Annotated Bibliography

Nutrient Content of Salmonids

Nitrogen Content

Atlantic Salmon (*Salmo salar*)

Aksnes, A., B. Gjerde, and S. O. Roald. 1986. Biological, chemical and organoleptic changes during maturation of farmed Atlantic salmon, *Salmo salar*. Aquaculture 53: 7-20.

Studied changes in farmed Atlantic salmon during sexual maturation. The % nitrogen (N) decreased from 3.76 (% protein= 23.5) in maturing salmon to 3.20 (% protein= 20) in sexually mature fish.

Anderson, J. S., S. P. Lall, D. M. Anderson, and M. A. McNiven. 1993. Evaluation of protein quality in fish meals by chemical and biological assays. Aquaculture 115: 305-325.

Investigated the effects of different diets on juvenile Atlantic salmon. The whole body % N of fish at beginning of the experiment was 2.54 (% protein= 15.9).

Arnesen, P., and A. Krogdahl. 1993. Crude and pre-extruded products of wheat as nutrient sources in extruded diets for Atlantic salmon (*Salmo salar*, L.) grown in sea water. Aquaculture 118: 105-117.

Looked at the effects on Atlantic salmon of different wheat products in their diet. The whole body % N of fish fed the control diet was 2.94 (% protein= 18.4).

Christiansen, R., O. Lie, and O. J. Torrissen. 1994. Effect of astaxanthin and vitamin A on growth and survival during feeding of Atlantic salmon, *Salmo salar* L. Aquaculture and Fisheries Management 25: 903-914.

Studies the effects on first feeding Atlantic salmon of astaxanthin and vitamin A supplementation in their diet. The whole body % N content of fish at the beginning of the experiment was 2.18 (% protein= 13.6).

Gardiner, W. R., and P. Geddes. 1980. The influence of body composition on the survival of juvenile salmon. Hydrobiologia 69: 67-72.

Changes in the fat, protein and energy content of juvenile (0+) Atlantic salmon in a stream were examined in order to determine whether the high mortality of these fish was due to poor nutrition. The whole body % N content fell from 2.67 to 2.37 over the winter (% protein fell from 16.7 to 14.8).

Hamre, K., and O. Lie. 1995. Minimum requirement of vitamin E for Atlantic salmon, *Salmo salar* L., at first feeding. Aquaculture Research 26: 175-184.

Fed late yolk-sac larvae of Atlantic salmon six different diets in order to determine their minimum requirement for vitamin E. The whole body % N content of fish at the beginning of the experiment was 1.90 (% protein= 11.9).

Hardy, R. W., T. M. Scott, and L. W. Harrell. 1987. Replacement of herring oil with menhaden oil, soybean oil, or tallow in the diets of Atlantic salmon raised in marine net-pens. Aquaculture 65: 267-277.

The effect of feeding adult Atlantic salmon diets containing different lipid sources were examined. The % N of muscle samples from fish fed the control diet were 12.74 on a dry weight basis (% protein= 79.6).

Hughes, S. G. 1988. Effect of dietary propylene glycol on growth, survival, histology, and carcass composition of Atlantic salmon. Prog. Fish-Cult. 50: 12-15.

Diets containing different concentrations of propylene glycol were fed to juvenile Atlantic salmon in order to see if their were any detrimental effects. The initial whole body % N content of the fish prior to the experiment was 10.12 on a dry weight basis (% protein= 63.3).

Lie, O., R. Waagbo, and K. Sandnes. 1988. Growth and chemical composition of adult Atlantic salmon (*Salmon salar*) fed dry and silage-based diets. Aquaculture 69: 343-353.

Three diets with fish silage products were fed to adult Atlantic salmon in order to test their effects on the fish. The initial whole body % N content of the fish prior to the experiment was 2.88 (% protein= 18.0).

Olli, J. J., A. Krogdahl, and A. Vabeno. 1995. Dehulled solvent-extracted soybean meal as a protein source in diets for Atlantic salmon, *Salmo salar* L. Aquaculture Research 26: 167-174.

Tested the effects of feeding adult Atlantic salmon diets varying in soybean protein content. The % N content of fish fed the control diet was 2.99 (% protein= 18.7).

Poston, H. A. 1990. Effect of body size on growth, survival, and chemical composition of Atlantic salmon fed soy lecithin and choline. Prog. Fish-Cult. 52: 226-230.

Studied the effects of the age at which juvenile Atlantic salmon are first fed lecithin and the responses of the fish to different sources of dietary lecithin. The whole body % N of fish on the control diet was 9.40 on a dry weight basis (% protein= 58.73).

Poston, H. A. 1991a. Effects of dietary aluminum on growth and composition of young Atlantic salmon. Prog. Fish-Cult. 53: 7-10.

Juvenile Atlantic salmon were fed diets containing varying levels of aluminum. Fish fed the nine experimental diets had an average whole body % N content 9.02 (% protein= 56.38).

Rumsey, G. L., and H. G. Ketola. 1975. Practical diets for Atlantic salmon (*Salmo salar*) fry and fingerlings. Prog. Fish-Cult. 37: 253-256.

Juvenile Atlantic salmon were fed five experimental diets. Fish with an initial weight of 0.12g which were fed the control diet had a whole body % N content of 9.28 on a dry weight basis (%

protein= 58.0). Fish with an initial weight of 1.8 g which were fed the control diet had a % N content of 10.56 on a dry weight bases (% proteirn= 66.0).

Usher, M. L., C. Talbot, and F. B. Eddy. 1991. Effects of transfer to seawater on growth and feeding in Atlantic salmon smolts (*Salmo salar* L.). Aquaculture 94: 309-326.

Studied the effects of transfering of 1+ Atlantic salmon smolts to seawater. The initial whole body % N of smolts in freshwater before transfer was 9.31 on a dry weight basis (% protein= 57.02). The whole body % N of smolts after transfer to seawater was 9.73 (% protein= 59.60). Smolts that were kept in freshwater rather than being transferred had a % N content of 8.28 (% protein= 50.76).

Sockeye Salmon (*Oncorhynchus nerka*)

Brett, J. R. 1973. Energy expenditure of sockeye salmon, *Oncorhynchus nerka*, during sustained performance. J. Fish. Res. Board Can. 30: 1799-1809.

Juvenile and adult sockeye salmon were tested under conditions of sustained swimming. The initial whole body % N content of juvenile fish was 10.95 on a dry weight basis (% protein= 68.44) and of adult fish was 10.48 (% protein= 65.5).

Brett, J. R., J. E. Shelbourn, and C. T. Shoop. 1969. Growth rate and body composition of fingerling sockeye salmon, *Oncorhynchus nerka*, in relation to temperature and ration size. J. Fish. Res. Board Can. 26: 2363-2394.

Studied changes in juvenile sockeye salmon in response to changes in temperature and ration size. The initial whole body average % N for fish at a range of temperatures was 2.51 (% protein= 15.69).

Groves, T. D. D. 1970. Body composition changes during growth in young sockeye (*Oncorhynchus nerka*) in fresh water. J. Fish. Res. Board Can. 27: 929-942.

Studied the changes in young sockeye salmon during growth. The average whole body % N content of 12 randomly selected young sockeye was 2.64 (% protein= 16.52).

Thurston, C. E., and H. W. Newman. 1962. Proximate composition changes in sockeye salmon (*Oncorhynchus nerka*) during spawning migration. Fishery Industrial Research 2: 15-22.

The changes in body moisture, fat, ash, and protein were studied in sockeye salmon at different points along their spawning migration. The whole body % N of the average adult male Columbia River sockeye at the mouth of the river was 3.55 (% protein= 22.2). The % N of an average male spawner at the spawning grounds was 2.90 (% protein= 18.1).

Coho Salmon (*Oncorhynchus kisutch*)

Hardy, R. W., K. D. Shearer, and I. B. King. 1984. Proximate and elemental composition of developing eggs and maternal soma of pen-reared coho salmon (*Oncorhynchus kisutch*) fed production and trace element fortified diets. Aquaculture 43: 147-165.

Studied the chemical and elemental changes in the maternal soma and in the developing ovaries of adult coho salmon during the time up to spawning. Six months prior to spawning, adult coho had a % N content of 6.72 on a dry weight basis (% protein= 42.0). One month prior to spawning, coho had a % N content of 9.76 (% protein= 61.0). At spawning, coho had a % N content of 8.80 (% protein= 55.0).

Hata, M., Y. Sato, T. Yamaguchi, M. Ito, and Y. Kuno. 1988. The chemical and amino acid compositions in tissues of cultured and wild coho salmon Oncorhynchus kisutch. Nippon Suisan Gakkaishi 54: 1365-1370.

Analyzed both wild and cultured coho salmon for chemical and amino acid composition. Cultured adult male coho had a whole body % N content of 2.86 (% protein=17.89). Cultured adult female coho had a whole body % N content of 2.84 (% protein=17.75). Wild coho had a whole body % N content of 3.16 (% protein=19.74).

Mahnken, C. V. W., J. Spinelli, and F. W. Waknitz. 1980. Evaluation of an alkane yeast (*Dandida* sp.) as a substitute for fish meal in Oregon Moist Pellet: feeding trials with coho salmon (*Oncorhynchus kisutch*) and rainbow trout *(Salmo gairdneri*). Aquaculture 20: 41-56.

A number of different diets were fed to rainbow trout in fresh water and to coho salmon in salt water. The % N content of rainbow trout was not determined. Juvenile coho salmon which were fed the control diet had a whole body % N content of 2.82 (% protein= 17.65).

Morrison, P. F., J. F. Leatherland, and R. A. Sonstegard. 1985. Proximate composition and organochlorine and heavy metal contamination of eggs from Lake Ontario, Lake Erie and Lake Michigan coho salmon (*Oncorhynchus kisutch* Walbaum) in relation to egg survival. Aquatic Toxicology 6: 73-86.

Investigated whether poor survival of Lake Erie coho salmon eggs was due to nutritional deficiency or to heavy metal or organochloride contamination. Coho salmon eggs from different locations had an average % N content of 3.84 (% protein=24.0).

Vanstone, W. E., and J. R. Markert. 1968. Some morphological and biochemical changes in coho salmon, *Oncorhynchus kisutch*, during parr-smolt transformation. J. Fish. Res. Board Can. 25: 2403-2418.

Studied changes in growth rate and in chemical composition of coho salmon around the smolting stage of their life cycle. They found that above a weight of 37.0 g, coho salmon would reach a limiting whole body nitrogen concentration of 3.1%.

Wood, E. M., W. T. Yasutake, J. E. Halver, and A. N. Woodall. 1960. Chemical and histological studies of wild and hatchery salmon in fresh water. Trans. Amer. Fish. Soc. 89: 301-307.

Studied juvenile wild and hatchery salmon over a 14 month period in order to note changes in chemical composition. Wild coho had an average whole body % N content over this time period of 12.44 on a dry weight basis (% protein=77.75) and hatchery coho had an average % N content of 11.50 (% protein=71.88).

Chinook Salmon (*Oncorhynchus tshawytscha*)

Greene, C. W. 1926. The physiology of the spawning migration. Physiological Reviews 6: 201-241.

