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FLUCTUATING WATER LEVELS IN RESERVOIRS: AN ANNOTATED BIBLIOGRAP--ETC(U)
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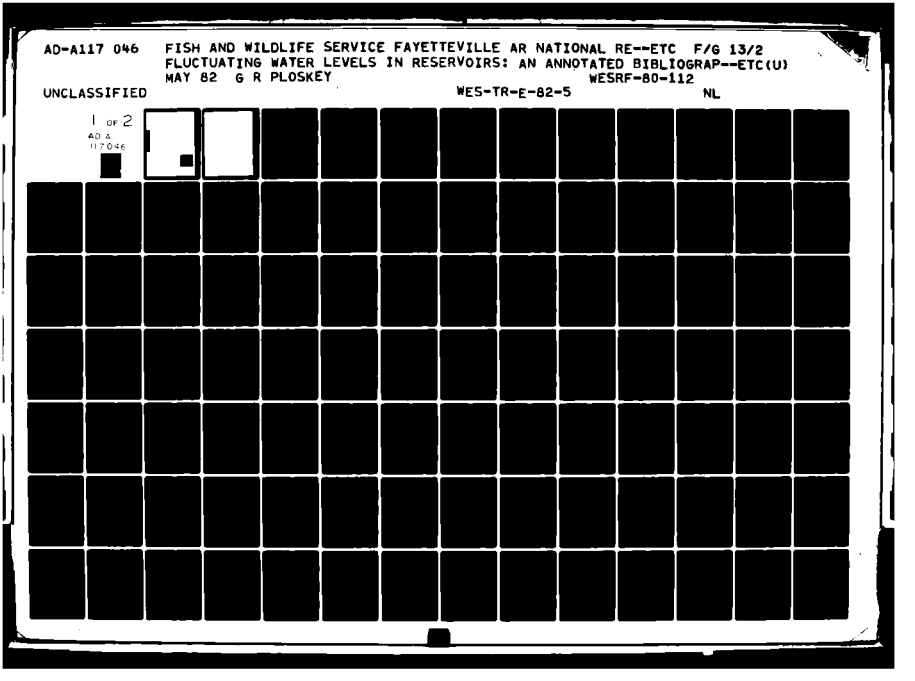

