and few form the following spring. Continuing, Dendy stated that schooling largely ceases by the time these fish are a year old. Jester (1962) observed many large schools of shad of all ages in Conchas Lake. Gizzard shad of all ages were caught in large numbers in individual nets in Elephant Butte Lake, which may be indicative of schooling or may merely reflect extremely high population density.

Parasites and Diseases

Gizzard shad appear to be relatively free from parasites and diseases. Bangham and Hunter (1939) examined five gizzard shad from Lake Erie and found an unidentified larval nematode in the intestine of one small specimen. Van Cleve found two species of Acanthocephala in 300 gizzard shad, and Essex and Hunter reported no parasites in more than 100 individuals from Mississippi (Bangham and Hunter, op. cit.). In Buckeye Lake, Ohio, young gizzard shad often carry heavy infestations of a myxosporidian which forms large white cysts in the body cavity (Miller, 1960).

Gizzard shad in Elephant Butte Lake exhibit the general freedom from parasites and diseases indicated above. Although not examined for a causative agent, gizzard shad frequently contained white cysts similar to those described by Miller. These could have resulted from an infection of Myxosporidia as in Buckeye Lake, Ohio.

The only ectoparasite observed on shad from Elephant Butte Lake was Argulus Miller. An acanthocephalan, Gracilicentis sp. Van Cleave, was found in the digestive tract. Only one specimen of each parasite was observed.

Common fungus or water-mold, Saprolegenia parasitica Coker, is occasionally found in Elephant Butte Lake, on gizzard shad and other fishes which show evidence of abrasion or other mechanical injury. Sanchez (1970) reported that dead gizzard shad were found to be heavily infected with this fungus during spring and summer. These conditions were not observed by the writers, but infestations of fungus are frequently observed in Caballo Lake, 20 miles (32 km) downstream.

Mass *Mortality*

Winter Die-off

Mass mortality of gizzard shad occurs in winter in Lake Erie (Bodola, 1965) and many other waters (Miller, 1960). Such die-offs are also known to occur in Conchas (Jester, 1962), Caballo, and Elephant Butte Lakes.

Winter mortality appears to be associated with low water temperatures in New Mexico. When temperature falls below approximately 3.3°C (38°F), young-of-the-year gizzard shad become noticeable as scattered, dead and moribund individuals floating at or near the surface. Larger specimens appear after several days and after five or more days a few members of the largest and oldest age groups may be found dead and floating.

Conchas Lake is located on the high plains approximately 250 miles (400 km)northeast of Elephant Butte and Caballo lakes. Temperatures of 3.3°C (38°F) and lower occur in Conchas Lake almost every winter, and winter mortality of small shad is common. However, high mortality rates which decimate young age groups and involve older fish are rare at temperatures above 2.2°C (36°F).

Caballo Lake, 20 miles (32 km) downstream from Elephant Butte, is the shallower and and colder of the two lakes in winter. Surface water temperatures as low as 2.8 to 3.3°C (37-38°F) usually occur. Mortality of small shad is always sufficient to be noticeable at 3.3°C (38°F). High mortality rates which decimated Age Groups 0 and I, and involved older fish, have been observed at 2.8 to 3.0°C (37-37.5°F), or 0.5 to 1°C warmer than temperatures at which such die-offs occur in Conchas Lake.

Annual minimum surface temperatures of Elephant Butte Lake usually vary about 4°C (38 to 40°F) in the limnetic zone and down to 1°C, with ice cover, in protected coves. Minor die-offs of small gizzard shad occur in the colder, shallower areas but are limited, probably because most shad inhabit deeper, warmer water at these times. Only on rare occasions, when limnetic temperatures drop to 2.8 to 3.3°C (37-38°F), are dead or moribund shad evident in significant numbers. Periods of winter mortality have been observed to persist from 3 to 11 days in the three lakes in New Mexico.

Summer Die-off

Mass summer mortality of gizzard shad is mentioned in literature only in context with discussions of classical vegetation-caused summer-kills which result from highly alkaline pH values. A different mass mortality phenomenon, associated with low water levels, has been observed in Elephant Butte Lake in 1964, 1968, and 1971.

In 1964, after storage volume had been in the range of 250,000 to 700,000 acre-feet (303.7 to 864.2 million m^3) for five years, the lake was drawn down to approximately 50,000 acre-feet (61.7 million m^3) (see figure 5). A large fish-kill occurred in July and August, as the water level dropped rapidly from approximately 150,000 to 50,000 acre-feet (185.2 to 61.7 million m^3). Distressed shad were first observed in large numbers in shallow headwaters of the lake. Mortality proceeded, wavelike, down the lake until it reached the dam in about eight days. Channel and flathead catfish, large-mouth bass, walleye, crappie, river carpsucker, smallmouth buffalo, and carp also died in a down-lake mortality wave which lagged behind the shad die-off by about three days. Distressed fish were observed periodically for about two weeks.

