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Canadian Research Results, 1993-1998: Report on the Canadian Workplans

by

D.J. Noakes and C.G. Wallace

Department of Fisheries and Oceans
Sciences Branch, Pacific Region
Pacific Biological Station
Nanaimo, B.C. V9R 5K6
CANADA

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Canada conducts and publishes studies on the biology and ecology of Pacific salmon to support the conservation and management of our stocks as well as to foster and contribute to international cooperative research. Areas of research include the impacts of climate change on salmon production, stock and species identification using either parasites as natural tags or DNA techniques, and studies of the biology, physiology and ecology of Pacific salmon.

The following list of publications and abstracts summarizes Canada's research in support of our NPAFC work plans for the period 1993-1998 (to-date). The papers are grouped in the three main areas of research identified above although some papers could be associated with more than one group.

1. Climate Change and Impacts on Pacific Salmon

TI: Climate and exceptional fish production off the west coast of North America
AU: **Beamish, RJ**
AF: Dep. Fish. Oceans, Biol. Sci. Branch, Nanaimo, BC V9R 5K6, Canada
SO: Canadian Journal of Fisheries and Aquatic Sciences [CAN. J. FISH. AQUAT. SCI.], vol. 50, no. 10, pp. 2270-2291, 1993
IS: 0706-652X
AB: From 1976 to 1978 there was a change in the climate over the North Pacific Ocean. The Aleutian low intensified and there was a warming of the sea surface adjacent to North America and a cooling offshore. Associated with this change was a period of exceptional fish production. Strong year classes and above-average survival occurred for many commercially important species all along the west coast of Canada and the United States. Trends in total salmon catches increased primarily from increased salmon production in Alaska. Some stocks of maturing pink (Oncorhynchus gorbuscha), coho (O. kisutch), and chinook salmon (O. tshawytscha) also had above-average growth in 1977. A majority of commercially important nonsalmon species that spawned from California to the Bering Sea and have a wide range of life history types also had exceptional strong year classes from 1976 to 1978.

TI: Marine fish production trends off the Pacific coast of Canada and the United States
AU: Beamish, RJ; Bouillon, DR
AF: Dep. Fish. and Oceans, Biol. Sci. Branch, Nanaimo, BC V9R 5K6, Canada
SO: Climate Change and Northern Fish Populations, 1995, pp. 585-591, Canadian special publication of fisheries and aquatic sciences/Publication speciale canadienne des sciences halieutiques et aquatiques Ottawa [CAN. SPEC. PUBL. FISH. AQUAT. SCI./PUBL. SPEC. CAN. SCI. HALIEUT. AQUAT.], no. 121
IS: 0706-6481
AB: Trends in production were reviewed for salmon and nonsalmon species in the principal commercial fisheries off the Pacific coast of Canada and the United States. Salmon species included pink (Oncorhynchus gorbuscha), chum (O. keta), sockeye (O. nerka), and nonsalmon species included demersal fishes and small pelagic species. The catches of the three species of salmon from all the Pacific salmon producing countries showed parallel trends, which varied almost three times from the period of high catches to the period of low catches. The average nonsalmon production as indicated by annual recruitment patterns also showed a trend, despite some variation in the individual species response. The combined salmon and nonsalmon production trend follows a pattern similar to the Aleutian Low Pressure Index, an index of winter weather over the northern North Pacific Ocean; this indicates a linkage between long-term abundance trends for most of the major fisheries off the west coast of Canada and the United States and climate.

TI: Pacific salmon production trends in relation to climate.
AU: Beamish, R.J. and Bouillon, D.R.
AF: Dep. Fish. and Oceans, Biol. Sci. Branch, Nanaimo, B.C. V9R 5K6, Canada
SO: Canadian Journal of Fisheries and Aquatic Sciences [CAN. J. FISH. AQUAT. SCI.], vol. 50, no. 5, pp. 1002-1016, 1993
IS: 0706-652X
NT: Incl. bibliogr.: 59 ref.
AB: Pink (*Oncorhynchus gorbuscha*), chum (*O. keta*), and sockeye salmon (*O. nerka*) represent approximately 90% of the commercial catch of Pacific salmon taken each year by Canada, Japan, the United States, and Russia. Annual all-nation catches of the three species and of each species, from 1925 to 1989, exhibited long-term parallel trends. National catches, in most cases, exhibited similar but weaker trends. The strong similarity of the pattern of the all-nation pink, chum, and sockeye salmon catches suggests that common events over a vast area affect the production of salmon in the North Pacific Ocean. The climate over the northern North Pacific Ocean is dominated in the winter and spring by the Aleutian low pressure system. The long-term pattern of the Aleutian low pressure system corresponded to the trends in salmon catch, to copepod production, and to other climate indices, indicating that climate and the marine environment may play an important role in salmon production.

TI: Hatchery and wild production of Pacific salmon in relation to large-scale, natural shifts in the productivity of the marine environment.
AU: Beamish, R.J; Mahnken, C; Neville, CM
AF: Dep. Fish. and Oceans, Hammond Bay Rd., Nanaimo, BC V9R 5K6, Canada
SO: ICES Journal of Marine Science, vol. 54, pp. 1200-1215, 1997.
AB: Pacific salmon have been fished extensively for at least a century and artificial production of Pacific salmon has been a management strategy to improve production for almost as long. Hatchery production is considered important because it is commonly believed that the carrying capacity for salmon in the ocean has remained more or less constant and is underutilized as a consequence of limited production of smolts in fresh water. Since the mid-1960s, there has been an increase in hatchery production, partly as a response to a desire to increase catch and partly because of improved hatchery techniques. Since the late 1970s there has been a dramatic increase in the total Pacific salmon catch. The increases in catch are now known to result from a large-scale shift in the productivity of the sub-arctic Pacific and management and enhancement actions. Environmental indices changed about 1989-1990 and may indicate that the productive regime of the 1980s has ended. This would imply that under natural conditions Pacific salmon abundance would decline. There are no clear indications of what to expect in the new regime, but it is apparent that the massive production of artificially reared Pacific salmon would not be necessary in a less productive regime. Of concern is the impact that the large number of artificially reared salmon will have on wild salmon stock levels.

