Nitrogen Supersaturation in the Columbia & Snake Rivers

A Disaster or Blessing in Disguise

By Carl H. Elling and Wesley J. Ebel

Depending on one's piscatorial preference, either the salmon or steelhead normally ranks as king of fishes among the angling fraternity of the Pacific Northwest. Thus, when events occur that can adversely affect the well-being of these species, all hell breaks loose. Such was the occasion when the spectre of nitrogen supersaturation and its lethal effects on fish in the Columbia Basin began to emerge in the late 1960s. Few regional environmental crises have drawn more attention, have created more furor, or have been attacked in a more vigorous and positive manner.

What is nitrogen supersaturation, how does it result, and why is it dangerous to fish?

The term "nitrogen supersaturation" has fallen into common use (largely through convenience) to describe a condition known as excessive total dissolved gas pressure. Air is composed of nitrogen (78%), oxygen (21%), argon (0.9%), and minor fractions of carbon dioxide, neon, and helium. Each of the component gases in air exerts a measurable pressure; the sum of these pressures constitutes atmospheric or barometric pressure. When these gases are dissolved in water and the sum of their pressures is greater than that in air, supersaturation occurs. Because air is nearly four-fifths nitrogen, references to the gas supersaturation problem have invariably highlighted nitrogen even.

Excessive gas pressure (supersaturation) results when more gas is dissolved in water than can be transferred back to the atmosphere in time. Supersaturation can be caused by several factors—e.g., algal blooms, rapid increases in water temperature, or water falling from heights into deep plunge basins. The latter factor has been shown to be the primary cause of nitrogen supersaturation in the Columbia and Snake rivers. Large volumes of water discharged through spillways at dams plunge into deep pools below the dam, forcing entrapped air into solution with the water. Under the great hydrostatic pressures prevailing at depths of 40 feet or more in the spillway basins, the gases are dissolved and continually added to the water as long as spilling continues at the dams. In free-flowing rivers, where riffles and cascades provide for quick release of dissolved gases, supersaturation rarely becomes a problem because gas pressures in water rapidly return to the atmospheric level. This is called equilibration.

Because of dams, most of the Columbia River (and a major portion of the lower Snake River) is now a series of impoundments. Thus, the long succession of pools no longer provides for the circulation that is necessary for rapid release of dissolved gases. As a result, gas pressures never completely equilibrate.

Now how does all of the foregoing chemistry and physics affect fish? Salmon and steelhead migrating in supersaturated waters contract what is

