

The Transportation of Live Fish

F. E. J. FRY

University of Toronto, Toronto, Canada

and

K. S. NORRIS

University of California, Los Angeles, California

I. Introduction	595
II. Requirements for Fish Respiration	597
III. Accumulation of Ammonia	602
IV. Effects of Overexertion	603
V. Principles of Aeration	603
VI. The Use of Anesthetics	605
References	606

I. Introduction

The major transporters of live fish are the various government agencies engaged in artificial propagation of game and commercial fish. The transporters of live food fish, notably those who carry carp, probably are still second in terms of weight of fish moved. In North America there is also a growing traffic in bait minnows and in the transport of various warm-water species and trout to ponds where they may be caught on a pay-as-you-fish basis. In terms of variety of species and distances shipped, the tropical fish industry stands first.

There are three general methods of transporting live fish. They may be shipped without any water at all under certain circumstances, except for being kept damp. The second method, which will be referred to as the "tank method," is to ship them in containers of various types open to the atmosphere. The third method, which may be called the "plastic-bag method," since these are so conveniently employed for the purpose, is to ship the fish in a closed container partly filled with water and with the air in the space over the water replaced by an atmosphere of pure oxygen.

There is a definite limit to the time that fish can be shipped out of water, but for very hardy species this can be a substantial period. On the West Coast of North America, the long-jawed mudsucker, *Gillichthys mirabilis*, is flown in moist moss from the lagoons of Mexico to California. The mummichog, *Fundulus heteroclitus*, of the Atlantic coast is also shipped for bait in a similar fashion. McDonald (1884) long ago demonstrated that carp would survive long periods of time in limited amounts of water. In recent years, various salmonids (Cuerrier, 1952; Loftus,

personal communication) have been transported in crushed ice, or moss with ice, as have been northern pike and the yellow pike perch (Schultz, 1956). These fish were all relatively large, from one to several pounds in weight. They were immobilized by urethan or tricaine methane sulfonate and were packed much as fresh fish would be, although not so closely together. The safe time for such transport is of the order of 4 hr.

Trout eggs are ordinarily carried out of water on cloth trays and kept sufficiently moist and cool. A description of typical transport methods and equipment for trout eggs may be found in Davis (1953, pp. 41-42), and for salmon eggs in Burrows (1949).

Present-day fish-handling equipment employed for the tank method is of many types, varying from simple metal cans carried on mule back to complex tank trucks holding as much as 2000 gallons of water. The larger tank units are usually equipped with circulation systems powered by small gasoline engines or electric motors. The circulated water is run through venturi aerators and thence into the tank, or through spray nozzle systems into the water surface (Copeland, 1947; Horton, 1956). Turnover rates vary from about once in 6 min. to once in 20 to 30 min. In general, tanks with the higher turnover rates haul the greatest weights of fish per unit volume. This is almost certainly related to the efficiency of gas exchange and distribution of aerated water throughout the tank. Average loads for larger tankers are 1½ pounds of trout per gallon, while the heaviest loads may exceed 2 pounds per gallon, for nondrugged fish. For short journeys, as in planting fish by airplane, loads may be as high as 5 pounds per gallon (Prévost and Piché, 1939).

Several successful large tankers use diffuser aeration, employing carbundum airstones, or perforated loup aerators. Most such units employ compressed oxygen released through regulating valves (Greene, 1956). Some tankers use electric stirrers which draw a vortex of air into the tank water or disperse air through perforations along the heels of the stirrer blades (Stubblefield *et al.*, 1949). Modern German transporting tanks for live fish were given a detailed description by Krause (1957).

Water temperature in transport tanks is usually controlled with ice and tank insulation. Refrigeration units are bulky and are in use only on very large tankers.

Fish transport tanks are generally constructed of heavy planking, welded steel, aluminum, or marine plywood coated with plastic resin. Fish-holding equipment used in the marine bait industry or on board tuna-bait boats consists of large rectangular or oval wells with lighted hatches through which fresh sea water is continually pumped at rates varying from one turn-over in 6 min. to about one turn-over in 12 min. (Carlson, 1955).

Most fish-planting agencies hold fish without food for 24 hr. or more prior to loading, to prevent regurgitation of partially digested food material into the water during transport.

Transfer of fish into transportation equipment is accomplished by dip net, by bucket, or by rubber conveyor belts (Leitritz and Macklin, 1956). Planting trucks generally transfer fish from the truck to the stream or lake by means of large-diameter hoses or portable metal piping which discharge from the tank itself. Weights of fish per unit volume are generally determined by displacement.