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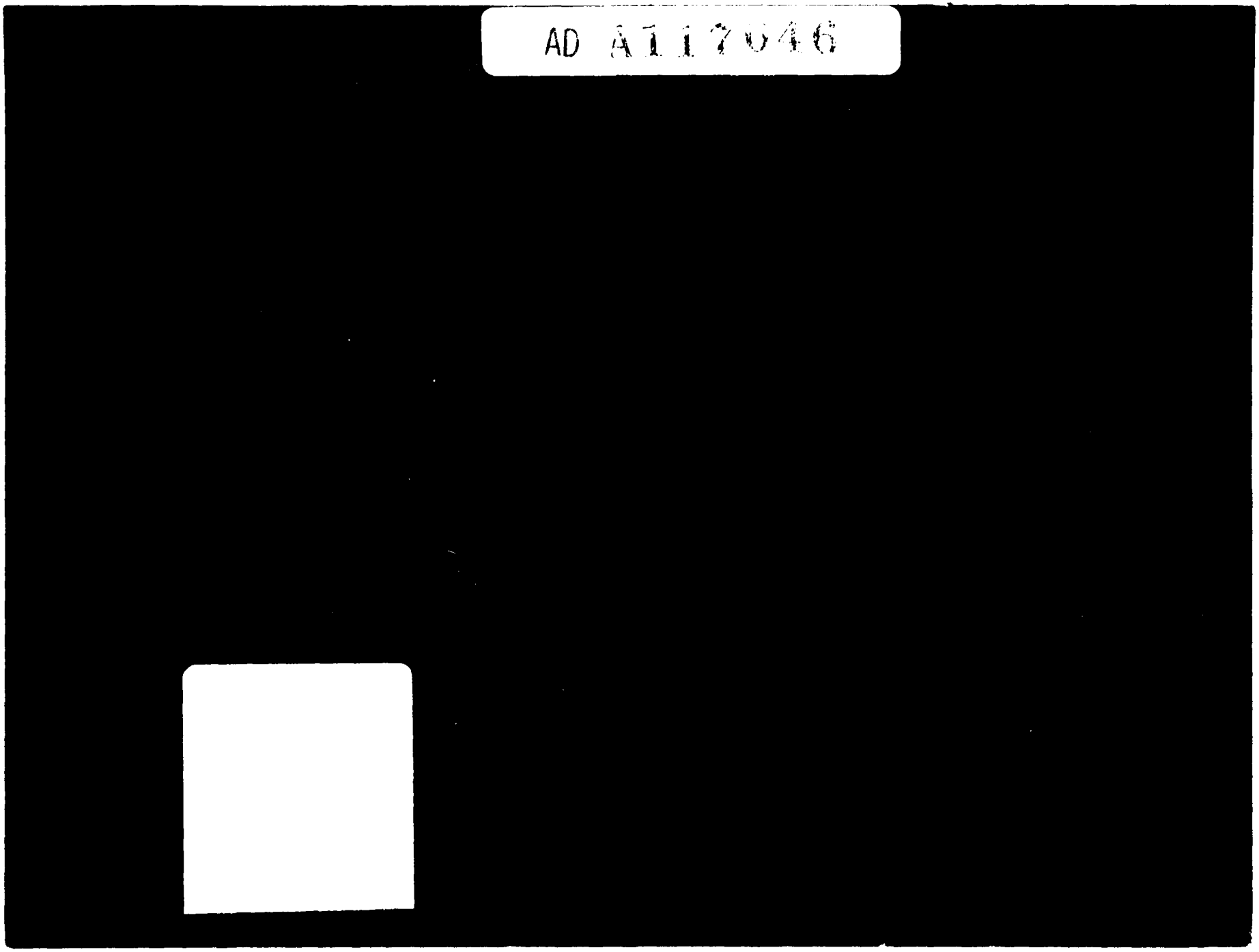
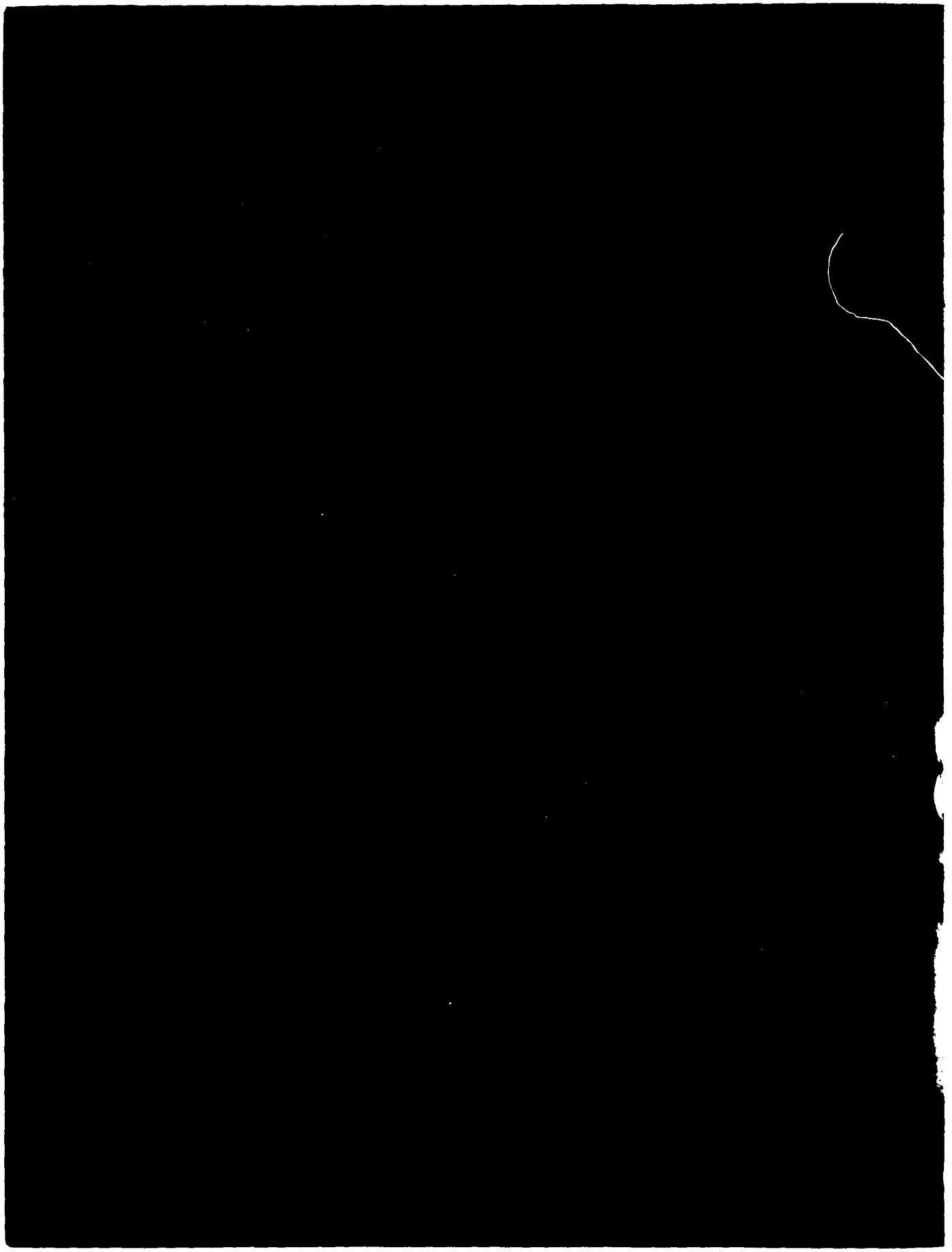




4. This annotated bibliography summarizes results of published and unpublished research up through 1980 concerning fluctuating water levels and their effects on reservoir fisheries. Impacts of water-level fluctuations on physicochemical variables, algae, aquatic invertebrates, fish, and fishing are emphasized in annotations. Topics indirectly related to reservoir fisheries, such as the effects of fluctuations on erosion and reservoir aesthetics are also discussed. To facilitate use, a subject index is presented in Appendix A. Although this bibliography addresses water levels in reservoirs, research conducted on natural lakes, ponds, marshes, and floodplains is included when results provide insight into mechanisms by which changing water levels affect aquatic systems in general.

5. Units of measure are consistent with those in the original papers or abstracts, and consequently vary among annotations. Scientific names are used only when common names might be ambiguous (e.g., bream may refer to Lepomis sp. in North America or Abramis sp. in Europe) or of limited usage. Where applicable, common names are those recommended by the American Fisheries Society ("A List of Common and Scientific Names of Fishes from the United States and Canada," 4th edition, American Fisheries Society Special Publication No. 12, 1980).

