CURRENT LITERATURE ON THE DIET, IMPORTANCE OF PREY SIZE, AND THE USE OF BIOENERGETIC MODELS FOR PREDICTING GROWTH AND CONSUMPTION OF PREY FOR YOUNG COHO AND CHINOOK SALMON

Carrie Cook

U.S. Fish and Wildlife Service

Western Washington Fishery Resource Office

Olympia, Washington

October 5, 1992

THE DIET AND IMPORTANCE OF PREY SIZE FOR JUVENILE COHO AND CHINOOK SALMON IN FRESH AND SALTWATER

INTRODUCTION

The diet and size of prey items eaten by young salmonids has been studied extensively. Information on the amount, type, locality, and time of predation in freshwater and saltwater is especially abundant for young sockeye salmon in lakes (Eggers 1980; Graynoth et al. 1986; Jaenicke et al. 1987; Kurenkov 1989; Morton and Williams 1990; O'Neill and Hyatt 1987; Stockner and Shortreed 1989), coho and chinook in coastal seawaters (Birtwell et al. 1984; Brodeur et al. 1987; Brodeur and Pearcy 1990; Emmett et al. 1986; Healey 1981; Karpenko and Piskunova 1984; Levings 1982; Levings et al. 1991; Novotny et al. 1986; Paul 1982; Peterson et al. 1982; Raymond et al. 1985; Wolf et al. 1983), and coho and chinook salmon in rivers (Brown et al. 1987; Lloyd et al. 1987; Peterman 1987; Sagar and Glova 1987; 1988). Information on the saltwater diet of Japanese chum salmon (Kasakara 1985; Terazaki and Iwata 1983) and chum originating from North American rivers is also extensive (Simenstad and Salo 1982).

Ware (1972) looked at the influence of hunger, prey density and prey size on predation by rainbow trout and Beauchamp (1990) investigated the seasonal and diel food habits of rainbow trout in Lake Washington. Not much has been studied and/or found in the literature on the diet and importance of prey size of

juvenile chinook and coho in lakes and reservoirs (Mauser et al. 1989).

DIET OF JUVENILE COHO AND CHINOOK SALMON IN RIVERS

Sagar (1988) found that the common drift and invertebrate prey consumed by a riverine population of young chinook salmon contained Deleatidium spp., Chironomidae, Aoteapsyche spp., and Hydrobiosis frater. Sagar and Glova (1987) observed juvenile chinook salmon selectively preying on Deleatidium spp., chironomids, and trichopterans.

DIET OF JUVENILE COHO AND CHINOOK SALMON IN COASTAL SEAWATERS

Brodeur and Pearcy (1990), Emmett et al. (1986), and Peterson et al. (1982) found that the diet of chinook and coho salmon off the North Oregon and Southern Washington coasts contained mostly larval and juvenile fishes, euphasiids, crab larvae, Pandalas jordani, Atylus tridens, calanoid, copepods, Hyperiid amphipods, Limacina sp., and Thysanoessa spinifera. Smith (1988) stresses the importance of zooplankton as a food base for smolts.

Brown et al. (1987) and Raymond et al. (1985) and found that the common prey species for juvenile salmon in the Campbell River Estuary were copepods, Calanoids, amphipods, harpacticoids, mysids, aquatic and terrestrial insects, planktonic crustaceans and cladocerans. Levings (1982) also studied the diet of young chinook salmon (average length of 42-55mm) in an estuary and

found that the salmon preyed upon adult insects, cumaceans, and Neomysis mercedis. While the fish preyed mostly upon these food items there were many more organisms potentially available as a food source. Brodeur (1992) also noticed that juvenile coho and chinook salmon were not fully utilizing the food base in their surroundings. He found that the feeding intensity of coho and chinook salmon in near-shore surface waters (<65m depth) off Washington and Oregon was not significantly related to the total water column zooplankton volume or species composition. In contrast, Birtwell et al. (1984) found the diet of coho and chinook generally reflected the composition of benthic invertebrate communities at the site of capture. Healey (1981) believes the diet of juvenile salmon in estuaries reflects a mixture of preference and availability, and the differences in prey eaten by young salmonids is due to significant variability in available food between years and between estuaries.

Paul (1982) has written a reference book containing illustrations and reports of the common marine prey eaten by salmon fry.