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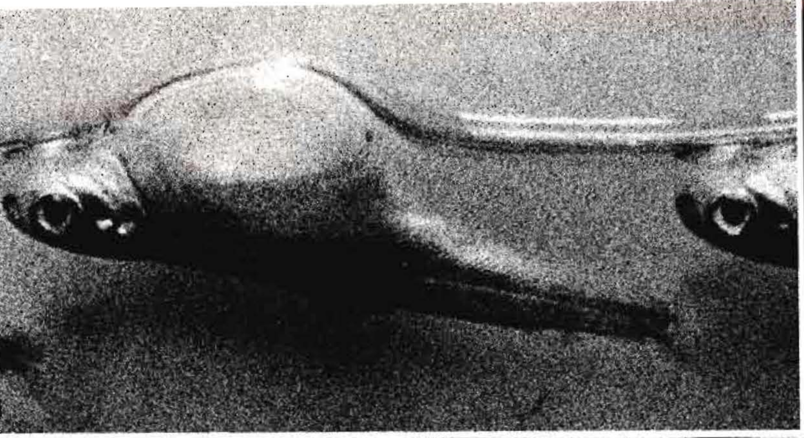
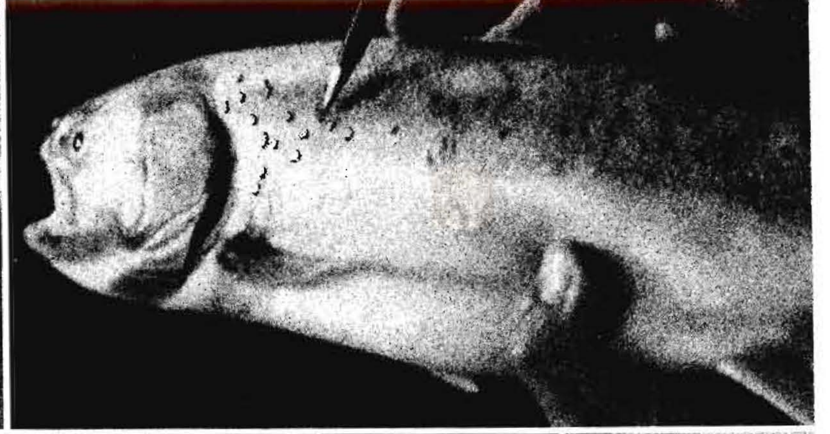
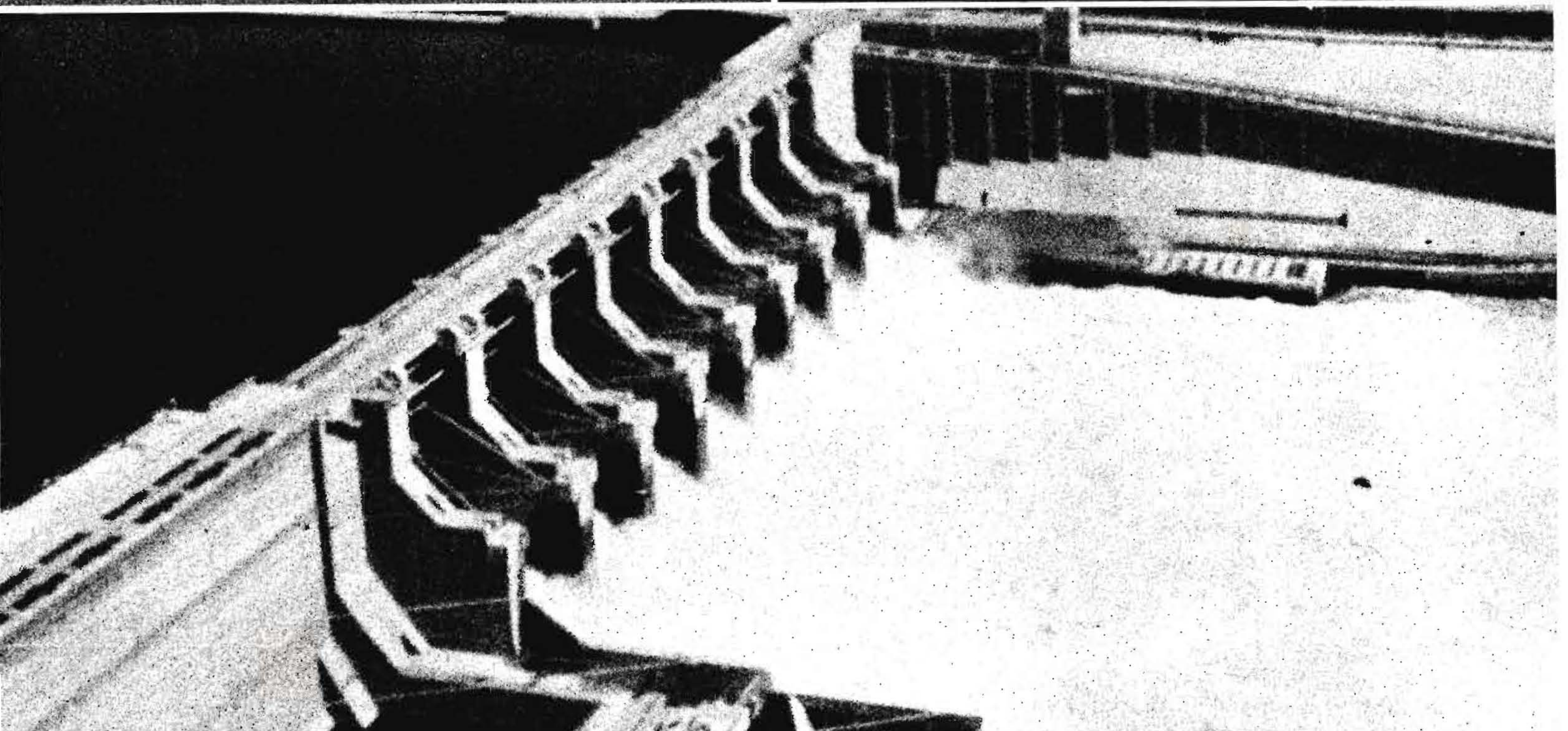
Top—Gas bubble disease in salmon fry.—Note the bubbles on the trout which will eventually rupture and cause a secondary infection.
Middle—One of many dams on the Snake and Columbia rivers.