Discusses the spawning migration of catadromous fishes briefly and of anadromous fishes in more detail. The wet muscle % N content of chinook salmon at sea was found to be 2.50 (% protein= 15.6). At the tide water before the spawning run the nitrogen concentration was 2.70% (% protein=16.9) and at the spawning grounds it was 2.30% (% protein=14.4).

Mazur, C. N., D. A. Higgs, E. Plisetskaya, and B. E. March. 1992. Utilization of dietary starch and glucose tolerance in juvenile chinook salmon (*Oncorhynchus tshawytscha*) of different strains in seawater. Fish Physiol. Biochem. 10: 303-313.

Juvenile chinook salmon were fed diets containing different amounts of gelatinized starch. The fish had an initial whole body % N content of 10.37 on a dry weight basis (% protein=64.83).

White, J. R., and H. W. Li. 1985. Determination of the energetic cost of swimming from the analysis of growth rate and body composition in juvenile chinook salmon, *Oncorhynchus tshawytscha*. Comp. Biochem. Physiol. 81A: 25-33.

Studied the effects of swimming activity on juvenile chinook. These fish had an initial whole body % N content of 2.32 (% protein=14.5).

Pink Salmon (*Oncorhynchus gorbuscha*)

Parker, R. R., and W. E. Vanstone. 1966. Changes in chemical composition of central British Columbia pink salmon during early sea life. J. Fish. Res. Board Can. 23: 1353-1384.

Studied the changes in the chemical composition of juvenile pink salmon. The % N of these fish was 2.50 (% protein=15.63).

Stansby, M. E. 1962. Proximate composition of fish. Pages 55-60 *in* E. Heen and R. Kreuzer, eds. Fish in nutrition. Fishing News (Books), London.

Comparison of the general categories of proximate composition of fish with some specific examples. The % N content of the light muscle tissue of pink salmon was reported as 3.26 (% protein= 20.4). The % N content of the dark muscle was 2.80 (% protein=17.5).

Chum Salmon (*Oncorhynchus keta*)

Shimizu, I., and M. Kaeriyama. 1991. Biological and chemical characteristics of chum salmon during their spawning migration period. Sci. Rep. Hokkaido Salmon Hatchery 45: 47-56.

Studied the changes in the chemical composition of chum salmon at immature to mature stages. The % N content of muscle from immature males was 3.50 and for immature females was 3.40. The % N content of mature males was 3.06 and for females was 2.85.

Masu Salmon (*Oncorhynchus masou*)

Li, H., and J. Yamada. 1992. Effects of different salinities on the growth, food intake and nutrient composition in underyearling masu salmon, *Oncorhynchus masou* (B.). Bull. Fac. Fish. Hokkaido Univ. 43: 33-41.

Studied the effects of different salinities on juvenile masu salmon. The average initial % N content of these fish was 12.69 on a dry weight basis.

Amago Salmon (*Oncorhynchus masou rhodurus*)

Teskeredzic, E., and Z. Teskeredzic. 1990. A successful rearing experiment with amago salmon (*Oncorhynchus masou rhodurus*) in floating cages in the Adriatic Sea. Aquaculture 86: 201-208.

Studied the growth and chemical composition of amago salmon which were raised in sea cages. The flesh of these fish was found to have a % N content of 3.34 (% protein=20.88).

Rainbow Trout (*Oncorhynchus mykiss*)

Alexis, M. N., E. Papaparaskeva-Papoutsoglou, and V. Theochari. 1985. Formulation of practical diets for rainbow trout (*Salmo gairdneri*) made by partial or complete substitution of fish meal by poultry by-products and certain plant by-products. Aquaculture 50: 61-73.

The changes in juvenile rainbow trout fed several different diets were studied. Whole body % N content of fish fed the control diet was 2.61 (% protein=16.31).

Brauge, C., F. Medale, and G. Corraze. 1994. Effect of dietary carbohydrate levels on growth, body composition and glycaemia in rainbow trout, *Oncorhynchus mykiss*, reared in seawater. Aquaculture 123: 109-120.

Studied the effect of dietary levels of carbohydrate on rainbow trout reared in seawater at low temperatures. The average whole body % N of fish on the three diets was 2.74 (% protein= 17.12).

Denton, J. E., and M. K. Yousef. 1976. Body composition and organ weights of rainbow trout, *Salmo gairdneri*. J. Fish Biol. 8: 489-499.

Studied the chemical components of rainbow trout during the first 14 months of life. The % N content of fish increased over time. At two months it was 1.86 and at 14 months it was 2.72.

Gamperl, A. K., J. Bryant, and E. D. Stevens. 1988. Effect of a sprint training protocol on growth rate, conversion efficiency, food consumption and body composition of rainbow trout, *Salmo gairdneri* Richardson. J. Fish Biol. 33: 861-870.

Studied the effect of sprint training on juvenile rainbow trout. The average whole body % N of the three experimental groups of fish was 2.22 (% protein=13.88).

Kaushik, S. J., and E. F. Gomes. 1988. Effect of frequency of feeding on nitrogen and energy balance in rainbow trout under maintenance conditions. Aquaculture 73: 207-216.

Studied the changes in juvenile rainbow trout fed at maintenance. The initial whole body % N was 11.12 on a dry weight basis (% protein=69.48).

Kaushik, S. J., J. P. Cravedi, J. P. Lalles, J. Sumpter, B. Fauconneau, and M. Laroche. 1995. Partial or total replacement of fish meal by soybean protein on growth, protein utilization, potential estrogenic and antigenic effects, cholesterolemia and flesh quality in rainbow trout, *Oncorhynchus mykiss*. Aquaculture 133: 257-274.

Studied the effects on juvenile rainbow trout of diets in which fish meal was partially or completely replaced by soybean protein. The initial whole body % N content of these fish was 2.75 (% protein= 17.2).

Kim, J. D., and S. J. Kaushik. 1992. Contribution of digestible energy from carbohydrates and estimation of protein/energy requirements for growth of rainbow trout (*Oncorhynchus mykiss*). Aquaculture 106: 161-169.

Studied the effect of diets varying in protein and carbohydrate on juvenile rainbow trout. The initial whole body % N content of these fish was 2.30 (% protein=14.4).

Kim, K., T. B. Kayes, and C. H. Amundson. 1992. Requirements for sulfur amino acids and utilization of D-methionine by rainbow trout (*Oncorhynchus mykiss*). Aquaculture 101: 95-103.

Juvenile rainbow trout were fed various diets in order to determine their methionine requirement. The initial % N content of these fish was 10.74 on a dry weight basis (% protein=67.1).

Martinez, F. J., M. P. Garcia, M. Canteras, J. De Costa, and S. Zamora. 1992. Effect of simultaneous variation of weight, density, temperature and O_2 concentration on rainbow trout (*Oncorhynchus mykiss*) body composition. Reprod. Nutr. Dev. 32: 105-112.

Studied the effect of variation of a number of factors on the body protein, fat, water, and ash content of juvenile rainbow trout. The fish in the 19 experimental conditions had an average %N content of 2.88 (% protein=18.03).

Oliva-Teles, A., and S. J. Kaushik. 1990. Growth and nutrient utilization by 0+ and 1+ triploid rainbow trout, *Oncorhynchus mykiss*. J. Fish Biol. 37: 125-133.

Investigated whether there are differences in growth, protein utilization, and body composition between diploid and triploid rainbow trout. The initial average whole body % N of 0+ diploid and triploid rainbow trout was 2.34. The initial average % N of 1+ rainbow was 3.98.

Poston, H. A. 1991b. Response of rainbow trout to soy lecithin, choline, and autoclaved isolated soy protein. Prog. Fish-Cult. 53: 85-90.

Fed rainbow trout fry a number of different experimental diets. The average % N of fish fed the 12 different experimental diets was 9.21 on a dry weight basis.

Rumsey, G. L., R. A. Winfree, and S. G. Hughes. 1992. Nutritional value of dietary nucleic acids and purine bases to rainbow trout (*Oncorhynchus mykiss*). Aquaculture 108: 97-110.

Juvenile rainbow trout were fed a variety of diets. The initial whole body % N of these fish was 11.6 on a dry weight basis.

Rumsey, G. L., S. G. Hughes, and R. A. Winfree. 1993. Chemical and nutritional evaluation of soya protein preparations as primary nitrogen sources for rainbow trout (*Oncorhynchus mykiss*). Anim. Feed Sci. Technol. 40: 135-151.

Diets containing soya preparations were fed to juvenile rainbow trout. The whole body % N content of fish on the control diet was 8.82 on a dry weight basis.

Smith, M. A. K., and A. Thorpe. 1976. Nitrogen metabolism and trophic input in relation to growth in freshwater and saltwater *Salmo gairdneri*. Biol. Bull. 150: 139-151.

Studied the nitrogen balance of groups of juvenile rainbow trout which were kept either in freshwater or saltwater and fed at different ration levels. Fish kept in saltwater or freshwater which were fed *ad libitum* had an average % N content of 10.98 on a dry weight basis.

Storebakken, T., and E. Austreng. 1987. Ration level for salmonids II. Growth, feed intake, protein digestibility, body composition, and feed conversion in rainbow trout weighing 0.5-1.0 kg. Aquaculture 60: 207-221.

Adult rainbow trout were fed different amounts of food. The average % N content of the eviscerated carcasses of fish sampled prior to the experiment was 2.90.

Storebakken, T., S. S. O. Hung, C. C. Calvert, and E. M. Plisetskaya. 1991. Nutrient partitioning in rainbow trout at different feeding rates. Aquaculture 96: 191-203.

Studied the effects of varying the amount of food fed to 10-month old rainbow trout. The average % N content of eviscerated carcasses of fish sampled prior to the feeding experiment was 3.06.

Takeuchi, T., and T. Watanabe. 1976. Nutritive value of ω3 highly unsaturated fatty acids in pollock liver oil for rainbow trout. Bull. Jpn Soc. Sci. Fish. 42: 907-919.

Juvenile rainbow trout were fed a number of diets containing different fatty acids in order to determine their effects. The initial whole body % N of these fish was 2.32.

Tidwell, J. H., C. D. Webster, and R. S. Knaub. 1991. Seasonal production of rainbow trout, *Oncorhynchus mykiss* (Walbaum), in ponds using different feeding practices. Aquaculture and Fisheries Management 22: 335-341.

Study comparing the effects of three different types of feeding practices on the production of rainbow trout in ponds. The carcasses (without head or viscera) of fish from the three different experimental treatments had an average % N content of 10.96 on a dry weight basis.

Velasquez, L., I. Ibanez, C. Herrera, and M. Oyarzun. 1991. A note on the nutritional evaluation of worm meal (*Eisenia fetida*) in diets for rainbow trout. Anim. Prod. 53: 119-122.

Studied the effects of diets containing different concentrations of worm meal on young rainbow trout. Fillets taken from fish fed the control diet had a % N content of 2.81.

Brown Trout (*Salmo trutta*)

Arzel, J., F. X. M. Lopez, R. Metailler, G. Stephan, M. Viau, G. Gandemer, and J. Guillaume. 1994. Effect of dietary lipid on growth performance and body composition of brown trout (*Salmo trutta*) reared in seawater. Aquaculture 123: 361-375.

Investigated the effects of dietary lipid content and source on brown trout. The initial whole body % N content of these fish was 2.94.

