THE SIGNIFICANCE OF MANAGED WATER LEVELS IN DEVELOPING THE FISHERIES OF LARGE IMPOUNDMENTS

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Introduction

Five years ago (1945), the United States Fish and Wildlife Service, Department of the Interior, began its first systematic surveys of water-development projects in the United States under the provisions of its newly created River Basin Studies program. The significance of these projects and the profound changes which have been wrought or made possible by them are described by Dieffenbach (1948) and Fredine (1949). The major objective of River Basin Studies is the preservation, rehabilitation, and development of fish and wildlife resources in connection with water-development projects. The large impoundments, naturally, have received the greatest attention, and considerable effort has been expended toward developing the fish and wildlife resources associated with them. Progress has been seriously impeded, however, by the scarcity of sound techniques which can be recommended for effective management. Also, by the fact that in many cases, measures to enhance fishery resources conflict with wildlife requirements or wildlife practices conflict with the fishery; and, in most cases, both conflict with the primary purpose of the project and with malaria control.

These problems emphasize the need for an overall plan of management whereby considerations sought for fish, wildlife, and malaria control can be coordinated with the primary purpose of the various water-development projects. Of course, the development of a single plan that would be applicable to all types of reservoirs in various parts of the country is virtually impossible. Nevertheless, it appears that there are certain principles of management applicable to all types of large impoundments, and that a general management plan suitable for one type may be modified to assist in the management (or at least in obtaining an understanding) of others.

In preparing such a plan, the biologist must consider the important fact that in almost all large reservoirs, the water level fluctuates. This fluctuation, of course, varies greatly in degree and pattern from one impoundment to another, or within the same impoundment from year to year. It is logical to assume that the effects of the fluctuations on fish and wildlife also vary. Some of these effects are detrimental as described by Ellis (1937) and Eddy and Surber (1947); and since water fluctuation is such an obvious characteristic, it is easy to understand why this factor has been blamed for many unsuccessful fishing trips. There are increasing data, however, which indicate that some water-level fluctuations may be of great benefit to fisheries, and that by managing water levels a valuable tool in fish management can be developed.

Managed water levels have been used in the development of waterfowl habitats for many years (Martin, 1947) and also to provide one of the most practical means of malaria control on impounded waters (U. S. Public Health Service and Tennessee Valley Authority, 1947). It seems reasonable to believe that managed water levels to improve fishing conditions may be developed and coordinated with wildlife and malaria control interests in an overall plan of water management. Such a plan was prepared by Wood, Roberts, and Booth (1947), although its effectiveness has not been demonstrated conclusively. To provide a basis for further studies, literature pertaining to the significance of water-level fluctuations has been reviewed and is discussed herein in relation to (1) basic fertility and productivity of impounded waters, (2) fish populations and management, and (3) increased yields.

Basic Fertility and Productivity of Impounded Waters

Basic fertility of a lake or reservoir as here implied refers to the availability of elements essential to the sustenance of the plant and animal life it supports. Productivity infers the weight of fish that a body of water will support. Swingle and Smith (1942) stated that the productivity of a lake is dependent upon the fertility of the watershed. Their observations disclosed that unfertilized ponds in Alabama produce from 40 to 200 pounds of fish per acre of water, the lower weight occurring in poor land areas and the higher in the best land areas. Chance (1950) described the much higher productivity of Bedford Lake in the fertile Central Basin Province of Tennessee over that of Tullahoma Lake in the poorer Highland Rim Section. Similar observations pertaining to fish production of large impoundments have been made by other workers in the Southeast. For example, the production of fish in Herrington Lake located in the fertile Bluegrass Region of Kentucky is reported to be high, whereas that of Martin Reservoir located in a poor section of the Piedmont Province in Alabama is very low.

The apparent decline in productivity of some large impoundments following the first few years of existence suggests that the weight of fish a lake can support is also related to the availability of plant nutrients in its bottom soils. The importance of these soils as a medium of production is described in the writings of numerous European fish-culturists whose works are reviewed by Nees (1949). The lake bottom has been divided into two regions: an upper, loose, well aerated, and often highly colloidal layer of decomposed organic material and plant debris, and a lower anaerobic zone, differing widely from place to place and often containing a large proportion of mineral matter. The ability of these soil layers to direct certain processes in the pond is the result of special properties summarized in the following paragraphs:

1. The mineral composition of pond water is to a large extent a reflection of the mineral composition of the soils of the pond bottom and the surrounding basin.

2. The often predominant colloid fraction, consisting of humic substances, ferric gels, and clay is a powerful adsorbant of certain soluble nutrient elements and a governor of their distribution among pond organisms. Phosphorus in particular is adsorbed in the bottom and does not wash out of the pond.

3. The bottom is also the medium in which live the diverse microrganisms that are responsible for the decomposition of organic debris and for chemical transformations such as the conversion of organic phosphorus and nitrogen to soluble compounds, oxidation of ammonia, production of carbon dioxide, and possibly the fixation of free nitrogen. In general, the rate and nature of decomposition are determined by the availability of oxygen, reaction of the substratum, and the presence of certain essential substances. Where the bottom is not aerated, decomposition is slow, and its products are only partially reduced or oxidized and thus tend to encourage acid conditions and to reduce the availability of essential elements for plant and animal growth.