Beard, T. D. 1973. Overwinter drawdown. Impact on the aquatic vegetation in Murphy Flowage, Wisconsin. Wisconsin Dep. Nat. Resour., Tech. Bull. No. 61. 18 pp.

31. A lowering of water levels on 180-acre Murphy Flowage during the winters of 1967-68 and 1968-69 significantly reduced the relative abundance and acreage of aquatic vegetation. Before the drawdown, about 75 acres (42% of the flowage) were covered by plants, to the extent that fishing was almost impossible from June through the summer. After two over-winter drawdowns, 60 of the 75 acres were open to fishing. Five of the six plant species that dominated the flowage before drawdown were most affected, and densities of these five species were reduced greatly after two drawdowns. Management implications involving the use of an over-winter drawdown to control aquatic vegetation are discussed.

Beard, T. D. and H. E. Snow. 1970. Impact of winter drawdown on a slow-growing panfish population and associated species. Wisconsin Dep. Nat. Resour., Bur. Res. Rep. 18 pp.

32. Two consecutive winter drawdowns of Murphy Flowage to improve the growth of panfish populations reduced the abundance of all species except yellow perch and white suckers. Numbers of bluegills less than 5 inches long were greatly reduced. Feeding activity of northern pike increased after drawdowns, and largemouth bass ate more fish and fewer crayfishes.

Beckman, L. G. and J. H. Elrod. 1971. Apparent abundance and distribution of young-of-year fishes in Lake Oahe, 1965-69. Pages 333-347 in G. E. Hall, ed. Reservoir Fisheries and Limnology. Am. Fish. Soc. Spec. Publ. No. 8.

33. A 100- by 8-foot seine and an otter trawl were used to estimate the abundance and distribution of young-of-year fishes in Lake Oahe, North and South Dakota, during the last 5 years of filling. Young-of-year fishes were most abundant in waters at the upper ends of embayments. Large year classes of northern pike, common carp, smallmouth buffalo, and bigmouth buffalo were associated with rising water levels that covered terrestrial grasses and remained stable throughout the spawning period. Small year classes occurred in years when no vegetation was flooded. Inasmuch as future water levels will normally fluctuate over mud bottoms, prospects for strong year classes are poor unless terrestrial vegetation recovers and is flooded in the spring, or some aquatic plants become established. Yellow perch used inundated brush for egg deposition, and year classes were good when more brushy areas were flooded. After 1967, much of the brush had deteriorated and was sparse at higher elevations. As a result, the abundance of perch began to decline thereafter.

water levels.

Fillion, D. B. 1967. The abundance and distribution of benthic fauna of three mountain reservoirs on the Kananaskis River in Alberta. J. Appl. Ecol. 4: 1-11.

102. Three oligotrophic reservoirs (Barrier Reservoir and Upper and Lower Kananaskis Lakes) do not support high standing crops or diversity of benthos. Maximum abundance occurs in the vicinity of the drawdown limits rather than in the littoral zone. In Barrier Reservoir, the regions with the greatest standing crops of benthos are those not directly influenced by water-level fluctuations, and which receive input of allochthonous materials from the river. The fluctuation zone contains various benthic organisms, but is dominated by chironomids, which survived in areas dewatered up to 85 days. Although chironomids in Barrier Reservoir were most diverse in the 0- to 10-m zone, greater numbers occurred below the drawdown limit.

Fitzgerald, G. P. 1970. Aerobic lake muds for the removal of phosphorus from lake waters. Limnol. Oceanogr. 15: 550-555.

103. Experiments indicated that aerobic lake muds have a strong affinity for phosphate phosphorus and can absorb as much as 0.125 mg PO_4 -P per gram (dry weight) of sediment in 30 minutes. Although two phosphorus-limited algae (Selenastrum and Cladophora) increased growth in response to as little as 0.02 mg PO_4-P in solution, growth did not increase after 1 or 2 weeks of exposure to 2 mg phosphorus in lake muds, under aerobic conditions. Findings suggest that under aerobic conditions lake muds can be used to remove phosphorus from lake water.

Fourt, R. A. 1978. The effects of a two year water-level management plan on the production of sport fish in Beaver Reservoir. Arkansas Game Fish Comm. 15 pp.

104. In 1977, water levels of Beaver Lake were reduced to permit the growth of terrestrial vegetation around the barren shoreline. In spring 1978, abundant rainfall enabled an inundation of terrestrial vegetation on about 6,880 acres of the fluctuation zone, without severely reducing generation of electric power. Favorable environmental conditions during spawning produced the highest density of young bass since the reservoir was impounded. Cove sampling with rotenone indicated a density of 733 young black bass per acre; the average number in August for the preceding 10 years was 281 per acre, and the highest density previously recorded was 491 per acre. Young-of-year crappies also were abundant (78 per acre). The abundance of prey fishes (sunfishes, minnows, and shad) was low -- an unfortunate occurrence, since the overwinter survival of young-of-year bass depends greatly on high sunfish production, especially

content of the water was reduced 10-20%; certain bacteria and phytoplankton populations increased exponentially; and zooplankton biomass in July increased from 0.77 g/m^3 in 1947 to 1.36 g/m^3 in 1956. The solid belt of moss and Chara at depths between 7 and 15 m was reduced to isolated patches. Total benthic biomass (metric tons) increased from 6150, before water levels were lowered, to 40,500 afterwards. Increases in the 10- to 40-m zone were due to increased abundance of chironomids and oligochaetes. The biomass in the 0- to 10-m zone decreased somewhat because the biomass of gammarids was reduced 23%. Because gammarids composed 90% of the trout food, the increase in benthic biomass (mostly inaccessable chironomids and oligochaetes) probably did not result in a more productive fishery.