Specimens of distressed gizzard shad and other species were subjected to bacterial examination by bacteriologists at New Mexico State University. The die-off was attributed to formation of nitrogen bubbles in the blood streams of the fishes, caused by a coliform bacteria, Aerobacter aerogenes. This bacteria is common in surface water and is not necessarily of fecal origin. It is harmless to fishes under ordinary conditions but causes a gas-bubble disease when fishes are subjected to strong environmental stress, such as extreme crowding (Dixon, J. R., personal communication).

In 1968, water storage in Elephant Butte Lake declined briefly to approximately 75,000 acre-feet (92.6 million m^3) *(see* figure 5). Moribund and dead shad and a few channel catfish were observed for three days but disappeared as the lake began rising.

Extent of the die-off which occurred in 1971 is not known as it was in progress when this paper was completed. Storage volume at that time was approximately 65,000 acre-feet (80.3 million m^3) and declining rapidly. Gizzard shad began dying in moderate numbers when the lake contained approximately 100,000 acre-feet (123.5 million m^3) of water. A light incidence of dead channel and flathead catfish was observed when volume declined to 72,000 acre-feet (88.9 million m^3). Mortality rates of gizzard shad and channel catfish were increasing and young-of-the-year white bass were dying in small numbers when storage reached 65,000 acre-feet (80.3 million m^3), approximately three weeks after moribund gizzard shad were first observed. Die-offs of these species were progressing, wave-like, down the lake as they did in 1964.

Predation

The gizzard shad is valuable as a forage fish, especially when small. Miller (1960) states that the gizzard shad has been reported to form a major part of the diet of at least 17 important game fishes. He also lists important qualifications of gizzard shad as forage: direct utilization of phytoplankton, high reproductive capacity and abundance, general freedom from parasites, a rapid rate of growth, and utilization as food by important game fishes. Direct utilization of plankton makes gizzard shad a short link in the food chain of game fishes.

In five Oklahoma reservoirs, gizzard shad comprised 76.1 percent of the total volume of food of flathead catfish, 84 percent of the volume of food in freshwater drum, Aplodinotus grunniens, and 59 percent of the volume of food in longnose gar, Lepisosteus osseus (Summerfelt, 1968). Schneidermeyer and Lewis (1956) studied food habits of largemouth bass in Crab Orchard Lake, Illinois, and found that gizzard shad occurred in 85 of 107 stomachs containing food. Dubets (1954), two years earlier, found largemouth bass in Crab Orchard Lake containing gizzard shad up to 250 mm (10 in.) long. In North Twin Lake, Iowa, gizzard shad were eaten by yellow bass, Morone mis s is sippienis; yellow perch; walleye; black crappie; largemouth bass; and black bullhead (Kutkuhn, 1958). Bonn (1952) found that the only vertebrate taken by young white bass was gizzard shad, which were abundant both in numbers and volume. In Conchas Lake, Jester (1962) found that these fish were preyed upon by largemouth bass, white crappie, black crappie, channel catfish, walleye, black bullhead, yellow bullhead, blue catfish, and one lone rainbow trout. In Norris Reservoir, Tennessee, Dendy (1946b) found that gizzard shad constitued the most important food supply for game fishes, including channel catfish; largemouth bass; smallmouth bass, Micropterus dolomieui; spotted bass, Micropterus punctulatus; black crappie; walleye; sauger, Stizostedion canadense; and freshwater drum.

The sport fishery in Elephant Butte Lake is dependent upon gizzard shad as a source of forage (table 19). In addition to these game fishes, northern pike have been introduced into the reservoir. Current data indicate that this fish also feeds primarily upon gizzard shad.

Many workers report importance of young-of-the-year gizzard shad, up to 130 mm (5.1 in.) long, in the diets of game fishes. Stroud (1949) found that walleye fed heavily upon shad up to 75 mm (3 in.) long, many contained shad up to 125 mm (5 in.) long, and a few contained gizzard shad up to 335 mm (13.2 in.) long. Forbes (1903) reported that walleye, sauger, and yellow bass preyed upon gizzard shad between 75 and 100 mm

Table 19. Food habits of some predaceous fishes in Elephant Butte Lake, 1968-69, shown as percent of number of items found in stomachs (after Jennings, 1969).