4. Under certain conditions the bottom is a direct source of nutrition for fish insofar as it may contain an extensive fauna of insect larvae, small mollusca, and other organisms.

An understanding of these characteristics of the bottom soils becomes of particular importance when we realize that permanent inundation coupled with the irregular fluctuations characteristic of most hydroelectric reservoirs may play an important role in the decline in the productivity of such impoundments after the first few years. Ellis (1937) stated that during the initial period of high productivity, the fixed nitrogen, phosphates, and ionizable salt content of the water are satisfactorily high. These favorable biochemical conditions are produced by the solution of material leached from the organic debris, chiefly trees, brush, and grass left on the floor of the basin before flooding. From the fixed nitrogen of the plant material leaching into the water, a nitrogen food chain for higher animals is started with bacteria and protozoa as basic links. However, after a time, when the fixed nitrogen of the plant material has been exhausted, production declines.

Following this initial period, the fertility of the lake is dependent upon what nutrients are washed in from the watershed or can be obtained from the bottom soils. Nutrients derived from the watershed are rather constant from year to year; on the other hand, the availability of nutrients from the bottom soils may become less as the impoundment ages. This may be influenced greatly by the topography of the lake basin. If the slopes of the basin are steep and its shores exposed to wind and wave action, the productive bottom soils of the shallow areas may be removed to the profundal depths and in some cases practically all of the essential decomposition materials become inaccessible. They settle into the hypolimnion where, according to Welch (1935) and Waksman (1941), their products become locked up except during the overturns when temporarily they participate in the general circulation.

The problem of increasing the productivity of inland waters has been given much study. Following extensive experiments on various types of fertilizers such as stable manure, hay, cottonseed meal, and commercial fertilizers, Swingle (1947) concluded that inorganic fertilizers provided the most practical means of increasing fish production in Alabama ponds. The use of organic fertilizers in combination with inorganic fertilizers was found to be most effective in the hard-water ponds of West Virginia (Surber, 1945).

The results achieved in increasing fish production and in improving fishing by the addition of fertilizer prompted the thought that the productivity of large hydroelectric and flood-control impoundments could be affected in a similar manner. In actual practice, however, the costs of fertilizers are too high to permit using them for this purpose, as indicated by Eschmeyer (1949). Therefore, some other method of maintaining or increasing the fertility of large impoundments is desirable.

Leopold (1941) described the important role of lakes in retarding the downhill flow of nutrients from the hills to the sea and the role of certain animals in returning some of these nutrients to the lands from whence they came. It was his belief that prudent technology should alter the natural order as little as possible. Since many large impoundments are depositories of much of our topsoils which are rich in nutrients, it appears that a plan which would return these nutrients to general circulation would be sound. This is accomplished to a considerable extent by the European method of fish culture which is founded on management of the bottom soils. The methods practiced, according to Nees (1949), have several aims. A soil must be built which is neither so adsorptive as to impoverish the water of the nutrients nor so inactive as to permit excessive loss of nutrients by seepage and outflow. It must be loose and sufficiently aerated to permit rapid oxidative decay and with buffering properties strong enough to overcome accumulations of acidic products of decomposition. In addition, the soils should provide a suitable medium for the growth of bottom organisms and soft aquatic animals. These aims are achieved in two general ways: by application of suitable chemicals, which is lime in most instances, and by treatment of the bottom soils after drainage of the pond.

The use of lime does not appear necessary or wise, however, in most ponds of the southeastern states. Experiments conducted by Lawrence (1944) indicated that the application of limestone to ponds in Alabama, even in small amounts, did not increase fish production and in most instances tended to decrease fish production. On the other hand, periodic dry fallowing, which is almost a universal part of European cultural practice, appears to offer a practical solution to the problem of maintaining the basic fertility of many large impoundments in the United States or at least furnish an understanding as to why we cannot maintain the basic fertility in others.

According to the literature reviewed by Nees (1949), growing ponds in Europe are wintered dry, the fish held in the meantime in special wintering ponds. At regular intervals, ponds are dried for a full calendar year. In older practice, crop plants or legumes were grown on the dry soil. Fallowing appears to hasten the process of decomposition. Gross correlations indicated that periodic fallowing alone raises fish production. Mechanical disturbance of the soil by harrowing probably increases the benefits. The *p*H of some soils is raised during periods of fallowing and some benefit was claimed from reduction in concentration of parasites. Benthonic organisms may or may not be adversely affected, depending on the length of time the ponds are dry.

Snieszko (1941) described how in Poland it was common to cultivate the soils of the ponds in the same way as ordinary fields, once every four to six years. In this way, the amount of plankton in the water was decidedly increased. Snieszko recommended that in the fall when the water is drained, or in the early spring, those ponds which are to be cultivated should be plowed and seeded with oats, rye, hemp, peas, vetch, turnips, or buckwheat. If the soils are rich in organic matter, the crops can be harvested; but if not they should be left as green manure. Decaying under water, they produce enormous amounts of fish food.

The European method of fish management duplicates some of the natural phenomena associated with seasonal flooding which are characteristic of the rivers in the lower Mississippi alluvial valley and which contribute to the high biological productivity of this region. The pattern of water-level fluctuation in many flood-control reservoirs such as Sardis Reservoir in Mississippi simulate natural conditions in the flood plains of our sourthern streams and for this reason are expected to remain very productive (Wood, Roberts, and Booth, 1947).