TI: Production of Fraser River sockeye salmon (Oncorhynchus nerka) in relation to decadal-scale changes in the climate and the ocean
AU: Beamish, RJ; Neville, CM; Cass, AJ
AF: Pacific Biological Station, Department Fisheries Oceans, Nanaimo, BC V9R 5K6, Canada
SO: Canadian Journal of Fisheries and Aquatic Sciences/Journal Canadien des Sciences Halieutiques et Aquatiques. Ottawa [CAN. J. FISH. AQUAT. SCI./J. CAN. SCI. HALIEUT. AQUAT.], vol. 54, no. 03, pp. 543-554, 1997
IS: 0706-652X
AB: The abundance of Fraser River sockeye salmon (Oncorhynchus nerka) stocks was low in the 1960s, increased to high levels in the 1980s, and possibly entered a period of low abundance in recent years. The abundance changes of the combined stocks can be

separated into productivity regimes that correspond to changes in climate trends. The most distinct change occurred when there was a major change over the Pacific Ocean in the winter of 1976-1977. The existence of natural shifts in abundance trends means that the high returns that occur during periods of high productivity would not be expected to occur during the low-productivity periods. The response of Fraser River sockeye to climate changes may be a specific example of a more general response by a number of species of fishes in the Pacific and perhaps in other oceans. Because the shift from one regime to the other occurred quickly in the 1970s, future shifts could also occur quickly. It is necessary to detect natural shifts in productivity when attempting to manage fishing impacts to ensure that economic expectations are sound and that overfishing does not occur.

TI: A relationship between Fraser River discharge and interannual production of Pacific salmon (Oncorhynchus spp.) and Pacific herring (Clupea pallasi) in the Strait of Georgia
AU: Beamish, RJ; Neville, C-EM; Thomson, BL; Harrison, PJ; St. John, M
AF: Dep. Fish. and Oceans, Hammond Bay Rd., Nanaimo, BC V9R 5K6, Canada
SO: Canadian Journal of Fisheries and Aquatic Sciences/Journal Canadien des Sciences Halieutiques et Aquatiques. Ottawa [CAN. J. FISH. AQUAT. SCI./J. CAN. SCI. HALIEUT. AQUAT.], vol. 51, no. 12, pp. 2843-2855, 1994
IS: 0706-652X
NT: Incl. 35 ref.
AB: Years of anomalously high and low discharge from the Fraser River were identified and compared with indices of anomalously high and low production of Pacific salmon (Oncorhynchus spp.) and Pacific herring (Clupea pallasi). For chinook (O. tshawytscha) and coho salmon (O. kisutch), it was found that brood years that went to sea in a year when the Fraser River discharge was very high compared with the previous year virtually never had an index of production that was higher than the previous year. Similarly, brood years that went to sea in a year when the Fraser River discharge was very low compared with the previous year almost never had an index of productivity that was lower than the previous year. The analysis identified a weaker association between extreme discharge anomalies and chum salmon (O. keta) production. A close association was not found between extreme discharge anomalies and pink salmon (O. gorbuscha), sockeye salmon (O. nerka), or herring production. The relationships identify a connection between annual fluctuations in river flow and production of some marine fishes and may be of use in forecasting abundance changes.

TI: Declines in chinook salmon catches in the Strait of Georgia in relation to shifts in the marine environment
AU: Beamish, RJ; Riddell, BE; Neville, C-EM; Thomson, BL; Zhang, Z
AF: Pac. Biol. Stn., Dep. Fish. Oceans, Nanaimo, BC V9R 5K6, Canada
SO: Fisheries Oceanography [FISH. OCEANOGR.], vol. 4, no. 3, pp. 243-256, 1995
IS: 054-6006
AB: Chinook, Oncorhynchus tshawytscha, catches in the Strait of Georgia increased in the 1970s and reached maximum levels from 1976 to 1978. Catches then declined until they stabilized through regulation at levels approximately one-quarter of the 1976 to 1978 levels. The timing of the decline in catch was synchronous with an increase in the mean temperature of the Strait of Georgia, a decline in annual Fraser River flows, and an abrupt decrease in the marine survival of hatchery-reared chinook released into the Strait of Georgia. Surprisingly, the number of young chinook salmon (smolts) more than doubled over the period of declining catches compared with the number produced during the period of high catches. The increase in smolt abundance was a consequence of the production from hatcheries that was approximately equal to wild production. We conclude that there was a change in the carrying capacity for chinook salmon in the Strait of Georgia in the late 1970s that contributed to the declines in abundance and that rebuilding

stocks to the high abundance of the late 1970s is unlikely until the carrying capacity for chinook salmon changes either naturally or through manipulation. Although we did not separate density-dependent and density-independent effects on marine survival, the current total number of chinook smolts produced appears larger than required for the current marine carrying capacity.

TI: Evidence of change in the winter mixed layer in the Northeast Pacific Ocean.
AU: Freeland, H; Denman, K; Wong, CS; Whitney, F; Jacques, R
AF: Inst. Ocean Sci., PO Box 6000, Sidney, BC V8L 4B2, Canada
SO: Deep-Sea Research [DEEP-SEA RES.], vol. 44, pp. 2117-2129, 1997.
AB: Sea-surface temperatures in the Northeast Pacific Ocean show a warming trend, and salinities show a declining trend, in data collected over the last 60 years. These changes combine to reduce the density of the surface layer over a large area of the Northeast Pacific. The declining surface density changes the energetic requirements for the formation of a surface mixed layer, and observations at Ocean Station Papa indicate that mid-winter mixed layer depths are showing a marked decline. The reduction in the depth of penetration of the winter-time mixed layer should reduce the nutrients entrained into the upper ocean each winter. Observations suggest that near surface nutrient levels are declining at Papa but remain well above levels that might inhibit productivity. However, at present the productivity of large phytoplankton appears to be limited by iron supply which is thought to be mainly from the atmosphere. A shallower mixed layer depth could increase the concentration of iron in this layer. The increase in iron would increase the utilization of nitrate, mainly by diatoms, and new production and the *f* ratio would increase.

TI: The optimal stability 'window': A mechanism underlying decadal fluctuations in North Pacific salmon stocks?
AU: Gargett, AE
AF: Inst. Ocean Sci., PO Box 6000, Sidney, BC V8L 4B2, Canada
SO: Fisheries Oceanography [FISH. OCEANOGR.], vol. 6, no. 2, pp. 109-117, Jun 1997
IS: 1054-6006
AB: While recent evidence suggests that North Pacific salmon stocks are influenced by decadal variability in atmospheric forcing of the ocean, the actual combination of physical and biological processes that determines this linkage has not been identified. This paper describes a possible scenario in which water column stability is the primary factor by which the physical environment influences phytoplankton production, the basis for production at higher trophic levels. Variation in the strength of the wintertime Aleutian Low pressure area affects water column stabilities, hence primary production, along the entire eastern boundary of the North Pacific. The 'optimal stability window' explains the qualitative relationship between fish stocks and the strength of the winter Aleutian Low, as well as the observed out-of-phase variation between northern and southern salmon stocks.