Martin, N. V. 1955. The effect of drawdowns on lake trout reproduction and the use of artificial spawning beds. Trans. North Am. Wildl. Conf. 20: 263-271.

213. Studies of the effects of drawdowns on lake trout reproduction in three Ontario lakes showed that reduced water levels during spawning in October stranded eggs and larval fish. Reduced water levels before spawning were unfavorable, because fewer spawning sites were available and trout were forced to spawn in less desirable areas, where egg mortality was high (due to predation by bullheads and natural causes). Artificial spawning beds, installed to help alleviate problems associated with water-level fluctuation, were only marginally successful. Only one of three artificial beds constructed on Lake Shirley was used by lake trout for spawning. This bed was positioned near a previous spawning ground -- which suggests that lake trout may require some kind of stimulus to initiate spawning, such as familiarity with the area or an odor.

Martin, N. V. 1957. Reproduction of lake trout in Algonquin Park, Ontario. Trans. Am. Fish. Soc. 86: 231-244.

214. The spawning grounds and reproduction of lake trout (e.g., behavior, sex ratios, egg distribution, incubation, and hatching) are described and major causes of egg loss such as fungus infection, predation, and water-level fluctuation, are identified. Some loss of eggs was observed because of drawdown in the late fall and winter when spawning occurs. In lakes Shirley and Hays, drawdowns exposed considerable areas (up to 200 square yards in Lake Shirley) of potential spawning ground before the spawning season.

material for this review. Two phases of development are recognized: "filling," characterized by sudden appearances of organisms and rapid growth of plant and animal populations; and "post-filling," characterized by the development and exploitation of existing habitats (e.g., beaches and mud flats). The role of water-level fluctuation in post-filling phases of development also is considered. Water levels result in an interaction between the terrestrial and aquatic ecosystems, providing new habitat such as flooded trees (at least in shallow areas). Water-level changes impede the establishment of rooted aquatic plants and the development of shorelines (formation of beach areas and mud habitat). Effects of fluctuations are more pronounced in gradually sloping or shelving areas. Drawdown on Lake Kariba, where water levels over gradually shelving areas receded as much as 2 km, stranded chironomid larvae (up to 200 mg m^{-2}). Because losses were rapidly made up by oviposition at the receding water line, the benthos was relatively unaffected by drawdown. During periods of low water, dense growths of grass developed on mudflats and feces of large game animals accumulated. Upon reflooding, dissolved oxygen decreased, and concentrations of potassium, nitrate, and phosphate increased in shallow water. The biomass of chironomids (especially one species) increased greatly. The annual interaction between the terrestrial and aquatic system, brought about by water-level fluctuations, may be of considerable importance to the nutrient economy of lakes. Inundated grasses that develop during low water release large quantities of organic materials and nutrients into the water.

McLachlan, A. J. 1977. The changing role of terrestrial and autochthonous organic matter in newly flooded lakes. Hydrobiologia 54: 215-217.

227. Newly flooded lakes pass through two phases (flooding and post-flooding). During flooding of lakes, mud-dwelling organisms depend on terrestrial organic matter for food. After inundation is complete, diets immediately shift to include more autochthonous-based foods. Gut contents of 500 insects (primarily chironomids) -- collected from lakes Kariba and Chilwa, Africa, and from Ladyburn Lough in England, during filling and post-filling phases -- were examined. Reduced biomass of benthos after filling of lakes was associated with a change in diet from terrestrial detritus to algae. The percent of allochthonous organic matter in diets decreased from 93% to 64% in Lake Chilwa and from 89% to 52% in Ladyburn Lough. Biomass (mg dry weight m^{-2}) declined from 2967 to 1051 in Lake Chilwa, from 1558 to 708 in Ladyburn Lough, and from 2911 to 215 in Lake Kariba.

McLachlan, S. M. 1970. The influence of lake level fluctuation and the thermocline on water chemistry in two gradually shelving areas in Lake Kariba, Central Africa. Arch. Hydrobiol. 66: 499-510.

252. Effects of water-level fluctuation were examined by comparing pre-regulation information on benthos and fish with post-regulation data on feeding by trout and char and by comparing the food habits of fish in regulated and unregulated natural lakes. After regulation in both lakes, trout ate more terrestrial insects and fish, perhaps because the abundance of native benthos was reduced and the littoral areas had deteriorated. Char, which feed to a large extent on plankton and forage over wider areas than trout, were less affected by fluctuating water levels. In comparing a regulated and unregulated lake, the following differences were noted: (1) Limnaea and Trichoptera were eaten more frequently in the unregulated than in the regulated lake; (2) Gammarus, which was very important to trout and char in the unregulated lake, was entirely lacking in the regulated lake; (3) Eurycercus lamellatus (Plecoptera) and terrestrial insects were eaten more frequently in the regulated than in the unregulated lake; and (4) young char were more important as food for trout in the regulated than in the unregulated lake.

Nilsson, N.-A. 1964. Effects of impoundment on the feeding habits of brown trout and char in Lake Ransaren (Swedish Lappland). Int. Verh. Verein. Limnol. 15: 444-452.