Arzel, J., R. Metailler, C. Kerleguer, H. Le Delliou, and J. Guillaume. 1995. The protein requirement of brown trout (*Salmo trutta*) fry. Aquaculture 130: 67-78.

Studied the protein requirement of brown trout fry. The initial whole body % N content of these fish was 2.13.

Elliott, J. M. 1975. Body composition of brown trout (*Salmo trutta* L.) in relation to temperature and ration size. J. Anim. Ecol. 45: 273-289.

Studied the effects on juvenile brown trout of varying temperature and ration size. The average whole body % N for fish in the different experimental conditions was 2.59.

Phillips, A. M., Jr., D. L. Livingston, and H. A. Poston. 1965. The effect of three supplemental fats on the growth rate and body chemistry of brown trout. Fish. Res. Bull., N.Y. 28: 28-34.

Diets containing different sources of supplemental fat were fed to juvenile brown trout. The average % N content of fish fed the different experimental diets was 2.11.

Brook Trout (*Selvelinus fontinalis*)

Phillips, A. M., Jr., D. L. Livingston, and H. A. Poston. 1963. The effect of diet mixture and calorie source on growth, mortality, conversion, and chemical composition of brook trout. Prog. Fish-Cult. 25: 8-14.

Studied the effects of different diets on juvenile brook trout. The average % N of fish fed different diets was 2.23 on a wet weight basis and 9.40 on a dry weight basis.

Phillips, A. M., Jr., D. L. Livingston, and R. F. Dumas. 1960. Effect of starvation and feeding on the chemical composition of brook trout. Prog. Fish-Cult. 22: 147-154.

Studied the changes in juvenile brook trout during periods of growth and starvation. The average % N of fish held under all experimental conditions was 1.94.

Arctic Charr (*Salvelinus alpinus*)

Elvingson, P., and J. Nilsson. 1994. Phenotypic and genetic parameters of body and compositional traits in Arctic charr, *Salvelinus alpinus* (L.). Aquaculture and Fisheries Management 25: 677-685.

Studied the heritability of body and carcass compositional traits in 2-year-old Arctic charr. The average whole body % N content of all fish analyzed was 2.83.

Miglavs, I., and M. Jobling. 1989. The effects of feeding regime on proximate body composition and patterns of energy deposition in juvenile Arctic charr, *Salvelinus alpinus*. J. Fish Biol. 35: 1-11.

Studied the effects of different feeding rates on juvenile Arctic charr. The % N content of the eviscerated carcasses of fish sampled prior to the feeding experiment was 1.44.

Multiple Species of Salmonids

Asgard, T., and E. Austreng. 1986. Blood, ensiled or frozen, as feed for salmonids. Aquaculture 55: 263-284.

Tested the suitability of blood from slaughtered cattle as a protein source in diets for large rainbow trout and Atlantic salmon. Fillets from rainbow trout fed different control diets had an average % N content of 3.65. Fillets from Atlantic salmon fed different control diets had an average % N of 3.47.

Asgard, T., and E. Austreng. 1985a. Casein silage as feed for salmonids. Aquaculture 48: 233-252.

Studied the effects of casein in the diets of large rainbow trout and Atlantic salmon. Fillets from rainbow trout and Atlantic salmon fed a control diet had a % N content of 3.26 and 3.01 respectively.

Asgard, T. and E. Austreng. 1985b. Dogfish offal, ensiled or frozen, as feed for salmonids. Aquaculture 49: 289-305.

Tested the offal from filleting dogfish as a protein source in the diets of large rainbow trout and Atlantic salmon. Fillets from rainbow trout and Atlantic salmon fed a control diet had a % N content of 3.65 and 3.63 respectively.

Asgard, T. 1987. Squid as feed for salmonids. Aquaculture 61: 259-273.

Evaluated using different parts of flying squid in diets for large rainbow trout and Atlantic salmon. Fillets from rainbow trout and Atlantic salmon fed a control diet had a % N content of 3.65 and 3.63 respectively.

Idler, D. R., and W. A. Clemens. 1959. The energy expenditures of Fraser River sockeye salmon during the spawning migration to Chilko and Stuart lakes. Int. Pac. Salmon Fish. Comm. Prog. Rep. Jackson Printing, New Westminster, B.C. 80 pp.

Analyzed the fat, protein and water content of male and female Fraser River sockeye salmon of the Stuart and Chilko Lake runs at points along their migration from the river mouth to the spawning grounds in order to compare their energy expenditures. This information was compared with data on the Amur River chum salmon. The % N content of adult male and female Amur River chum salmon at the river mouth prior to the spawning migration was 3.37 and 3.31 respectively. The % N content of spawned-out male and female chum was 2.54 and 2.19 respectively. The % N content of male and female Stuart Lake sockeye salmon at the river mouth prior to the spawning migration was 3.12 and 3.18 respectively. The % N content of spawned-out male and female sockeye was 2.56 and 2.48 respectively.

Krzynowek, J., and J. Murphy. 1987. Proximate composition, energy, fatty acid, sodium, and cholesterol content of finfish, shellfish, and their products. NOAA Technical Report, National Marine Fisheries Service 55. U.S. Dept. of Commerce, Washington, D.C. 53 pp.

Reviewed 228 articles which were published between 1976 and 1984 and complied tables of information on the proximate composition and energy, fatty acid, sodium, and cholesterol content of finfish and shellfish. The average % N content of the muscle of adult Arctic charr was found to be 3.92. The whole body % N content of adult Atlantic salmon was 2.40. The % N content of the edible flesh of adult chinook, chum, coho, pink, and sockeye salmon was 3.12, 3.41, 3.47, 3.04, and 3.53 respectively. Fillets from adult brook trout had an average % N content of 3.44. The edible flesh of cutthroat trout and Dolly Varden had a % N content of 3.18 and 3.17 respectively. Fillets of lake and rainbow trout had a % N content of 2.98 and 3.01 respectively. Muscle from Lake Whitefish had a % N content of 3.39.

MacLeod, R. A., R. E. E. Jonas, and J. R. McBride. 1958. Variations in the sodium and potassium content of the muscle tissue of Pacific salmon with particular reference to migration. Can. J. Biochem. Physiol. 36: 1257-1268.

Studied the amount of sodium and potassium in chinook, sockeye, and coho salmon at the juvenile stage and at different points along the route of their spawning migration. The % N content of adult chinook carcass was 3.10 at sea and 1.72 at the spawning grounds. Adult sockeye salmon had a % N content of 3.70 at sea and 3.07 at the spawning grounds.

Nettleton, J. A., and J. Exler. 1992. Nutrients in wild and farmed fish and shellfish. J. Food Sci. 57: 257-260.

Analyzed the proximate composition and vitamin content of wild and farmed channel catfish, red swamp crayfish, white river crayfish, Eastern oysters, rainbow trout, and coho salmon. The % N content of wild and farmed adult coho was 3.41 and 3.49 respectively. The % N content of wild and farmed rainbow trout was 3.20 and 3.34 respectively.

Shostrom, O. E., R. W. Clough, and E. D. Clark. 1924. A chemical study of canned salmon. Industrial and Engineering Chemistry 16: 283-289.

Analyzed the composition of canned sockeye, chum, chinook, coho, pink, Atlantic salmon, and steelhead trout. The % N content of each of these fish was found to be 3.36, 3.44, 3.14, 3.38, 3.29, 3.38, and 3.29 respectively.

Vlieg, P. 1986. Proximate composition of two trout and three carp species from New Zealand waters. New Zealand Journal of Technology 2: 215-218.

Analyzed adult brown trout, rainbow trout, grass carp, silver carp, and koi carp for protein, oil, moisture, and ash content. The % N content of brown and rainbow trout was 3.07 and 3.17 respectively.

Wood, E. M., W. T. Yasutake, A. N. Woodall, and J. E. Halver. 1957. The nutrition of salmonid fishes. I. Chemical and histological studies of wild and domestic fish. J. Nutr. 61: 465-478.

Studied the proximate composition and the anatomical characteristics of juvenile wild and hatchery-reared salmonids. The % N content on a dry weight basis of hatchery-reared chinook, coho, pink, steelhead, rainbow, cutthroat, brown trout, and brook trout was 11.40, 10.58, 11.20, 10.32, 10.85, 11.49, 10.88, and 10.66 respectively. The % N content on a dry weight basis of wild chinook, coho, chum, steelhead, rainbow, cutthroat, brown trout, and brook trout was 12.45, 12.38, 12.26, 12.32, 11.14, 12.26, 11.65, and 11.47 respectively.

Nitrogen and Phosphorus Content

Atlantic Salmon (*Salmo salar*)

Shearer, K. D., T. Asgard, G. Andorsdottir, and G. H. Aas. 1994. Whole body elemental and proximate composition of Atlantic salmon (*Salmo salar*) during the life cycle. J. Fish Biol. 44: 785-797.

Analyzed the proximate and elemental composition of Atlantic salmon periodically throughout their life-cycle. The concentration of nitrogen in the fish increased gradually with growth from 1.92 % to 2.88 % when the fish reached 125 g and after this point the nitrogen content was not effected by salt water entry or maturation. The concentration of phosphorus in the fish increased during the juvenile stage to 0.5000 % and then decreased prior to transfer to sea water and remained at 0.4500 % during residence in sea water. A decrease and then an increase in phosphorus concentration were observed during maturation.

Talbot, C., T. Preston, and B. W. East. 1986. Body composition of Atlantic salmon (*Salmo salar* L.) studied by neutron activation analysis. Comp. Biochem. Physiol. 85A: 445-450.

Analyzed Atlantic salmon for elemental and proximate composition. Juvenile Atlantic salmon in freshwater had a % N content of 3.107 and a % phosphorus (P) content of 0.446. Adult Atlantic salmon in sea water had a % N content of 3.331 and a % P content of 0.395. Spawned-out Atlantic salmon had a % N content of 2.997 and a % P content of 0.578.

Chum Salmon (*Oncorhynchus keta*)

Watanabe, T., A. Murakami, L. Takeuchi, T. Nose, and C. Ogino. 1980. Requirement of chum salmon held in freshwater for dietary phosphorus. Bull. Jpn. Soc. Sci. Fish. 46: 361-367.

Studied the effects of different dietary levels of calcium and phosphorus on juvenile chum salmon. Chum salmon fed a number of different diets had an average % N content of 2.63 and an average % P content of 0.374.

Rainbow Trout (*Oncorhynchus mykiss*)

Heinen, J. M., J. A. Hankins, and M. Subramanyam. 1993. Evaluation of four commercial diets for rainbow trout. Prog. Fish-Cult. 55: 265-269.

Investigated the effects of four different diets on juvenile rainbow trout. The average % N content of fish fed the different diets was 2.72 and the average % P content was 0.43.

Lall, S. P., and F. J. Bishop. 1979. Studies on the nutrient requirements of rainbow trout, *Salmo gairdneri*, grown in sea water and fresh water. Pages 580-584 *in* T. V. R. Pillay and W. A. Dill, eds. Advances in aquaculture: papers presented at the FAO technical conference on aquaculture, Kyoto, Japan, 26 May- 2 June 1976. Fishing News (Books), Farnham, U.K.