TI: On the coherence of salmon abundance trends and environmental factors
AU: Noakes, DJ; Beamish, RJ; Klyashtorin, L; McFarlane, GA
AF: Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC V9R 5K6, Canada
CA: Vancouver, BC [Canada]
SO: NPAFC Bulletin Number 1: Assessment and status of Pacific Rim salmonid stocks, pp. 454-463, BUll. NPAFC, 1998
AB: Salmon (Oncorhynchus spp.) catches from Pacific Rim countries have shown a high degree of consistency in trend over time. This pattern is exhibited over wide spatial and temporal scales suggesting a significant influence of the marine environment. The relationships among all-nation catches of sockeye (O. nerka), pink (O. gorbuscha) and chum (O. keta) salmon and three indices of atmospheric conditions are considered in this paper. Time series models are employed to remove the trend component of the data as

well as any autocorrelation. Cross-correlation analyses of the residuals from each of the models are used to identify plausible links between salmon catches and the various climate indices. Significant relationships were observed between the all-nation salmon catch time series and each of the climate indices. The Atmospheric Circulation Index exhibited a downward change around 1990 and if the relationship holds, this may indicate all-nation salmon production could be reduced in the near future.

TI: A century and a half of change in the climate of the NE Pacific
AU: Ware, DM
AF: Dep. Fish., Nanaimo, BC V9R 5K6, Canada
SO: Fisheries Oceanography [FISH. OCEANOGR.], vol. 4, no. 4, pp. 267-277, 1995
IS: 1054-6006
AB: Spectral analysis of twenty-one climate records indicates that NE Pacific temperatures and winter wind stress have fluctuated at four dominant time scales in this century: 2-3 years (quasi-biennial oscillation), 5-7 years (El Nino-Southern Oscillation, ENSO), 20-25 years (bidecadal oscillation, BDO), and a poorly resolved, very-low-frequency (VLF) oscillation with a 50-75 year period. Forty-four per cent of the low-frequency variability in British Columbia air temperatures is associated with the strength of the Aleutian Low pressure system in winter. Only 42% of the 'strong' and 25% of the 'moderate' ENSO events in this century have produced large warm anomalies off BC. Interactions between the ENSO, bidecadal and very-low-frequency oscillations produce a pattern of alternating warm and cool climate states, with major warmings every 50 to 75 years. Since 1850 there have been seven warm periods, lasting an average of 11.4 years, and six cool periods lasting an average of 10.8 years. Sharp transitions from cool to warm climate states (as in 1977/78) occur when warming phases of the BDO and VLF oscillations coincide. Recent evidence suggests that the BDO may originate in either the tropical or the subtropical North Pacific. The NE Pacific has experienced a major warming since 1978. A long-range forecast suggests that the BDO and VLF oscillations peaked in 1989 and are currently in a cooling phase. Consequently, coastal temperatures should moderate for the rest of this century. A transition to the next cool climate state could occur about the year 2001. The forecast for moderating temperatures could begin the first phase of the recovery of the southern BC coastal chinook and coho salmon and herring stocks, which are currently at low abundance levels.

TI: Spring bloom in the central Strait of Georgia: Interactions of river discharge, winds and grazing
AU: Yin, K; Harrison, PJ; Goldblatt, RH; Beamish, RJ
AF: Department of Oceanography, University of British Columbia, Vancouver, BC V6T 1Z4, Canada
SO: Marine ecology progress series. Oldendorf [Mar. Ecol. Prog. Ser.], vol. 138, no. 1-3, pp. 255-263, 1996
IS: 0171-8630
AB: A 3 wk cruise was conducted to investigate how the dynamics of nutrients and plankton biomass and production are coupled with the Fraser River discharge and a wind event in the Strait of Georgia estuary (B.C., Canada). The spring bloom was underway in late March and early April, 1991, in the Strait of Georgia estuary. The magnitude of the bloom was greater near the river mouth, indicating an earlier onset of the spring bloom there. A week-long wind event (wind speed >4 m/s) occurred during April 3-10. The spring bloom was interrupted, with phytoplankton biomass and production being reduced and NO sub(3) in the surface mixing layer increasing at the end of the wind event. Five days after the wind event (on April 15), NO sub(3) concentrations were lower than they had been at the end of the wind event, indicating a utilization of NO sub(3) during April 10-14. However, the utilized NO sub(3) did not show up in phytoplankton biomass and production, which were lower than they had been at the end (April 9) of the wind event.

During the next 4 d, April 15-18, phytoplankton biomass and production gradually increased, and NO sub(3) concentrations in the water column decreased slowly, indicating a slow recovery of the spring bloom. Zooplankton data indicated that grazing pressure had prevented rapid accumulation of phytoplankton biomass and rapid utilization of NO sub(3) after the wind event and during these 4 d. As a result, NH sub(4) was generated at a rate faster than it was utilized by phytoplankton and hence, its concentrations remained at higher levels during April 15-18 than during the wind event. Also, total nitrogen in the water column decreased after the wind event. This study presents the first set of data on daily scales to demonstrate how biological variables are coupled with physical variables in vertical profiles in the Strait of Georgia estuary and to reveal how a wind event affected the spring bloom and consequently the phasing between phytoplankton and zooplankton in the region.

2. Stock Identification

TI: The use of minisatellite DNA variation for stock identification of chum salmon, Oncorhynchus keta
AU: Beacham, TD
AF: Pacific Biological Station, Department of Fisheries and Oceans, 3190 Hammond Bay Road, Nanaimo, BC, V9R 5K6, Canada
SO: Fishery Bulletin [FISH. BULL.], vol. 94, no. 4, pp. 611-627, 1996
IS: 0090-0656
AB: Geographic variation in minisatellite DNA was examined in 42 stocks of chum salmon, Oncorhynchus keta, from the eastern and western Pacific by restricting genomic DNA with HaeIII and hybridizing it with two minisatellite probes. Regional differentiation in allelic frequencies at the two minisatellite loci was observed; Japanese stocks were distinct from Russian and Yukon River stocks, and stocks from those two regions were distinct from stocks in southeast Alaska and British Columbia. No significant annual variation was observed in allelic frequencies at the two loci for three stocks. Simulated mixed fishery samples of 100 Japanese chum salmon were resolved with a baseline of nine Japanese stocks with an average error of 0.5% per mixture stock. Similarly, simulated mixtures of Yukon River chum salmon resolved with a baseline of five stocks resulted in an average error of 0.6% per mixture stock. Fraser River chum salmon mixtures were resolved with an average error of 3% per mixture stock. With Asian and North American stocks pooled into two groups, accuracy of classification for individual fish to continent of origin was 78% for 323 Asian fish, and 94% for 797 North American fish. Minisatellite DNA variation can be successfully applied to problems of stock discrimination in chum salmon.