DIET OF JUVENILE COHO AND CHINOOK SALMON IN LAKES AND RESERVOIRS

As mentioned earlier, not much is in the literature regarding the diet of juvenile wild chinook and coho salmon in lakes and reservoirs. The few references found include Hard (1986). He found young chinook salmon in lakes to prefer large zooplankton over benthic invertebrates and cladocerans. Novotny

et al. (1986) reared fall chinook salmon in pens in the John Day reservoir and looked at the available natural foods in the reservoir for penned salmon. The fish with supplemental feeding exhibited good growth while unfed penned salmon did not due to insufficient zooplankton densities.

IMPORTANCE OF PREY SIZE

Sagar and Glova (1988) found that young chinook salmon (average mean length of 64mm) of a riverine population exhibited size selective predation, consuming larger zooplankton during the day and smaller ones at twilight. English (1983) looked at juvenile chinook salmon (average mean length of 86mm) in "in situ" enclosures in the ocean. He found an appearance of a significant relationship between growth and the abundance of larger zooplankters (>3.0mm) while fish growth rates did not appear to be related to the abundance of small zooplankton (<1.4mm). Brodeur (1991) looked at the stomach contents of purse seined chinook and coho salmon off the coast of Washington nd Oregon and found a direct relationship between predator and prey size for both coho and chinook and that there was a general trend toward increased consumption of fish with increasing body size. As mentioned above, Hard (1986) found that planted age-0 chinook salmon (average mean length of 52.4mm) in two lakes in southeastern Alaska preferred and ate large zooplankton and grew rapidly during the first three weeks. However, growth rates declined markedly when large zooplankton disappeared from both

lakes and the fish began to primarily eat benthic invertebrates and cladocerans.

On the other hand, Brodeur (1992) found the feeding intensity of juvenile chinook and coho salmon insignificantly related to the larger zooplankton (>5mm, the size fraction of zooplankton which corresponds to the minimum particle size generally consumed by juvenile coho and chinook salmon).

USE OF BIOENERGETIC MODELS FOR GROWTH AND CONSUMPTION OF PREY FOR YOUNG SALMONIDS

INTRODUCTION

A variety of ecological questions about fish growth, predator-prey interactions, and consumption have been answered using bioenergetics models of fish growth. The basic components of an energetic model include: energy intake (prey), growth, and waste (respiration, energy expended by swimming, and waste losses) (Glova and McInerney 1977; Maxine et al. 1989). One of the most common bioenergetic models used in the field of fisheries is "A Generalized Bioenergetics Model of Fish Growth for Microcomputers" by Hewett and Johnson 1987. This model has been used for a variety of fish species. Most of the applications of bioenergetics modeling found in the literature have been done on non-salmonids (Boisclair and Leggett 1989; Carline et al. 1984; Cochran and Rice 1982; Kitchell et al. 1977; Kitchell and Breck 1980; Lyons 1984; Rice et al. 1983; Rice and Cochran 1984). There are few references to juvenile salmonid bioenergetics.

JUVENILE SALMON BIOENERGETICS

The majority of bioenergetics work on juvenile salmonids has been done on chum salmon Oncorhynchus keta (Wissmar and Simenstad 1988), sockeye salmon Oncorhynchus nerka (Beauchamp et al. 1989, Levy 1990), and brown trout Salmo trutta (Mortensen 1985,

Preall and Ringler 1989). Wissmar and Simenstad (1988) looked at using a bioenergetics model to evaluate the growth of juvenile chum salmon during outmigration in an estuary. Very little has been done and/or found on the bioenergetics of juvenile coho salmon Oncorhynchus kisutch (Puckett and Dill 1985) and chinook salmon Oncorhynchus tshawytscha in lakes and reservoirs.

Some examples of how bioenergetic models may provide useful information are: in predicting the effects of foraging on prey communities by salmonids (Preall and Ringler 1989), in gaining information to determine the "optimal" mode of operating nursery ponds and estuaries (Umnov 1990), in predicting the prey attack distance of coho salmon when in the presence of a predator (Dill and Fraser 1984), and in developing a foraging time budget for territorial, nonterritorial, and floater fish (Puckett and Dill 1985).

BIBLIOGRAPHY

Beauchamp, D.A. 1990. Seasonal and diel food habits of rainbow trout stocked as juveniles in Lake Washington. Trans. Am. Fish. Soc. 119: 475-482.

