Growth and Survival of White Suckers (*Catostomus commersoni*) in an Acidified Lake

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White suckers (*Catostomus commersoni*) in the acidic Lumsden Lake in 1967 and 1968 exhibited reduced annual growth followed by death. The reduced growth and death appeared directly related to the low *p*H and not to a shortage of food caused by the decreasing *p*H.

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Les meuniers noirs (*Catostomus commersoni*) d'un lac acide, le lac Lumsden, n'ont pas réussi à se reproduire en 1967 et 1968, ont subi un ralentissement de croissance annuelle et moururent. La diminution de la croissance et la mort ne proviennent pas d'un manque de nourriture causé par un abaissement du *p*H. La diminution des stocks et l'insuccès de la reproduction ont été observées chez d'autres espèces dans le lac Lumsden et dans d'autres lacs.

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IN previous reports (Beamish and Harvey 1972; Beamish 1974) it was shown that lakes in the La Cloche Mountain region of Ontario, Canada, were becoming acidified. Acid precipitation, resulting from the combination of water vapor and sulfur dioxide to form dilute concentrations of sulfuric acid in the atmosphere, was considered to have caused more than a 100-fold increase in the acid concentration of some lakes. Metal smelters in Sudbury, Ont., 65 km northeast of the study area, were considered to be the largest single source of the sulfur dioxide. As a consequence of the increase in acid, fish populations had disappeared from several of the more severely acidified waters. It was the purpose of subsequent studies to examine the methods by which the increasing acid content of the lakes was causing the extinction of fish populations.

In this report the growth, population size, and food of white suckers (*Catostomus commersoni*) from Lumsden Lake (46°01′N, 81°26′W) and from the less acidic George Lake (46°02′N, 81°24′W) were examined, to determine if the resulting loss of the white sucker population in Lumsden Lake was a direct effect of low *p*H on the fish, or an indirect effect causing the reduction of food supply.

Materials and Methods

The La Cloche Mountain area, George and Lumsden lakes, and the chemistry of these two lakes have been described previously (Beamish and Harvey 1972; Beamish 1970). Hydrogen ion was determined in the laboratory within several hours of collection. Methods for the determination of the heavy metal concentrations were similar to those described in Beamish (1974).

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FOOD AND GROWTH

A survey of the food of white suckers was undertaken in 1968. The amount of each organism present in the gut of white suckers was estimated as a percentage by volume of the total gut contents. Food items were preserved in a 5% formalin solution prior to microscopic identification.

Yearly growth of white suckers was estimated by counting annual marks on sections of pectoral fin rays (Cuerrier 1951; Ovchynnyk 1965; Beamish 1973a) or by the scale method for some immature fish. Growth was also estimated using tagged fish, and growth of George Lake white suckers in Lumsden Lake was estimated by introducing 107 tagged George Lake fish into Lumsden Lake in 1968. An additional 64 George Lake white suckers were handled in a similar manner and released into George Lake as controls. The majority of the white suckers for this experiment were selected to correspond in size to the average size of white suckers in Lumsden Lake. A few were selected that corresponded to the average age of the Lumsden Lake white sucker population.

POPULATION ESTIMATES OF WHITE SUCKERS IN GEORGE AND LUMSDEN LAKES

Estimates of the number of mature white suckers in each lake were made according to Petersen (1896). The optimum number of fish needed to be tagged and recovered was estimated from nomograms according to Robson and Regier (1964). Fish were captured with seines or trapnets (Beamish 1973b) for tagging, and recovered using gillnets. The tagging procedure involved anesthetizing the fish in tricaine methanesulfonate (M.S.222). Fork lengths, weights, and several scales were taken from all tagged fish. No pectoral fins were removed at the time of tagging, but all recaptured individuals had the first two to four pectoral fin rays removed for age determination.