TI: A comparison of methods of stock identification for sockeye salmon (Oncorhynchus nerka) in Barkley Sound, British Columbia
AU: Beacham, TD; Margolis, L; Nelson, RJ
AF: Department Fisheries Oceans, Pacific Biological Station, Nanaimo, BC V9R 5K6, Canada
CA: North Pacific Anadromous Fish Comm., Vancouver, BC [Canada]
SO: NPAFC Bulletin Number 1: Assessment and status of Pacific Rim salmonid stocks., 1998, no. 1, pp. 227-240, Bull. NPAFC, no. 1
IS: 1028-9127
AB: Sockeye salmon (Oncorhynchus nerka) returning to Barkley Sound on the west coast of Vancouver Island originate from three stocks. Evaluation of four methods of stock identification were conducted, with the annual stability of the stock-discriminating markers also examined. Variation observed in parasite infection rates, at protein electrophoretic loci, minisatellite DNA loci, and microsatellite DNA loci was used to assess the accuracy and precision of estimates of stock composition for these three stocks. Significant annual

variability in parasite infection rates was observed in two of six comparisons for the stocks sampled annually during 1977-84, and in two of four comparisons for two stocks sampled annually during 1993-1995. No significant annual variability in allele frequencies was observed at three electrophoretic loci (two stocks sampled in two years, 1983 and 1990) or four microsatellite DNA loci examined (three stocks each sampled for three years during 1987-95 for two loci, two stocks sampled for two years, 1990 and 1992, for two loci). Highest accuracy and greatest precision of estimated stock compositions were observed using the prevalences of two myxosporean parasites (Myxobolus arcticus and Henneguya salminicola) observed in the stocks during 1977-84. Changes in the prevalence of both parasites in Great Central Lake sockeye during 1993-95 substantially reduced the precision of estimates.

TI: Minisatellite DNA variation and stock identification of coho salmon
AU: Beacham, TD; Miller, KM; Withler, RE
AF: Dep. Fish. and Oceans, Pacific Biol. Stn., Nanaimo, BC, Canada V9R 5K6
SO: Journal of Fish Biology [J. FISH BIOL.], vol. 49, no. 3, pp. 411-429, Sep 1996
IS: 0022-1112
AB: Geographic variation in minisatellite DNA variation was examined in 18 stocks of coho salmon Oncorhynchus kisutch from British Columbia and three stocks from Kamchatka or Western Alaska. Genomic DNA was restricted with MboI or HaeIII and hybridized with two minisatellite probes (pSsa-A34, OtsPBS-1). Allele frequencies and DNA band counts derived from the two probes were combined with band counts from the probe Ssa1 to show a regional stock structure. In British Columbia, stocks from the Fraser River were distinct from those on Vancouver Island, and all were differentiated from those on the mainland of British Columbia. Average heterozygosity at the Ssa-A34 locus was 71%. Compared with a previous study of British Columbia coho salmon population structure in which variation at 26 allozyme loci was examined, greater population differentiation and higher heterozygosity were observed at minisatellite loci. Estimated stock compositions of simulated mixtures of fishery samples from British Columbia stocks were accurate and precise, with the potential of identifying stocks within the drainage basin of a major river, the Fraser River. Minisatellite DNA variation may provide accurate and precise estimates of stock composition in actual fishery applications, and has the potential of identifying individual fish to region or stock of origin.

TI: Stock identification of chinook salmon (Oncorhynchus tshawytscha) using minisatellite DNA variation
AU: Beacham, TD; Withler, RE; Stevens, TA
AF: Pacific Biological Stn., Dep. Fish. Oceans, Nanaimo, BC V9R 5K6, Canada
SO: Canadian Journal of Fisheries and Aquatic Sciences/Journal Canadien des Sciences Halieutiques et Aquatiques. Ottawa [CAN. J. FISH. AQUAT. SCI./J. CAN. SCI. HALIEUT. AQUAT.], vol. 53, no. 2, pp. 380-394, 1996
IS: 0706-652X
NT: Incl. 65 ref.
AB: Geographic variation in minisatellite DNA was examined in 28 stocks of chinook salmon (Oncorhynchus tshawytscha) from British Columbia and 3 stocks from the Yukon Territory. Genomic DNA was restricted with enzymes and hybridized with 3 minisatellite probes. Regional differentiation in allele frequencies and DNA fragment band counts was observed, with stocks from the Fraser River, east coast of Vancouver Island, west coast of Vancouver Island, southern mainland, and northern British Columbia forming distinct groups. With allele frequencies or band counts in the baseline stocks considered fixed or exact, estimates of stock composition from simulated mixtures within the Fraser and Skeena River drainages were accurate and precise, suggesting that discrimination among stocks within river drainages may be possible. Individual chinook salmon were classified

with an average accuracy of 35% to stock in a 30-stock baseline and an average accuracy of 65% to region for 8 regions.

TI: Stock identification of sockeye salmon by means of minisatellite DNA variation
AU: Beacham, TD; Withler, RE; Wood, CC
AF: Dep. Fish. Oceans, Biol. Sci. Branch, Pac. Biol. Stn. Nanaimo, BC V9R 5K6, Canada
SO: NORTH AM. J. FISH. MANAGE., vol. 15, no. 2, pp. 249-265, 1995
IS: 0275-5947
AB: Geographic variation in nuclear DNA among 10 populations of sockeye salmon Oncorhynchus nerka was examined over the Pacific-wide distribution of the species. Nuclear DNA was restricted with the enzymes Alu I and Hae III and hybridized with three minisatellite probes. The greatest differences in allele or DNA fragment (band) frequencies with all three probes occurred between northern (Russia, western Alaska) and southern (British Columbia, Washington) populations. Variation in frequencies was also observed among the six river drainage systems examined and between populations within drainages. It was not possible to classify individual fish to specific populations with a high degree of accuracy. However, for test samples consisting of a single population (true value, 100%), the estimated contribution of that population averaged about 89% for a 10-stock baseline. Estimates increased to about 92% when populations within drainages were pooled to determine contribution by drainage for the six drainages surveyed. Thus, the nuclear DNA variation surveyed in this study allowed reasonably accurate estimates of the percentage contributions of either individual populations or basin groups of populations to a sample, even when the analysis was applied to the coastwide or Pacific-wide distribution of sockeye salmon.