In order to determine the differences in protein, lipid, and mineral utilization by juvenile rainbow trout grown in sea water or fresh water, groups of juvenile rainbow trout were kept in either fresh water or sea water and were fed a number of different experimental diets. The initial % N content of fish prior to the experiment was 2.38. Fish kept in fresh water and fed three different diets had an average % N content of 2.45 and an average % P content of 0.467. Fish kept in salt water and fed three different experimental diets had an average % N content of 2.59 and an average % P content of 0.443.

Ogino, C., and H. Takeda. 1978. Requirements of rainbow trout for dietary calcium and phosphorus. Bull. Jpn. Soc. Sci. Fish. 44: 1019-1022.

Fed juvenile rainbow trout three different levels of calcium and phosphorus in order to determine their dietary requirement for these elements. At the beginning of the experiment, these fish had a % N content of 2.03 on a wet weight basis and a % P content of 2.43 on a dry weight basis.

Ogino, C., and M. Kamizono. 1975. Mineral requirements in fish. I. Effects of dietary salt-mixture levels on growth, mortality, and body composition in rainbow trout and carp. Bull. Jpn. Soc. Sci. Fish. 41: 429-434.

Studied the effects of feeding juvenile rainbow trout and carp different levels of salt-mixture. Juvenile rainbow had a % N content of 2.45 and a % P content of 0.34.

Penczak, T., W. Galicka, M. Molinski, E. Kusto, and M. Zalewski. 1982. The enrichment of a mesotrophic lake by carbon, phosphorus, and nitrogen from the cage aquaculture of rainbow trout, *Salmo gairdneri*. Journal of Applied Ecology 19: 371-393.

Determined the amount of carbon, phosphorus, and nitrogen that was entering Glebokie Lake as a result of the production of a caged 1 kg rainbow trout. Juvenile rainbow were found to have a whole body % N content of 10.00 and a % P content of 2.00 on a dry weight basis.

Ronsholdt, B. 1995. Effect of size/age and feed composition on body composition and phosphorus content of rainbow trout, *Oncorhynchus mykiss*. Wat. Sci. Tech. 31: 175-183.

Groups of adult and juvenile rainbow trout were fed two different diets in order to determine the effect of size/age and feed composition on the body composition and phosphorus content of rainbow trout. The adult fish had an initial % N content of 2.85 and an initial % P content of 0.429. Juvenile rainbow had an initial % N content of 2.76 and a % P content of 0.431.

Phosphorus Content

Atlantic Salmon (*Salmo salar*)

Poston, H. A., and H. G. Ketola. 1989. Chemical composition of maturing and spawning Atlantic salmon from different locations. Prog. Fish-Cult. 51: 133-139.

Examined the relationship between the environmental or nutritional background and the chemical composition of body tissues and reproductive success in wild and hatchery-reared Atlantic salmon. The % P content of the muscle of adult Atlantic salmon was found to be 0.84 on a dry weight basis.

Rottiers, D. V. 1993. Elemental composition of a migratory and a land-locked strain of Atlantic salmon *Salmo salar*. Comp. Biochem. Physiol. 104A: 93-100.

The whole-body inorganic composition of smolt-sized anadromous and non-anadromous Atlantic salmon was determined in order investigate whether the two groups differ in their elemental content during smolting. The average % P content of juvenile anadromous and land-locked Atlantic salmon was found to be 0.4465 on a wet weight basis and 1.537 on a dry weight basis.

Rainbow Trout (*Oncorhynchus mykiss*)

Behmer, D. J., R. W. Greil, and B. P. Fessell. 1993. Evaluation of cone-bottom cages for removal of solid wastes and phosphorus from pen-cultured rainbow trout. Prog. Fish-Cult. 55: 255-260.

Studied rainbow trout in pen culture and the effectiveness of cone-bottom cages for trapping solid wastes for subsequent removal in order to prevent loss of phosphorus into the environment. The % P content of young rainbow trout was 0.40 on a wet weight basis and 1.59 on a dry weight basis.

Cain, K. D., and D. L. Garling. 1995. Pretreatment of soybean meal with phytase for salmonid diets to reduce phosphorus concentrations in hatchery effluents. Prog. Fish-Cult. 57: 114-119.

Studied the effects on the performance of juvenile rainbow trout of diets containing either phytase-treated or untreated soybean meal with graded levels of supplemental phosphorus. The whole body of rainbow trout was found to have a % P content of 0.51.

Ketola, H. G., and B. F. Harland. 1993. Influence of phosphorus in rainbow trout diets on phosphorus discharges in effluent water. Trans. Amer. Fish. Soc. 122: 1120-1126.

Juvenile rainbow trout were fed diets containing varying levels of supplemental phosphorus in order to determine the effects on discharges of phosphorus in hatchery effluent water. The fish had an average % P content of 0.445.

Ketola, H. G., and M. E. Richmond. 1994. Requirement of rainbow trout for dietary phosphorus and its relationship to the amount discharged in hatchery effluents. Trans. Amer. Fish. Soc. 123: 587-594.

Juvenile rainbow trout were fed diets containing different levels of non-phytin phosphorus with or without supplemental phosphorus in order to determine their requirement for dietary phosphorus. The fish which were fed a control diet had a % P content of 0.52.

Ketola, H. G., 1991. Managing fish hatchery discharges of phosphorus through nutrition. Pages 187-197 *in* Engineering aspects of intensive aquaculture: proceedings from the aquaculture symposium, Cornell University, April 4-6, 1991. Northeast Regional Agricultural Engineering Service, Ithaca, N.Y. 352 pp.

Diets containing different concentrations of phosphorus were fed to juvenile rainbow trout in order to determine which diet would be best for reducing the amount of phosphorus discharged in hatchery effluent. These fish had a whole body concentration of phosphorus of 0.45%.

Satoh, S., T. Takeuchi, and T. Watanabe. 1987. Changes of mineral compositions in whole body of rainbow trout during growing stages. Nippon Suisan Gakkaishi 53: 273-279.

Studied changes in the mineral composition of rainbow trout at different life stages until the fish reached 40 weeks old. The fish were fed diets with or without supplementation of trace metals. The phosphorus concentration of eyed eggs was 0.38%. Yolk-sac fry had a % P content of 0.42 and swim-up fry had a % P content of 0.30. At the 4th week of development, fish which were fed a control diet had a P concentration of 0.29% and from the 12th week until the 40th week the fish had an average P concentration of 0.45%.

Shearer, K. D., and R. W. Hardy. 1987. Phosphorus deficiency in rainbow trout fed a diet containing deboned fillet scrap. Prog. Fish-Cult. 49: 192-197.

Studied the effects of feeding juvenile rainbow trout diets containing fillet scrap. The whole body phosphorus concentration of fish fed the control diet was 0.4690%.

Shearer, K. D. 1984. Changes in elemental composition of hatchery-reared rainbow trout, *Salmo gairdneri*, associated with growth and reproduction. Can. J. Fish. Aquat. Sci. 41: 1592-1600.

Studied the whole body and tissue elemental composition of rainbow trout over their life-cycle (ova to 1500 g). Ninety-five fish weighing from 10.0 g to 1822.0 g were averaged in order to determine a whole body phosphorus concentration for rainbow trout of 0.4804%.

Wiesmann, D., H. Scheid, and E. Pfeffer. 1988. Water pollution with phosphorus of dietary origin by intensively fed rainbow trout (*Salmo gairdneri* Rich.) Aquaculture 69: 263-270.

Investigated whether phosphate concentration increases in water as it passes through commercial trout farms and whether diets with lower phosphorus contents can be used without negative effects on juvenile rainbow trout. At the start of the experiment, the phosphorus concentration of fish with an initial weight of 33 g, 40 g, or 91 g was 0.37%, 0.415%, and 0.46% respectively.

Zeitoun, I. H., D. E. Ullrey, W. G. Bergen, and W. T. Magee. 1976. Mineral metabolism during the ontogenesis of rainbow trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 33: 2587-2591.

Studied the mineral composition of unfertilized rainbow trout eggs and of every stage until day 37 of development. Rainbow trout fry have a whole body phosphorus concentration of 1.04 on a dry weight basis.

Brook Trout (*Selvelinus fontinalis*)

McCay, C. M., A. V. Tunison, M. Crowell, and H. Paul. 1936. The calcium and phosphorus content of the body of the brook trout in relation to age, growth, and food. J. Biol. Chem. 114: 259-263.

Juvenile brook trout were fed a diet which was thought to have less calcium than required by the fish in order to determine if the fish would utilize calcium from the water in order to make up the difference. Change in the amount of calcium and phosphorus in brook trout during the early stages of development was also investigated. Fish with a weight range of 0.08 g to 5.5 g had an average % P content of 0.2852.

McCay, C. M., A. Tunison, M. Crowell, D. K. Tressler, S. P. MacDonald, J. W. Titcomb, and E. W. Cobb. 1931. The nutritional requirements of trout and chemical composition of the entire trout body. Trans. Amer. Fish. Soc. 61: 58-79.

Studied the effects of a number of different diets on juvenile brook trout. Fish fed the six different diets had an average whole body phosphorus concentration of 0.392 %.

Multiple Species of Salmonids

Stansby, M. E., and A. S. Hall. 1965. Chemical composition of commercially important fish of the United States. Fishery Industrial Research 3: 29-46.

Complied data on the proximate composition, water content, mineral content, protein content, amino acids, lipids, vitamins, and other constituents of a number of different fish species. Canned sockeye, chinook, coho, pink, and chum salmon were found to have a % P content of 0.3364, 0.2778, 0.3382, 0.3206, and 0.3518 respectively.

Taylor, H. F. 1926. Mineral constituents of fish and shellfish. Pages 539-547 *in* Nutritive value of fish and shellfish. Appendix X, Report, U. S. Bureau of Fisheries, Washington.

Discusses the importance of trace elements and presents data on the mineral and the heavy metal content of some fish and shellfish species. The edible portion of chinook and Atlantic salmon were found to have a % P content (calculated as P_2O_5) of 0.57 and 0.59 respectively.

Nutrient Contribution of Salmonids to Rivers and Lakes

Brickell, D. C., and J. J. Goering. 1970. Chemical effects of salmon decomposition on aquatic ecosystems. Pages 125-138 *in* R. S. Murphy and D. Nyquist, eds. International symposium on water pollution control in cold climates. U.S. Govt Printing Office Washington, D.C.

Studied the fate of 75 metric tons of salmon carcasses in Little Port Walter estuary (Sashin Creek) in southeastern Alaska. In Sashin Creek, the decomposing pink salmon carcasses caused an increase in the ammonium and the dissolved organic nitrogen concentration. A large increase in dissolved organic nitrogen concentrations in the surface waters of Little Port Walter was also seen.

Cederholm, C. J., and N. P. Peterson. 1985. The retention of coho salmon (*Oncorhynchus kisutch*) carcasses by organic debris in small streams. Can. J. Fish. Aquat. Sci. 42: 1222-1225.

Studied the distribution of introduced coho salmon carcasses in nine small streams on the Olympic Peninsula, Washington during the fall-winter spawning period. One week after release, 43 % of the carcasses were found still in the streams and 80% of those were in the first 200 m downstream. A greater amount of debris in the stream channel resulted in a greater number of carcasses being retained.