Plastic-bag transport (Miller, 1956) first came into general use less than a decade ago. However, closed systems were employed prior to that time (Vaas, 1952), and glass or polyethylene carboys are still sometimes preferable to the relatively fragile polyethylene bags. The usual method of using plastic bags for shipping is to place two bags, one inside the other, in a cardboard box. This box is often insulated with slabs of glass wool or expanded cardboard. The desired amount of water, usually 5 gallons or less, is poured into the inner bag. The fish are introduced and the bag is partially inflated with oxygen and sealed with rubber bands. The box is then sealed and shipped to its destination by air. The primary advantages of the method are reduction in shipping weight and reduction of injury resulting from fish hitting container walls.

The problems which must be met in the successful transportation of live fish are many and diverse. The primary problem arises from the low capacity of water for oxygen together with its low capability to dissipate the end products of metabolism. The secondary problem is that of handling. In delicate species, abrasion needs only to be sufficient to remove the mucus from a fraction of the area of the skin in order to rob them of essential protection from osmotic stress. Many fish, too, are so stimulated by handling that they readily accumulate dangerous levels of lactic acid in their blood (Black, 1958). Excessive changes in temperature are also deleterious, as is well known. For a recent review on these crucial factors see Norris *et al.* (1960). The optimum number of fish to be transported in each tank is determined by the species (rate of respiration), fish size, general physiological and health condition of the fish, the water temperature in the transporting vessel, and the duration of the transport (Krause, 1957).

II. Requirements for Fish Respiration

The level of oxygen required is something more than the bare minimum that will prevent asphyxia in an undisturbed fish. Fish must at least perform compensatory movements throughout the journey. Furthermore, fish are easily stimulated to increase their oxygen consumption to near

their maximum rates, and are slow to return to the resting level, so that the excitement of capture and transfer to the transport tanks is likely to increase greatly the need for oxygen. There is also the possibility that an initial severe struggle may lessen the ability of the blood to transport oxygen for some time afterward.

It is proposed here that a suitable physiological standard for the oxygen consumption of fish in transport is half the rate of respiration of which a fish is capable above the rate required strictly for maintenance in the resting state. To determine the rate required to meet this standard, two measurements of respiration are made, one with the fish forced to be

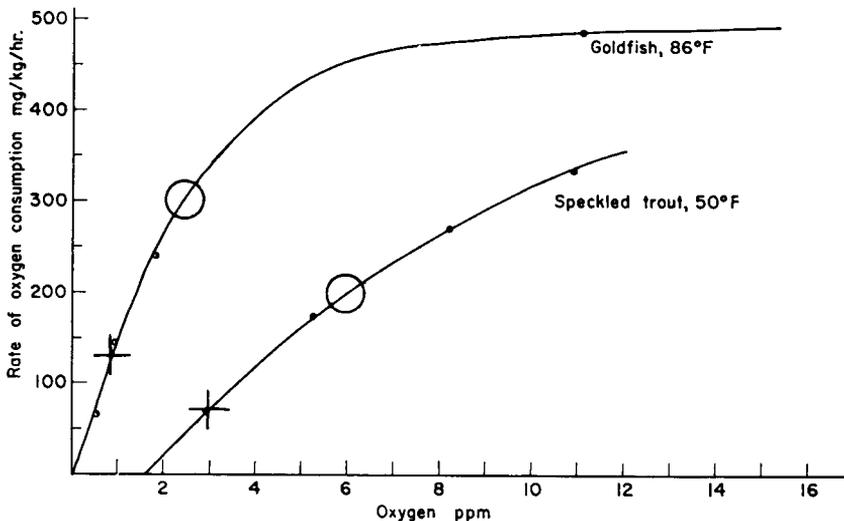


FIG. 1. The relation between oxygen consumption of active fish and concentration of dissolved oxygen. For explanation see text. Average weight of goldfish approximately 80 g., of speckled trout approximately 200 g. From Basu (1959).

active and the other with the fish quiescent. A general description of methods of making these measurements, together with other considerations on the respiration of fish, will be found in Fry (1957).

Figure 1 illustrates examples of the respiratory requirements of two species of fish, one sensitive and the other insensitive with respect to oxygen lack. The curves show the respiration of the fish stimulated to activity. First, it may be seen that above a certain concentration of oxygen, the rate of oxygen consumption does not change with further increase in the external level of oxygen. If the stimulation of the fish has been adequate, it may be taken that the rate of oxygen consumption at these high levels will be the maximum steady rate of oxygen consumption of which the fish is capable. Second, it will be noted that at lower levels of oxygen

concentration, the fish, though still stimulated to activity, will not consume oxygen at its maximum rate. At these lower levels of oxygen concentration, it is considered that the respiration of the fish is limited by the amount of oxygen in the water. Figure 1 illustrates these characteristics of the respiration of active fish for two species, one very sensitive to oxygen lack—the speckled trout—and one resistant species—the goldfish.