TI: Are naturally-occurring parasite 'tags' stable? An appraisal from four case histories involving Pacific salmonids
AU: Margolis, L
AF: Department Fisheries Oceans, Pacific Biological Station, Nanaimo, BC V9R 5K6, Canada
CA: North Pacific Anadromous Fish Comm., Vancouver, BC [Canada]
SO: NPAFC Bulletin Number 1: Assessment and status of Pacific Rim salmonid stocks, 1998, no. 1, pp. 205-212, Bull. NPAFC, no. 1
IS: 1028-9127
AB: This paper summarizes the biological characteristics of naturally acquired parasites that serve as `tags' for anadromous salmonid stocks, and reviews the advantages of parasite `tags' over traditional methods of tagging and marking. Four case histories of Canadian studies on the use of freshwater parasites in Pacific salmonid stock identification are examined with respect to the annual stability of the parasite `tags'. Two of these studies involve the use of parasites to determine the ocean distribution of stock groups of sockeye salmon (Oncorhychus nerka) and steelhead trout (O. mykiss), one relates to seaward migration routes of mainly Fraser River (British Columbia) juvenile sockeye salmon, and the fourth concerns quantitative estimates of the stock composition in a mixed stock sockeye salmon fishery on the west coast of Vancouver Island, British Columbia. Conclusions reached are: 1) Where stock identification is based on the unique presence of certain heteroxenous helminth parasites, the use of such parasite `tags' usually provides a stable basis for qualitative stock identification. In these instances the presence of the parasite `tag' in a salmonid stock is dependent on the co-existence of the salmonid and one of the other essential hosts in the life cycle of the parasite; 2) where parasites are used for quantitative estimates of stock composition, baseline data may have to be re-established annually to take into account annual variations in parasite prevalence (% of stock with the parasite) and intensity (numbers of parasites in each host) among the stocks to be distinguished; and 3) some quantitative parasite differences among salmonid stocks may appear to be stable for periods up to 10 or more years, but may show marked changes over the longer term.

TI: *Mhc* diversity in Pacific salmon: Population structure and trans-species allelism.
AU: Miller, KM; Withler, RE
AF: Pac. Biol. Stn., Dep. Fish. Oceans, Nanaimo, BC V9R 5K6, Canada
SO: Hereditas, vol. 127, pp. 83-95, 1997
AB: Geographic variation at a Mhc class I A1 exon was surveyed in 14 populations of coho salmon (Oncorhynchus kisutch) and 15 populations of chinook salmon (O. tshawytscha) inhabiting rivers of British Columbia, Canada. A total of 2,504 fish were sampled using denaturing gradient gel electrophoresis (DGGE), which distinguished 17 alleles in coho salmon and 20 alleles in chinook salmon. Heterozygosity at the A1 locus was moderately high for both coho (0.7) and chinook (0.6) salmon but sequence divergence was low, with mean inter- and intraspecific nucleotide similarities of approximately 0.96. In a maximum parsimony tree, all of the observed alleles clustered into two trans-specific lineages. Within each lineage, coho and chinook alleles tended to fall into species-specific subclusters. Much of the intraspecific allelic variation within each lineage could be accounted for by nonsynonymous point mutation, indicative of balancing selection. The $F\text{-}_{ST}$ values for both coho (0.11) and chinook (0.13) salmon indicated that much of the allelic diversity was partitioned among populations. Neighbour-joining analyses of A1 allelic frequences among coho and chinook salmon populations showed strong patterns of geographic differentiation similar to those based on neutral genetic markers such as microsatellite loci. Both natural selection and the salmonid zoogeographic history of frequent population bottlenecks have shaped the patterns of diversity observed at this and other Mhc exons in Pacific salmonids.

TI: Sequence analysis of a polymorphic Mhc class II gene in Pacific salmon
AU: Miller, KM; Withler, RE
AF: Dep. Fish. and Oceans, Sci. Branch, Pacific Biol. Stn., Nanaimo, BC V9R 5K6, Canada
SO: Immunogenetics, vol. 43, no. 6, pp. 337-351, 1996
IS: 0093-7711
AB: Polymorphism of the nucleotide sequences encoding 149 amino acids of linked major histocompatibility complex (Mhc) class II B1 and B2 peptides, and of the intervening intron (548-773 base pairs), was examined within and among seven Pacific salmon (Oncorhynchus) species. Levels of nucleotide diversity were higher for the B1 sequence than for B2 or the intron in comparisons both within and between species. For the codons of the peptide binding region of the B1 sequence, the level of nonsynonymous nucleotide substitution (d sub(N)) exceeded the level of synonymous substitution (d sub(S)) by a factor of ten for within-species comparisons, and by a factor of four for between-species comparisons. The excess of d sub(N) indicates that balancing selection maintains diversity at this salmonid Mhc class II locus, as is common for Mhc loci in other vertebrates. Levels of nucleotide diversity for both the exon and intron sequences were greater among than within species, and there were numerous species-specific nucleotides present in both the coding and noncoding regions. Thus, neighbor-joining analysis of both the intron and exon regions provided phylogenies in which the sequences clustered strongly by species. There was little evidence of shared ancestral (trans-species) polymorphism in the exon phylogeny, and the intron phylogeny depicted standard relationships among the Pacific salmon species. The lack of shared allelic B1 lineages in these closely related species may result from severe bottlenecks that occurred during speciation or during the ice ages that glaciated the rim of the north Pacific Ocean approximately every 100 000 years in the Pleistocene.