Beauchamp, D.A., D.J. Stewart, and G.L. Thomas. 1989. Corroboration of a bioenergetics model for sockeye salmon. Trans. Am. Fish. Soc. 118: 597-607.

Birtwell, L.K., M. Wood, and D.K. Gordon. 1984. Fish diets and benthic invertebrates in the estuary of the Somass River, Port Alberni, British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. no. 1799. 58pp.

Boisclair, D., and W.C. Leggett. 1989. The importance of activity in bioenergetics models applied to actively foraging fishes. Can. J. Fish. Aquat. Sci. 46: 1859-1867.

Brodeur, R.D. 1991. Ontogenetic variations in the type and size of prey consumed by juvenile coho, Oncorhynchus kisutch, and chinook, O. tshawytscha, salmon. Environ. Biol. Fish. 30(3): 303-315.

1992. Factors related to variability in feeding intensity of juvenile coho salmon and chinook salmon. Trans. Am. Fish. Soc. 121(1): 104-114.

Brodeur, R.D., and W.G. Pearcy. 1990. Trophic relations of juvenile Pacific salmon off the Oregon and Washington coast. Fish. Bull. 88(4): 617-636.

Brodeur, R.D., B.C. Mundy, W.G. Pearcy, and R.W. Wisseman. 1987. Neustonic fauna in coastal waters of the Northeast Pacific: abundance, distribution, and utilization by juvenile salmonids. Publ. Or. State Univ. Sea Grant Coll. Program. 69pp.

Brown, T.J., C.D. McAllister, and B.A. Kask. 1987. Plankton samples in Campbell River and Discovery Passage in relation to juvenile chinook diets. Can. Manuscr. Rep. Fish. Aquat. Sci. no. 1915. 42pp.

Carline, R.F., B.L. Johnson, and T.J. Hall. 1984. Estimation and interpretation of proportional stock density for fish populations in Ohio impoundments. N. Amer. J. Fish. Manag. 4: 139-154.

Cochran, P.A., and J.A. Rice. 1982. A comparison of bioenergetics and direct field estimates of cumulative seasonal food consumption by largemouth bass (Micropterus salmoides). In: Gutshop '81: Fish Food Habits Studies, G. Cailliet and C. Simenstad. pp.88-96. Seattle, Washington Sea Grant.

Dill, L.M., and H.G. Fraser. 1984. Risk of predation and the feeding behavior of juvenile coho salmon (Oncorhynchus kisutch). Behav. Ecol. Sociobiol. 16(1): 65-71.

Eggers, D.M. 1980. Feeding ecology of Lake Washington juvenile sockeye salmon and the salmon enhancement problem. Proc. of a symposing on salmonid ecosystems of the north Pacific ocean. pp. 165-170.

Emmett, R.L., D.R. Miller, and T.H. Blahm. 1986. Food of juvenile chinook, Oncorhynchus tshawytscha, and coho, O. kisutch, salmon off the northern Oregon and southern Washington coasts, May-September 1980. Calif. Fish Game 72(1): 38-46.

English, K.K. 1983. Predator-prey relationships for juvenile chinook salmon, Oncorhynchus tshawytscha, feeding on zooplankton in "in situ" enclosures. Can. J. Fish. Aquat. Sci. 40(3): 287-297.

Glova, G.V., and J.E. McInerney. 1977. Critical swimming speeds of coho salmon (Oncorhynchus kisutch) fry to smolt stages in relation to salinity and temperature. J. Fish. Res. Board Can. 34: 151-154.

Graynoth, E., L.C. Bennett, and J.C. Pollard. 1986. Diet of landlocked sockeye salmon (Oncorhynchus nerka) and trout in the Waitaki lakes, New Zealand. N.Z. J. Mar. Freshwat. Res. 20(4): 537-549.

Hard, J.J. 1986. Production and yield of chinook salmon in two Alaskan lakes. Trans. Am. Fish. Soc. 115(2): 305-313.

Healey, M.C. 1981. Juvenile Pacific salmon in estuaries: The life support system. Estuaries 4(3): 285.
1991. Diets and feeding rates of juvenile pink, chum, and sockeye salmon in Hecate Strait, British Columbia. Trans. Am. Fish. Soc. 120(3): 303-318.

Hewett, S.W., and Johnson. 1987. A generalized bioenergetics model of fish growth for microcomputers. Univ. Wisc. Sea Grant Tech. Rep. WIS-SG-87-245: 47pp.