Each curve in Fig. 1 bears two symbols, a cross and a circle. In each, the cross indicates the resting metabolic rate of the fish (determined elsewhere by observations on undisturbed fish) and the level of oxygen required in the water to satisfy this rate. The levels thus indicated represent essentially the absolute minimum oxygen concentration required for undisturbed fish. The circles on the two respiration curves represent the rates of oxygen consumption which give the fish a margin over their resting rates of half the further amount that they can consume, together with the level of oxygen concentration which will permit the fish to meet this rate. In the example the half-scope rate of oxygen consumption of the oxygen-sensitive species, the speckled trout, is 200 ml./kg./hr. at 50°F. That for the oxygen-insensitive species, the goldfish, is 305 ml./kg./hr. at 86°F. Such rates of oxygen consumption will be termed "half-scope rates." The rates in the example would be met at oxygen concentrations of 6.0 p.p.m. in the case of the speckled trout and 2.6 p.p.m. for the goldfish. Such concentrations of oxygen which permit the half-scope rate of oxygen consumption to be met will be termed "half-scope levels."

Large individuals consume less oxygen per unit weight than do small ones. The general relation between oxygen consumption and size is $Y = bX^{0.8}$, where Y is the rate of oxygen consumption, X the body weight, and b is a constant appropriate to the species. The exponent varies from 0.6 to 1, but the extremes seem rare. With an exponent of 0.8 a tenfold increase in size of an individual will lead only to a little more than a sixfold increase in oxygen consumption. Conversely, this means that the total weight of fish carried in a given transport must be reduced to 60% of the capacity load for larger fish when the individuals are only one-tenth as large. The well-known Q_{10} rule whereby the rate doubles for a temperature rise of about 18°F. is a sufficient approximation for estimating the effect of temperature. This applies, of course, only within a species, for cold-water species consume approximately the same amount of oxygen at lower temperatures as do the warm-water species at higher ones. The half-scope level of oxygen concentration varies with species and temperature, but is relatively independent of size (Job, 1955). It rises with temperature, but not unduly so. In a later study on milkfish, Job (1957) revealed a proportionate rise in the metabolic rate at higher temperature

(29°C.). The relative increase in rate of oxygen consumption was greatest in small-sized fish.

For every milliliter of oxygen that a fish consumes, it will produce approximately 0.9 ml. of carbon dioxide. The fate of this gas will be to enter into the equilibrium system of carbonates, bicarbonates, and free carbon dioxide dissolved in the water. From the point of view of respira-

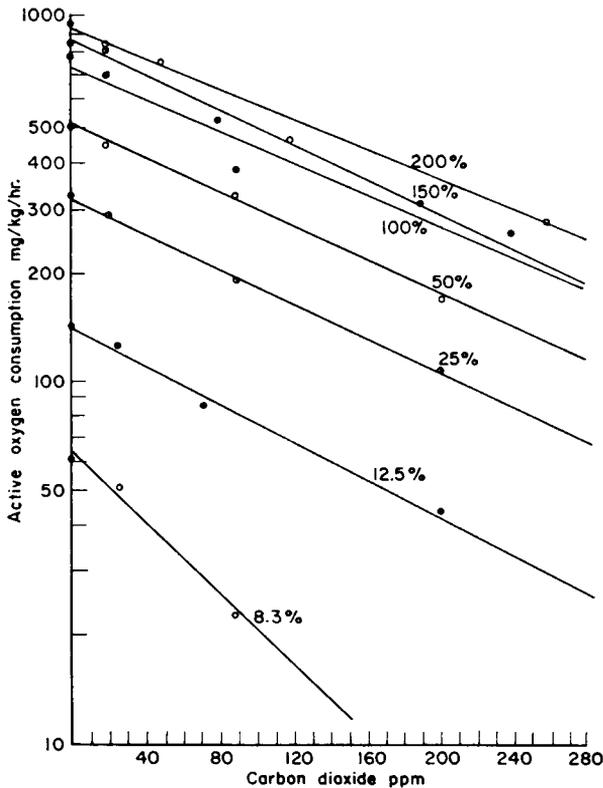


FIG. 2. The combined effects of various concentrations of dissolved oxygen and carbon dioxide on the oxygen consumption of active carp, *Cyprinus carpio*, at 86°F. Average weight of fish approximately 100 g. Each curve represents the data for a given level of oxygen in terms of per cent air saturation. From Basu (1959).

tion, only the fraction that accumulates as free carbon dioxide needs to be considered. The effect of increase in free carbon dioxide is to depress the ability of active fish to take up oxygen as is illustrated in Fig. 2.

