FISHING WATERS

HOWARD T. ODUM, *Assistant Professor*, Department of Zoology
Duke University, Durham, N. C.

From the mangrove swamps of southern Florida to the trout streams of the Smoky Mountains, stretches a southland whose fishing waters are rich and diverse. The bass grow fast in the farm ponds of the piedmont, in the healing waters of old phosphate pits, in the red reservoirs of growing towns, and in the black swamp waters of the coastal plain. Great runs of striped bass course the Roanoke, big catfishes thrive in the muddy brown rivers of Georgia; and vast areas of marine coastal waters support the bountiful fisheries of mullet, shrimp, and menhaden. What do all of these resources have in common? How can we specify reasonable needs for fishing amidst the demands for maximum, multiple use of these ponds, streams, and estuaries for drinking, bathing, agriculture, and especially for routes of waste disposal?

Advances in the ecological sciences in recent years permit us to give tentative specifications which fall in five categories. The specific and measurable properties of waters which must serve as guides to the creation of good fishing values in our underwater pastures pertain to:

1. Toxicity
2. Minimum oxygen requirement
3. Fertility
4. Diversity
5. Food Chain Liability

The first requirement is that the water not be directly toxic to fish. This is very obvious and readily measured. Either the fish themselves or representative organisms like the water flea, Daphnia, are tested for survival in water containing different concentrations of the substances in question. For example, Van Horn, Anderson, and Katz (1949) found that the most toxic constituent of Kraft Pulp Mill Wastes was Methyl Mercaptan with a minimum lethal dose of .5 ppm as tested by minnows over five days.

We will not dwell on this important aspect further except to suggest that sad pollution can result from the assumption that direct toxicity is the only consideration. Too often fish are placed in cages in a water in question and when they do not die, the interpretation is made that the water is a favorable environment and unharmed. Imagine a blind farmer who wishes to evaluate his farm for cattle-raising putting some cows in a box in the middle of his pasture. Upon being told that they are healthy the next day, should he then presume that he could get a large beef yield in that pasture that year? Of course not. His cows in boxes would have lived as well in a concrete parking lot as in a richly laden alfalfa field.

Such a procedure sounds absurd and yet too often has toxicity measurement been the sole test made in evaluating aquatic pastures and fish yields in polluted waters. The requirements for fishing waters are much more.

One of the principal water conditions that produces catastrophic destruction of life in a stream is the removal of the dissolved oxygen masses of living organisms. The small organisms like bacteria are especially important because the oxygen used per gram of tissue increases roughly logarithmically as the organism's size decreases. The loss of oxygen occurs

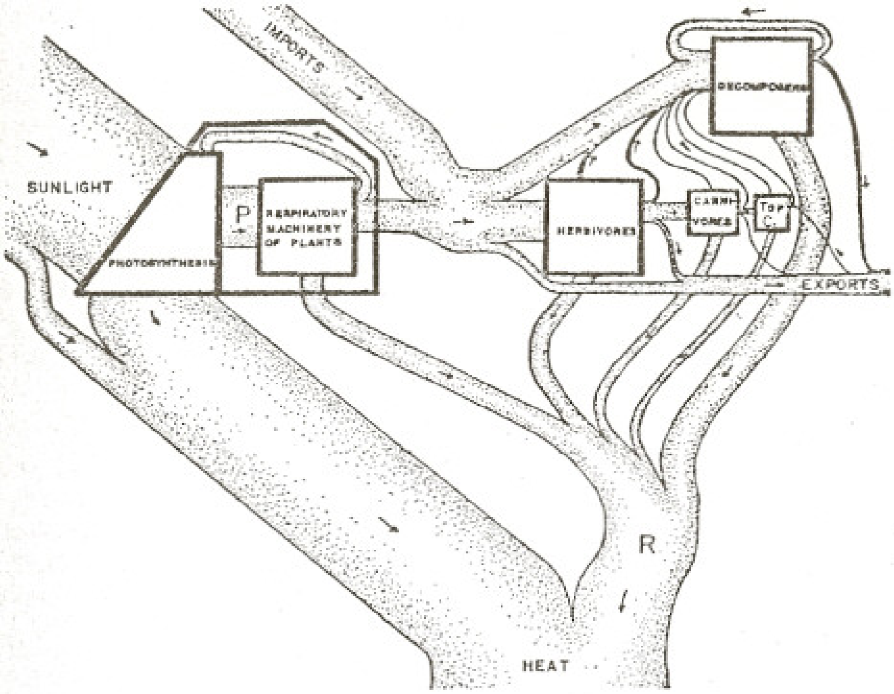

Figure 1.