To secure a more complete understanding of the mechanism whereby lowering of water levels in an impoundment, cultivating the soils, and growing of plants contribute to the availability of nutrients in an impoundment, one must turn to the works of various soil scientists, biochemists, plant physiologists, and other biological investigators. The processes involved in the storing of essential elements for life in the bottom muds, their release, and their assimilation as plant tissue are extremely complex, as we are often reminded. Partial explanation of these phenomena are to be found in the works of Albrecht (1938), Starkey (1938), Pearsall and Mortimer (1939), Meyer and Anderson (1939), Hutchinson and Wollack (1940), Waksman (1941), Mortimer (1941; 1942), Lyon and Buckman (1943), and Fippin (1945). Of the many marvelous processes revealed by their works, the following deserve special mention.

Albrecht (1938) in describing soil organic matter as one of our most important natural resources and the manner in which it accumulated in our northern soils writes that

> *Wherever there was* poor drainage and limited aeration of the sod cover . . . more complete simplification of this accumulated store of plant nutrients was very slow. In other words, the organic matter that now held the major stock of previously mobile nitrogen and minerals now kept these essentials stored in compounds not simple enough for prompt consumption by growing plants. This represented a very large supply of nutrients not far from the condition in which growing plants could use them. Unable to decay completely or to accumulate much more, they were poised as it were for rapid conversion, when a slight change in conditions occurred, into forms of maximum utility for plant growth.
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> But with the removal of water through furrows, ditches, and tiles, and the aeration of the soil by cultivation, what the pioneers did in effect was to fan the former simmering fires of acidification and preservation into a blaze of bacterial oxidation and more complete combustion. The combustion of the accumulated organic matter began to take place at a rate far greater than its annual accumulation. The age-old process was reversed and the supply of organic matter in the soil began to decrease instead of accumulating.

It is reasonable to believe that a drawdown of water levels in large impoundments and the cultivation of the bottom soils would encourage similar phenomena.

The role of plants in releasing nutrients from the bottom soils is described by Lyon and Buckman (1949) thus:

> *When phosphorus is held* in organic combination, decay will encourage its simplification. The mineral phosphorus, however, presents a more difficult problem. The various soil phosphates are usually rather insoluble, and even when the normal solvent agent, carbon dioxide, is supplied in large amounts, the rate of solution is slow. Plant rootlets by their contact and possibly by means of certain exudates seem to encourage the transfer (of insoluble phosphates to water soluble forms). They may force a solution and availability that might otherwise be almost negligible. Thus, a soil may be able to supply a crop with appreciable quantities of phosphorus, and yet when uncropped its solution and drainage water may contain very small amounts of this element. Also, organic matter is continuously being sloughed off by plant roots, thus providing food and energy for micro-organisms. The concentration of microbial activity within the rhizosphere is ample proof of this. Such biochemical phenomena cannot fail to increase greatly the rate and ease of transfer of nutrients from soil to plant.

Thus, it seems that the productivity of large impoundments would be increased by the invasion of plant life into the zone of fluctuation. According to the findings of Stroud (1948), fish grew more rapidly in Norris Reservoir immediately following a period of dry years when the waters in the reservoir fluctuated at a low level. This increase in growth rate was attributed to an increase in abundance of food brought about by a decomposition of vegetation which had invaded the reservoir during the dry years. Phenomenal growth rates of largemouth black bass in flooded lands of the lower Mississippi River have been noted by Viosca (1943), which he attributed to the abundance and easily available food supplies in these newly created areas. He also observed that the shallow inland swamps, when filled only periodically by rainfall did not possess the richness of the same areas as when they were flooded by the rivers (Viosca, 1928).

In experiments, Swingle (1947) found that Johnson grass and Kudzu hay introduced into a pond increased production nineteen pounds for each ton of dry hay. On the basis that an acre of good land will produce about three tons of hay, an increase of about sixty pounds per acre could be expected by flooding such a growth. Swingle and Smith (1943) described the fertilizing effects of flooding a luxurious growth of jungle rice (*Echinochloa colona* (L.) Link) which had grown on the bottom of a twelve-acre pond following drainage but pointed out that after refilling the pond, fishing was interfered with for two years, since the lignified stems were resistant to decay. Viosca (1927) vividly described the relationship of flood waters to the well being of the fish and wildlife resources of the great alluvial valley of the Mississippi River and stated that the most obvious benefit resulting was the enrichment of the soil by deposition of sediment. This fertility in a very short time was converted through a biological succession into an inconceivably large supply of living plant and animal organisms. Vegetation responses to water-level fluctuations in this region were portrayed by Brown (1943). The vast abundance of food in the waters of the Illinois River Valley was described by Forbes and Richardson (1920).

Data presented in this section strongly suggest that management of water levels to alternately expose and flood bottom soils can be an important tool in maintaining the productivity of large impoundments. Aldrich (1946) recommended that we consider building a series of impoundments in order that they can be drained in rotation and reconditioned for fish production. Hogan (1946) described the relationship between the fertility of Nimrod Reservoir, Arkansas, and water fluctuations resulting from flood-control operations and suggested that the Corps of Engineers be made aware of the fishery benefits that would accrue from managed water levels. Hasler (1948) recommended that lakes be dry fallowed as an effective and cheap fertilizing measure. Eschmeyer (1950) recognized the value of cyclic fluctuations in increasing the productivity of TVA reservoirs.