In addition to the direct effect on respiration, any excess of carbon dioxide over the amount required for equilibrium with the bases available will attack any unprotected metals. In particular, toxic quantities of

zinc or copper may be dissolved from galvanized piping or containers or copper tubing (Affleck, 1952). The toxic effects of such metals may be delayed, and the fish may complete the journey in apparent safety only to die a day or so afterward. Zinc or copper should, therefore, not be contained in the material out of which the transport tanks or any equipment in contact with the water are manufactured.

Basu (1959) has calculated the various combinations of oxygen and carbon dioxide that permit several species to fill their half-scope needs,

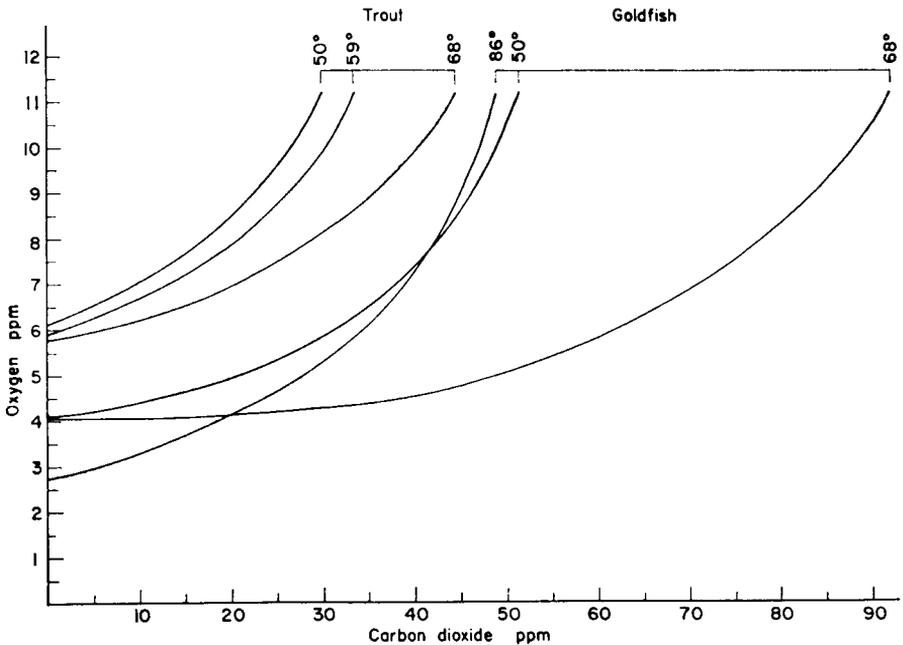


FIG. 3. Concentrations of carbon dioxide and oxygen that permit speckled trout and goldfish to consume oxygen at the half-scope rate at various temperatures. From Basu (1959).

and his data for the two species taken here as examples are illustrated for different temperature levels in Fig. 3. It can be seen that an accumulation of free carbon dioxide up to 25 p.p.m. can be readily tolerated by a sensitive species under adequate aeration, and up to 50 p.p.m. by an insensitive one. It is also apparent that when the concentration of carbon dioxide considerably exceeds the limits mentioned above, the amount of oxygen is no longer important, since any reasonable increase will have no beneficial effect.

It can be concluded that the need for aeration during transport is to

provide oxygen at a rate and level that will fill the half-scope needs, together with means of keeping the concentration of carbon dioxide at a satisfactorily low level.

III. Accumulation of Ammonia

A large fraction, which for practical purposes here can be taken as half of the nitrogenous excretion of fish, is ammonia, which in the appropriate form ($\text{NH}_3 \cdot \text{H}_2\text{O}$, nonionic free ammonia or undissociated ammonium hydroxide) is a highly toxic substance (*cf.* Doudoroff and Katz, 1950). The fraction of the excreted ammonia which appears in the toxic form is markedly affected by the presence of acids in the water, as was emphasized by Wuhrman *et al.* (1947) and Wuhrman and Woker (1948). For example, at pH's of 7.5, 8.0, or 8.5 respectively, at approximately 60°F., a concentration of 0.5 p.p.m. of un-ionized ammonia (as NH_3) would be associated with 100, 17, or 5 p.p.m. ammonium nitrogen (as N) as ordinarily determined. A concentration of 0.5 p.p.m. approximates the 24-hr. median lethal dosage for rainbow trout at 68°F. in water half air-saturated with oxygen (Water Pollution Research, 1956). The precise quantity of un-ionized ammonia associated with a given pH varies with temperature, being higher at a higher temperature (Everett and Wynne-Jones, 1938). There is little effect of temperature on the sensitivity of a given species to a given level of un-ionized ammonia (Woker, 1949).