Energy flow diagram for a stream community. Useful and available energy enters the community from the sun and from organic matter drifting in with the water from upstream as imports. If the community is in a steady state this energy passes downstream as heat and as organic matter exported thus illustrating the action of the first law of thermodynamics in streams. The main biological components of the community of organisms are indicated by heavy squares, the primary plant producers, the herbivores, the carnivores, top carnivores, and decomposers. Following requirements of the second law of thermodynamics most of the energy in each food transformation is lost as unavailable heat. The gross production of a community is indicated by P and the total community respiration (oxygen utilization) is indicated by R.

when the organic matter, that serves as bacterial food in a stream, becomes excessive so that there are too many organisms growing. In this situation the oxygen, which is about 8 parts per million in water initially, may disappear in a few hours followed by death of all higher organisms such as the fish. For example Butcher, an English stream limnologist, found the zone of sub-minimal oxygen extended 8 miles below a sewage outfall in the Trent River, followed by 20 miles of marginal conditions (see Macan and Worthington, 1951).

Some success has been achieved in sanitary engineering and public health handling of domestic sewage pollution and some types of industrial wastes high in organic matter by predicting the oxygen effect. The necessary dilution to avoid trouble is calculated on the basis of measurement of the rate of oxygen disappearance in bottles of diluted wastes (BOD or biochemical oxygen demand test). Although the behavior in the bottle is known to differ from that in the stream, many oxygen kills have been prevented by keeping the organic matter in the stream below the level that uses up 3 parts per million in 5 days. This value is no indicator of pollution, however, since many entirely natural streams have higher organic matter decomposition rates. In any case we conclude that the second primary requirement of fishing waters is that the oxygen in the water not be depleted. Although most fish cannot live without oxygen the converse is not true. Fresh air does not guarantee the farmer large beef yields any more than oxygenated water guarantees fish yields. There are other requirements also.

In order to see how fish are related to their environment consider the passage of energy through the food chains of the community. Figure 1 shows the principle divisions of an ecological community and the flows of energy through these divisions. The value of a water for fish is potentially a function of the rate of production (growth) of the fish, which in turn is a function of the rate of growth of the fish-food organisms, which in turn is a function of the rate of growth of the plants or of the rate of import of suitable organic food matter. It has been observed that the efficiency of conversion of light into organic matter in most natural waters due to photosynthesis is usually about ½%. The conversion of plant produce into the tissues of small plant-eating animals is conservatively 10%. The conversion of herbivorous animal tissues into the tissues of the carnivorous fishes is similarly about 10%. If these carnivorous fishes are eaten by even larger carnivorous fishes 10% of the tissue eaten may again be established as growth of the top carnivores. Thus as illustrated in Figure 1, most of the energy in each transfer becomes unavailable just as in man-made engines. In a rough way, therefore, one can calculate the potential production of fish per acre from the light intensity of the sun. Where nutrient conditions are good, somewhat higher efficiencies prevail, but when nutrient conditions are poor, lower efficiencies prevail. For a general discussion of energy flows in communities see E. P. Odum (1953).

Because of the dependence of fish populations on the energy flows of the community, no survey of polluted and unpolluted waters is adequate unless it includes the determination of fertility from production measurements. Either with the light and dark bottle method or the diurnal curve analysis method it is possible in one day to determine the photosynthetic rate, the respiratory rate, and efficiency with which the sunlight is used. In these ways the rate of manufacture of food available to fish-food chains is determined at the source. One is thus determining whether the pasture is barren or fertile. It is too bad that recent surveys of water resources in southern states have not included productivity determinations in their surveys of lakes and streams. Let us consider two examples of the determination of the productivity of waters.