The growth of terrestrial vegetation in lake basins can be encouraged by a summer recession of water levels. The species and abundance of plants produced can be greatly influenced by the time and manner in which the recession is effected as described by Penfound, Hall, and Hess (1945), Hall, Penfound, and Hess (1946), and Cypert (1947). The value of plants and other organic material in precipitating colloidal soil particles from impounded water, thereby increasing the zone of photosynthesis, was described by Irwin (1945). The United States Public Health Service and the Tennessee Valley Authority (1947) suggested that their approved plan of water-level management for malaria control probably increased fish production through the annual addition of marginally grown organic material which served as natural fertilizer. Ellis (1942) recognized benefits to be derived from flooded marginal vegetation and suggested that the shores of Lake Murray, South Carolina, be planted to legumes following the drawdown for power production. The belief that fertility and productivity of impoundment waters could be increased by seasonal raising and lowering of water levels was one of the principal reasons for the schedule of managed water fluctuations as proposed by Wood, Roberts, and Booth (1947).

Fish Populations and Management

Present-day objectives of most fish-management programs concerned with fresh waters are to provide better sport fishing. That most ponds and lakes do not provide the fishing success anticipated by the angling public has been the chief stimulus to find ways and means to remedy this situation. In this quest, a distinction has been drawn between production and yield. The former is used to imply the weight of fish a body of water will support, the latter to denote the weight and numbers harvested.

It is logical to assume that in order to reap a great harvest a lake must be productive. It does not necessarily follow that a productive lake always affords good fishing. Bennett's (1944) review of the works of various fishery biologists indicated that the quality of fishing afforded by a lake was dependent as much upon the type of fish population it supports as upon its productivity.

Three types of fish populations suggested by a correlation of pertinent literature and general observation are: (1) crowded populations, (2) balanced populations, and (3) expanding populations.

1. *Crowded populations.* Crowded fish populations, which are one of the principal causes of poor fishing, usually occur as a result of inadequate predation, although it is logical to assume that they also are favored by the relative absence of environmental factors adverse to fish reproduction and survival. Fish have enormous reproductive potentials and as Swingle and Smith (1941) demonstrated, without some means of controlling spawning or the survival of their young, an impoundment becomes overrun with prodigious numbers of small, slow growing, stunted fish, and very few large individuals. When available living space has been filled to capacity, reproduction ceases or takes place only to the extent necessary to replace those which are lost. In populations of this type, stunting of one or all species of fish apparently results from a dominant population of one or more non-predatory species or from a general stunting of all fish without a dominant population (Bennett, 1944).

Crowded fish populations also may result from a dominant brood or year class composed of a single species that from year to year controls the spawning or survival of young of all species within a lake, until a sudden natural die-off so reduces its numbers as to allow the survival of another large year class of the same species. These dominant broods, appearing every three to five years, require two or three years to reach useful size, and furnish good fishing for only one or two seasons out of four or five (Bennett, 1944). The occurrence of such overcrowded populations appears likely in some large impoundments of the southeastern United States.

Crowded fish populations in which all species are stunted are sometimes referred to as static populations since their species composition, total weight, and numbers vary within a narrow range. It seems unlikely that populations of this type would occur in natural lakes and streams in which the inhabitants are subject to predation, diseases, floods, droughts, and drastic changes in temperature, oxygen, and other environmental factors. On the other hand, it appears logical that without management, such populations are likely to occur in farm ponds, stabilized impoundments, or other bodies of water in which changes in environmental conditions are minimized.

2. *Balanced populations.* Balanced fish populations usually afford good fishing. In balanced populations, there is adequate predation to control the survival of young produced by all species to the extent that overpopulation and stunting do not occur. Fish in a balanced population grow rapidly, attain an average to large size and reproduce in proportion to the need for replacement of those removed by predation, harvest, or other means. Such a population may or may not include rough fish. The method of farm-pond management as developed by Swingle and Smith (1941) is predicated on establishing and maintaining a balance between predator and prey. A bluegill-largemouth bass combination has given best results. Evidence presented tends to indicate that good fishing can be sustained as long as a balanced population composed of largemouth black bass and bluegills can be maintained. The importance of a balance between predator and prey in providing good sport fishing is also emphasized by Bennett (1947) and Eschmeyer (1949).

Excessive numbers of rough fish in a balanced fish population usually will result in poor sport fihing. By ough fish are implied those species of fish which are not desired by the angler. They are, in other words, the weeds of the aquatic pastures, although they may have high commercial values. According to Bennett (1944), this type of population affords poor fishing since the kinds of fish useful to angling are so outnumbered by those of no angling value that few fish are caught. The seriousness of the rough fish problem in TVA mainstream reservoirs has been emphasized by Tarzwell (1941), Wiebe (1942), Eschmeyer (1944), and their associates.