TI Stock identification of coho salmon (Oncorhynchus kisutch) using minisatellite DNA variation
AU: Miller, KM; Withler, RE; Beacham, TD
AF: Dep. Fish. Oceans, Biol. Sci. Branch, Nanaimo, BC V9R 5K6, Canada

SO: Canadian Journal of Fisheries and Aquatic Sciences/Journal Canadien des Sciences Halieutiques et Aquatiques. Ottawa [CAN. J. FISH. AQUAT. SCI./J. CAN. SCI. HALIEUT. AQUAT.], vol. 53, no. 1, pp. 181-195, 1996
IS: 0706-652X
NT: 33 ref.
AB: The minisatellite DNA probe Ssa1 was used to survey variation in 19 British Columbia, 1 Yukon, 1 Alaskan, and 1 Russian populations of coho salmon (Oncorhynchus kisutch). Hybridization of Ssa1 to DNA restricted with five restriction enzymes revealed 2-12 restriction fragments derived from a single locus. Geographically, although no marked regional definition was found within stocks from northern British Columbia, the lower mainland, the Fraser River, and Vancouver Island, genetic variation between individual stocks was high. Fish were correctly identified to stock of origin with an accuracy of 45% using discriminant analysis and a jackknifed classification procedure with a 22-stock baseline. Estimated mixture proportions for the contributing stock in test samples comprising a single stock averaged 100% using a fixed baseline of 22 stocks (i.e., no error), and 89% when the baselines were resampled.

TI: Molecular evolution at Mhc genes in two populations of chinook salmon Oncorhynchus tshawytscha
AU: Miller, KM; Withler, RE; Beacham, TD
AF: Dep. Fish. and Oceans, Science Branch, Pacific Biol. Stn., Nanaimo, BC, Canada V9R 5K6
SO: Molecular Ecology [MOL. ECOL.], vol. 6, no. 10, pp. 937-954, Oct 1997
IS: 0962-1083
AB: The DNA sequences of four exons of the MHC (major histocompatibilty complex) were examined in chinook salmon (Oncorhynchus tshawytscha) from an interior (Nechako River) and a coastal (Harrison River) population in the Fraser River drainage of British Columbia. Mhc class I A1, A2 and A3 sequences and a class II B1 sequence were obtained by PCR from each of 16-20 salmon from each population. The class I A1 and a pair of linked A2-A3 exons were derived from two different classical salmonid class I genes, Sasa-A and Onmy-UA, respectively. Allelic variation for B1, A1 and A2 was characterized by the high levels of nonsynonymous substitution indicative of the effects of natural selection on Mhc domains that contain peptide binding regions. The number of alleles detected at each of the four exons ranged from three (B1) to 22 (A1), but levels of nucleotide sequence divergence at all four exons were low relative to classical mammalian Mhc genes. The nucleotide similarity among alleles ranged between 89 and 99% over all exons, and all four domains possessed only two major sequence motifs. Allelic distributions at B1, A1 and A3 confirmed the genetic distinctiveness of the Harrison and Nechako chinook salmon populations revealed in previous studies. The two major allelic motifs of B1 and A1 segregated strongly between the populations. In spite of evidence that allelic diversity at these chinook salmon Mhc exons has been generated by selection, the level and distribution of diversity in the two salmon populations strongly reflected the demographic history of the species, which has been characterized by repeated bottlenecks and isolation-by-distance in glacial refugia.

TI: Discriminating coho salmon (Oncorhynchus kisutch) populations within the Fraser River, British Columbia, using microsatellite DNA markers
AU: Small, MP; Beacham, TD; Withler, RE; Nelson, RJ
AF: Pacific Biol. Stn., Dep. Fish. and Oceans, Nanaimo, BC V9R 5K6, Canada
SO: Molecular Ecology [MOL. ECOL.], vol. 7, no. 2, pp. 141-155, Feb 1998
IS: 0962-1083
AB: Three microsatellite loci were used to examine genetic variation among 16 coho salmon (Oncorhynchus kisutch) populations within the Fraser River drainage system, in British Columbia, Canada. Each locus was highly polymorphic with 30 alleles at the Ots101

locus, 15 alleles at the Ots3 locus and 38 alleles at the Ots103 locus. Average observed heterozygosities were 86.1%, 70%, and 56.1%, respectively. With the exception of the Dunn and Lemieux River populations, Chi-square tests and F sub(ST) values indicated that all populations had significantly different allele frequencies. Two distinct population groups within the Fraser River drainage were observed. Lower Fraser River populations were strongly differentiated from populations spawning in the upper Fraser River, which includes the Thompson River (a tributary flowing into the upper Fraser) and the portion of the Fraser River beyond the precipitous Fraser River canyon. This regional population structure may have resulted from colonization of the upper and lower Fraser River regions by different founder populations following Pleistocene glaciation, and be maintained by adaptive differences between the two groups of coho salmon. Coho salmon populations in the upper Fraser and Thompson River drainages form an evolutionarily significant unit (ESU) of importance for conservation of biodiversity in coho salmon. Microsatellite DNA loci show promise as technically simple and highly informative genetic markers for coho salmon population management.

TI: Population structure and stock identification of British Columbia coho salmon (*Oncorhynchus kisutch*) based on microsatellite DNA variation

AU: Small MP; Withler RE; Beacham TD

AF: Pacific Biological Station, Department of Fisheries and Oceans, 3190 Hammond Bay Road, Nanaimo, BC V9R 5K6, Canada

SO: Fishery Bulletin [FISH. BULL.], vol. 96, pp. 843-858, 1998

AB: We used genetic variation at three microsatellite DNA loci to describe population structure in 34 coho salmon populations from British Columbia, and to perform stock composition analysis on simulated mixed-stock fishery samples. Each microsatellite locus was highly polymorphic, with 31 alleles at *Ots*101, 20 alleles at *Ots*3, and 38 alleles at *Ots*103. Average observed heterozygosities were 86.3%, 73.3% and 74.9%, respectively. Analysis of genetic distances revealed three relatively homogeneous, geographically-based groups of coho salmon populations in the following regions: the upper Skeena and Nass River watersheds, the lower Fraser River drainage, and the upper Fraser River/Thompson River watersheds. Coastal populations from the mainland of British Columbia, Vancouver Island, and the Queen Charlotte Islands formed a more heterogeneous regional stock grouping. Significantly different allele frequencies were observed among populations within regions, and allele frequencies were generally temporally stable in multi-year samples. Phylogenetic lineages within British Columbia coho salmon likely reflect geographic patterns of recolonization from at least three separate glacial refugia after the last ice age. Local spawning populations within regions may form metapopulations, but current levels of gene flow among subpopulations are apparently insufficient to prevent differentiation at neutral genetic loci. Maximum-likelihood estimates of stock composition were accurate and precise, indicating great potential for management of coho salmon at the level of metapopulations or 'evolutionarily significant units' in domestic and international mixed-stock fisheries. Individual fish were identified to stock using a discriminant analysis with a high degree of accuracy in a few regions, but more generally with approximately 50% success.