In a recent paper the Dane, Steeman Neilsen (1955) used the light and dark bottle method to measure the photosynthetic production of a lake receiving purified sewage wastes. Oxygen measurements in bottles suspended at several depths were made before and after 6-hour periods. From the oxygen changes a daily production of 7 gm/m^2 was obtained during the summer months. The production in this fertile water was several times that obtained with similar methods in a North Carolina farm pond by Harry Wells and Charles Hoskin in limnological work at Duke University. Although some of the properties of the water were extreme, there was a great fertility expressed in the growth of the algae. This method is not applicable, however, to flowing waters where much of the community is attached.

For many years diurnal oxygen curves have been published in the scientific journals for polluted and unpolluted streams, lakes, and estuaries. Following studies on the natural metabolism of Silver Springs, Florida,

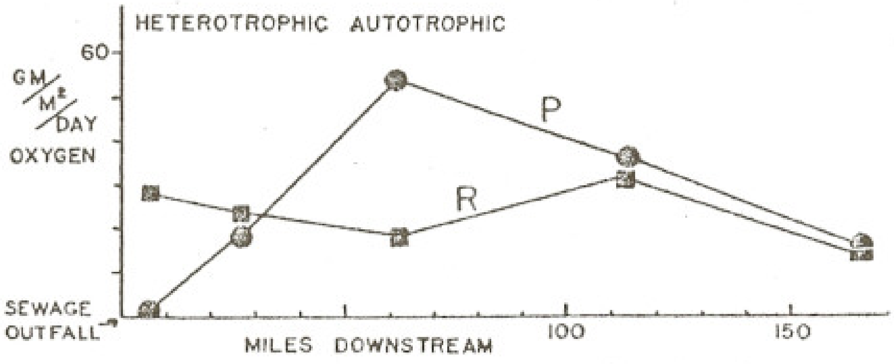

Figure 2.

Community gross production (P) and community respiration (R) as determined by analysis of diurnal curves of oxygen for stations downstream from a sewage outfall in the White River Indiana in July 1934 (based on data of Calvert in Denham. 1938).

ways of converting the diurnal oxygen and carbon dioxide curves into production values have been suggested (Odum, 1956). The oxygen rate of decrease at night is subtracted from the oxygen rate of increase during the day to obtain the gross photosynthetic rate. A correction for change in diffusion rate during the day is also applied. Although this method requires analyses at two stations one upstream from the other, it is possible to obtain an order of magnitude of the production from the analysis of a single station oxygen curve by assuming a homogeneous community upstream. In Figure 2 is shown the results of the diurnal curve analysis method applied to data collected years ago by Calvert on the White River in Indiana (Denham, 1938). The very low production immediately below the sewage outfall is quickly followed by a very immense production and respiration rate as the harmful influences of the pollution are exceeded by the fertilizing influences. That the fish productions below such pollution may be both low and high is documented by Forbes (1919) for the Illinois rivers and Swingle (1953) for Alabama rivers. These examples show how natural and polluted waters may possess wide ranges of fertility which are responsible for wide variations in fish harvests. That the production of fish is increased when algal production of the community increased is the basic fact proved by the present era of pond fertilization. Maintaining or increasing the pastures for the fish-food chains must be considered a third principal requirement for fishing waters.

Whereas the potential poundage of fish which can be supported is a function of the energy sources at the base of the food chains, the type of fish which will dominate the production is a function of the types of fish-food organisms and the type of organic source at the base of the food chain. It has frequently been found that extremes of temperature, pH, oxygen, and other properties do not limit the total productivity but do restrict the number of species in the community. Thus it is that pollution often restricts the species variety without changing the basic quantitative fertility (Bartsch and Churchill, 1949). In fact high fertility itself may lead to a dominance of a few species, for high productivity is itself an extreme. Whether the dominant is good or bad depends on whether the particular fish is considered desirable by the users of the stream. A recently reported example of the restriction of diversity of fish faunas due to pollution is given by Katz and Gaufin (1952) below a sewage pollution discharge in a midwestern stream. The action of extremes in limiting the species of organisms is not restricted to pollution situations but occurs naturally in special situations such as hot springs or in the cool and highly fertile springs of Florida. Restricted faunas are thus not necessarily an indication of pollution but do indicate some extreme factor.