JACKSON LAKE
PALISADES
BURNS CREEK
AMERICAN FALLS
MINIDOK
MILNER
BOISE RIVER
SWAN FALLS
OWYHEE
OX BOW
BROWNLEE
HUNGRY HORSE
KERR
NOXON RAPIDS
THOMPSON FALLS
CABINET GORGE
ALBENI FALLS
MICA
BRILLIANT
BOX CANYON
COLUMBIA RIVER
LEWISTON
SNAKE RIVER
LOWER GRANITE
LITTLE GOOSE
GRAND COULEE
CHIEF JOSEPH
ZOSEL
LOWER MONUMENTAL
PRIEST RAPIDS
WANAPUM
ICE HARBOR
WELLS
ROCK REACH
McNARY
ROCK ISLAND
ROZA
WALPATO
PROSSER
SUNNYSIDE
CANADA
U.S.A.
JOHN DAY
EASTON
THE DALLES
PUGET SOUND
BONNEVILLE
WILLAMETTE FALLS

IRISH RAIN

watched its reflection in the mirrored underside of the surface. When the nymph met up with its reflection, the curved jaw opened, sucking in the water around it. As the heavy jaws closed the water flowed out through the gill rakers, and the tiny fly was caught.

The big trout was not alarmed at first, but as he dropped down from his rise position something pulled his head to the left. Angrily, he shook his head, some of the olive nymphs coming up from his gullet and floating away as his powerful tail pushed him down through the pool. Near the tail of the pool he turned and swam into the bed of buttercups where he frightened several salmon parr eating snails and shrimps. Now, the pressure on the side of his jaw was gone, but the thing that had stung him was still there.

With his slender rod only slightly bent because he had eased the pressure on it as the big trout dashed downstream, the young angler climbed out of the water and up the grassy bank. The older man was at his side as they ran downstream.

The big trout felt the vibrations of the footfalls and increased pressure on his jaw as he hid under the dancing weeds. A large eel slithered out from under the bank and, frightened, he leaped into the air. The anglers on the bank saw the huge golden side and they trembled with excitement.

The trout moved toward the head of the pool, and he was only yards from his hide when with new pressure he turned again to go downstream. In his fear, he lost all sense of direction, but he found a quiet pocket of water behind a large stone where he rested. As his body was being drawn upward, he kicked feebly with his tail, and through the cone of his window, he could see two huge, broad shapes hovering over the water. When the big trout floated to the surface, the American slipped a net under him.

The fisher weighed, measured, and photographed the heavy trout. After this, gentle hands lifted him into the water, and when his strength returned, the fish dropped down to the bottom and slowly made his way upstream toward his lie. Never again would he rise to olive nymphs. He would hide in the weeds and eat the shrimps and water lice.

Later that week, a large trout was seen taking emerging olives at the head of the Apple Tree Pool.

And as the two anglers went on downstream, they hardly noticed that the Irish rain had begun again.

SAVE A RIVER—THE CARSON

ful brief for submission to the Supreme Court. The work far exceeded what anyone had anticipated and the consequent costs exceeded the maximum estimates. Fran donated the difference for which all of Trout Unlimited should be most grateful.

The case was presented before the Supreme Court. And then months passed waiting for the decision.

When it came, Trout Unlimited and the people of Nevada had won. The Carson River was determined to be navigable and a relatively new precept introduced by Trout Unlimited's brief was put forth in the opinion of the Court. Expressed in the Court's opinion was "The Public Trust Doctrine in Natural Resource Law" which holds that the states hold title to the beds of navigable watercourses in trust for the people of their respective states! In addition, the Court determined, as a first and historic case, that "Although no Supreme Court case has expressly based its decision of title navigability on the capacity of a stream to float out logs" it now states that this is a basis for determination of navigability. In the West this is a monumental case with implications of use extending to "any commercial purpose" and/or recreation."

There is a satisfaction in the small Nevada Chapter that we can do it when we need to. We accomplished what we set out to do and with even more pride, we did the job without help from Trout Unlimited's National Treasury. We challenge any Chapter to accomplish that.