3. *Expanding populations.* In large impoundments, there exists for a few years following initial filling, a type of fish population which almost invariably provides good fishing; although it does not seem to fit any of the types previously described. In this type, balance between predator and prey may or may not prevail and the population may contain considerable numbers of rough fish; nevertheless, the population is composed of an assemblage of fishes rapidly expanding in numbers, average size, and total weight. In explanation of the excellent fishing afforded by expanding fish populations, various theories have been advanced.

Swingle's (1950) explanation for the initial good fishing in an impoundment followed by a decline is related principally to changes in composition of the fish populations due to rates of harvest. During the first few years of impoundment, the weight of fish is composed of large numbers of young fish which provide an abundance of food for the black basses, crappies, and other predatory species which are most desired by anglers. A high poundage of these fishes, therefore, is sustained. As the impoundment ages, however, the young fish rapidly increase in size and become too large to serve as food for the predatory species or else they are removed by the pressure of predation. Failure to adequately harvest the large non-predatory species, which include carp, buffalofishes, bullheads, and catfishes as well as bluegills, reduces their rate of reproduction. Without adequate food in the form of small fish, a decline in the number of predatory species and in fishing success is inevitable.

This also explains why some improperly stocked ponds oftentimes afford excellent fishing for one or two years before the pond is overpopulated by one or more of the introduced species of forage fish. In further explanation of the good fishing usually afforded by an expanding population, Swingle has taught in his class of impounded waters that more food is required to sustain the physiological processes of growth and reproduction than that required for mere subsistence.

Trends in the relative abundance of species composing the populations of large impoundments, which have been observed by Eschmeyer, Manges, and Haslbauer (1947), clearly indicate why at least some fish are easier to take while others are more difficult. There are several reasons for these trends, including changes in environmental conditions, as will be discussed later in this paper.

The whole truth for the excellent fishing afforded by expanding fish populations, however, may be more deeply rooted in the physiology and temperament of fish than we will permit ourselves to believe. The spectacular increase in numbers of fish during the initial years of an impoundment's existence calls to mind the biological law described by Grange (1949) that animal populations of low level but which are not bereft of essential habitat seem to experience some special spur to reproduction. Spectacular increases of muskrats in certain habitats were cited as an example. According to Grange, such increases may be explainable on the grounds of superb food supply and low mortality rates from both predation and disease; but whatever the cause, the percentage and total number of offspring produced rises sharply. One may theorize further that during this period of food abundance, plentiful living space, and freedom from disease, the population is composed of vigorous, aggressive individuals.

Expanding fish populations are dynamic and, aside from being typical of new impoundments, characterize best the fish populations of natural lakes in the flood plain of the lower Mississippi River. The fish populations of these lakes usually afford good fishing, even though, in many instances they seem to be dominated by rough-fish species. Also, it is doubtful that a delicate balance prevails between predatory and non-predatory fishes, since there are many other factors other than predation which control the spawning and survival of the fish populations. Reproduction and rapid growth of fish populations in this region are associated with the creation of new habitat by extensive overflows each winter and spring. And, naturally, these characteristics are followed by a high mortality or loss of fish, particularly the non-predatory species after the waters have receded in the summer. The significance of the expanding population is evident when we realize that if it can be sustained in large impoundments, good fishing can be provided without stocking to achieve a delicate balance between predator and prey and without excluding rough fish from the waters.

Management of fish populations to provide good fishing. Successful farm-pond management, as previously described, has been achieved in establishing and maintaining a balanced fish population composed essentially of game-fish species. Rough fish are generally excluded. This balance is usually established by providing and maintaining a favorable environment and by stocking with the desired numbers of predatory and forage fish at the time the pond is first filled with water. Principles of farm-pond construction, as described in detail by Lawrence (1949) include careful selection of site, proper construction of dam, deepening of pond edge, excavating diversion ditch, sodding the dam and pond edge, and certain other measures. Principles of managing farm fish ponds, as described by Swingle and Smith (1949), include, in addition to those principles already mentioned, fertilization to prevent the growth of aquatic plants, harvest of fish to maintain a balanced population, draining and restocking an overpopulated pond or partial poisoning to reduce the population and to restore a balanced fish population, and other measures.

Application of these principles to the management of large impoundments, however, is greatly restricted. Most large impoundments are not constructed with any view of fish production. Thus, in many cases, the topography, water supply, and other factors do not afford optimum conditions for fish production. Stocking to secure a balanced population appears to be of little importance in view of the various species of fish already present in the lakes and streams of the lake basin. Partial or complete poisoning of a large impoundment is probably inhibited by the expense involved in the purchase and application of the poison, although experiments have demonstrated its effectiveness on small lakes (Beckman, 1941). Drainage to enable the removal of undesirable fish populations is effective where this can be accomplished (Wickliff, 1948). In most reservoirs, however, this is impossible due to the absence of a drainage structure, or because of its conflict with the primary purpose of the project, as in hydroelectric reservoirs. Fertilization of most large impoundments to prevent the growth of acquatic plants is impractical. Diversion of muddy waters is usually an impossibility.