Estimate of Standing Crops of Benthic Invertebrates

During May 21–28, 1968, 159 benthic samples from George Lake and 70 benthic samples from Lumsden Lake were taken during the daylight hours. From September 23–30 a second set of 180 samples in George Lake and 80 samples in Lumsden Lake were also taken during the daylight hours. Standing crops of benthic invertebrates were estimated in Lumsden and George lakes using a KB corer (Brinkhurst et al. 1969). Sampling sites were randomly selected according to depth and according to the variation in distribution of major food items found in a preliminary survey. All the spring samples collected in Lumsden Lake and one-half the spring samples from George Lake were sorted according to the sugar-flotation technique outlined in Anderson (1959) and Gerking (1962). After sorting these samples it was apparent that hand picking organisms from the surface of the sugar solution did not recover many of the smaller organisms, was slow, and introduced a bias according to the operator's ability to find floating individuals. Therefore, the second one-half of the George Lake spring samples and all fall samples were sorted by pouring the floating organisms through 75 μ plankton netting. All organisms retained in the netting were preserved in 3% formalin. Further details concerning the selection of sampling sites and the separation procedures are available from the author or from Beamish (1970).

Results

Growth of White Suckers in Lumsden and George Lakes

In 1966 a total of 150 m of gillnet, of mesh size suitable for the capture of white suckers, was set over a 24-hr period. The amount of gillnet set for a 24-hr period was increased to 3000 m in 1967, 1160 m in 1968, 4275 m in 1969, and reduced nettings have continued each year up to 1973. In 1966, 179 white suckers were captured; 315 white suckers were gillnetted in 1967; only 3 were gillnetted in 1968, and no Lumsden Lake white suckers were captured after 1968. Trapnets set in 1968 also captured 26 white suckers. The mean fork lengths of fish of a given age decreased in 1967 and 1968 (Fig. 1). The mean fork lengths of the 1963 and 1964 year-classes (4 and 5 year-olds) in 1968 were less than the mean fork lengths of the corresponding year-classes in 1967 (3 and 4 year-olds).

Only one of the 411 white suckers tagged in 1967 was recaptured in 1968. This fish, a 4 year-old in 1968, had grown 0.7 cm in fork length and increased 2 g in weight. The average growth increment for an individual of similar age from 1966 to 1967 was 2.9 cm and 45 g. From 1967 to 1968 this individual achieved only 21% of the increment in fork length and only 5% of the increment in weight that was achieved by the average fish of similar age in 1966–1967.

Of the 107 George Lake white suckers introduced into Lumsden Lake in May–June 1968, 23 were recovered in gillnets or trapnets in June–July and removed from the lake. An additional 12 were captured in trapnets and returned to the water in good condition. Only one of the possible remaining 84 introduced white suckers was recaptured in the extensive netting program of 1969, and none thereafter. The single introduced white sucker, recaptured for the first time after marking 1 year earlier, measured 23.5 cm fork length and weighed

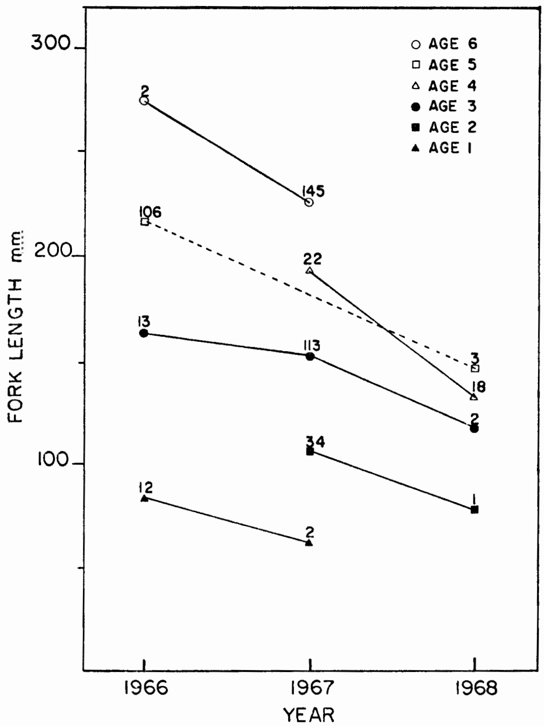

Fig. 1. Mean fork length of similar aged white suckers captured in Lumsden Lake in 1966, 1967, and 1968. No 2-year-olds were sampled in 1966. Numbers indicate size of sample in each year-class. Because of the absence of 5-year-old fish in 1967, the 1962 year-class, a broken line was used to connect the mean lengths of the 5 year-olds in 1966 and 1968.

148 g when tagged, and 23.7 cm and 109 g when recaptured. There was an estimated error of approximately 25 g in the weight of this individual as a small portion of the body cavity had been consumed by crayfish. George Lake white suckers of similar age averaged an increase of 42 mm and 300 g over the same period in George Lake.