Predaceous	Food Items				
Species	Gizzard Shad	Crawfish	Yellow Perch	Crappie	Other
Walleye	93.6	--	5.3	1.1	--
Channel catfish	91.7	8.3	--		--
White bass	77.5	7.5	12.5		2.5
Largemouth bass	68.8	18.8		6.2	6.2

(3 and 4 in.) long in the Illinois River. Jester (1962) reported gizzard shad up to 200 mm (8 in.) long in walleye in Conchas Lake. Gizzard shad up to 200 mm (8 in.) long are commonly taken by game fishes in Elephant Butte Lake. As many as seven shad of this size have been found in one largemouth bass.

Gizzard shad also serve as forage for numerous species of water-fowl and some raptors. Trautman (1940) reported 30 species of waterfowl on Buckeye Lake, Ohio, feeding on gizzard shad which had died in large numbers. Southern (1966) reported that the primary food of bald eagles wintering in Illinois was gizzard shad. In addition to game fish, Jester (op. cit.) lists mergansers, grebes, loons, ospreys, bald eagles, golden eagles, gulls, coots, and goldeneyes as other predators of gizzard shad. He found that mergansers took gizzard shad in a range of 43 to 333 mm (1.7 to 13.1 in.) total length and that 86.1 percent of their diet consisted of these fish.

Many species of waterfowl, at Elephant Butte Lake, especially mergansers, utilize gizzard shad as forage. Large numbers of western grebes also frequent the lake. Sperry (1938; from Clark, 1938) reported that one merganser collected on Elephant Butte Lake contained 36 two-inch (50 mm) shad in its gullet and the remains of 87 others of similar size in its stomach. Estimates of wintering populations of mergansers at that time ran as high as 15,000 birds (Clark, op. cit.). Roberts and Huntington (1959) found that gizzard shad comprised 88.9 percent of the diet of mergansers on Elephant Butte Lake and that they took these fish up to 300 mm (12 in.) long (table 20). Despite the heavy predation indicated by this discussion, populations of these fish continue to provide necessary forage for game fish populations. Adaptability and high reproductive potential of gizzard shad undoubtedly maintain this species at a level among the most numerous fishes in most reservoirs where established populations occur.

Table 20. Numbers and size range of gizzard shad taken by mergansers in Elephant Butte Lake, 1954-57 (adapted from Roberts and Huntington, 1959).

	Size Groups (mm)											
	0-99		100-199		200-249		250-299		300-349		Total	
							N	%				
Gizzard shad	228	77.3	45	15.3	15	5.1	6	2..0	1	0.3	295	100.0

Population Trends

Gizzard shad are the most important and abundant forage fish in Elephant Butte Lake. They have increased from 41.1 percent of relative density in experimental-gill-net-catches during 1964-65 to 71.2 percent during 1970-71 (table 21). Relative biomass increased from 6.2 percent to 23.6 percent of the total weight during the same period. These relative values are subject to changes in susceptibility of gizzard shad to gill nets, to changes in other fish populations, and are misleading when considered alone.

Number and weight caught per unit of effort vary with actual changes in the gizzard shad population. Number of gizzard shad caught per net-unit decreased by 62 percent from 26.9 to 10.2, while weight per net-unit decreased by 51 percent from 1,536 to

Table 21. Trends in catches of gizzard shad in experimental gill nets in Elephant Butte Lake, 1964-1971.

	1964-65	1965-66	1966-67	1967-68	1968-69	1969-70	1970-71
Percent Number	41.1	62.6	56.7	54.5	56.5	64.8	71.2
Rank	1	1	1	1	1	1	1
Percent Weight	6.2	8.7	8.9	8.9	13.6	20.1	23.6
Rank	5	4	4	4	3	2	1
Exceeded by	Smallmouth buffalo River carp-sucker Walleye Channel catfish	Smallmouth buffalo Flathead catfish River carp-sucker	Walleye Smallmouth buffalo River carp-sucker	Walleye River carp-sucker Smallmouth buffalo	River carp-sucker Walleye	River carp-sucker	--
N/net-unit	26.9	24.4	20.1	14.2	10.1	11.2	10.2
W/net-unit (grams)	1,536	1,378	1,694	1,044	755	815	775
Mean W (grams)	57	57	85	74	75	74	76

775 grams (54 to 27 ozs). These data indicate that average size of shad increased while numbers declined.