253. Effects of regulation were examined by using previously published information concerning the effects of regulation on allochthonous organisms, zooplankton, prey fishes, and benthos and by comparing the food of brown trout and char, before and after regulation. Regulation initially floods new areas, provides a temporary surplus of terrestrial invertebrates as fish food, and increases zooplankton production. Some prey fishes have strong year classes during the early years of impoundment. Littoral benthos usually declines drastically after impoundment. Damming results in increased fish predation on allochthonous organisms and zooplankton. Drawdown increases consumption of zooplankton and prey fish by trout. Fish predation on benthos decreases after drawdown, and different taxa of benthos are eaten.

Nilsson, N.-A. 1966. The effect of hydro-electric power utilization on Swedish fishery. Pages 10-22 in Limnologisymposion, Limnologiska Föreningen i Finland, Helsinki.

254. Research mainly by the Salmon Research Institute and the Institute of Freshwater Research, Drottningholm, indicates that the loss of salmon reproduction after dam construction has been successfully compensated for by stocking of hatchery-reared smolt. In impounded lakes, water-level fluctuations damage food resources of fish, and thus exert adverse effects on growth and possibly on survival. In the lower courses of rivers, where water-level fluctuations are less extensive, a relatively large amount of food is present. Adverse effects primarily alter the fish fauna (from salmonids to coarse fish). Experiments are being made to

favorable O_2 conditions increased for a time because fish congregated there. The reservoir level was unfavorable for most fishes except for bream (Abramis) and pike-perch (Stizostedion), and even they lacked spawning grounds. A 0.5-m drop in water level during the third 10-day period of June would ensure a higher yield of fish without hindering navigation or power production. (From Referat. Zhur. Biol., 1968, No. 1I174; Biol. Abstr. 49: 108944.)

Pelzman, R. J. 1980. Impact of Florida largemouth bass, Micropterus salmoides floridanus, introductions at selected northern California, U.S.A., waters with a discussion of the use of meristics for detecting introgression and for classifying individual fish of intergraded populations. Calif. Fish Game 66: 133-162.

269. Populations of largemouth bass in Folsom Lake, New Hogan Reservoir, Lake Amador, Lake Isabella, and Clear Lake, California, possessed a wider spectrum of performance capabilities (i.e., reduced susceptibility to angling, rapid growth, and larger mean size) after the inclusion of desirable genetic traits from Florida bass. This is advantageous in reservoirs where heavy angling pressure, water-level fluctuations, and competition between young bass and prey fishes hinder the maintenance of a bass production.

Perrin, C. 1976. Effects of water level manipulation of black bass spawn and survival - Greers Ferry Lake. Arkansas Game Fish Comm., Little Rock, Arkansas. 9 pp.

270. Since Greers Ferry Lake was impounded in 1962, the spawning success of black basses has fluctuated form year to year, and above average spawns have been associated with high water levels throughout the spawning season. High water levels also improved the reproduction of shad, which undoubtedly increased the survival of bass and permitted the development of strong year classes of bass. Data indicate that water levels that are higher than those of the previous year may often produce similar results. In 1976, a strong year class was produced when water was held 2 feet above power pool. Remarkably, this success was obtained in a year when some conditions for spawning were relatively poor (below-average temperature and frequent passage of frontal systems).

Petkevich, A. N. 1963. Biological bases for a rational fishery on Lakes Baraba and Kulunda. Pages 13-22 in The development of Siberian lake fisheries. Novosibirsk. (In Russian)

271. Feeding and reproductive conditions for fish worsened as a result of periodic fluctuations in water level that periodically obstructed the movement of fish to and from spawning inlets. Inlets become shallow and narrow as a result of declining water levels. (From Referat. Zhur. Biol., 1964, No. 7I59; Biol. Abstr. 46: 23414.)

Riel, A. D. 1965. The control of an overpopulation of yellow perch in Bow Lake, Strafford, New Hampshire. Prog. Fish-Cult. 27: 37-41.

286. After a dam was constructed on this 1,198-acre lake, the lake was drawn down in the fall. For years, fall drawdown to the original lake level forced perch into open water where they were subjected to increased predation. In later years, water levels were more constant, because less water stored behind the dam was used. After fall drawdowns were eliminated or reduced, yellow perch became overabundant, and other means of control had to be developed. Control by netting and destruction of eggs are discussed.

Robbins, T. W. and D. Mathur. 1976. The Muddy Run pumped storage project: a case history.

287. Effects of pumped-storage operations on fish populations in Conowingo Pond (the lower pond) and Muddy Run Pumped Storage Pond (the upper pond) are discussed. Water-level fluctuations in Muddy Run limit the effective reproduction of nest-building fishes. Recruitment to Muddy Run depends largely on a transfer of fishes from Conowingo Pond during pumping. Bluegills and pumpkinseeds spawn in one location of the fluctuating pond (a quarry 9 m below full pool) which retains water even after the level of Muddy Run falls below that elevation.

Rodhe, W. 1964. Effects of impoundment on water chemistry and plankton in Lake Ransaren (Swedish Lappland). Verh. Internat. Verein. Limnol. 15: 437-443.

288. The effects of rising water levels and initial impoundment were evaluated by comparing water chemistry, phytoplankton, and zooplankton in newly impounded lakes and natural lakes. Dam construction and burning of brush along the shore temporarily increased the level of phosphate and primary production. Though primary production increased in the first year, algal biomass remained the same. In the second and third years of impoundment, the standing crop and production of algae and zooplankton doubled or tripled. Increased productivity must have resulted from input of nutrients from flooded or eroded terrestrial areas. Observed changes in phosphate, total phosphorus, and total nitrogen were small, probably because the nutrients were rapidly assimilated. Increased phytoplankton and zooplankton production seemed to corroborate this hypothesis.