Cederholm, C. J., D. B. Houston, D. L. Cole, and W. J. Scarlett. 1989. Fate of coho salmon (*Oncorhynchus kisutch*) carcasses in spawning streams. Can. J. Fish. Aquat. Sci. 46: 1347-1355.

Studied the fate of coho salmon carcasses which were introduced into seven spawning streams on the Olympic Peninsula. The number of carcasses retained in the streams and adjacent forests was high. Mammals and birds consumed much of the fish carcass mass.

Foerster, R. E. 1968. The sockeye salmon, *Oncorhynchus nerka*. Bull. Fish. Res. Board Can. 162: 422 pp.

Review of all the studies carred out in the area around the north Pacific Ocean (from the Columbia River to the streams of the west coast of Kamchatka, USSR). Contains information on sockeye production under a variety of conditions and assesses sockeye survival at each stage of their life cycle. Discusses the contribution of sockeye carcasses to the nutrient supply of nursery lakes. Adult sockeye are reported to have a % N content of 3.5 and a % P content of 0.3364.

Hartman, W. L., and R. L. Burgner. 1972. Limnology and fish ecology of sockeye salmon nursery lakes of the world. J. Fish. Res. Board Can. 29: 699-715.

Discribes the limnology and fish ecology of oligotrophic lakes in British Columbia, Alaska, and Kamchatka. Discusses the contribution of nutrients released from salmon carcasses to nursery lake phosphate balances, the use of nursery lakes by young sockeye, the interactions between sockeye salmon and resident fish, the self-regulation of sockeye abundance in nursery lakes, the relationship between young sockeye biomass and growth rates and zooplankton abundance, and finally, the migratory behavior of young sockeye within a lake. The % P content of adult sockeye was reported as 0.28. Pre-spawning adult sockeye had a % P content of 0.38. Sockeye smolts had a % P content of 0.33 for Lake Iliamna and 0.49 for Lake Dalnee.

Johnson, J. H., and N. H. Ringler. 1979. Predation on Pacific salmon eggs by salmonids in a tributary of Lake Ontario. J. Great Lakes Res. 5: 177-181.

Studied the diet of salmonids in a tributary stream of Lake Ontario. Pacific salmon eggs made up 90% of the October diet and 38-95% of the November diet of juvenile steelhead and coho salmon and adult brook trout and brown trout.

Johnson, J. H., and N. H. Ringler. 1979. The occurrence of blow fly larvae (Diptera: Calliphoridae) on salmon carcasses and their utilization as food by juvenile salmon and trout. Great Lakes Entomol. 12: 137-140.

Discusses the occurrence of blow fly larvae in coho and chinook salmon carcasses found along a Lake Ontario tributary. It also reports the consumption of these larvae by young salmon and trout.

Juday, C., W. H. Rich, G. I. Kemmerer, and A. Mann. 1932. Limnological studies of Karluk Lake, Alaska 1926-1930. Bull. U.S. Bur. Fish. 47: 407-436.

The Karluk watershed was studied and information on the physical features, water chemistry, phytoplankton, and zooplankton of the watershed was presented. The contribution of nitrogen and phosphorus to the streams of this watershed by decomposing sockeye salmon was discussed. The nitrogen concentration of sockeye was reported as 3.46%. This value was used to determine that of the 2,000,000 kg of decomposable organic material contributed by dead salmon, 70,000 kg would be nitrogen. The phosphorus concentration of sockeye was reported to be 0.26%. This value was used to calculate that 5,000 kg of phosphorus would be contributed by the sockeye salmon which migrate into these waters to spawn every year.

Kitchell, J. F., R. V. O'Neill, D. Webb, G. W. Gallepp, S. M. Bartell, J. F. Koonce, and B. S. Ausmus. 1979. Consumer regulation of nutrient cycling. Bioscience 29: 28-34.

A review of the information on the ways that consumers influence nutrient cycling through physical or chemical processes which are not directly reflected in energy flow. Examples are drawn from studies of phosphorus cycling in lakes and cation cycling in deciduous forests. Migration and nutrient storage in fish biomass is discussed.

Koenings, J. P., and R. D. Burkett. 1987. An aquatic Rubic's cube: restoration of the Karluk Lake sockeye salmon (*Oncorhynchus nerka*). Pages 419-434 in H. D. Smith, L. Margolis, and C. C. Wood, eds. Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96.

The decline in the abundance of sockeye salmon in Karluk Lake since 1889 has been attributed to overfishing. It was concluded that the decline in sockeye numbers caused a decline in lake fertility due to a decrease in the amount of phosphorus entering the lake from the decomposition of sockeye carcasses. It was found that adult sockeye salmon had a phosphorus concentration of 0.3364% or nearly 8-9 g P/fish for a 2.4 kg sockeye. From this data, a total P input from one million carcasses was calculated as being between 8,074 kg/yr and 8,755 kg/yr.

Krokhin, E. M. 1968. Effect of size of escapement of sockeye salmon spawners on the phosphate content of a nursery lake. Izv. Tikhookean. Nauchno-Issled. Inst. Rybn. Khoz. Okeanogr. 57. (Transl. from Russian by Fish. Res. Board Can. Transl. Ser. No. 1186: 45pp.)

Data was presented showing the influence of spawned-out sockeye carcasses on the nutrient regime of lakes in which salmon spawn. It was concluded that an obvious effect on the phosphate balance of the lake must occur if the spawning escapement is not lower than 500-700 fish per 10^6 m^3.

Krokhin, E. M. 1969. Influence of the intensity of passage of the sockeye salmon Oncorhynchus nerka (Wald.) on the phosphate content of spawning lakes. Transactions of the Institute for the Biology of Inland Waters, the USSR Academy of Sciences 15. (Translated from Russian by Fish. Res. Board Can. Transl. Ser. No. 1273: 14pp.

Presented data on the contribution of decomposing sockeye carcasses to the phosphorus balance of Dalneye River and Lake. Data from other lakes was presented as well.

Krokhin, E. M. 1975. Transport of nutrients by salmon migrating from the sea into lakes. Pages 153-156 *in* A. D. Hasler, ed. Coupling of land and water systems. Springer-Verlag, New York.

Presents information on the contribution of sockeye salmon carcass decomposition to the phosphorus income of lakes. For the period of 1937 to 1947, nearly 26% of the P income to Lake Dalnee and nearly 20% of that to Lake Blizhnee was supplied by decomposing spawned-out sockeye. States that oligotrophication is occurring in these lakes because depressed stocks deprive the headwaters of replenishing nutrients to balance those which continue to be removed to the ocean.

Mathisen, O. A. 1971. Escapement levels and productivity of the Nushagak sockeye salmon run from 1908 to 1966. Fishery Bulletin (U.S.) 69: 747-763.

Outlined the decline of the Nushagak sockeye salmon stocks over time. Suggested that the declining return per spawner resulted in fewer nutrients being returned to the system through decomposition of fish carcasses and this caused a decline in the productivity of nursery areas.

Mathisen, O. A. 1972. Fish and fisheries: biogenic enrichment of sockeye lakes and stock productivity. Verh. Internat. Verein. Limnol. 18: 1089-1095.

Discussed the enrichment of sockeye lakes by decomposing spawned-out fish and the consequences of declining returns per spawner on the productivity of lakes.

Minshall, G. W., E. Hichcock, and J. R. Barnes. 1991. Decomposition of rainbow trout (*Oncorhynchus mykiss*) carcasses in a forest stream ecosystem inhabited only by nonanadromous fish populations. Can. J. Fish. Aquat. Sci. 48: 191-195.

Rainbow trout were secured in the West Fork of Mink Creek, Idaho in order to study the changes associated with carcass decomposition. Nutrients which leached from the fish appeared to be utilized rapidly by micorbes associated with the carcass, since algal growth downstream of the carcasses was not stimulated.

Narver, D. W. 1967. Primary productivity in the Babine Lake system, British Columbia. J. Fish. Res. Board Can. 24: 2045-2052.

This study investigated the rates of carbon-fixation in different areas of the Babine Lake system with the assumption that differences in production of phytoplankton would affect production of juvenile salmon. Reported an unusually high rate of photosynthesis at one part of the main lake in September and suggested that it may have been due to the decomposition of sockeye salmon carcasses in a nearby stream.

Northcote, T. G. 1988. Fish in the structure and function of freshwater ecosystems: a "top-down" view. Can. J. Fish. Aquat. Sci. 45: 361-379.

Reviewed papers relating to how fish effect ecosystems. Discussed the role of fish in nutrient cycling and nutrient transport to freshwater systems.

Parmenter, R. R., and V. A. Lamarra. 1991. Nutrient cycling in a freshwater marsh: the decomposition of fish and waterfowl carrion. Limnol. Oceanogr. 36: 976-987.

Measured the nutrient loss sequences of decomposing rainbow trout and pintail duck carcasses in a Wyoming marsh over a 10-month period. The initial % N content (on a dry weight basis) of rainbow trout was 10.12 and the % P content was1.78. Fish carrion lost 95% of the original carcass N and 60% of carcass P.

Rand, P. S., C. A. S. Hall, W. H. McDowell, N. H. Ringler, and J. G. Kennen. 1992. Factors limiting primary productivity in Lake Ontario tributaries receiving salmon migrations. Can. J. Aquat. Sci. 49: 2377-2385.

Studied the contribution of phosphorus from salmon carcasses to two Lake Ontario tributaries. Concluded that salmon migrations are unlikely to increase the rate of primary productivity in these already fertile streams.

Richey, J. E., M. A. Perkins, and C. R. Goldman. 1975. Effects of kokanee salmon (*Oncorhynchus nerka*) decomposition on the ecology of a subalpine stream. J. Fish. Res. Board Can. 32: 817-820.

Studied the nutrient contribution of kokanee salmon carcasses to Taylor Creek during a season of high and a season of low spawner abundance. Found that primary production, periphyton biomass, heterotrophic activity, and nutrient concentrations were greater downstream the upstream during the period of carcass decomposition, whereas they were the same at other times.

Schuldt, J. A., and A. E. Hershey. 1995. Effect of salmon carcass decomposition on Lake Superior tributary streams. J. N. Am. Benthol. Soc. 14: 259-268.

Investigated the fate of organic matter and inorganic nutrients derived from decomposing chinook spawners in Lake Superior tributary streams. Results showed that total P, soluable reactive P, and periphyton biomass were higher in a river reach which contained decomposing salmon carcasses than in a reach without a salmon run. Stable isotope analyses revealed that salmon-derived nitrogen was incorporated into mayflies and caddisflies.

Sugai, S. F., and D. C. Burrell. 1984. Transport of dissolved organic carbon, nutrients, and trace metals from the Wilson and Blossom rivers to Smeaton Bay, southeast Alaska. Can. J. Fish. Aquat. Sci. 41: 180-190.

Examined the regional and seasonal differences in the dissolved organic carbon, nutrients, Cu, Fe, and Mn input from the Wilson and Blossom rivers in southeast Alaska. Found that the maximum nutrient export seemed to be tied to the annual salmon run. They assumed that the average fish in a mixed chum and pink salmon group would be composed of 1.3% N and 0.38% P.