The control of rough-fish populations on large impoundments by commercial fishing methods has received much attention since in many instances this method would involve the establishment of an industry of economic importance. Where there exist sufficient numbers of rough fish such an industry has become established. The importance of the commercial fishery on mainstream reservoirs of the Tennessee Valley Authority system is reflected by the studies of Tarzwell and Bryan (1945). Methods used in the harvest of the fish, however, which included the use of snag lines, trot lines, and hoop nets have been ineffective in alleviating the problem due to the high selectivity of these methods. To be effective a large percentage of the total population of all fish must be removed. The only commercial fishing method which would accomplish this is seining. The use of seines on most large impoundments is prohibited by the lack of suitable seining grounds as occasioned by topography, stumps, boulders, or debris. Hutchins (1949) has recommended that 10 percent of the bottom of reservoirs between 0 and 20 feet in depth be conditioned for seining operations. Seine hauls observed by Eschmeyer, Stroud, and Jones (1944) on a shoal area in Chickamauga Reservoir, a mainstream reservoir, revealed that the rough fish, which decidedly predominated were of small size, most of them being too small to be of interest to commercial fishermen.

Among other management practices that have been suggested, the management of water levels appears to be the most promising. Observations by various investigators indicate that by managing water levels, it should be possible to create certain types of habitats and to influence the welfare of the fish which inhabit them. The animal ecologist in studying the relationship of the animal to its environment gives particular consideration to plant successions beginning with the first plants invading a denuded area to the final vegetative expression or climax type. The significance of his studies assume importance when it becomes evident that certain species of wildlife occur in greater abundance during some stages of plant succession than during others. In the case of waterfowl management, early succession stages in marsh development usually provide the best habitat; thus, the task of management revolves around finding a practical means of arresting plant succession. Penfound and Schneidau (1945) express the opinion that, in wet-land areas, with few exceptions any practice that will prevent or retard aquatic succession, or return it to an earlier successional stage, will result in an increase in wildlife production. These practices include controlled flooding, draining and reflooding, recession, salting, freshening, poisoning, burning, grazing, and overpopulating.

Limnological studies have failed to reveal the well-defined "seres" or succession stages in limnetic environments. That profound changes do occur, however, are suggested by the trends and cycles of fish populations with the aging of an impoundment (Tarzwell, 1941; Eschmeyer, 1941; Stroud, 1949; Eschmeyer, Manges, and Haslbauer, 1946) coupled with the dominance of certain species in environments particularly favorable to them. Thus, it appears that we should seek to determine the conditions most favorable to, or which will facilitate maintaining the desired type of fish population.

Eschmeyer (1947) was convinced that extensive water drawdowns for flood control on Tennessee Valley Authority reservoirs were highly beneficial to fishing. He believed that beneficial effects are obtained largely by eliminating food for bottom-feeding fish. On the other hand permanent-level pools, he believes, favor conditions ideal for rough fish and provide poor fishing. In the control of rough fish, Eschmeyer, Stroud, and Jones (1944) pointed out that theoretically properly timed drawdowns present the best solution to this problem, though this probably would not affect the reproduction of shad and some other rough-fish species. To them, it is conceivable that one drawdown might control buffalofishes and that another limited drawdown might expose the eggs of carp without interfering with the nests of bass and crappies when and if the spawning seasons overlap. Silvey (1946) has employed a drawdown in destroying the spawn of bluegills and redear sunfish without affecting bass or crappies which nest in deeper water and at different seasons. Holloway (1949) reported that a drawdown of from 50 to 75 percent of the volume of water in ponds and lakes is effective in restoring a balanced population. Silvey (1949) recommended, in some cases, a 90 percent drawdown and stated that a slight reduction in water levels has the effect of suppressing growth rather than reducing the population.

The growth of terrestrial vegetation in the basin of a lake can be encouraged by a summer recession of water levels. The species and abundance of plants produced can be greatly influenced by the time and manner in which the recession is effected, as described by Penfound, Hall, and Hess (1945), Hall, Penfound, and Hess (1946), and Cypert (1947). The use of water fluctuations in controlling aquatic plants in lakes is mentioned by Silvey and Harris (1947).

The value of plants and other organic material in precipitating colloidal soil particles from impounded waters, thereby improving the habitat for desired species of game fish, is described by Irwin (1945).

The removal of excessive populations of rough fish can be facilitated by water-level management. In the lower Mississippi alluvial valley, there are two principal fishing seasons: one when the water has receded from the bottomlands and the fish are concentrated in the lakes and streams from which they are removed by seining. The other is during the spring when waters are usually rising and the rough fish are moving out into the backwater areas. At this time, hoop nets and wing nets are employed to great advantage. Similar conditions are reported to exist on Sardis Flood-Control Reservoir in Mississippi (Smith, 1950).

Recognizing the significance of overflow in Louisiana, Viosca (1928) discussed means of adapting the flood-control program in the lower Mississippi River Valley to fish production. Lin (1949) described a method of pond culture in India based on management of water levels to induce the spawning of certain fishes. Wood, Roberts, and Booth (1947) attempted to formulate a plan that would provide many of the benefits described herein by the management of water levels in flood-control reservoirs.

Increased Yields

It stands to reason that little is gained by increasing the productivity of an impoundment and establishing a desired type of fish population unless the fishery is utilized. Effective utilization is measured in terms of the ratio of yield of desirable kinds and sizes to the carrying capacity (Wright, 1944). Swingle and Smith (1942) found that even in well managed farm fish ponds, a maximum of about 50 percent of the total weight is harvested. Recognition of these facts by many individuals has been responsible for a trend to encourage a greater harvest.