Roseberry, D. A. 1951. Fishery management of Claytor Lake, an impoundment on the New River in Virginia. Trans. Am. Fish. Soc. 80: 194-209.

289. The fish population, harvest, and fishery management of Claytor Lake, Virginia, in 1948 and 1949 are described. The shore zone did not

perimeter-to-area ratios in nine lakes. Although primary factors such as mean depth, climate, and total dissolved solids may be important in influencing productivity in broad geographical areas, other factors (e.g., water-level fluctuation, perimeter-to-area ratios, basin shape, and the size and nature of the drainage area) modify the expression of the primary factors within a restricted geographic region. Lazy and Horseshoe lakes have seasonal water-level fluctuations that may contribute to the low-to-moderate standing crops of benthos. Rooted macrophytes, which increase the production of benthos, also were lacking in Lazy and Horseshoe lakes, possibly because of the amplitude of water-level changes.

Sreenivasan, A. 1966. Limnology of tropical impoundments. I. Hydrological features and fish production in Stanley Reservoir, Mettur Dam. Int. Revue ges. Hydrobiol. 51: 295-306.

314. The impact of physicochemical features on fish production in Stanley Reservoir, India, is discussed. Fish yield was relatively low (21.3 pounds per acre), but had not declined with increased reservoir age. Although nutrients were constantly leached out and discharged downstream, plant growth was frequently lacking because of rapid fluctuations in water level. The littoral zone was sterile. Rapid fluctuations also appeared to adversely affect fish spawning. Discharge of plankton-rich surface waters when water levels were high and generally rapid rates of water exchange limited productivity. Limited drawdown may help retain nutrients and plankton.

Sreenivasan, A. 1974. Limnological features of a tropical impoundment, Bhavanisagar Reservoir (Tamil Nadu), India. Int. Revue ges. Hydrobiol. 59: 327-342.

315. Physicochemical features of Bhavanisagar Reservoir are described and related to primary production and harvest of fish. The only factors likely to negatively affect fish populations and yield are the failure of monsoons (and therefore fish spawning) and parasitic infections.

Starrett, W. C. and A. W. Fritz. 1965. A biological investigation of the fishes of Lake Chautaugua, Illinois. Illinois Nat. Hist. Surv. Bull. 29. 104 pp.

316. The relative abundance, biomass, and commercial harvest of fishes of Chautaugua Lake were studied from 1950 to 1959. Water level probably was the most important factor affecting the dynamics of fish populations in the lake. During periods of low stable water levels, sago pondweed became abundant, turbidity decreased, large populations of benthic insects developed, and many bluegills and crappies were collected by seining. When vegetation was abundant in low-water years, the carrying capacity for fish probably was greater than in years of high or fluctuating water

Stewart, R. W. 1967. The development of a management program for Spruce Run Reservoir. New Jersey Conserv. Dep. Rep. 13 pp.

320. When Spruce Run Reservoir, New Jersey, was drawn down in spring and summer 1966, receding water levels (1 foot per week) adversely affected the spawning of bluegills and pumpkinseeds by dewatering nests. Sunfishes spawned from about mid-June when water temperatures reached 77°F to mid-July. Reproduction of largemouth bass (May 20 - June 20), which began when water temperatures reached 65°F, was almost complete before the drawdown and therefore was largely unaffected by receding waters.

Stewart, R. W. 1971. Survey of Spruce Run Reservoir. New Jersey Div. Fish, Game, and Shellfisheries. Fed. Aid Proj. F-23-R-6. Job I-5. 44 pp.

321. This baseline study described the physicochemical characteristics, harvest statistics, and data on fish populations of Spruce Run Reservoir, New Jersey, from 1965 to 1969. Water levels declined significantly during the summer and fall of each year except 1967. Dewatering destroyed much of the aquatic vegetation (primarily Elodea) and suppressed its growth. The lack of vegetation seemed to provide predators with easier access to prey fishes.

Stewart, R. W. 1979. Survey of Rising Sun Lake. New Jersey Div. Fish, Game, and Shellfisheries. Fed. Aid Proj. F-23-R-14, Job I-9. 10 pp.

322. Data are presented on the physicochemical limnology and the development of fish populations of Rising Sun Lake in 1978. Terrestrial vegetation, which developed when water levels were low in the spring of 1977, affected O_2 tensions and water clarity throughout the summer of 1978, after the lake was filled in the spring. However, oxygen tensions were at least 4 mg ℓ^{-1} at depths above 15 feet, and no deleterious effects on fish resulted.

Stroud, R. H. 1948. Growth of the basses and black crappie in Norris Reservoir, Tennessee. J. Tenn. Acad. Sci. 23: 31-99.

323. Growth of black basses and black crappies from Norris Reservoir from 1942 to 1946 was determined by the scale method. All species studied grew rapidly during the first 3 years of impoundment, but growth rates slowed in the fourth or fifth and sixth years. Growth improved in the seventh year and decreased again in the eighth and ninth years. Changes in growth were correlated with a long-term cycle of spring and

Summerfelt, R. C. and K. E. Shirley. 1978. Environmental correlates to year-class strength of largemouth bass in Lake Carl Blackwell. Proc. Oklahoma Acad. Sci. 58: 54-63.