In George Lake there was no suggestion of year-class failure, nor was there any apparent decrease in the average amount of yearly growth of fish of similar age, from 1967 to 1969 (R. J. Beamish unpublished data). While the gillnetting effort was reduced in 1968 the number of white suckers captured per unit effort was reduced only slightly from the catches in 1967. In the summers of 1971 and 1972, the *p*H of George Lake dropped below 4.8 and the average annual growth of white suckers was reduced (R. J. Beamish unpublished data).

George Lake white suckers tagged in a similar manner as those introduced into Lumsden Lake, but put back into George Lake in 1968, survived and grew at normal rates. Of these 64 George Lake white suckers used as a control for the introduction of George Lake white suckers into Lumsden Lake, five were recaptured in 1969 and two in 1970. The average annual growth of the recaptured fish in 1969 and 1970 was similar to the average annual growth of fish of similar age in 1967 and 1968. Two of the 64 control fish were recaptured in 1971 and eight in 1972, however, as growth of all white suckers in George Lake was reduced in 1971 and 1972, these fish could no longer be considered as controls. The recapture of 14 different control fish from 1969 to 1972 in the larger George Lake, with considerably less effort than applied in Lumsden Lake, indicated that tagging and handling could not be considered important in the disappearance and reduced growth of the introductions into Lumsden Lake.

Population and Biomass Estimates

An estimated 1184 (95% confidence interval of 889–1479) mature white suckers existed in Lumsden Lake in 1967. In 1967, the total catch of immature white suckers of age-class 1 and 2 represented less than 2% of the total catch by weight. Therefore, the contribution of immature white suckers in Lumsden Lake was not considered to significantly affect the calculated biomass estimate. Using the surface area to approximate the bottom area, and the mean weights of 285 white suckers for all age classes, a biomass of 0.49 g of mature white sucker per m^2 was estimated to be in Lumsden Lake in 1967. It was estimated that in 1967, George Lake contained 934 (95% confidence interval of 825–1102) mature white suckers. In George Lake immature white suckers contributed significantly to the total biomass. An estimate was made of the number of these immature individuals (under 400 mm fork length), based on the observation that between the marking period and the spring of 1969, 870 white suckers were marked or taken out of the lake that would have been in the size range for immature white suckers in 1967. Biomass values were determined for George Lake white suckers using the population estimate of 934 plus 870 individuals, and the mean weights of a sample of 600 mature and immature white suckers collected in 1967, and using the surface area of George Lake to approximate the bottom area. A value of 1.10 g of white sucker per m^2 was based on a number of immature fish known to be in the lake, and while this estimate was low because not all immature fish were identified, it was the best estimate available.

Standing Crops of Benthic Invertebrates

Cladocera and to a lesser extent chironomids were the major food of white suckers in both lakes for the period June to October. *Acantholeberis curvirostris* was the dominant food organism of white suckers during this period. Chironomids, pelecypods, and a small percentage of cladocera comprised their winter diet. The estimates of standing crops are limited to organisms found in the gut contents of the white sucker (Table 1). A complete list of organisms and the identification of major genera of chironomids can be obtained from the author. Estimates are listed separately according to the unmodified sorting method that involved hand picking organisms and the modification by pouring through 75 μ plankton netting. The 95% confidence intervals have been assigned to all estimates. Cladocera and diptera made up the greatest proportion of biomass samples, both being slightly more numerous in George Lake than in Lumsden Lake. The cladoceran *Acantholeberis curvirostris* was an abundant species in both lakes. This species was also an abundant food item of white suckers in each lake. Major species of chironomids common to the guts of white suckers in both lakes were not identified. The major genera in the benthic samples from both lakes were similar and thus it is likely that genera in the guts were similar.

Comparing the 1967 white sucker population estimates with the 1968 benthos standing crop estimates, the slower-growing white suckers in Lumsden Lake potentially had a greater amount of food organisms per unit weight than white suckers in George Lake (Table 1). The spring benthic samples indicated that white suckers had approximately 10 times the dry weight of cladocera and chironomids in Lumsden Lake than they did in George Lake. The fall standing crop determinations indicated that Lumsden Lake white suckers had approximately six times the dry weight of chironomids and three times the dry weight of cladocera per unit weight of fish.