This somewhat new philosophy has been largely responsible for liberalizing fishing regulations and the initiation of investigations and management practices to aid fishermen. Langlois (1944) advocated that the removal of legal restrictions on fishermen should proceed as rapidly as public opinion will permit. Evidence is presented by Eschmeyer (1944) that fish in the large TVA impoundments were not being harvested adequately. Observations made by Eschmeyer and Manges (1945) on the effects of a year-round open season in Norris Reservoir revealed that by this means the catch could be substantially increased without adverse effects. These and other studies later resulted in opening all TVA reservoirs to year-round fishing. Fishing during the spring months on TVA reservoirs is encouraged for several reasons, as explained by Eschmeyer (1945). Also, fishing in the reservoir tailwaters, although contrary to the regulations of some states, is one of the most effective methods of taking fish in Tennessee (Bryan and Miller, 1945-1946, Eschmeyer and Miller, 1949).

Fishery biologists are now giving particular consideration to studies which will aid the angler in determining the location or whereabouts of his quarry, means of localizing or concentrating fish in predetermined locations, and to induce certain feeding habits that will improve fishing success. Since this phase of fishery biology is relatively new in scientific circles (the sport fisherman has been seeking such information for years), there is a paucity of accurate data on these subjects.

Distribution studies. Of studies conducted to assist the angler in determining the location of his quarry, studies of density currents (Wiebe, 1939, Wiebe, 1941), and depth distribution of fishes in Norris Reservoir, Tennessee (Cady, 1945; Dendy, 1945; Dendy, 1946; Haslbauer, 1946), are of particular interest. These studies indicated that subsurface strata of stagnant water formed by density currents exert an effect upon the vertical distribution of lakes and contribute to fish mortality; also, that density currents may affect productivity. Depth distribution studies in Norris Reservoir indicated that the largemouth black bass favored shallow waters in the spring and that in June, after spawning, its distribution extended from the surface to a depth of 20 feet. In July, this species was most commonly taken between 10 and 20 feet in depth; and in the fall, evidence obtained indicated that the range in depth increased as the warm upper layers of water became thicker (due to drawdown). Thus, the average angler, who fishes in the usually accepted method of casting or shallow trolling, may enjoy excellent success in the spring but very poor fishing in the summer and fall. Further analysis of distributional data in relation to environmental factors by Dendy (1946) indicated that temperature seemed to be most significant in influencing depth distribution; also, that in normal years a close enough correlation exists between temperature and fish distribution to permit prediction of summertime distribution by making temperature determination and by noting the distribution for comparable temperatures for previous years.

There is very little information available on the lateral distribution of fishes in large impoundments. We know that some species of fish move into shallow waters during a rise in water levels, presumably for the purpose of feeding on terrestrial insects and other animal life available in the new habitat, or on minnows and small fish which seek the shelter of inundated vegetation and debris. In studying the fish populations in the backwaters of Wheeler Reservoir, Tennessee, Tarzwell (1941), observed that largemouth black bass are among the first fish to move into the backwater areas when the water rises and the first to leave when it begins falling. Migrations to new areas took place in less than 48 hours. Buffalofishes move upstream during the spring and spawn in backwater areas. It is common knowledge among the commercial fishermen that successful spawning is dependent upon rising water levels.

Localizing fish in predetermined areas. Baiting is an age-old practice of commercial fishermen to concentrate fish in the seining areas. In Florida, commercial fishermen use herring and gizzard shad as bait, which they often cook before depositing in shallow waters of the lakes in which they operate their haul seines. Baiting is also being employed on private lakes and farm fish ponds to attract fish into localized areas where they may be more easily harvested. Experiments on a 100-acre lake in East Texas by Silvey and Harris (1947) indicated that deposition of food materials in feeding boxes on the lake bottom was highly effective in increasing the yield, although the success of the program was correlated with an increase in the growth rate of the fishes.

The brush shelter appears to offer a practical means of improving fishing. The felling of trees into lakes and sloughs to improve crappie fishing has been practiced for many years by the anglers residing in the lower White River Valley, Arkansas. The use of brush shelters throughout the country is increasing in popularity. During 1947 and 1948 the State of Michigan placed over 1,200 brush shelters in a number of lakes, according to Eschmeyer (1949), who also points out that tree-top shelters in Norris Reservoir, Tennessee, have improved the crappie harvest. Approximately 100 brush shelters were constructed during clearing operations in the new Allatoona Reservoir in Georgia. This work was carried out by the Corps of Engineers in cooperation with the Fish and Wildlife Service and the Georgia State Game and Fish Commission. The use of the brush shelter to improve fishing is predicated on concentrating some species of fish, or providing lair or den for others, in a known location. Although it probably does furnish refuge for small fish (which may partially explain why crappies are attracted into its vicinity), and may afford spawning areas for others, its use for such purposes has not met with favor by many fishery biologists. That largemouth black bass are being consistently taken from certain places in lakes or streams, such as behind boulders, in a particular cove, or near the base of an overhanging limb, suggest that the creation of such favored haunts may be practicable. The Agricultural Experiment Station of Alabama Polytechnic Institute constructed a farm pond near Auburn, Alabama, in which all trees and brush were left in the center of the impoundment. Rapid growth of fishes in this pond was observed during the first three years of impoundment and excellent fishing was afforded in the shelter area. It is believed that the presence of the brush in the pond may have increased the productivity of the lake by providing a greater surface for the attachment of food organisms, which attracted the fish to the shelter area. It has not been determined whether the pond actually afforded better fishing than ponds in which no timber was left in the basin.