The rate of excretion of nitrogen is related to the rate of metabolism. Gerking (1955) found that the bluegill, *Lepomis macrochirus*, excreted about 7 mg. N per kilogram calorie of energy expended. As with other products of metabolism, large fish of a given species produce less per unit weight than do small ones. In addition, they are somewhat more resistant to the toxicity of ammonia (Wuhrman and Woker, 1950). Thus, at 78°F., Gerking found that 20-g. bluegills excreted nitrogen at a rate of approximately 500 mg./kg./day, whereas the rate for fish weighing 100 g. was only 120 mg./kg./day. The exponent relating weight to nitrogen excretion in the case of the bluegill above was slightly under 0.6, which may be exceptionally low in light of the general range of the exponents found relating oxygen consumption to weight. The rate of nitrogen excretion can also be expected to be dependent on temperature and to vary with different species. In aquarium experiments, Phillips and Brockway (1954) found that speckled trout weighing 16–30 g. and starved 15 hr. excreted approximately 115 mg./kg./day NH_3 at 51°F. At 31°F. the rate for these fish was reduced to 30 mg./kg./day. Tanizaki *et al.* (1957) report that at 59°F. rainbow trout weighing 60 g. excreted 150 mg./kg./day total N. These values, of course, do not apply to feeding fish. The longer fish are kept in a transporting vessel, the larger the oxygen

demand of the water (as measured with KMnO_4), outside of the direct fish respiration. This presumably can be attributed to an accumulation of organic substances (Krause, 1957).

IV. Effects of Overexertion

Black (1958) has summarized the information on the effects of overexertion on fish. Death occurs in certain circumstances following severe muscular activity, such as struggling in a live box, vigorous avoidance of capture, and swimming against swift currents. The precise cause of death is not known; however, it is likely that the severe acid-base disturbance following the large accumulation of lactic acid may be the principal cause of death. The acid concentration is sufficient to reduce the acid-combining power of the blood, and its oxygen-carrying capacity must be profoundly affected as well. There appears also to be a marked reduction in the ability of the heart to pump blood following severe exercise. Severe muscular activity rapidly reduces the maximum swimming capacity of fish, and recovery is slow (6 hr. for adult steelhead trout; Paulik and DeLacy, 1957). Thus, fish planted in a fatigued state may be at a disadvantage aside from any deaths that may have resulted directly from overexertion. Hasler and Wisby (1958) report that most of a sample of largemouth bass taken on hook and line and released over deep water failed to home, while the majority of trap-netted fish were successful. Their explanation was that the failures were largely fish that were so fatigued that they could not swim to keep above the oxygen-poor depths over which they were released. Studies on fatigue to date have apparently all been carried out in well-aerated water. It is to be expected that under less ideal conditions the problem would be intensified.

V. Principles of Aeration

Because of its importance in fermentation and in waste disposal, the transfer of oxygen from gas to water has received a great deal of attention. Downing and Truesdale (1956) give an excellent elementary account of the principles involved, together with pertinent references. When water is sufficiently stirred so that the concentration of oxygen is essentially uniform throughout its volume, the rate of transfer of oxygen from gas to water can be expressed by Bohr's equation

$$\frac{dC}{dt} = K(C_s - C)$$

where C is the concentration of oxygen in the water at time t and C_s is the concentration of oxygen in equilibrium with the gas phase. The constant K is ordinarily termed the "specific rate of aeration." The best

values for C_s are those of Truesdale *et al.* (1955), which may also be found in Mortimer (1956), Lagler (1956), and Hutchinson (1957). These values refer to saturation with air at sea level and should be multiplied by five when pure oxygen is used for aeration. The constant K can be expressed in terms of more fundamental constants by use of the expression

$$K = f \frac{A}{V}$$

in which A is the area of the gas-water interface and V is the total volume of water. Thus it can be seen that K is unique for each individual piece of equipment. In diffusion equipment, A is the area of the gas-water interface presented by all the bubbles in suspension at any given time and thus can only be approximated. With stirring, the surface will also be continuously varying and cannot be measured exactly. Even the constant f , which represents the rate of travel of the gas through the interface, fluctuates greatly, too. The great source of variation in f is the degree of turbulence of the water. It is advisable, as Haskell (1941) did, to make a determination of K for each given piece of equipment, using water in which fish have been respiring, since f is also influenced by contaminants. The values of f that will hold for transportation equipment will be of one of two orders of magnitude, being either in the range of 1–10 in the plastic-bag system or in the range of 50–100 for systems in which aeration is achieved by diffusion of air or oxygen or recirculation of the water through jets. The value of f will increase some 1–2% per degree Fahrenheit so that the rate of aeration at a given concentration of dissolved oxygen will tend to be independent of temperature, as Hutchinson (1957, p. 589) has pointed out. As follows from the relation of K to f , the area of the gas-water interface is of prime importance, the most efficient aeration being achieved when the gas is presented to the water in the greatest number of bubbles, or the water to the gas in the finest spray. Bowers (1955) gives a good account of the principles governing the size of bubbles formed by aerators. When gas is fed to any given diffuser beyond a certain critical rate, the bubbles issuing from it will coalesce, and the efficiency of the system will fall. (Diffusers, therefore, should have adequate capacity.) This principle is well illustrated by Haskell's (1941) data.