These calculations were based on 1967 population estimates of white suckers and 1968 standing crop estimates. The fishing effort indicated that the population in Lumsden Lake was greatly reduced in 1968 while the George Lake population appeared only slightly less numerous in 1968. The calculations of the amount of food per unit weight of fish are biased in favor of a reduced amount of food per unit weight of Lumsden Lake white suckers. If the true population estimates were known for 1968, the differences between the amount of food per unit weight of white sucker in each lake would be much greater.

Dry weights of some of the major groups were determined by heating at 60 C for 24 hr, using animals that were previously preserved in a 3% formalin solution. The use of dry weights determined from preserved specimens as quantitative indicators of biomass has been questioned (Johnson and Brinkhurst 1971). In this study, dry weights determined from a number of preserved specimens were used to compare approximate sizes of animals between lakes, and not with the intention of deriving absolute measurements of biomass.

Discussion

Growth

The reduced annual growth of the tagged Lumsden Lake white suckers from 1967 to 1968 and the absence of growth of the tagged introduced George Lake white sucker, while controls in George Lake grew normally, indicated that the reduced growth of the Lumsden Lake white suckers was real. Problems associated with the mechanics of determination of age or the effects of the tagging procedures could not account for the decrease in growth. Because of the intensive efforts invested, as well as the variety of gear and mesh sizes used to capture fish in Lumsden Lake throughout the study, it was unlikely that the observed growth decreases were an artifact of the sampling procedure. The decrease in mean size of the 1963 and 1964

TABLE 1. Standing crop of benthic invertebrates in George and Lumsden lakes in 1968, and the approximate weight of cladocera and chironomid larvae per gram of white sucker in each lake.

	Organism	Total number in lake/m^2	Mean dry weight of organisms[a] $g \times 10^{-5}$	Dry weight of organism per g of fish
May 21–28[b] George Lake	Total diptera	3590± 930[c]	–[d]	–
	Chironomid larvae	3270± 920	7.40(941)	0.2204
	Total cladocera	320± 90	1.30(87)	0.0030
May 21–28 George Lake	Total diptera	7000±1260	–	–
	Chironomid larvae	6140±1200	5.27(725)	0.2948
	Total cladocera	1970± 740	0.53(247)	0.0095
May 21–28[b] Lumsden Lake	Total diptera	6240±1050	–	–
	Chironomid larvae	5350± 890	20.41(543)	2.2128
	Total cladocera	650± 300	6.00(115)	0.0789
Sept. 23–30 George Lake	Total diptera	18840±3060	–	–
	Chironomid larvae	18170±3060	2.69(372)	0.4449
	Total cladocera	24160±8680	0.89(281)	0.1957
	Acantholeberis curvirostris	2350± 510	–	–
Sept. 23–30 Lumsden Lake	Total diptera	17560±2240	–	–
	Chironomid larvae	17360±2250	10.18(114)	2.5781
	Total cladocera	17280±2330	1.62(136)	0.5668
	Acantholeberis curvirostris	3240±1200	–	–

[a]Number of organisms weighed in parentheses.
[b]Unmodified sugar flotation method.
[c]95% confidence limit.
[d]Dash indicates no measurement.

year-classes from 1967 to 1968 appeared to result from a selective mortality of the larger individuals within the population as the decrease in *p*H approached lethal levels.

In general the diets of white suckers in both lakes were similar as were the major species of cladocera and genera of chironomids. As shown, there was potentially more of the major food items per unit weight available to the Lumsden Lake white suckers. A comparison of the white sucker biomass in each lake also indicated that the white suckers in Lumsden Lake were probably slow-growing (Beamish 1973a) as a consequence of environmental pressures and not as a result of overcrowding.

Disappearance of Fishes

Other fishes in Lumsden Lake appeared to have disappeared despite the presence of adequate food reserves. Before 1960, two major predators existed in the lake, the lake trout (*Salvelinus namaycush*) and the burbot (*Lota lota*). The last lake trout captured was taken in 1967 and no burbot were captured during the study. Both these species disappeared from the lake while sizeable populations of common food items (lake herring (*Coregonus artedii*), lake chub (*Couesius plumbeus*), white sucker, and crayfish) existed.