326. The density of young-of-year largemouth bass in an area of suitable habitat was determined in August for 11 consecutive years and considered to be representative of year-class strength. Year-class strength was positively correlated with water level, change in water level, and turbidity, and negatively correlated with water hardness, alkalinity, and pH. The four smallest year classes occurred when water levels decreased in May and June. Strongest year classes occurred in years when water levels where high and flooded terrestrial areas, thereby simulating conditions present in new impoundments. Water levels were negatively correlated with hardness and alkalinity. Turbidity occasionally was affected by changes in water level.

Svärdson, G. and G. Molin. 1973. The impact of climate on Scandinavian populations of the sander, Stizostedion lucioperca (L.). Rep. Inst. Freshwater Res. Drottningholm 53: 112-139.

327. Yields of sander in six lakes are discussed, as are the climatic factors that affected their population dynamics in Lakes Hjälmaren and Mälaren from 1955 to 1972. The strength of 15 year classes in the separate lakes fluctuated in a similar manner, indicating a climatic influence. Year-class strength was correlated with temperatures during some summer months (especially June through August) and was associated with high water levels in the spring. The two best year classes occurred in years when water levels were highest in spring. High water in May 1966 also produced a very dominant year class of pike in Lake Mälaren. In lakes where sander numbers are low for years until they suddenly explode in a single strong year class, water levels may be an important factor regulating reproductive success.

Swanson, G. A. 1967. Factors influencing the distribution and abundance of Hexagenia nymphs (Ephemeroptera) in a Missouri River reservoir. Ecology 48: 216-225.

328. The abundance and distribution of burrowing mayfly nymphs were affected by a number of factors including season, depth, current, wind, substrate, and water levels. Substrates normally inhabited by Hexagenia nymphs were not disturbed by fluctuations of water level except in shallow bays and backwater areas. From May to September, the maximum range of fluctuations was 1.5 m. Nymphs may have responded to minor, slow drawdowns by migrating over the bottom. A normal drop of water levels in Lewis and Clark Lake limited the abundance of nymphs by exposing reservoir substrates to increased wave action.

Swee, U. B. and H. R. McCrimmon. 1966. Reproductive biology of the carp, Cyprinus carpio L., in Lake St. Lawrence, Ontario. Trans. Am. Fish. Soc. 95: 372-380.

329. Temperature and water levels were major environmental factors affecting the spawning of common carp and the survival of their eggs in marsh areas. Frequent summer fluctuations of water levels of 6 to 12 inches destroyed millions of eggs by exposure, but reproduction was not completely controlled by fluctuations. Fxamination of gonads revealed that males could release sperm over an extended period of time, and experiments showed that females could spawn twice. Although no population estimates were made, spot poisoning showed that a substantial number of young-of-year common carp hatched at various times in May, June, and July and survived at least until mid-Autumn.

Sylvester, R. O. and R. W. Seabloom. 1965. Influence of site characteristics on quality of impounded water. J. Am. Water Works Assoc. 57: 1528-1546.

330. Inundation of vegetation and bottom areas with fertile soils may produce undesirable water quality by (1) ion exchange through clay and humic colloids; (2) microbial degradation of organic matter from soil or vegetation, thereby releasing dissolved materials, CO_2, and minerals; (3) leaching of organic and mineral compounds that enhance algal growth; and (4) microbial activity at the soil-water interface, thereby creating anoxic conditions and altering the products of decay processes. The three effects of soils on water quality are physical (color, turbidity, taste, odor), chemical (pH, dissolved solids, and gases), and biological (enhanced growth of algae and other aquatic organisms). Most changes are associated with the decomposition of organic matter in soil and water. Howard A. Hanson reservoir was studied to document effects of basin characteristics (site preparation, vegetation, and soils) and filling regime on reservoir water quality. Soil organic content was most responsible for undesirable effects on overlying water, but its effects depended on time, temperature, and light. The effect of organic content was proportional to the age or state of decay of organics. Repeated leaching of soils by flushing (rapid water exchange) reduced the effect of organic soils on water quality. Wood, bark, grasses, leaves, and ferns have a high biological oxygen demand and adversely affected water quality.

Thompson, J. D. 1964. Age and growth of largemouth bass in Clear Lake, Iowa. Proc. Iowa Acad. Sci. 71: 252-258.

331. Age composition and growth of 281 largemouth bass were determined from scales collected from 1947 to 1963. Growth rate was below the average for the 17-year period in 1957-60, when water levels were decreasing and the lake volume was 30% below normal. Annual growth was correlated with water levels but not with temperature or turbidity.

and from 304 to 1364 (on or associated with macrophytes). Densities returned to levels characteristic of the pre-treatment period within 2 years. The decline in numbers was associated with increases in the number of fish and invertebrate predators. Sport fishes that ate macroinvertebrates nearly doubled in weight, from 151 to 236 pounds per acre in the littoral zone and from 34 to 54 pounds per acre in the limnetic zone.

White, D. S. and S. J. White. 1977. The effect of reservoir fluctuations on populations of Corbicula manilensis (Pelecypoda: Corbiculidae). Proc. Oklahoma Acad. Sci. 57: 106-109.

356. Fluctuations in water level greatly reduced populations of the Asiatic clam in Lake Texoma, Oklahoma. Clams were most numerous near the shore in 2-30 cm of water. A drop in water level from August through February 1976 stranded so many clams that their shells formed wind rows along beaches. Laboratory experiments showed that clams exhibited 50% mortality after 4 days of desiccation, 75% after 6 days, and 90 to 98% after 10 days.