The important practical consideration is to develop measurements which will indicate the extent that special conditions have limited the diversity of the ecological community. Work by Dr. Ruth Patrick and associates has been aimed at bioassay of the diversity of the species that constitute the food chain. Whereas Dr. Patrick's total community analysis involves a research team, complex techniques, and trained personnel, attempts are being made to abbreviate the procedure so as to provide reliable, rapid, inexpensive and practical indices to community diversity. Dr. Patrick has successfully used the diversity of diatoms on glass slides suspended in standardized plastic boxes on floats.

One difficulty has been in devising a single measure which would report the community diversity in a single number that would not be a function of the thoroughness of the worker or the type of sampling. To simply report the number of species of diatoms present is not possible because it has been found that additional species are always found as the sampling effort is extended, although the appearance of additional species with further searching effort roughly decreases logarithmically.

This property of logarithmic decrease of additional new species found as one searches is as yet unexplained but has been observed in a great variety of natural ecological communities as documented in graphs of Vestal (1949) or of Hopkins (1955). The log normal frequency distribution adopted from Preston by Patrick, Hohn and Wallace (1954) may be a result of the same phenomenon. We can conveniently use the logarithmic property to obtain a simple measure of diversity as has been done by Yount (1956) in studies of diatoms in Florida springs. This promising measure is the slope of the line of a graph of species found versus the log of the number of individuals surveyed. A diverse community is one with 20 to 50 new species found per tenfold increase in individuals counted. A community of limited variety has 5 species per tenfold increase in organisms examined. Whether one only examines 100 organisms or whether 1000 are examined, the diversity in units of species/cycle is the same. It remains to be seen if counts on insect larvae, bacteria, diatoms, and protozoa will give similar numbers. Identification of the species is not necessary, but the species must be recognized as different.

If this or other measures of the diversity of the environment can be standardized, practical means of specifying the diversity requirement for fishing will permit adequate management of water resources in this regard. Thus a requirement of waters for fishing is that their diversity of food chain organisms not be too greatly reduced as this may lead to reduction of the fish variety in an undesirable way. One cannot grow beef on the wrong kinds of grass. Therefore maintaining the diversity of the pasture is the fourth principal requirement in maintenance of fishing waters.

The fifth requirement for fishing waters is not yet a problem but promises to be the most serious of all pollution problems as far as protecting public health and guarding against inflammatory and irrational public alarm. This is the disposal of radioactive wastes from atomic reactors and in the event of war the widespread contamination of natural waters from fallout.

Fresh water organisms, living as they do in media where the required chemical constituents are present in only a few parts per million or less, possess incredible powers of concentration. This is especially true of the algae at the base of the food chain. For example, practically all of the radioactive phosphorus broadcast in a pond is immediately taken up and bound by the algae (Hayes et al., 1952). When the algae are eaten by the small herbivorous animals and these are in turn eaten by the carnivorous fishes, these chemical constituents are conserved and carried along so that very dilute concentrations of radioactive ions are quickly bound into lethal packages in the fish as studied extensively in White Oak Lake at Oak Ridge (Krumholz, 1954) and in the marine waters at Eniwetok (Donaldson et al., 1950).

Consider the radioactive isotope strontium 90 which is a major by-product of atomic processes being considered for peacetime energy uses. With a half-life of 28 years, this substance is dangerous because of its chemical similarity to calcium which sends it to the bones where it may act over a long period of time. A calculation may help to illustrate the role of the fish. In a fairly typical stream in Connecticut the ordinary strontium concentration is .045 ppm. Even though the fish tends to exclude strontium relative to calcium, the meat contains about .24 ppm strontium, and the bones .2% (Odum, 1950). If .5 microcurie/liter of strontium 90 were present in the water, it would not be detectable in the field with ordinary survey model Geiger counters. However, the radioactive strontium would be concentrated in the bones of the fish so that a .1 gram sliver of fish bone ingested would give a person the 1 microcurie considered dangerous (U. S. Dept. of Commerce). Whereas waters in streams flush ordinary pollutions to the sea and recover quickly, the fish and other organisms collect and hold the strontium making the stream dangerous for long periods of time. Especially in public relations it may become crucial to provide convincing evidence of the safety of the streams and lakes. Safety from the food chain liability is the fifth requirement for fishing waters.