TI: A multilocus probe for DNA fingerprinting in chinook salmon (Oncorhynchus tshawytscha), and comparisons with a single-locus probe.

AU: Stevens, TA; Withler, RE; Goh, SH; Beacham, TD

AF: Dep. Fish. and Oceans, Biol. Sci. Branch, Nanaimo, BC V9R 5K6, Canada

SO: Canadian Journal of Fisheries and Aquatic Sciences [CAN. J. FISH. AQUAT. SCI.], vol. 50, no. 7, pp. 1559-1567, 1993

IS: 0706-652X

NT: Incl. 42 ref.

AB: A multilocus DNA probe, B2-2, isolated from chinook salmon (Oncorhynchus tshawytscha) and a single-locus Atlantic salmon (Salmo salar) probe, 3.15.34, were examined for discriminatory ability among seven parents and 33-37 juveniles from five families of chinook salmon. DNA fingerprint patterns were observed in Hae III-digested chinook salmon DNA probed with B2-2. pedigree analysis confirmed that 3.15.34 detected both alleles of a single polymorphic locus whereas B2-2 detected autosomal, unlinked, predominantly heterozygous DNA fragments that were inherited in a Mendelian fashion at a minimum of 10 polymorphic loci. Among juvenile chinook salmon, levels of band sharing detected with probe B2-2 increased with increasing relatedness, and clustering based on differences in banding patterns distinguished unrelated progeny, half sibs, and full sibs even in the absence of parental genotypic data.

TI: Genetic variation at minisatellite DNA loci among North Pacific populations of steelhead and rainbow trout (Oncorhynchus mykiss)

AU: Taylor, EB

AF: Dep. Zool., Univ. British Columbia, Vancouver, BC V6T 1Z4, Canada

SO: Journal of Heredity [J. HERED.], vol. 86, pp. 354-363, 1995

IS: 0022-1503

AB: Genetic variation at minisatellite DNA, or variable number tandem repeat (VNTR), loci is widely studied in the context of animal breeding and pedigree analyses, but comparatively little information exists on the levels of variation at such loci in natural populations. Allelic variability was examined at two VNTR loci (Ssa1 and T34) by Southern hybridization analyses within and between populations of steelhead and rainbow trout, the sea-run and freshwater resident life-history forms of Oncorhynchus mykiss from eight populations tributary to the northeast Pacific Ocean. Single-locus expected heterozygosities ranged from an average of 61% (Ssa1) in the eight populations, and no significant departures from Hardy-Weinberg expected genotype frequencies were detected. Eighteen putative allelic fragments were resolved in the 267 steelhead and rainbow trout examined at Ssa1 [molecular weight range, 3.6-9.5 kilobase pairs (kbp)], and 26 alleles were resolved at T34 (1.7-9.4 kbp). At Ssa1, however, one allele accounted for 58% of all alleles scored and at T34 three alleles accounted for 72% of those scored. Allele frequencies at both loci were stable within two populations sampled over successive years, but varied significantly between populations within watersheds, and large frequency differences were detected between major geographic areas (e.g., Alaska versus British Columbia). Neighbor-joining analyses of genetic distances among populations accompanied by bootstrap analysis provided strong support (>70%) for clustering populations by geographic region, as well as for a major genetic distinction between interior Fraser River populations of rainbow trout and coastal steelhead trout.

TI: Population structure and identification of Nforth Pacific Ocean chum salmon (*Oncorhynchus keta*) revealed by an annalysis of minisatellite DNA variation

AU: Taylor, EB; Beacham, TD; Kaeriyama, M

AF Dep. Fish. and Oceans, Biol. Sci. Branch, Nanaimo, BC V9R 5K6, Canada

SO: Canadian Journal of Fisheries and Aquatic Sciences [CAN. J. FISH. AQUAT. SCI.], vol. 51, pp. 1430-1442, 1994

AB: We examined geographic variability in minisatellite DNA in chum salmon (*Oncorhynchus keta*) from 42 populations from the North Pacific Ocean to (1) determine the extent of regional population structure at minisatellite loci and (2) assess the ability of minisatellite variability to determine the geographic origin in individual chum salmon. Restriction fragments from 1.76 to 13.6 kilobase pairs in molecular weight were resolved with a minisatellite probe. The fragments were inherited from parent to offspring and appeared to represent segregation at two linked loci. Minisatellite DNA variability was negligible between annual samples from the same rivers, and chum salmon fell into three regional population groupings: (I) Japanese, (ii) Russian/Yukon River, and (iii) southeastern

Alaska/British Columbia salmon. These regional groupings probably reflect historical patterns of postglacial dispersal of chum salmon from three distinct refugia in the North Pacific. We used restriction fragment counts as input to linear discriminant and neural network classification of independent test samples of salmon. Accuracies of 90-95, 81-86, and 72-80% were achieved when classifying fish as of either Japan/Russia/Yukon River versus southeastern Alaska/British Columbia origin, Japan versus Russia/Yukon River origin, or Russia versus Yukon River origin, respectively.

TI: Stock identification of chinook salmon (Oncorhynchus tshawytscha) in the North Pacific Ocean and Bering Sea by parasite tags

AU: Urawa, S; Nagasawa, K; Margolis, L; Moles, A

AF: Research Division, National Salmon Resources Center, Fisheries Agency Japan, 2-2 Nakanoshima, Toyohira-ku, Sapporo 062, Japan

CA: North Pacific Anadromous Fish Comm., Vancouver, BC [Canada]

SO: NPAFC Bulletin Number 1: Assessment and status of Pacific Rim salmonid stocks., 1998, no. 1, pp. 199-204, Bull. NPAFC, no. 1

IS: 1028-9127

AB: The continental origins of chinook salmon (Oncorhynchus tshawytscha) in the North Pacific Ocean and Bering Sea were estimated by using two freshwater parasites (Myxobolus arcticus and M. kisutchi) as biological tags. The parasite survey of adult chinook salmon from major spawning rivers in North America and Kamchatka indicated that M. arcticus was commonly found in Asian chinook stocks (prevalence=57-94%), while rarely among most North American stocks except for those from Vancouver Island, B.C. The unweighted overall sample prevalence of M. arcticus was 67.7% and 2.3% in Asian and North American stocks, respectively. M. kisutchi was found only in chinook salmon from the Columbia River (prevalence=8-11% and 43-65% in fall and spring adult stocks, respectively) and its vicinities. The prevalence of M. arcticus in high-seas samples of chinook salmon showed a distinct longitudinal cline in the North Pacific Ocean. Results suggest that Asian chinook salmon are widely distributed in the North Pacific Ocean, occurring possibly as far east as 150 degree W, and are probably predominant in the waters west of 180 degree . The extreme low prevalence of M. arcticus in central Bering Sea chinook salmon suggests that up to 98% of chinook salmon caught in this area are of North American origin. One chinook salmon infected with M. kisutchi was found in the Gulf of Alaska, suggesting the presence of Columbia River chinook salmon in this area.