Lake trout became extremely rare in gillnet catches in George Lake by 1971 and 1972 as the *p*H decreased below 4.8 (R. J. Beamish unpublished data). Burbot, walleye (*Stizostedion vitreum vitreum*), and smallmouth bass, (*Micropterus dolomieui*) that at one time were common in George Lake, were not captured after 1970. The decrease in abundance or disappearance of these species occurred even though prey were still abundant. Lake trout also disappeared in nearby O.S.A. Lake before the disappearance of prey species (Beamish 1974).

Cause of Reduced Growth and Ultimate Mortality of Lumsden Lake White Suckers

Both lakes are deep oligotrophic lakes that are thermally stratified in the summer and have adequate oxygen concentrations (Beamish 1970). Beamish (1974) has shown that lakes in the La Cloche Mountains differ from other dilute lakes primarily in their low *p*H, and high sulfate and heavy metal concentrations.

A *p*H of 6.8 in September 1961 was the earliest recorded value for Lumsden Lake (Beamish and Harvey 1972). Determinations of *p*H in 1967 and 1968 were not reliable because of inherent *p*H changes during the period between collection and determination of samples. This problem was corrected in early 1969 and an average annual *p*H of 4.6 for Lumsden and 5.2 for George Lake was estimated for 1969. It was concluded from subsequent studies of the rate of acidification of both lakes (R. J. Beamish unpublished data) that in 1967 and 1968 Lumsden Lake probably ranged in *p*H from 5.0 to 4.5 and George Lake from 6.0 to 5.5. The higher *p*H in George Lake in 1969 and that estimated to exist in 1967 and 1968 appeared acceptable for the normal growth of white suckers.

A reduction in food utilization by chinook salmon (*Oncorhynchus tshawytscha*) in sublethal concentrations of kraft mill effluents was reported by Tokar (1968). A decrease in feeding intensity was observed for white suckers held for several months in sublethal concentrations of acid (Beamish 1972). It is suggested that white suckers in Lumsden Lake may have behaved in a similar manner and reduced feeding or food utilization or both as *p*H levels became lethal.

Other possible contaminants such as heavy metals also appear to be entering the lakes in the precipitation (Beamish 1974), and possibly through increased weathering rates. Heavy metal determinations for both lakes in 1972–73 (R. J. Beamish unpublished data) showed that of the heavy metals zinc, copper, iron, nickel, lead, and cadmium, only zinc levels (24–33 μg/liter in Lumsden Lake and 19–45 μg/liter in George Lake) were sufficiently high to be potentially hazardous to fishes (Canadian Department of Environment 1972). The observed zinc concentrations were well below incipient LC50 values considered representative for most salmonid fishes in water of a hardness similar to the study lakes (Canadian Department Environment 1972). The zinc levels were within the range of "safe" concentrations of 30 μg/liter, which had no effect, and 180 μg/liter, which caused an 83% reduction in egg production of fathead minnows (*Pimephales promelas*) in hard water (Brungs 1969). Mount (1966) reported zinc to be less toxic at lower *p*H values although his results did not agree with other published work. In a 5-year survey of trace metals in rivers and lakes of the United States of America, zinc was detected in 76.5% of the samples (Kopp and Kroner 1969). The mean concentration of 64 μg/liter in the 1207 positive occurrences was higher than the zinc concentrations in the study lakes. Fourteen day-old George Lake lake herring fry survived in George Lake water of *p*H 5.3, but 50% died within 48 hr after the *p*H was reduced to 4.9 (R. J. Beamish unpublished data). Time to 50% mortality was unchanged when fry were subjected to a solution of *p*H 4.9 consisting of one part George Lake water and three parts distilled water. Thus the concentrations of heavy metals were reduced by 75% but survival time was unaffected. Concentrations of zinc, copper (George Lake 3 μg/liter, Lumsden Lake 1 μg/liter) and nickel (George Lake 10 μg/liter, Lumsden Lake 8 μg/liter) were below the concentrations considered "safe" for some aquatic organisms (Biesinger and Christensen 1972). Thus while zinc concentrations in the study lakes were high and the acidic nature of the water probably resulted in a greater proportion of metal in the ionic form, it was considered that they were not of sufficient magnitude to be considered the principle stressing agent. It is possible that synergistic effects of acid and heavy metals, especially zinc or acid, and the additive effect of heavy metals may have had an influence on the concentration of acid that first stressed the population. However, acid levels were in the range that have been considered unacceptable for fishes (EIFAC 1968; Mount 1974) and the low *p*H must be considered to be the principle factor affecting the growth and survival of fishes in Lumsden and other lakes.