Whitehouse, J. W. 1971. Some aspects of the biology of Lake Trawsfynydd; a power station cooling pond. Hydrobiologia 38: 253-288.

357. In Lake Trawsfynydd, Wales, water levels fluctuated $\pm$ 1.5 m about mean sea level in response to water discharge for generating electric power. Beginning in 1962, the lake also provided cooling water for a nuclear power plant. Rising and falling lake levels intermittently exposed and reflooded the shore and prevented the growth and survival of aquatic macrophytes and the development of littoral benthos. There was no true profundal fauna, and the abundance of sub-littoral benthos (chironomids and oligochaetes) was patchy. Zooplankton did not seem to be affected by fluctuating water levels.

Wickliff, E. L. 1932. Are newly impounded waters in Ohio suitable for fish life? Trans. An. Fish. Soc. 62: 275-277.

358. Fish productivity of 12 Ohio impoundments was compared on the basis of physical, chemical, and biological variables. Substantial populations of crustaceans and algae were found in all reservoirs, regardless of reservoir age. The number of benthic animals was as high in new as in old reservoirs. Detrimental effects of fluctuating water levels are mentioned in relation to fish spawning and the establishment of aquatic vegetation.

APPENDIX A: SUBJECT INDEX TO ANNOTATIONS

1. This index has been included to facilitate use of the annotated bibliography. Topics have been broadly grouped into biological, taxonomic, and limnological areas to increase the flexibility of the index, allowing a user to identify citations on general or specific subject areas. For example, a user may require general information on the effects of drawdown on the reservoir ecosystem. By looking under "Drawdown" within the limnology section, the user can identify the following 106 citations (listed by paragraph number):

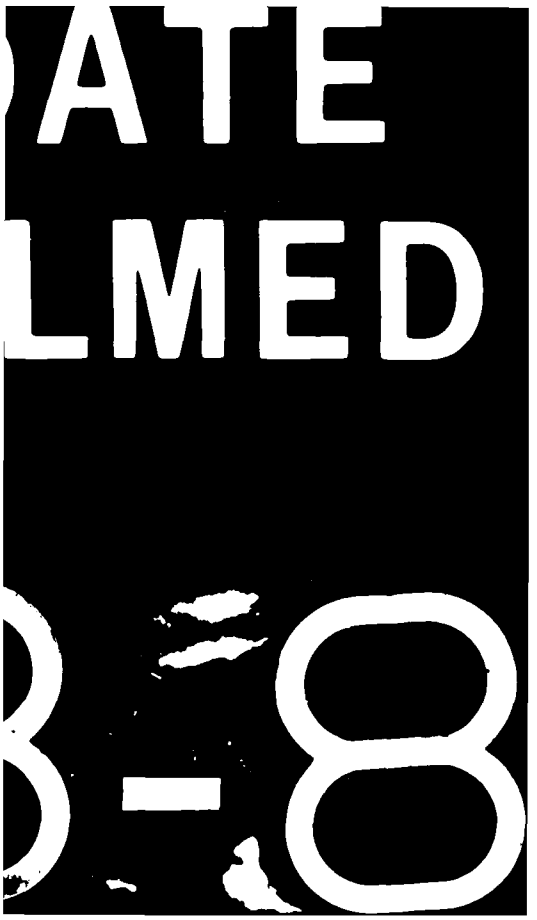
Drawdown 7, 22, 29, 30, 31, 32, 36, 37, 38, 39, 42, 46, 47, 49, 51, 54, 59, 61, 62, 67, 70, 72, 77, 78, 79, 84, 85, 88, 93, 98, 99, 102, 105, 108, 112, 113, 122, 124, 129, 130, 131, 139, 140, 145, 150, 151, 152, 156, 162, 164, 165, 168, 170, 183, 190, 191, 192, 193, 194, 202, 204, 206, 207, 213, 214, 221, 223, 226, 232, 253, 255, 260, 261, 265, 268, 272, 275, 282, 283, 286, 290, 295, 303, 304, 305, 306, 311, 212, 320, 328, 334, 335, 344, 347, 348, 349, 351, 352, 353, 354, 355, 359, 360, 361, 362, 365.

2. However, the user may require more specific information, such as the effects of drawdown on growth of reservoir fish. By selecting references that occur under both "Drawdown" and "Growth," the user can identify the following 23 citations (underlined):

Growth 6, 11, 12, 17, 20, 22, 32, 51, 52, 53, 54, 59, 63, 66, 71, 77, 95, 100, 104, 106, 109, 112, 116, 120, 130, 131, 137, 138, 140, 146, 149, 154, 164, 165, 166, 176, 177, 181, 182, 183, 185, 191, 192, 193, 205, 207, 208, 217, 219, 220, 221, 223, 229, 232, 234, 235, 241, 248, 250, 254, 258, 259, 267, 269, 274, 276, 281, 293, 294, 297, 307, 311, 316, 323, 324, 331, 339, 348, 354, 364, 365, 367.

3. Even more specific information may be obtained, such as the effects of drawdown on the growth of black basses. The following 11 (underlined) references were located by identifying citations under the above two areas and under "black basses" within the taxonomic section:

black basses 11, 12, 15, 20, 21, 22, 32, 34, 35, 37, 38, 39, 41, 49, 52, 66, 76, 80, 84, 100, 104, 117, 138, 139, 140, 146, 148, 151, 152, 164, 165, 168, 169, 170, 172, 175, 181, 185, 192, 193, 195, 201, 203, 204, 207, 215,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