Stable Isotope Studies

Marine-derived Nutrients

Bilby, R. E., B. R. Fransen, and P. A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes. Can. J. Fish. Aquat. Sci. In press.

Used stable isotope ratios in order to investigate the incorporation of salmon-derived carbon and nitrogen into stream biota. Found that the mechanisms of incorporation were through direct consumption of eggs, carcasses and fry and through sorption into the stream bed substrate. Isotope ratios indicated that the proportion of carbon contributed by coho spawners ranged from 0% in shredders and in the foliage of riparian plants to 34% in juvenile coho. Also found that proportion of nitrogen contributed by spawning salmon ranged from 17% in collector-gatherers to more than 30% in juvenile coho.

Kline, T. C., Jr., J. J. Goering, O. A., P. H. Poe, P. L. Parker, and R. S. Scalan. 1993. Recycling of elements transported upstream by runs of Pacific salmon: II. $\delta^{15}N$ and $\delta^{13}C$ evidence in the Kvichak River watershed, Bristol Bay, southwestern Alaska. Can. J. Fish. Aquat. Sci. 50: 2350-2365.

In order to determine the significance of marine-derived nitrogen delivered by returning sockeye salmon, the $\delta^{15}N$ and $\delta^{13}C$ values of biota in a sockeye nursery lake (Iliamna Lake) were compared with the values of biota in anadromous-salmon-free lakes. Iliamna Lake biota had higher $\delta^{15}N$ values compared with control lakes, which verified a mixing model correlating $\delta^{15}N$ with marine-derived nutrients. Periphyton $\delta^{15}N$values reflected input from spawning salmon. Juvenile sockeye and other resident fish showed shifts in marine-derived nitrogen between years of high and low escapements.

Kline, T. C.,Jr., J. J. Goering, O. A. Mathisen, P. H. Poe, and P. L. Parker. 1990. Recycling of elements transported upstream by runs of Pacific salmon: I. $\delta^{15}N$ and $\delta^{13}C$ evidence in Sashin Creek, southeastern Alaska. Can. J. Fish. Aquat. Sci. 47: 136-144.

In orer to determine the source of nitrogen and carbon in Sashin Creek, a stream which recieves an annual pink salmon run, the values of $\delta^{15}N$ and $\delta^{13}C$ in stream biota were measured. Marine-derived nitrogen was the predominant source of N for food webs in the portion of the stream available to returning salmon. Used isotope analysis in order to determine the proportion of marine-derived nutrients in stream periphyton, insects, rainbow trout and other fish.

Mathisen, O. A., P. L. Parker, J. J. Goering, T. C. Kline, P. H. Poe, and R. S. Scalan. Recycling of marine elements transported into freshwater systems by anadromous salmon. Verh. Internat. Verein. Limnol. 23: 2249-2258.

Investigated whether marine-derived nitrogen transported from the sea to freshwater by salmon escapements was traceable to different trophic levels and enhanced system fertility. Found that the unspawned adult sockeye has a nitrogen concentration of 2.67% whereas spawned-out sockeye had a concentration of 2.31%. The phosphorus concentration in unspawned sockeye was 0.485% and in spawned-out sockeye was 0.434%. Compared the δ^{15}N values for adult sockeye, sculpins, sticklebacks, charr, rainbow trout, juvenile sockeye, sediment, and periphyton from Iliamna Lake and a control lake. Concluded that the probable path of use of marine-derived nutrients was from carcass to periphyton and then to feeding salmon fry the following spring.

Carbon Sources-Terestrial versus In-situ

Angradi, T. R. 1994. Trophic linkages in the lower Colorado River: multiple stable isotope evidence. J. N. Am. Benthol. Soc. 13: 479-495.

Studied the trophic linkages in the Glen and Grand Canyons of the lower Colorado River using multiple stable isotope analysis. The δ^{13}C , δ^{15}N, and δ^{34}S values of seston, aquatic and terrestrial plants, and aquatic animals were determined. Isotope analysis revealed three trophic levels in Glen Canyon: algae, macroinvertebrates, and fish which were primarily rainbow trout. For Grand Canyon, the isotope values of fish showed a variation in trophic levels. In one tributary the fish population appeared to be supported by autochthonous production and others were linked to riparian matter inputs.

Araujo-Lima, C. A. R., B. R. Forsberg, R. Victoria, and L. Martinelli. 1986. Energy sources for detritivorous fishes in the Amazon. Science 234: 1256-1258.

Investigated the carbon source for detritivorous fishes in the Amazon basin. Stable isotope data indicated that Characiformes species received most of their carbon through food chains originating with phytoplankton, while the Siluriformes received a significant part of their energy from other plant sources.

Bilby, R. E., and P. A. Bisson. 1992. Allochthonous versus autochthonous organic matter contributions to the trophic support of fish populations in clear-cut and old-growth forested streams. Can. J. Fish. Aquat. Sci. 49: 540-551.

Not a stable isotope study. Studied the annual organic matter inputs and production of coho salmon, cutthroat trout, and shorthead sculpin in a clear-cut and a old-growth forested tributaries of the Deschutes River, Washington. Although the combined allochthonous and autochthonous inputs were almost twofold greater in the old-growth site, fish production was greater at the clear-cut site. Concluded that fish populations appeared to depend upon food derived from autotrophic pathways during the spring and summer in the presence or absence of forest canopy.

Bunn, S. E., D. R. Barton, H. B. N. Hynes, G. Power, and M. A. Pope. 1989. Stable isotope analysis of carbon flow in a tundra river system. Can. J. Fish. Aquat. Sci. 46: 1769-1775.

Stable isotope analysis was used to identify the major sources of carbon utilized by fish and aquatic invertebrates in the Koroc River. Terrestrial organic matter wat the most likely source of energy fueling the animal communities in the tributary streams and the rapids of the mainstem of the river. In conrast, epilithic algae made a significant contribution to food chains within Alik Lake.

Estep, M. L., and S. Vigg. 1985. Stable carbon and nitrogen isotope tracers of trophic dynamics in natural populations and fisheries of the Lahontan Lake system, Nevada. Can. J. Fish. Aquat. Sci. 42: 1712-1719.

Used stable isotope ratios of carbon and nitrogen as indicators of food source and trophic dynamics in the Lahontan Lake system. Studied the isotope ratios of different levels of the food web: phytoplankton, zooplankton, benthic invertebrates, and fish. Found that hatchery-reared and wild cutthroat trout had different food sources and different isotope ratios.

Fry, B., and E. B. Sherr. 1984. $\delta^{13}C$ measurements as indicators of carbon flow in marine and freshwater ecosystems. Contribributions in Marine Science 27: 13-47.

Review of papers on the use of stable carbon isotopes $\delta^{13}C$ and $\delta^{12}C$ as tracers in coastal ecosystems. Focused on the origins of sedimentary and suspended organic matter in coastal ecosystems and the relative importance of various plants as foods for consumers in aquatic food webs. Evaluated stable isotopes as food/energy source indicators.

Hall, R. O., Jr. 1995. Use of a stable carbon isotope addition to trace bacterial carbon through a stream food web. J. N. Am. Benthol. Soc. 14: 269-277.

Assessed the use of bacterial carbon by stream invertebrates by dripping ^{13}C into a headwater spring a Coweeta Hydrologic Laboratory. Bactivory by stream insects was assessed by measuring their $\delta^{13}C$ values.

Hamilton, S. K., W. M. Lewis, Jr., and S. J. Sippel. 1992. Energy sources for aquatic animals in the Orinoco River floodplain: evidence from stable isotopes. Oecologia 89: 324-330.

Measurements of the stable carbon and nitrogen isotope ratios in autotrophs, aquatic invertebrates, and fishes from the Orinoco River floodplain revealed that microalgae, including phytoplankton and epiphytic forms were the predominant energy source for many aquatic animals even though aquatic vascular plants were more abundant.

Hesslein, R. H., M. J. Capel, D. E. Fox, and K. A. Hallard. 1991. Stable isotopes of sulphur, carbon, and nitrogen as indicators of trophic level and fish migration in the lower Mackenzie River basin, Canada. Can. J. Fish. Aquat. Sci. 48: 2258-2265.

Studied the stable isotope ratios of fish, invertebrates, and plants in order to investigate the incorporation of nutrients into the food chain and to determine the influence of migration on the nutritional origins of fish in two freshwater systems.

Junger, M., and D. Planas. 1994. Quantitative use of stable carbon isotope analysis to determine the trophic base of invertebrate communites in a boreal forest lotic system. Can. J. Fish. Aquat. Sci. 51: 52-61.

Used stable carbon isotope ratios and inventories of macroinvertebrate biomass in order to assess the the trophic base of three contrasting lotic ecosystems in a boreal forest ecosystem. Found that the food base was dominated by lacustrine inputs in the lake outlet, by terrestrially-derived inputs in the partially shaded stream, and by autochthonous production in the unshaded stream.

Lester, P. J., S. F. Mitchell, D. Scott, and G. L. Lyon. 1995. Utilisation of willow leaves, grass and periphyton by stream macroinvertebrates: a study using stable carbon isotopes. Arch. Hydrobiol. 133: 149-159.

In order to determine the importance of willow leaves as a food sypply in two New Zealand streams, natural carbon isotopes were examined in stream invertebrates and their potential foods. Results showed that allochthonous material played an important role in energy flow.

Minshall, G. W. 1978. Autotrophy in stream ecosystems. Bioscience 28: 767-771.

Not an isotope study. Presented evidence that in a number of streams autotrophic production was the major or the only source of energy supplied to the system. Also argued that primary production plays an important role in streams which were previously assumed to have a terrestrially-derived carbon source.

Peterson, B. J., and B. Fry. 1987. Stable isotopes in ecosystem studies. Ann. Rev. Ecol. Syst. 18: 293-320.

Review which provided an explanation of isotope terminology and fractionation, summarized isotopic distributions in the C, N, S biogeochemical cycles, and described five case studies.

Peterson, B. J., J. E. Hobbie, and T. L. Corliss. 1986. Carbon flow in a tundra stream ecosystem. Can. J. Fish. Aquat. Sci. 43: 1259-1270.

Not an isotope study. Found that the carbon cycle of the Kuparuk River was dominated by inputs of eroding peat and leaching dissolved organic carbon from the tundra. Net production of epilithic algae was an order of magnitude less than inputs of allochthonous particulate organic carbon and two orders of magnitude less than inputs of dissolved organic carbon.

Rau, G. H. 1980. Carbon-13/carbon-12 variation in subalpine lake aquatic insects: food source implications. Can. J. Fish. Aquat. Sci. 37: 742-746.

Investigated the carbon-13 ratios of periphyton, plankton, and conifer tree detritus, the three primary organic carbon sources for aquatic insects. Measured the isotope ratios of the insects in order to determine which carbon source they were utilizing. Found that 38% of the 51 kg C of insect biomass annually emerging from Findlely Lake was estimated to originate from terrestrial plant sources.

Rosenfeld, J. S., and J. C. Roff. 1992. Examination of the carbon base in southern Ontario streams using stable isotopes. J. N. Am. Benthol. Soc. 11: 1-10.