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ANDERSON, R. O. 1959. A modified floatation technique for sorting bottom fauna samples. Limnol. Oceanogr. 4: 223–225.

BEAMISH, R. J. 1970. Factors affecting the age and size of the white sucker *Catostomus commersoni* at maturity. Ph.D. Thesis. Univ. Toronto, Toronto, Ont. 170 p.

1972. Lethal *p*H for the white sucker *Catostomus commersoni* (Lacépède). Trans. Am. Fish. Soc. 101: 355–358.

1973a. Determination of age, and growth of populations of the white sucker (*Catostomus commersoni*) exhibiting a wide range in size at maturity. J. Fish. Res. Board Can. 30: 607–616.

1973b. Design of a trapnet with interchangeable parts for the capture of large and small fishes from varying depths. J. Fish. Res. Board Can. 30: 587–590.

1974. Loss of fish populations from unexploited remote lakes in Ontario, Canada as a consequence of atmospheric fallout of acid. Water Res. Vol. 8. (In press).

BEAMISH, R. J., AND H. H. HARVEY. 1972. Acidification of the La Cloche Mountain lakes, Ontario, and resulting fish mortalities. J. Fish. Res. Board Can. 29: 1131–1143.

BIESINGER, K. E., AND G. M. CHRISTENSEN. 1972. Effects of various metals on survival, growth, reproduction, and metabolism of *Daphnia magna*. J. Fish. Res. Board Can. 29: 1691–1700.

BRINKHURST, R. O., K. E. CHUA, AND E. BATOOSHINGH. 1969. Modifications in sampling procedures as applied to studies on the bacteria and tubificid oligochaetes inhabiting aquatic sediments. J. Fish. Res. Board Can. 26: 2581–2593.

BRUNGS, W. A. 1969. Chronic toxicity of zinc to the fathead minnow, *Pimephales promelas* Rafinesque. Trans. Am. Fish. Soc. 98: 272–279.

CANADIAN DEPARTMENT OF THE ENVIRONMENT, INLANDS WATERS BRANCH. 1972. Guidelines for water quality objectives and standards. Tech. Rep. 67. 156 p.

CUERRIER, J. P. 1951. The use of pectoral fin rays for determining age of sturgeon and other species of fish. Canadian Fish Culturist 11: 10–18.

EIFAC WORKING PARTY ON WATER QUALITY. 1968. Water quality criteria for European freshwater fish. Report on extreme *p*H values and inland fisheries. EIFAC Tech. Pap. 4: 24 p. Water Res. 1969. 3: 593–611.

GERKING, S. D. 1962. Production and food utilization in a population of bluegill sunfish. Ecol. Monogr. 32: 31–78.

JOHNSON, M. G., AND R. O. BRINKHURST. 1971. Production of benthic macroinvertebrates of Bay of Quinte and Lake Ontario. J. Fish. Res. Board Can. 28: 1699–1714.

KOPP, J. F., AND R. C. KRONER. 1969. Trace metals in waters of the United States (Oct. 1, 1962–Sept. 30, 1967). U.S. Dept. Inter. Fed. Water Pollut. Control Adm. Cincinnati, Ohio 28 p.

MOUNT, D. I. 1966. The effect of total hardness and *p*H on acute toxicity of zinc to fish. Air Water Pollut. Int. J. 10: 49–56.

1974. Chronic effect of low *p*H on fathead minnow survival, growth and reproduction. Water Res. (In press).

OVCHYNNYK, M. M. 1965. On age determination with scales and bones of the white sucker, *Catostomus commersoni* (Lacépède). Zool. Anz. 175: 325–345.

PETERSEN, C. G. F. 1896. The yearly immigration of young plaice into the Limfjord from the German Sea, etc. Rep. Danish Biol. Sta. 1895, 6: 1–45. (Cited by W. E. Ricker, 1958, p. 81. Handbook of computations for biological statistics of fish populations. Bull. Fish. Res. Board Can. 119: 300 p.)

ROBSON, D. S., AND H. A. REGIER. 1964. Sample size in Petersen mark-recapture experiments. Trans. Am. Fish. Soc. 93: 215–226.

TOKAR, E. M. 1968. Some chronic effects of exposure to kraft mill effluent on juvenile chinook salmon. MS. Thesis. Oregon State University, Corvallis, Ore. 59 p.