When air is diffused through water, the f values for the exchange of oxygen and carbon dioxide are the same (Water Pollution Research, 1955; see also Downing, 1958), and preliminary experiments indicate that the same holds true for aeration by stirring. Hence, the advantage with respect to the removal of carbon dioxide which the spray system has been considered to have, as opposed to bubbling air, does not appear to

exist. However, if oxygen is used as the aeration gas instead of air, and is supplied only in sufficient quantity to satisfy the demands for that gas, it is not likely that the carbon dioxide will be cleared sufficiently rapidly. It follows that if f_{O_2} equals f_{CO_2} then, for example, a saturation deficit of 5 p.p.m. O_2 left by diffusing air when $C_{s(O_2)}$ equals 10 p.p.m. will lead to a carbon dioxide excess of about 6 p.p.m. over air saturation. But if oxygen were the diffusing gas and the same level of oxygen were maintained in the water, then the oxygen deficit would be 45 p.p.m., and the lesser gas flow which could then maintain the necessary influx of oxygen would permit the carbon dioxide to build up to 54 p.p.m. above air saturation with that gas. Haskell and Davies (1959) recognized this latter problem and recommended methods of purging the excess carbon dioxide including the addition of lime water. In the plastic-bag system, carbon dioxide will necessarily build up in the water, since any that diffuses out into the atmosphere above the water will be held there and reduce the excess pressure in the liquid phase. To counteract the accumulation of free carbon dioxide in such systems, McFarland and Norris (1958) have tested an organic buffer, tris(hydroxymethyl)aminomethane, as a transport agent and report a fiftyfold increase in buffering capacity at 20 g. per gallon with maximum hydrogen ion absorption between a pH of 7.5 and 8.5. Accumulation of free CO_2 is temporarily eliminated by this buffer. Inorganic buffers such as sodium monophosphate and sodium bicarbonate have been tested, with conflicting results (Vaas, 1952; Saha *et al.*, 1956):

Ammonia, although volatile, cannot be effectively kept below toxic levels by aeration (Water Pollution Research 1955, p. 35). However, it can be expected that it will be largely neutralized by the respiratory carbon dioxide (Alabaster and Herbert, 1954). Under conditions where the carbon dioxide is removed by means other than aeration or where for other reasons, such as a high ratio of fish to water, a dangerous increase of ammonia may be expected, it can be removed by ion-exchange resins (Nemoto, 1957; Saha *et al.*, 1956; Tanizaki *et al.*, 1957).

VI. The Use of Anesthetics

The use of anesthetics to reduce the metabolic rate of fish in transport has not been universally advantageous (Webb, 1958). To be effective, the anesthetic has to be carefully chosen and the dosage closely controlled. McFarland (1959; 1960) appears to have been the only worker who has done extensive fundamental work on this problem. He considers the most useful anesthetics for inducing quiescence during transport to be chloral hydrate, tertiary amyl alcohol, and methyl parafynol. Sodium amylal has the disadvantage of being affected by the calcium content of

the water, and tricaine methane sulfonate tends to break down. Urethan, now largely discarded by most workers because of its potential danger as a carcinogen (Wood, 1956), also has the disadvantage of low potency.

The stage of anesthesia produced should not go beyond a sedation that depresses reactivity to external stimuli without loss of equilibrium. Thus, the dose must be carefully gaged. McFarland (1960) found the concentrations in grams per U.S. gallon tabulated below to give the desired effect in the California killifish and the opaleye.

Anesthetic	Concentration per gallon
Tertiary amyl alcohol	2 ml.
Methylparafynol (Dormison)	1.0-2.0 ml.
Chloral hydrate	3.0-3.5 g.

A twofold variation in dosage will usually take the stage of anesthesia beyond the desired limits. Smaller fish are more resistant to anesthetics than are larger ones. The rate of induction of anesthesia is hastened by higher temperatures, but there is little temperature effect on level.

McFarland (1960) emphasizes that the effect of anesthetics in their useful range of concentration is sedation, not the reduction of cellular metabolism. For example, stimulation of metabolism caused by feeding will not be suppressed.