Let us not forget any of the five requirements for maintaining fishing waters. Surveys of polluted and unpolluted waters designed to protect the fishing in multiple use programs should include proper objective indices of 5 properties: Toxicity, oxygen requirements, fertility, diversity, and food chain liability. Toxicities are measured with direct survival tests in water; oxygen requirement is estimated from the BOD test; fertility is measured by oxygen or carbon dioxide production measurements in the field; diversity is measured by the variety of species of fish food organisms, and the food chain liability is measured by radiological examination of the fish.

Let us close with a plea for adequate surveys of waters prior to the establishment of complex and controversial multiple uses. Simple and inexpensive methods are now becoming available to permit these surveys that protect the industries, the municipalities, and the public from either unwarranted accusations or carelessness regarding fishing waters resources. Pollution survey need not be feared by towns and industries using fishing waters. Factual evidence has often shown beneficial effects of some types of moderate pollution.

The author is grateful to A. P. Sanders, Duke University Medical School, for his comment.

REFERENCES

Bartsch, A. F. & W. S. Churchill. 1949. Biotic responses to stream pollution during artificial stream reaeration, pp. 33-48 in AAAS Symposium: Limnological aspects of water supply and waste disposal.

Denham, Stacey C. 1938. A limnological investigation of the west fork and common branch of White River. Investigations of Indiana lakes and streams. Indiana Dept. of Conservation 5: 17-72.

Donaldson, Lauren R. et al. 1950. Radiobiological survey of Bikini, Eniwetok and Likiep Atolls—July-August 1949. U. S. Atomic Energy Commission, Technical Information Service Bull. AECD-3446: 7-145.

Forbes, S. A. & R. E. Richardson. 1919. Some recent changes in Illinois River biology. Bull. Ill. Natural History Survey 8: 139-156.

Hayes, F. R., J. A. McCarter, M. L. Cameron & D. A. Livingstone. 1952. On the kinetics of phosphorus exchange in lakes. J. of Ecology 40: 202-216.

Hopkins, Brian. 1955. The species-area relations of plant communities. J. of Ecology 43: 409-425.

Katz, M. & A. R. Gaufin. 1952. The effects of sewage pollution on the fish population of a midwestern stream. Trans. Am. Fish. Soc. 82: 156-165.

Krumholz, Louis A. 1954. A summary of findings of ecological survey of White Oak Creek, Roane Co., Tenn. 1950-1953. U. S. Atomic Energy Commission Technical Information Service. ORO-132.

Macan, T. T. & E. B. Worthington. 1951. Life in lakes and rivers. Collins, London, 272 pp.

Odum E. P. 1953. Fundamentals of ecology. Saunders, Philadelphia, 384 pp.

Odum, H. T. 1950. Biogeochemistry of strontium, Ph.D. thesis. Yale University (unpubl.).

Odum, H. T. 1956. Primary production in flowing waters. Limnology and Oceanography 1: 102-117.

Patrick, R., M. H. Hohn & J. H. Wallace. 1954. A new method for determining the pattern of the diatom flora. Notulae Naturae No. 259, 12 pp.

Steeman, Nielsen E. 1955. The production of organic matter by the phytoplankton in a Danish lake receiving extraordinarily great amounts of nutrient salts. Hydrobiologia 7: 68-74.

Swingle, H. S. 1953. Fish populations in Alabama rivers and impoundments. Trans. Am. Fish. Soc. 83: 47-57.

U. S. Dept. of Commerce, National Bureau of Standards. 1953. Maximum permissible amounts of radioisotopes in the human body and maximum permissible concentrations in air and water. Handbook 52: 1-43.

Van Horn, W. M., J. B. Anderson & M. Katz. 1949. The effect of kraft pulp wastes on some aquatic organisms. Trans. Am. Fish Soc. 79: 55-63.

Vestal, A. G. 1949. Minimum areas for different vegetations. Illinois Biological Monograph 20: 1-129.

Yount, J. L. 1956. Factors that control species numbers in Silver Springs, Florida. Limnology and Oceanography 1: 286-295.