Investigated the dependence of the invertebrate and fish community on terrestrial versus aquatic carbon sources. Carbon isotope ratios at the unforested sites showed a dependence of invertebrates on primarily autochthonous C, but at forested sites they found that invertebrates were dependent on algal C. Fish appeared to derive more carbon from terrestrial sources than aquatic invertebrates at both the forested and unforested sites.

Rounick, J. S., and B. J. Hicks. 1985. The stable carbon isotope ratios of fish and their invertebrate prey in four New Zealand rivers. Freshwater Biology 15: 207-214.

Analyzed the stable isotope ratios of carbon sources utilized by invertebrates and fish four New Zealand streams. Found that invertebrates in open sites used algae and in shaded reaches the utilized more carbon of terrestrial origin. Fish at all sites had isotope ratios which were more similar to terrestrial carbon sources.

Rounick, J. S., and M. J. Winterbourn. 1986. Stable carbon isotopes and carbon flow in ecosystems. Bioscience 36: 171-177.

Review which discussed measuring stable carbon isotopes and presented examples from terrestrial ecosystems, inland waters, and marine and estuarine ecosystems.

Rounick, J. S., M. J. Winterbourn, and G. L. Lyon. 1982. Differential utilization of allochthonous and autochthonous inputs by aquatic invertebrates in some New Zealand streams: a stable carbon isotope study. Oikos 39: 191-198.

Used stable carbon isotope analysis in order to study energy utilization by benthic invertebrates from some New Zealand streams. Found that the biota of forested streams depended primarily on allochthonous carbon sources whereas species from a grassland stream utilized both allochthonous and autochthonous materials.

Winterbourn, M. J., and J. S. Rounick. 1985. Benthic faunas and food resources of insects in small New Zealand streams subjected to different forestry practices. Verh. Internat. Verein. Limnol. 22: 2148-2152.

Studied the food of some common insects and the invertebrate communities in streams draining 6 catchments modified to different degrees by deforestation. Collected benthos, analyzed gut contents of insects, and measured carbon isotope ratios of stream animals and organic matter.

Winterbourn, M. J., B. Cowie, and J. S. Rounick. 1984. Food resources and ingestion patterns of insects along a West Coast, South Island, river system. New Zealand Journal Marine Freshwater Research 18: 43-51.

Studied food utilization by benthic insect larvae at 6 sites along a West Coast, South Island river system by gut content and stable carbon isotope analysis.

Winterbourn, M. J., J. S. Rounick, and A. G. Hildrew. 1986. Patterns of carbon resource utilization by benthic invertebrates in two British river systems: a stable carbon isotope study. Arch. Hydrobiol. 3: 349-361.

Stable carbon isotope ratios were determined for aquatic invertebrates and their potential foods in streams. Found that animals were using a greater range of carbon resources and more autochthonous materials at more open sites.

<u>Stream Fertilization Experiments</u>

Studies on the Kuparuk River, Alaska

Bioassay Experiments

Bowden, W. B., B. J. Peterson, J. C. Finlay, and J. Tucker. 1992. Epilithic chlorophyll *a,* photosynthesis, and respiration in control and fertilized reaches of a tundra stream. Hydrobiologia 240: 121-131.

Miller, M. C., P. DeOliveira, and G. G. Gibeau. 1992. Epilithic diatom community response to years of PO_4 fertilization: Kuparuk River, Alaska (68 N Lat.). Hydrobiologia 240: 103-119.

Peterson, B. J., J. E. Hobbie, and T. L. Corliss. 1983. A continuous-flow periphyton bioassay: tests of nutrient limitation in a tundra stream. Limnol. Oceanogr. 28: 583-591.

Effects of Fertilization on Algae

Peterson, B. J., J. E. Hobbie, A. E. Hershey, M. A. Lock, T. E. Ford, J. R. Vestal, V. L. McKinley, M. A. J. Hullar, M. C. Miller, R. M. Ventullo, and G. S. Volk. 1985. Transformation of tundra river from heterotrophy to autotrophy by addition of phosphorus. Science 229: 1383-1386.

Effects of Fertilization on both Algae and Aquatic Invertebrates

Hershey, A. E., A. L. Hiltner, M. A. J. Hullar, M. C. Miller J. R. Vestal, M. A. Lock, and S. Rundle. 1988. Nutrient influence on a stream grazer: *Orthocladius* microcommunities respond to nutrient input. Ecology 69: 1383-1392.

Hershey, A. E., and A. L. Hiltner. 1988. Effect of a caddisfly on black fly density: interspecific interactions limit black flies in an arctic river. J. N. Am. Benthol. Soc. 7: 188-196.

Hiltner, A. L., and A. E. Hershey. 1992. Black fly (*Diptera: Simuliidae*) response to phosphorus enrichment of an arctic tundra stream. Hydrobiologia 240: 259-265.

Effects of Fertilization on Aquatic Invertebrates

Hershey, A. E., J. Pastor, B. J. Peterson, and G. W. Kling. 1993. Stable isotopes resolve the drift paradox for *Baetis* mayflies in an arctic river. Ecology 74: 2315-2325.

Hinterleitner-Anderson, D., A. E. Hershey, and J. A. Schuldt. 1992. The effects of river fertilization on mayfly (*Baetis* sp.) drift patterns and population density in an arctic river. Hydrobiologia 240: 247-258.

Effects of Fertilization on Algae, Aquatic Invertebrates, and Fish

Peterson, B., B. Fry, and L. Deegan. 1993. The trophic significance of epilithic algal production in a fertilized tundra river ecosystem. Limnol. Oceanogr. 38: 872-878.

Peterson, B. J., L. Deegan, J. Helfrich, J. E. Hobbie, M. Hullar, B. Moller, R. E. Ford, A. Hershey, A. Hiltner, G. Kipphut, M. A. Lock, D. M. Fiebig, V. McKinley, M. C. Miller, J. R. Vestal, R. Ventullo, and G. Volk. 1993. Biological responses of a tundra river to fertilization. Ecology 74: 653-672.

Effects of Fertilization on Fish

Deegan, L. A., and B. J. Peterson. 1992. Whole-river fertilization stimulates fish production in an arctic tundra river. Can. J. Fish. Aquat. Sci. 49: 1890-1901.

Effects of Fertilization on Bryophytes

Bowden, W. B., J. C. Finlay, and P. E. Maloney. 1994. Long-term effects of PO_4 fertilization on the distribution of bryophytes in an arctic river. Freshwater Biology 32: 445-454.

Finlay, J. C., and W. B. Bowden. 1994. Controls on production of bryophytes in an arctic tundra stream. Freshwater Biology 32: 455-466.

Studies on the Keogh River, British Columbia

Effects of Fertilization on Algae

Perrin, C. J., M. L. Bothwell, and P. A. Slaney. 1987. Experimental enrichment of a coastal stream in British Columbia: Effects of organic and inorganic additions on autotrophic periphyton production. Can. J. Fish. Aquat. Sci. 44: 1247-1256.

Effects of Fertilization on Algae, Aquatic Invertebrates, and Fish

Johnston, N. T., C. J. Perrin, P. A. Slaney, and B. R. Ward. 1990. Increased juvenile salmonid growth by whole-river fertilization. Can. J. Fish. Aquat. Sci. 47: 862-872.

Slaney, P. A., C. J. Perrin, and B. R. Ward. 1986. Nutrient concentration as a limitation to steelhead smolt production in the Keogh River. Proc. Annu. Conf. West. Assoc. Fish. Wildl. Agencies 66: 146-157.

Studies on Carnation Creek, British Columbia

Effects of Fertilization on Algae

Stockner, J. G. and K. R. S. Shortreed. 1978. Enhancement of autotrophic production by nutrient addition in a coastal rainforest stream on Vancouver Island. J. Fish. Res. Board Can. 35: 28-34.

Effects of Fertilization on Algae and Aquatic Invertebrates

Mundie, J. H., K. S. Simpson, and C. J. Perrin. 1991. Responses of stream periphyton and benthic insects to increases in dissolved inorganic phosphorus in a mesocosm.. Can. J. Fish. Aquat. Sci. 48: 2061-2072.

Studies on Miscellaneous Streams and Rivers

Bioassay Experiments

Pringle, C. M. 1987. Effects of water and substratum nutrient supplies on lotic periphyton growth: an intergrated bioassay. Can. J. Fish. Aquat. Sci. 44: 619-629.

Effects of Fertilization on Algae

Bothwell, M. L. 1988. Growth rate responses of lotic periphytic diatoms to experimental phosphorus enrichment: the influence of temperature and light. Can. J. Fish Aquat. Sci. 45: 261-270.

Manuel-Faler, C., G. Wayne Minshall, R. W. Dunn, D. A. Bruns.1984. In situ nitrogen enrichment exepriments in two Idaho (USA) streams. Environmental Monitoring and Assessment 4: 67-79.

Slaney, P. A., B. O. Rublee, C. J. Perrin, and H. Goldberg. 1994. Debris structure placements and whole-river fertilization for salmonids in a large regulated stream in British Columbia. Bull. Mar. Sci. 55: 1160-1180.

Stevenson, R. J., C. G. Peterson, D. B. Kirshtel, C. C. King, and N. C. Tuchman. Density-dependent growth, ecological strategies, and effects of nutrients and shading on benthic diatom succession in streams. J. Phycol. 27: 59-69.

Effects of both Fertilization and Grazing on Algae

Biggs, B. J. F., and R. L. lowe. 1994. Responses of two trophic levels to patch enrichment along a New Zealand stream continuum. New Zealand Journal of Marine and Freshwater Research 28: 119-134.

McCormick, P. W. 1994. Evaluating the multiple mechanisms underlying herbivore-algal interactions in streams. Hydrobiologia 291: 47-59.

Pan, Y., and R. L. Lowe. 1994. Independent and interactive effects of nutrients and grazers on benthic algal community structure. Hydrobiologia 291: 201-209.

Winterbourn, M. J. and F. A. 1989. Effects of nutrient enrichment and grazing on periphyton assemblages in some spring-fed, South Island streams. New Zealand Natural Sciences 16: 57-65.

Effects of Fertilization on Algae and Aquatic Invertebrates

Elwood, J. W., J. D. Newbold, A. F. Trimble, and R. W. Stark. 1981. The limiting role of phosphorus in a woodland stream ecosystem: effects of P enrichment on leaf decomposition and primary producers. Ecology. 62: 146-158.

Hart, D. D., and C. T. Robinson. 1990. Resource limitation in a stream community: phosphorus enrichment effects on periphyton and grazers. Ecology 71: 1494-1502.

Hill, W. R., and A. W. Knight. 1988. Nutrient and light limitation of algae in two northern California streams. J. Phycol. 24: 125-132.

Effects of Fertilization on Aquatic Invertebrates

Mundie, J. H., D. E. Munce, and L. E. Smith. 1973. Observations on the response of zoobenthos to additions of hay, willow leaves, alder leaves and cereal grain to stream substrates. Fish. Res. Board of Can. Tech. Rep. No. 387: 123p.

Mundie, J. H., S. M. Mckinnell, and R. E. Traber. 1983. Responses of stream zoobenthos to enrichment of gravel substrates with cereal grain and soybean. Can. J. Fish. Aquat. Sci. 40: 1702-1712.

Effects of Fertilization on Algae and Fish

Huntsman, A. G. 1948. Fertility and fertilization of streams. J. Fish. Res. Board Can. 7: 248-253.