REFERENCES

- Affleck, R. J. (1952). Zinc poisoning in a trout hatchery. *Australian J. Marine and Freshwater Research* **3**, 142-169.
- Alabaster, J. S., and Herbert, D. W. M. (1954). Influence of carbon dioxide on toxicity of ammonia. *Nature* **174**, 404-405.
- Basu, S. P. (1959). Active respiration of fish in relation to ambient concentrations of oxygen and carbon dioxide. *J. Fisheries Research Board Can.* **16**, 175-212.
- Black, E. C. (1958). Hyperactivity as a lethal factor in fish. *J. Fisheries Research Board Can.* **15**, 573-586.
- Black, E. C., and Barrett, I. (1957). Increase in levels of lactic acid in the blood of cutthroat and steelhead trout following handling and live transportation. *Can. Fish Culturist* **20**, 12-24.
- Bowers, R. H. (1955). The mechanics of bubble formation. *J. Appl. Chem. (London)* **5**, 542-548.
- Burrows, R. E. (1949). Recommended methods for fertilization, transportation and care of salmon eggs. *Progressive Fish-Culturist* **11**, 175-177.
- Carlson, C. B. (1955). Live-bait equipment. In "Fishing Boats of the World," pp. 494-497. Food and Agr. Organization. U.N. Rome.
- Copeland, T. H. (1947). Fish distribution units. *Progressive Fish-Culturist* **9**(4), 193-202.
- Cuerrier, J. P. (1952). Transfer of anaesthetized adult lake trout by means of aircraft. *Can. Fish Culturist* **13**, 1-4.
- Davis, H. S. (1953). "Care and Diseases of Game Fishes," 332 pp. Univ. Calif. Press, Berkeley and Los Angeles, California.

- Doudoroff, P., and Katz, M. (1950). Critical review of literature on the toxicity of industrial wastes and their components to fish. I. Alkalies, acids and inorganic gases. *Sewage and Ind. Wastes* **22**(11), 1432-1458.
- Downing, A. L. (1958). Aeration in aquaria. *The Aquarist and Pond Keeper* **23**, 2-7.
- Downing, A. L., and Truesdale, G. A. (1956). Aeration in aquaria. *Zoologica* **41**, 129-143.
- Everett, H. D., and Wynne-Jones, W. F. K. (1938). The dissociation of ammonium ion and the basic strength of ammonia in water. *Proc. Roy. Soc.* **A169**, 190-204.
- Fry, F. E. J. (1957). The aquatic respiration of fish. In "The Physiology of Fishes" (Brown, M. E., ed.), Vol. I, pp. 1-63. Academic Press, New York.
- Gerking, S. D. (1955). Endogenous nitrogen excretion of bluegill sunfish. *Physiol. Zool.* **28**, 283-289.
- Greene, A. F. C. (1956). Oxygen equipment for fish transportation. *Progressive Fish-Culturist* **18**(1), 47-48.
- Haskell, D. C. (1941). An investigation of the use of oxygen in transporting trout. *Trans. Am. Fisheries Soc.* **70**, 149-160.
- Haskell, D. C., and Davies, R. O. (1959). Carbon dioxide as a limiting factor in trout transportation. *N.Y. Fish and Game J.* **5**(2), 171-183.
- Hasler, A. D., and Wisby, W. J. (1958). The return of displaced largemouth bass and green sunfish to a "home" area. *Ecology* **39**, 289-293.
- Horton, H. F. (1956). An evaluation of some physical and mechanical factors important in reducing delayed mortality of hatchery-reared rainbow trout. *Progressive Fish-Culturist* **18**, 3-14.
- Hutchinson, G. E. (1957). "A Treatise on Limnology," Vol. I: Geography, Physics and Chemistry, 1015 pp. Wiley, New York.
- Job, S. V. (1955). The oxygen consumption of *Salvelinus fontinalis*. *Univ. Toronto Studies Biol. No. 61*; *Publ. Ontario Fisheries. Research Lab. No. 73*, 39 pp.
- Job, S. V. (1957). The routine-active oxygen consumption of the milkfish. *Proc. Indian Acad. Sci.* **B45**(6), 302-313.
- Krause, G. (1957). Ein Beitrag zum Transport lebender Fische mit Hilfe von künstlicher Sauerstoffzufuhr. *Z. Fischerei* [N.S.] **6**, 505-517.
- Lagler, K. F. (1956). "Freshwater Fisheries Biology," 2nd ed., 434 pp. Brown, Dubuque, Iowa.
- Leitritz, E., and Macklin, R. (1956). Fish-escaweigher. *Progressive Fish-Culturist* **18**, 178-180.
- McDonald, M. (1884). Report on the distribution of carp during the season of 1882. *U.S. Comm. Fish and Fisheries*; Commissioners Rept., 1882 (38): 915-942.
- McFarland, W. N. (1959). A study of the effects of anaesthetics on the behavior and physiology of fishes. *Publ. Inst. Marine Science (Texas)* **6**, 23-55.
- McFarland, W. N. (1960). The use of anaesthetics for the handling and the transport of fishes. *Calif. Fish Game* **46**, 407-431.
- McFarland, W. N., and Norris, K. S. (1958). The control of pH by buffers in fish transport. *Calif. Fish Game* **44**, 291-310.
- Miller, R. R. (1956). Plastic bags for carrying and shipping live fish. *Copeia* **2**, 118-119.
- Mortimer, C. H. (1956). The oxygen content of air-saturated fresh waters and aids in calculating percentage saturation. *Mitt. intern. ver. Limnol.* **6**, 1-20.