Jaenicke, H.W., M.S. Hoffman, and M.L. Dahlberg. 1987. Food habits of sockeye salmon (oncorhynchus nerka) fry and threespine stickleback (Gasterostreus aculeatus) in Lake Numavaugaluk, Alaska, and a strategy to improve sockeye salmon survival and growth, p. 161-175. In: Sockeye salmon (Oncorhynchus nerka) population biology and future management. Can. Spec. Publ. Fish Aquat. Sci. 96.

Karpenko, V.I., and L.V. Piskunova. 1984. Importance of macroplankton in the diet of joung salmons of genus Oncorhynchus (Salmonidae) and their trophic relationship in the Southwestern Bering Sea. J. Ichthyol. 24(5): 98-106.

Kasakara, K. 1985. Ecological studies on the chum salmon, Oncorhynchus keta fry and its surroundings in the coastal water of the Nemuro Strait in spring, 1984. Sci. Rep. Hokkaido Salm. Hatch. 39: 91-111.

Kitchell, J.F., D.J. Stewart, and D. Weininger. 1977. Applications of a bioenergetics model to yellow perch (Perka flavescens) and walleye (Stizostedion vitreum vitreum). J. Fish. Res. Board Can. 34: 1922-1935.

Kitchell, J.F., and J.E. Breck. 1980. Bioenergetics model and foraging hypothesis for sea lamprey (Petromyzon marinus). Can. J. Fish. Aqaut. Sci. 37: 2159-2168.

Kurenkov, I.I. 1989. The fertilization of lakes in Kamchatka. Can. Transl. Fish. Aquat. Sci. no. 5466. 8pp.

Levings, C.D. 1982. Short term use of a low tide refuge in a sandflat by juvenile chinook (Oncorhynchus tshawytscha), Fraser River estuary. Can. Tech. Rep. Fish. Aquat. Sci. no. 1111. 37pp.

Levings, C.D., K. Conlin, and B. Raymond. 1991. Intertidal habitats used by juvenile chinook chinook salmon (oncorhynchus tshwytscha) rearing in the north arm of the Fraser River Estuary. Mar. Pollut. Bull. 22(1): 20-26.

Levy, D.A. 1990. Reciprocal diel vertical migration behavior in planktivores and zooplankton in British Columbia lakes. Can. J. Fish. Aquat. Sci. 47(9): 1755-1764.

1990. Sensory mechanism and selective advantage for diel vertical migration in juvenile sockey salmon (oncorhynchus nerka). Can. J. Fish. Aquat. Sci. 47: 1796-1802.

Lloyd, D.S., J.P. Koenings, and J.D. Perriere. 1987. Effects of turbidity in freshwaters of Alaska. N. Am. J. Fish. Manage. 7(1): 18-33.

Lyons, J. 1984. Walleye predation, yellow perch abundance and the population dynamics of an assemblage of littoral-zone fishes in Sparkling Lake, Wisconsin. Ph. D. Thesis, University of Wisconsin-Madison. 189pp.

Mauser, G., D. Cannamela, and R. Downing. 1989. Dworshack Dam impact assessment and fishery investigation. Annual Report, 1988. Rep. U.S. Dep. Energy 42pp.

Maxime, V., G. Boeuf, J.P. Pennec, and C. Peyraud. 1989. Comparative study of the energetic metabolism of Atlantic Salmon (Salmo salar) parr and smolts. Salmonid smoltification III. Proceedings of a workshop sponsered by the Directorate for Nature Management, Norwegian Fisheries Research Council, Norwegian Smolt Producers Association and Statkraft, held at the Univ. of Trondheim Norway, 27 June-1 July 1988. Aquaculture 82(1-4): 163-171.

Mortensen, E. 1985. Population and energy dynamics of trout, Salmo truuta, in a small Danish stream. J. Anim. Ecol. 54(3): 869-882.

Morton, K.F., and I.V. Williams. 1990. Sockeye salmon (Oncorhynchus nerka) utilization of Quesnel Lake, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. no. 1756. 33pp.

Novotny, J., T.L. Macy, and J.T. Gardenier. 1986. Pen rearing and imprinting of fall chinook salmon. Final report. Fish and Wildlife Service, Cook, WA. (U.S.A.). Willard Field Station. 72pp.