NITROGEN SUPERSATURATION

known as gas bubble disease. The affliction is similar to the bends in deep-sea divers, which results from an overdose of nitrogen in the blood stream due to rapid ascent of the diver from depths. Fish, however, can suffer from gas bubble effects merely by remaining in supersaturated surface waters, i.e., without experiencing a drop in hydrostatic pressure.

The process of gas bubble formation in fish has yet to be fully explained. Presumably, minute gas nuclei are taken in through the gills where they enter the bloodstream and develop into microbubbles which eventually grow in size by diffusion of gas molecules into the initial bubbles. Evidence of gas bubble symptoms usually appears initially on the exterior surfaces of the fish. Bubbles are noted along the lateral line, then in the fins, body skin, and head. If confined to these areas, the affliction is usually not lethal but can result in ruptures of the eye or skin, resulting in blindness or secondary infection and possibly death. Most fish, however, are killed outright by bubble blockage of the main arterial system or heart which can occur before bubble formation on the exterior surfaces. Death can result in less than 24 hours depending on level of gas supersaturation, hydrostatic pressure, size and species of fish, etc.

Although gas bubble disease was first reported in fish nearly 75 years ago, evidence that the disease might be a problem in the Columbia Basin did not come to light until mid-1965. In June of that year a biologist of the Washington Department of Fisheries reported on a recent survey of nitrogen concentrations in various sectors of the Columbia River. The survey indicated that supersaturated levels of dissolved nitrogen prevailed in the Columbia from Grand Coulee to Bonneville Dams!

Following the initial release of information that a new and potentially serious problem might be developing in the Columbia River, there began a gradual and methodical assembly of data on the prevalence, causes, and effects of gas supersaturation in the basin. Additional water surveys by the Bureau of Commercial Fisheries (now National Marine Fisheries Service) in 1966 and 1967 verified that supersaturation did indeed occur and that on occasion the supersaturated waters extended throughout the Columbia and even into the estuary.

These studies further demonstrated that supersaturation was seasonal and associated with the spilling of water at dams and that water passed through turbines does not supersaturate. Normal high flows in the Columbia and Snake rivers occur in the spring and early summer, largely from snow melt in the mountainous interior regions. At this time river discharge is usually far

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in excess of that which can be passed through the turbines. Hence, all surplus flows must be discharged through the spillways. Once the river flows recede and spilling ceases, the waters rapidly return to normal saturation.

Unfortunately, the timing of high-river discharge coincides with the period of major migrations of juvenile and adult salmonids—young salmon and steelhead migrating to the sea and the adults homeward bound for the spawning grounds, all in concert with a deteriorating river environment.

Initial studies with juvenile fish held in cages in supersaturated river water demonstrated that fish in surface waters could be killed in a comparatively short period, but those held at depth generally survived and showed no ill effects. These observations bore out the role of hydrostatic pressure in gas bubble formation. Fish held in surface waters rapidly developed the classic symptoms of gas bubble disease. Those held at depth did not, the explanation being the hydrostatic pressure prevented the formation of gas bubbles. In other cage tests where the fish were permitted to range from the surface to depth (as might occur during normal migration in the river), some fish were lost but overall survival was significantly higher than that of fish held on the surface.

With these fragmentary beginnings, the search continued for more concrete evidence of actual losses of fish in the river. First indications of the severity of the nitrogen problem in the Columbia came in the spring of 1968 with the completion of John Day Dam. As was characteristic at the time, the dam went into operation with no turbines on the line. These were to be installed in subsequent months and years as funds became available and the contractor fulfilled orders for turbine deliveries. As a consequence, all flows of the Columbia River had to be passed through the spillways of the John Day Project. The result was a horrendous maelstrom below the dam. Nitrogen gas levels downstream from the spillway soared to as high as 145% (100% is considered normal saturation)! During the same period, a large migration of adult Chinook salmon was headed upstream for the spawning areas in the upper watershed. As they approached John Day Dam, they had to probe their way through the massive turbulence and nitrogen-laden waters to enter fishways and ascend the dam. What followed shouldn't have been too surprising, but no one really anticipated the outcome would be as bad as it was.

Daily counts of fish are made at each dam as the various species pass through the fishways. Thus, the fishery agencies are constantly apprised of the progress of a given run of fish at various points in the river system.