From June, 1964, through March, 1967, gizzard shad were taken only in two-inch (5.1 cm) stretch mesh. During 1967-68, they were collected in both two and three-inch (5.1 and 7.6 cm) meshes, indicating an increase in size. In 1968-69, they were caught consistently in two- and three-inch (5.1 and 7.6 cm) meshes and a few individuals were taken in four-inch (10.2 cm) mesh. During 1969-70, they were caught more frequently in four-inch (10.2 cm) stretch mesh and by 1970-71, they were caught throughout the sampling year in four-inch (10.2 cm) mesh.

These changes have resulted from a reduction of numbers of gizzard shad caused by heavy predation by walleye, channel catfish, white bass, largemouth bass, and northern pike (table 19). It is evident that establishment of walleye and white bass populations has contributed to reduction of numbers of shad. Reduction of numbers has partially relieved stunting and increased growth rates of the species. This is apparent in comparing Patterson's growth data with currect data (see tables 2 and 3 and figure 9). Shad grew faster as intraspecific competition was relieved. Therefore, proportionally larger numbers of these fish became large enough to be caught in larger gill-net meshes. This accounts for the increase in relative density and biomass while catch per unit of effort declined.

Relative stability in catches per unit of effort during 1968-71 is indicative that the gizzard shad population is beginning to stabilize and may fluctuate about means near present density and biomass unless additional predation occurs. Present abundance and stunting indicate that gizzard shad are still sufficiently numerous to support additional populations of predaceous species.

Economic Values

Commercial

The gizzard shad is not esteemed as food by man because of its soft and rather tasteless flesh and numerous fine bones (Miller, 1960). In the Chesapeake Bay region, it once sold fairly well to a class of trade that demanded a cheap fish, and among the commercial fishes of that region in 1920, it ranked 20th in value (Hildebrand and Schroeder, 1938). Miller further indicated the limited commercial value of this fish: "The species has been used to some extent in making guano, and in 1874 a guano factory existed at Black Point, above Palatka, Florida (Bean, 1893). Many years ago, on Lake Erie, it was split and salted and sporadically marketed with other low-grade fish as 'lake shad' (Jordan, 1882), and in the 1840's it appeared on the markets in Ohio but was not highly regarded (Kirtland, 1844)." When gizzard shad become excessively abundant, as they did in Black Hawk Lake, Iowa, in 1951, they may be removed from waters by chemical treatment and used as hog food or for field fertilizer (Madden, 1951). The Southern Division of the American Fisheries Society placed a retail value of $0.15 per pound on gizzard shad in 1971 (SFI, 1971).

The species has a limited value as a bait fish. Kuhne (1939) stated that since it dies very easily it is an unsatisfactory bait minnow. Although the market is limited, frozen gizzard shad from Elephant Butte Lake are frequently sold as "cut-bait" for trotlines (B. C. Sparkman, commercial fisherman, personal communication).

Under current management practices, gizzard shad in Elephant Butte Lake will probably not increase to the level that the population will be detrimental to game fishes. The current population level, in part, limits the desirability of commercial exploitation of this species. Commercial potential for gizzard shad in Elephant Butte Lake is limited to their value as "cut-bait" for sport fishing.

Forage

The value of gizzard shad as a link in the food chain of game fishes has been discussed above. Their ability to utilize plankton and convert this resource to food for predaceous fishes is paramount in determining density and biomass of game fish populations in Elephant Butte Lake. Adequate plankton and paucity of benthic flora and fauna are characteristic of Elephant Butte Lake. In such a morphometrically oligotrophic lake, game fishes have few other resources to utilize for food.

According to Patterson (1968), gizzard shad are subject to heavy predation until they are about 130 mm (5 in.) long, moderate predation up to 200 mm (8 in.), and larger specimens are exposed only to light predation. Thus, in most waters, gizzard shad are liable to heavy predation only as young-of-the-year and to moderate predation up to two years. However, in Elephant Butte Lake gizzard shad are slower-growing, and thus, are available as forage for a longer period than in most waters. They are subject to heavy predation for two years and are exposed to moderate predation for two additional years. Such conditions appear to be beneficial to game fishes.

H[illegible] (1934), referring to the short and efficient food chain, stated that this species is "the most efficient, biologically, of all of the forage fishes." W[illegible] (1933) stated that "upon the presence or absence of this fish seems to rest the burden of whether or not impounded waters in Ohio will be productive of several game fish..." These statements apply strongly to gizzard shad in Elephant Butte Lake. All game fish populations in the lake, with the exception of flathead catfish, depend on gizzard shad as the primary source of forage.

Gizzard shad in Elephant Butte Lake have greater value as forage for sport fishes than they have for commercial fishing.

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