O'Neill, S.M., and K.D. Hyatt. 1987. An experimental study of competition for food between sockeye salmon (Oncorhynchus nerka) and threespine sticklebacks (Gasterosteus aculeatus) in a British Columbia coastal lake. pp. 143-160. In: Sockeye salmon (Oncorhynchus nerka) population biology and future management. Can. Spec. Publ. Fish Aquat. Sci. 96.

Paul, J.M. 1982. A guide to marine prey of juvenile salmon. ASG, Fairbanks, AK (U.S.A.). Alaska Sea Grant Mar. Adv. Bull. 65pp.

Peterman, R.M. 1987. Review of the components of recruitment of Pacific salmon, p. 417-427. In: Common strategies of anadromous and catadromous fishes. Proceedings of an international symposium held in Boston, Massachusetts, U.S.A., March 9-13, 1986. Am. Fish. Soc. Symp. Ser. 1.

Peterson, W.T., R.D. Brodeur, and W.G. Pearcy. 1982. Food habits of juvenile salmon in the Oregon coastal zone, June 1979. Fish. Bull. 80(4): 841-851.

Preall, R.J., and N.H. Ringler. 1989. Comparison of actual and potential growth rates of brown trout (Salmo trutta) in natural streams based on bioenergetic models. Can. J. Fish. Aquat. Sci. 46(6): 1067-1076.

Puckett, K.J., and L.M. Dill. 1985. The energetics of feeding territoriality in juvenile coho salmon (Oncorhynchus kisutch). Behaviour 92(1-2): 97-111.

Raymond, B.A., M.M. Wayne, and J.A. Morrison. 1985. Vegetation, invertebrate distribution and fish utilization of the Campbell River Estuary, British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. no. 1829. 50pp.

Rice, J.A., J.E. Breck, S.M. Bartell, and J.F. Kitchell. 1983. Evaluating the constraints of temperature, activity and consumption on growth of largemouth bass. Environ. Biol. Fish. 9: 263-275.

Rice, J.A., and P.A. Cochran. 1984. Independent evaluation of a bioenergetics model for largemouth bass. Ecology 65: 732-739.

Sagar, P.M., and G.J. Glova. 1987. Prey preference of a riverine population of juvenile chinook salmon, Oncorhynchus tshawytscha. J. Fish Biol. 31(5): 661-673.

1988. Diel feeding periodicity, daily ration and prey selection of a riverine population of juvenile chinook salmon, Oncorhynchus tshawytscha (Walbaum). J. Fish Biol. 33(4): 643-653.

Simenstad, C.A., and E.O. Salo. 1982. Foraging success as a determinant of estuarine and nearshore carrying capacity of juvenile chum salmon (Oncorhynchus keta) in Hood Canal, Washington. Proc. N. Pacific. Aquac. Symp. Alaska Sea Grant Program, Alaska University. pp. 21-37.

Stockner, J.G., and K.S. Shortreed. 1989. Algal picoplankton production and contribution to food-webs in oligotrophic British Columbia lakes. Hydrobiologia 173(2): 151-166.

Smith, J.A. 1988. Zooplankton - the option for smolts. Fish Farmer 3: 19-23.

Terazaki, M., and M. Iwata. 1983. Feeding habits of chum salmon Oncorhynchus keta collected from Otsuchi Bay. Bull. Jap. Soc. Sci. Fish./Nissuishi. 49(8): 1187-1193.

Umnov, A.A. 1990. Application of energetics to optimize stocking and yield from aquaculture lakes. J. Ichthyol. 30(1): 148-163.

Ware, D.M. 1972. Predation by rainbow trout (Salmo gairdneri): the influence of hunger, prey density, and prey size. J. Fish. Res. Bd. Canada 29: 1193-1201.

Wissmar, R.C., and C.A. Simenstad. 1985. Estimating estuarine carrying capacity for juvenile chum salmon (Oncorhynchus keta). Estuaries 8(28): 30A.

1988. Energetic constraints of juvenile chum salmon (Oncorhynchus keta) migrating in estuaries. Can. J. Fish. Aquat. Sci. 45: 1555-1560.

Wolf, E.G., B. Morson, and K.W. Fucik. 1983. Preliminary studies of food habits of juvenile fish, China Poot Marsh and Potter Marsh, Alaska, 1978. Estuaries. 6(2): 102-114.