Therefore, in 1968, it was known that a given number of Chinook salmon had passed Bonneville and The Dalles Dam and were headed upstream for John Day Dam. Based on past experience it could be expected that several days would be required for the fish to reach John Day and that some fish would be unaccounted for (or lost) due to the rigors of migration. First indication of trouble came when passage of the run at John Day lagged many days behind that expected, indicating a serious delay of fish was probably occurring below the dam. Finally the run did pass the dam, but the cruncher came when the Fish Commission of Oregon estimated that over 20,000 Chinook salmon were missing!

Implications of the John Day disaster were that the delay of fish below the dam, coupled with the abnormally high nitrogen supersaturation, caused a high percentage of the mortalities. Many fish were observed in the fishways with body blisters, swollen or ruptured eyes, and other usual symptoms of gas bubble disease. Hundreds of dead salmon were also counted as they floated downstream below the John Day area.

One of the first recommendations to come out of the John Day fiasco was that in future construction of dams at least one or more turbines should be operable when the reservoir is filled. Such action would reduce the amount of flow over the spillway and consequently lessen the level of supersaturation below the dam.

With the completion of the John Day project, the Corps of Engineers focussed attention on development of the lower Snake River for power and navigation. Ice Harbor Dam, near the mouth of the Snake, had already been completed in 1962 and two other dams —Lower Monumental and Little Goose —were nearing completion. A fourth dam—Lower Granite—was also on the drawing boards. Because the Snake River drainage provides spawning areas for a large portion of the Columbia's spring and summer Chinook salmon runs plus major runs of steelhead, projected effects of the new dams on fishery resources were of prime importance to the fishery agencies.

In 1966 studies were initiated at Ice Harbor Dam to acquire information on the movements and survival of juvenile salmon during their migrations down the Snake River. Young salmon were marked and released in the Salmon River, the most important Chinook salmon producer in the Snake River system. Recovery of these fish at Ice Harbor Dam, some 250 miles downriver from the Salmon, provided data on numbers of juveniles migrating down the Snake River, survival during this migration, and the speed at which fish traveled. This information was then related to prevailing environmental conditions—the volume of river discharge, water temperature, gas content of the river, and turbidity.

By the fall of 1970, sufficient data had been collected by the National Marine Fisheries Service to make an assessment of the effects of changing river conditions on the fate of young salmon. Two new dams had been added to the network during the period of study—Lower Monumental in 1969 and Little Goose in 1970. This then allowed comparison of data collected before additional dams were constructed in the Snake (1966-1968) with those taken in a post-dam period (1969-1970).

Essentially the study showed that before the dams were built, young fish moved rapidly downriver and suffered little or no losses; water quality was good and fish arriving at Ice Harbor Dam were in excellent condition. Following construction of the new dams and further impoundment of river flows, fish migrations were delayed, water quality deteriorated due to supersaturation from the spillways, and fish survival plummeted even worse than the stock market in 1970. Furthermore, fish examined at Ice Harbor were in poor condition, many showing evidence of gas bubble disease. The severity of the situation could be recognized in the estimate of fish survival during the downstream migration of 1970. Survival was only 30% to 40% of that in the period before dams! The obvious implication was that nitrogen was the primary culprit.

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NITROGEN SUPERSATURATION

Within two months the Corps' Walla Walla District had initiated a contract with the National Marine Fisheries Service to conduct a study on the feasibility of collecting and then transporting young salmon around hazardous areas in the Snake and Columbia Rivers. Giant fish screens were built and inserted in the intakes of turbines at Little Goose Dam. These screens diverted young downstream migrant salmon into a bypass that carried them to a collection area below the dam. Here they were marked and transferred to tank trucks which transported them 400 miles downstream for discharge into the Columbia River below Bonneville Dam. In the two years (1971-1972) that these studies have been carried out, nearly 1,000,000 young salmon and steelhead have been transported downstream. Assessment of these operations must await the return of adult fish to the Snake River in the next several years.