Lowering of water levels to concentrate fishes and to facilitate seining is a practical measure in fish hatcheries and farm ponds, and it is the natural means by which commercial fishing is facilitated in the lakes and bayous of the lower Mississippi River Valley. The lowering of water levels to concentrate game fishes to facilitate sport fishing is being considered. From the little information available, it appears that lowering of water levels to some extent may improve fishing, but excessive lowering may concentrate fish to the extent that they will not bite readily.

Inducing fish to bite. Of all subjects in which the angler is interested, this is probably the most important. It is also the one about which we know the least. In pursuit of one of America's most important outdoor sports, anglers have fashioned the fishing calendar, consulted the almanac, studied the barometer, and examined their horoscope in search of signs that suggest when the fish are going to bite. Their tackle box is filled with baits of various sizes, shapes, material, color, and action in the hope that one will lure the fish. In this quest, they have received little help from professional biologists, who have overlooked perhaps one of the greatest opportunities in the field of fisheries management.

That fish bite best when they are feeding is an accepted fact. It is also common knowledge that under natural conditions, the habits of feeding are cyclic; that is, there are periods in which fish have almost insatiable appetities, and there are other times when there is little evidence of feeding. Certainly, environmental factors greatly influence this trait. Markus (1932) has made some studies on the extent to which temperature changes influence food consumption in largemouth black bass. His findings indicated that the rate of metabolism in the largemouth black bass is very low at 4° C. and increases rapidly as the temperature increases up to 22° C. After that temperature is reached, the rate of increase in metabolism diminishes (which may help to explain why fish do not usually bite during the hot summer months of July and August). He also found that none of the largemouth black bass took food voluntarily in water temperatures below 10° C. and that the rate of metabolism is much greater in small bass than in large ones, especially at the lower and higher temperatures.

There is need for more information on this subject and on the influence of other environmental factors in the feeding habits of fish. The belief that fish show preferences for different kinds of bait and that a change in the availability of food (such as the sudden emergence of May flies or cicadas) may stimulate fishing also deserves a great deal of study.

The role of managed water levels. The observations and studies described in this section suggest that managed water levels may be used effectively as a means of increasing fishing success. A midsummer drawdown that would permit the invasion of vegetation into the zone of fluctuation followed by raising water levels in the fall would prevent erosion of the shores of an impoundment, maintain the productivity of shallow waters, and provide habitat for an abundance of fish-food organisms. This would tend to discourage wide dispersion of fishes in an impoundment and tend to localize them where they could be more easily harvested. The time of the drawdown could be scheduled in such manner that trees growing in the zone of fluctuation could be preserved as living shelters as exemplified in Sardis Flood-Control Reservoir in Mississippi. The late summer drawdown could be effective at a time when water temperatures are highest and when fishing is usually poor. The common belief that fish bite better when the water is rising and Tarzwell's (1941) observations that largemouth black bass move readily into backwater areas as waters rise indicate that by raising water levels at predetermined intervals, better fishing can be provided. These measures were given preliminary consideration in a plan for the fish and wildlife management of impounded waters prepared by Wood, Roberts, and Booth (1947).

Conclusions

Data reviewed in this paper suggest the following:

1. The productivity of an impoundment is dependent upon the fertility of the watershed and the availability of essential plant nutrients in its bottom soils.

2. The availability of plant nutrients in the bottom soils can be increased by management of water levels.

3. Fishing success is related to the type of fish population supported by an impoundment as well as to its productivity. Good fishing is usually afforded by expanding populations and balanced populations consisting principally of game fish; poor fishing is usually afforded by overcrowded populations and balanced populations dominated by rough fish.

4. Of the various types of fish populations described, the expanding population probably affords the best opportunity for management to provide good fishing in large impoundments.

5. The type of fish population supported by an impoundment is dependent not only upon the kinds and numbers of fish present or introduced at the time of initial filling, but also upon habitat conditions and rates of harvest.

6. Habitat conditions favorable to desired fish populations may be provided, and removal of undesired fish populations may be facilitated by management of water levels.

7. Management of water levels to improve fishing success and to increase yields may also be practicable.

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Three out of four traffic accidents happen in clear weather on dry roads.

* * *

About 75 percent of last year's automobile accidents involved passenger cars.

* * *

More than 80 percent of all accidents last year on our streets and highways involved vehicles going straight.

* * *

An overwhelming majority of motor vehicles involved in accidents last year were reported in apparently good condition.

* * *

Fifty-seven percent of last year's fatal accidents occurred during hours of darkness.

* * *

Forty-two percent of last year's motor vehicle accidents involving injuries happened in the dark.

* * *

Saturday and Sunday remain the most dangerous days of the week in traffic.

* * *

You are almost three times as likely to be killed in an automobile accident between seven and eight in the evening as you are between seven and eight in the morning.