- Nemoto, C. M. (1957). Experiments with methods for air transport of live fish. *Progressive Fish-Culturist* **19**(4), 147-157.
- Norris, K. S., Brocato, F., Calandrino, F., and McFarland, W. N. (1960). A survey of fish transportation methods and equipment. *Calif. Fish Game* **46**, 5-33.
- Paulik, G. J., and DeLacy, A. C. (1957). Swimming abilities of upstream migrant silver salmon, sockeye salmon and steel-head at several water velocities. Tech. Rept. No. 44, School of Fisheries, Univ. of Washington, Seattle, 40 pp. (Cited from Black, 1958.)
- Phillips, A. M., Jr., and Brockway, D. R. (1954). Effect of starvation, water temperature, and sodium amytal on the metabolic rate of brook trout. *Progressive Fish-Culturist* **16**, 65-68.
- Prévost, G., and Piché, L. (1939). Observations on the respiration of trout fingerlings and a new method of transporting speckled trout (*Salvelinus fontinalis*). *Trans. Am. Fisheries Soc.* **68**, 344-353.
- Saha, K. C., Sen, D. P., and Mazumdar, P. (1956). Effect of inimical substances from products in the medium of spawn life and their control. *Indian J. Fisheries* **3**, 135-140.
- Schmidt, P. J., and Platanov, G. P. (1937). Anabiosis and fish transport without water. *Compt. rend. acad. sci. U.R.S.S.* **15**, 255-260.
- Schultz, F. H. (1956). Transfer of anaesthetized pike and yellow walleye. *Can. Fish Culturist* **18**, 1-5.
- Stubblefield, A. G., Lefevre, L., and Smart, R. (1949). Montana fish-distribution tank. *Progressive Fish-Culturist* **11**(4), 245-252.
- Tanizaki, M., Fujimura, S., Kawamoto, N. Y., and Nakai, Y. (1957). A consideration on live transportation of rainbow trout *Salmo gairdneri irideus* G. *Rept. Faculty Fisheries, Prefectural University Mie* **2**, 429-436.
- Truesdale, G. A., Downing, A. L., and Lowden, G. F. (1955). The solubility of oxygen in pure water and sea water. *J. Appl. Chem. London* **5**, 53-62.
- Vaas, K. F. (1952). Preliminary report on air transport of live fish in sealed cans under oxygen pressure. *Indo-Pacific Fisheries Council, Proc. 3rd Meeting Sect. II & III*, pp. 119-128.
- Water Pollution Research 1955. (1956). Report, 81 pp. Her Majesty's Stationery Office, London.
- Water Pollution Research 1956. (1957). Report, 75 pp. Her Majesty's Stationery Office, London.
- Webb, R. T. (1958). Distribution of bluegill treated with tricaine methane-sulfonate. *Progressive Fish-Culturist* **20**, 69-72.
- Woker, H. (1949). Die Temperaturabhängigkeit der Giftwirkung von Ammoniak auf Fische. *Proc. Intern. Assoc. Theoretical and Appl. Limnol.* **10**, 573-579.
- Wood, E. M. (1956). Urethane as a carcinogen. *Progressive Fish-Culturist* **18**, 135-136.
- Wuhrmann, K., and Woker, H. (1948). Experimentelle Untersuchungen über Ammoniak- und Blausäurevergiftung. *Schweiz. Z. Hydrol.* **11**, 210-244.
- Wuhrmann, K., and Woker, H. (1950). Statistische Überlegungen zu toxikologischen Experimenten und Fischvergiftungen in freien Gewässern. *Schweiz. Z. Hydrol.* **12**, 79-93.
- Wuhrmann, K., Zehender, F., and Woker, H. (1947). Über die fischereibiologische Bedeutung des Ammonium- und Ammoniakgehaltes fließender Gewässer. *Vierteljahrschr. Naturf. Ges. Zürich* **92**, 198-204.