Effects of Fertilization on Fish

Bergheim A., and T. Hesthagen. 1990. Production of juvenile Atlantic salmon, *Salmo salar* L., and brown trout, *Salmon trutta* L., within different sections of a small enriched Norwegian river. J. Fish. Biol. 26: 545-562.

Mason, J. C. 1976. Response of underyearling coho salmon to supplemental feeding in a natural stream. Journal of Wildlife Management 40: 775-788.

Warren, C. E., J. H. Wales, G. E. Davis, and P. Doudoroff. 1964. Trout production in an experimental stream enriched with sucrose. Journal of Wildlife Management 28: 617-660.

Effects of Fertilization on Bryophytes

Steinman, A. D. 1994. The influence of phosphorus enrichment on lotic bryophytes. Freshwater Biology 31: 53-63.

<u>Lake Fertilization Experiments</u>

Studies on Lake Anjan, Sweden

Effects of Fertilization on Phytoplankton, Zooplankton, Aquatic Invertebrates, and Fish

Milbrink, G., and S. Holmgren. 1981. Addition of artificial fertilizers as a means of reducing negative effects of "oligotrophication" in lakes after impoundment. Institute of Freshwater Research, Drottingholm Rept. 59: 97-120.

Milbrink, G., and S. Holmgren. 1981. Fish Species interactions in a fertilized reservoir. Institute of Freshwater Research, Drottingholm Rept. 59: 121-127.

Milbrink, G., and S. Holmgren. 1988. Nutrient enrichment and increase in fish growth. Verh. Internat. Verein. Limnol. 23: 1730-1736.

Milbrink, G., and S. Holmgren. 1984. Restoration of charr populations in impounded lakes in Scandinavia by locally applied fertilization. Pages 493-508 *in* L. Johnson and B. L. Burns, eds.

Biology of the Arctic Charr, Proceedings of the International Symposium on Arctic Charr, Winnipeg, Manitoba, May 1981. Univ. Manitoba Press, Winnipeg.

Studies on Bare Lake, Alaska

Effects of Fertilization on Phytoplankton and Zooplankton

Nelson, P. R., and W. T. Edmondson. 1955. Limnological effects of fertilizing Bare Lake, Alaska. Fish. Bull. (U.S.) 56: 413-436.

Effects of Fertilization on Phytoplankton, Zooplankton, and Fish

Kyle, G. B. 1994. Assessment of trophic-level responses and coho salmon (*Oncorhynus kisutch*) production following nutrient treatment. Fisheries Research 20: 243-261.

Nelson, P. R. 1958. Effects of fertilizing Bare Lake, Alaska, on growth and production of red salmon (*O. nerka*). Fish. Bull. (U.S.) 60: 59-86.

Nelson, P. R. 1958. Relationship between rate of photosynthesis and growth of juvenile red salmon. Science 128: 205-206.

Studies in the Experimental Lakes Area, Ontario

Effects of Fertilization on Phytoplankton

Findlay, D. L., and S. E. M. Kasian. 1987. Phytoplankton community responses to nutrient addition in Lake 226, Experimental Lakes Area, northwestern Ontario. Can. J. Fish. Aquat. Sci. 44: 35-46.

Shearer, J. A., E. J. Fee, E. R. DeBruyn, and D. R. DeClerq. 1987. Phytoplankton productivity changes in a small, double-basin lake in response to termination of experimental fertilization. Can. J. Fish. Aquat. Sci. 44: 47-54.

Effects of Fertilization on Phytoplankton and Zooplankton

Malley, D. F., P. S. S. Chang, and D. W. Schindler. 1988. Decline of zooplankton populations following eutrophication of Lake 227, Experimental Lakes Area, Ontario: 1969-1974. Can. Tech. Rep. Fish. Aquat. Sci. 1619: 25p.

Effects of Fertilization on Phytoplankton, Zooplankton, and Lake Whitefish

Mills, K. H. 1985. Responses of lake whitefish (*Coregonus clupeaformis*) to fertilization of Lake 226, the Experimental Lakes Area. Can. J. Fish. Aquat. Sci. 42: 129-138.

Effects of Fertilization on Lake Whitefish

Mills, K. H., and S. M. Chalanchuk. 1987. Population dynamics of lake whitefish (*Coregonus clupeaformis*) during and after the fertilization of Lake 226, the Experimental Lakes Area. Can. J. Fish. Aquat. Sci. 44: 55-63.

Studies on Flathead Lake, Montana

Bioassay Experiment: Effects on Phytoplankton

Dodds, W. K., and J. C. Priscu. 1990. A comparison of methods for assessment of nutrient deficiency of phytoplankton in a large oligotrophic lake. Can. J. Fish. Aquat. 47: 2328-2338.

Enclosure Experiment: Effects on Phytoplankton and Zooplankton

Dodds, W. K., and J. C. Priscu. 1990. Mesocosm studies on the influence of phosphate enrichment on ammonium and nitrate flux in an oligotrophic lake. Hydrobiologia 206: 235-243.

Studies on Great Central Lake, British Columbia

Effects of Fertilization on Phytoplankton, Zooplankton, and Sockeye Salmon

LeBrasseur, R. J., C. D. McAllister, W. E. Barraclough, O. D. Kennedy, J. Manzer, D. Robinson, and K. Stephens. 1978. Enhancement of sockeye salmon (*Oncorhynchus nerka*) by lake fertilization in Great Central Lake: summary report. J. Fish. Res. Board Can. 35: 1580-1596.

Parsons, T. R., C. D. McAllister, R. J. LeBrasseur, and W. E. Barraclough. 1972. The use of nutrients in the enrichment of sockeye salmon nursery lakes (a preliminary report). Pages 519-525 *in* M Ruivo, ed. Marine Pollution and Sea Life. Fishing News (Books), London.

Effects of Fertilization on Zooplankton and Sockeye Salmon

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Effects of Fertilization on Sockeye Salmon

LeBrasseur, R. J., C. D. McAllister, and T. R. Parsons. 1979. Addition of nutrients to a lake leads to greatly increased catch of salmon. Environmental Conservation 6: 187-190.

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Robinson, D. G., W. E. Barraclough. 1978. Population estimates of sockeye salmon (*Oncorhynchus nerka*) in a fertilized oligotrophic lake. J. Fish. Res. Board Can. 35: 851-860.

Studies in the Kuokkel Area, Sweden

Effects of Fertilization on Algae

Bjork-Ramberg, S., and C. Anell. 1985. Production and chlorophyll concentration of epipelic and epilithic algae in fertilized and nonfertilized subarctic lakes. Hydrobiologia 126: 213-219.

Holmgren, S. K. 1984. Experimental lake fertilization in the Kuokkel area, northern Sweden. Phytoplankton biomass and algal composition in natural and fertilized subarctic lakes. Int. Revue ges. Hydrobiol. 69: 781-817.

Studies on Lake Okaro, New Zealand

Bioassay Experiment: Effects on Phytoplankton

Lean, D.R.S., F. R. Pick, S. F. Mitchell, M. T. Downes, P. H. Woods, and E. White. 1989. Lake Okaro enclosure experiments: test ecosystems to evaluate plankton phosphorus and nitrogen deficiency. Ergebn. Limnol. 32: 195-211.

Enclosure Experiment: Effects on Phytoplankton

Mitchell, S. F. 1989. Responses of the zooplankton to nutrient enrichment of large enclosures in Lake Okaro, New Zealand. Ergebn. Limnol. 32: 189-193.

Studies on the lakes at Saqvaqjuac, N.W.T.

Effects of Fertilization on Phytoplankton

Welch, H. E., J. A. Legault, and H. J. Kling. 1989. Phytoplankton, nutrients, primary production in fertilized and natural lakes at Saqvaqjuac, N.W.T. Can. J. Fish. Aquat. Sci. 46: 90-107.

Effect of Fertilization on Macrobenthos

Jorgenson, J. K., H. E. Welch, and M. F. Curtis. 1992. Response of amphipoda and trichoptera to lake fertilization in the Canadian Arctic. Can. J. Fish. Aquat. Sci. 49: 2354-2362.

Studies on Sproat Lake, British Columbia

Effect of Fertilization on Phytoplankton

Shortreed, K. S., and J. G. Stockner. 1990. Effect of nutrient additions on lower trophic levels of an oligotrophic lake with a seasonal deep chlorophyll maximum. Can. J. Fish. Aquat. Sci. 47: 262-273.

Suttle, C. A., W. P. Cochlan, and J. G. Stockner. 1991. Size-dependent ammonium and phosphate uptake, and N: P supply ratios in an oligotrophic lake. Can. J. Fish. Aquat. Sci. 48: 1226-1234.

Studies at the Toolik Lake Long Term Ecological Research (LTER) Site, Alaska

Effects of Fertilization on Microplankton

Rublee, P. A. 1992. Community structure and bottom-up regulation of heterotrophic microplankton in arctic LTER Lakes. Hydrobiologia 240: 133-141.

Effects of Fertilization on Benthic Macroinvertebrates

Hershey, A. 1992. Effects of experimental fertilization on the benthic macroinvertebrate community of an arctic lake. J. N. Am. Benthol. Soc. 11: 204-217.

Enclosure Experiment: Effects of Fertilization on Phytoplankton, Zooplankton, Benthic Community, and Fish

O'Brien, N. J., A. E. Hershey, J. E. Hobbie, M. A. Hullar, G. W. Kipphut, M. C. Miller, B. Moller, and J.R. Vestal. 1992. Control mechanisms of arctic lake ecosystems: a limnocorral experiment. Hydrobiologia 240: 143-188.

Studies which Compare Several Lake Fertilization Experiments

Effects of Fertilization on Phytoplankton

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Stockner, J. G., and K.S. Shortreed. 1985. Whole-lake fertilization experiments in coastal British Columbia lakes: empirical relationships between nutrient inputs and phytoplankton biomass and production. Can. J. fish. Aquat. Sci. 42: 649-658.

Stockner, J. G., K. S. Shortreed, and K. Stephens. 1980. The British Columbia lake fertilization program: Limnological results from the first 2 years of nutrient enrichment. Can. Tech. Rep. Fish. Aquat. Sci. 924: 91p.

Effects of Fertilization on Algae, Zooplankton, Sockeye Salmon, and other Fish

Hyatt, K. D., and J. G. Stockner. 1985. Responses of sockeye salmon (*Oncorhynchus nerka*) a fertilization British Columbia coastal lakes. Can. J. Fish. Aquat. Sci. 42: 320-331.

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Walters, C. J., E. Krause, W. E. Neill, and T. G. Northcote. 1987. Equilibrium models for seasonal dynamics of plankton biomass in four oligotrophic lakes. Can. J. Fish. Aquat. Sci. 44: 1002-1017.

Evaluation of the Salmon Enhancement Program

Guthrie, I. C., and R. M. Peterman. 1988. Economic evaluation of lake enrichment strategies for British Columbia sockeye salmon. North American Journal of Fisheries Management 8: 442-454.

Hilborn, R., and J. Winton. 1993. Learning to enhance salmon production: lessons from the Salmonid Enhancement Program. Can. J. Fish. Aquat. Sci. 50: 2043-2056.

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