The foregoing effort was, of course, primarily a stopgap action to afford some fish with a measure of protection from supersaturated waters in the Snake and Columbia rivers. What was needed, and soon, was a means of controlling the levels of nitrogen in the river. Here again the Corps took rapid and positive action. One of the first measures was to develop a coordinated plan for controlled release of water throughout the Columbia Basin in the spring of the year. By metering out water discharges from upriver storage projects, the volume of spilling (and hence gas saturation) could be contained in the lower river projects. Exchanges of power were also made with utility and private power companies in other areas of the Northwest to enable maximum use of turbines in the Columbia and Snake rivers, again to reduce the volume of spill. Although such actions were of limited duration, they did provide substantial relief during the critical periods of salmon migration in the spring of 1971 and 1972.

In the meantime, hydraulic and engineering sections of the Corps were burning the midnight oil to devise means of discharging water at dams without increasing the dissolved gas content. Model studies were run and prototypes of a slotted bulkhead gate and a spillway deflector were built and tested at dams.

Initial tests of the slotted gates were most encouraging. Water passed through these structures did not supersaturate, and laboratory tests to simulate passage of juvenile salmon through the slots indicated that losses of fish due to hydraulic sheer forces would be moderate—at least considerably less than would be expected if the fish were exposed to nitrogen supersaturation.

Based on these heartening developments, the Corps proceeded to install bulkhead gates in all dams on the lower Snake River before the spring of 1972. Although use of the gates effectively controlled gas saturation levels in the lower Snake, subsequent studies indicated that loss of fish due to passage through the gates was far higher than expected. As a result, the gates were ordered removed and were not reinstalled until most of the downstream migration of juveniles was completed. Future use of the bulkhead gates will hinge on the outcome of further fish survival tests planned for the spring of 1973.

Tests of the spillway deflectors have also been promising and offer perhaps the best overall means of controlling gas saturation levels in the river. The spillway deflector is a concrete sill placed near the base of the spillway to divert flows horizontally into the spill basin. This lateral deflection of spillway discharges prevents the deep plunging action that is the present source of nitrogen supersaturation in the rivers. Prototype trials of these deflectors in spillway bays at Bonneville and Lower Monumental Dams have indicated that gas saturation levels can be appreciably reduced. Other tests with fish indicate that expected losses due to passage over the deflector would be far less than that experienced during passage through the bulkhead gates.

As a result of these breakthroughs, the Corps' Portland District has recently proposed a landmark program for control of nitrogen supersaturation in the Columbia River. In essence this plan projects a timetable for installation of spillway deflectors at all Corps projects where appreciable spilling will occur in the future. The plan also provides for construction of fish screens that would be placed in turbine intakes at key dams on the river. Since future operation of Corps' projects in the Columbia Basin will involve increasing use of turbines, the latter action is proposed to afford protection for the large numbers of juvenile migrants that would otherwise suffer losses due to passage through the turbines. Although these measures are contingent on approval by higher authority, there is no question that local Corps management is solidly behind the plan.

And so in the span of a few years, an apparent crisis situation has been solidly attacked and appears on the verge of being turned into a definite plus for fish. As is often characteristic of man's actions, the threat of an impending disaster was the moving force that turned the tide. Paradoxically, in the long run, salmon and steelhead runs of the Columbia may well become the benefactors rather than the losers, all because of the massive actions now being taken to reverse an ecological oversight of the past.

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A SHORT HISTORY OF EARLY FISHING

strike the rising fish, six brown trout were taken. They were not large, averaging eight inches in length and rather thin, but trout they were. These fish were in the pass traveled so many times by Caesar's legions. It seemed strange to consider that these creatures were the descendants of trout seen or taken by the Romans.

The Rhone was a poor stream where we fished it. From there we retraced the course of history, over the Italian Alps, thence back through France to the British Isles. Wherever we went, our large canvas bag with the aluminum cases containing the light tonkin cane rods was our constant companion and our Hodgman waders hung in the closet of many hotels. On the streams and lakes, trout, sea trout and salmon were offered both good casts and bungled casts, changes in leaders, and many flies.

It was in the British Isles that fishing as a sport, as angling, was first presented in literature. The development of the rod and other refined equipment added greater finesse to fishing and it became an art as well as a science. The first manuscript with known reference to angling in the English language was *Piers of Fulham,* presumed to have been written about 1420. Another early

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K. Perry Campbell, Department of Biology, The Pennsylvania State University, authored the article, "The White Sucker: A Trout Competitor," which appeared in the winter issue of TROUT. Our sincere apology to Mr. Campbell for the omission of his name.