TI: Species identification of Pacific salmon by means of a major histocompatibility complex gene

AU: Withler, RE; Beacham, TD; Ming, TJ; Miller, KM

AF: Dep. Fish. and Oceans, Sci. Branch Pacific Biol. Stn., Nanaimo, British Columbia V9R 5K6, Canada

SO: North American Journal of Fisheries Management [N. AM. J. FISH. MANAGE.], vol. 17, no. 4, pp. 929-938, Nov 1997

IS: 0275-5947

AB: A rapid genetic test to identify Pacific salmonid tissue samples to the species level is described. An exon (coding DNA) and its adjacent intron (noncoding DNA) of a major histocompatibility complex (MHC) class II gene were amplified by the polymerase chain reaction from eight Oncorhynchus species and the two Salmo species that have been transplanted to British Columbia. Among Pacific salmonids, the length of the amplified sequence was between 809 and 826 base pairs (bp) for cutthroat trout Oncorhynchus clarki, rainbow trout and steelhead O. mykiss, chinook salmon O. tshawytscha, coho salmon O. kisutch, masu O. masou, and some sockeye salmon O. nerka; it was between 993 and 1,034 bp for pink salmon O. gorbuscha, chum salmon O. keta, and other sockeye salmon. Sequence length ranged from 1,000 to 3,000 bp for brown trout Salmo trutta and from 1,500 to 3,000 bp for Atlantic salmon S. salar. Amplified sequences from

all Pacific salmonids except rainbow trout-steelhead and cutthroat trout displayed species-specific restriction fragment length polymorphisms (RFLPs) after independent digestion with three restriction enzymes (Avr II, Bcl I, Bsof I). Restriction patterns of Pacific salmon sequences between 993 and 1,034 bp distinguished them from the 1,000-bp brown trout sequences. Intraspecific RFLP variability revealed regional differentiation in phenotypic frequencies in three species: coho salmon populations in southern British Columbia differed from those in northern British Columbia and the Fraser River; sockeye salmon from Kamchatka and Bristol Bay differed from those of British Columbia; and Japanese and North American chum salmon were well differentiated, enabling an accurate classification to continent of origin.

TI: Structure of an unusual minisatellite locus, Ssa1, in Pacific salmonids
AU: Withler, RE; Miller, KM
AF: Dep. Fish. and Oceans, Sci. Branch, Pacific Biol. Stn., Nanaimo, B.C. V9R 5K6, Canada
SO: Journal of Heredity [J. HERED.], pp. 415-422, Oct 1997
IS: 0022-1503
AB: The genetic structure of the salmonid Ssa1 minisatellite locus was examined in chinook (Oncorhynchus tshawytscha) and coho salmon (O. kisutch). Analysis of 222 progeny from 22 chinook salmon families revealed that the observed multibanded patterns of Ssa1 hybridization consisted of cosegregating (linked) DNA fragments constituting the two alleles (haplotypes) of a single highly polymorphic locus. The haplotypes, containing up to five restriction fragments, were inherited in a Mendelian manner. Two progeny, sired by different males, inherited some restriction fragments from both paternal haplotypes, indicating that crossing over or gene conversion had occurred during male meiosis. Gene-centromere mapping in diploid gynogenetic progeny of three coho salmon females revealed a high rate (98%) of recombination between the centromere and Ssa1. These data support a model of Ssa1 structure in which the original minisatellite array plus flanking sequence have become tandemly duplicated in a distal autosomal location. Male meioses are characterized by high rates of recombination and/or conversion within the Ssa1 locus that are responsible for the generation of new Ssa1 alleles.

TI: Biochemical genetic survey of sockeye salmon (Oncorhynchus nerka) in Canada
AU: Wood, CC; Riddell, BE; Rutherford, DT; Withler, RE
AF: Dep. Fish. and Oceans, Pac. Biol. Stn., Nanaimo, BC V9R 5K6, Canada
CF: Int. Symposium on Genetics of Subarctic Fish and Shellfish, Juneau, AK (USA), 17-19 May 1993
ED: Gharrett, AJ; Smoker, WW; Wilmot, RL; Helle, JH; Seeb, JE; Seeb, LW (eds)
SO: INTERNATIONAL SYPOSIUM ON GENETICS OF SUBARCTIC FISH AND SHELLFISH., 1994, pp. 114-131, Canadian Journal of Fisheries and Aquatic Sciences [CAN. J. FISH. AQUAT. SCI.], vol. 51, no. suppl. 1
IS: 0706-652X
NT: Incl. 63 ref.
AB: Allozyme variation was examined in sockeye salmon (Oncorhynchus nerka) from 83 distinct spawning sites representing all major sockeye-producing river systems in Canada. Of 33 nonselected loci examined, only 14 were highly polymorphic and 10 were less polymorphic. Extensive differentiation among nursery lakes affords excellent opportunities for genetic stock identification within river systems, but the relatively weak regional structuring limits opportunities for coast-wide stock identification. Genetic variation at highly structured loci corroborates the view that modern populations in Canada originated from sockeye that survived the late Wisconsin Glaciation in the Bering and Columbia refuges, and also suggests the existence of coastal refuges in British Columbia.

3. Biology, Physiology and Ecology of Pacific Salmon

TI: Recent changes in the marine distribution of juvenile chum salmon off Canada
AU: Beamish, RJ; Folkes, M
AF: Department Fisheries Oceans, Pacific Biological Station, Nanaimo, BC V9R 5K6, Canada
CA: North Pacific Anadromous Fish Comm., Vancouver, BC [Canada]
SO: NPAFC Bulletin Number 1: Assessment and status of Pacific Rim salmonid stocks., 1998, no. 1, pp. 443-453, Bull. NPAFC, no. 1
IS: 1028-9127
AB: In 1995, abundance surveys for juvenile Pacific salmon (Oncorhynchus spp.) were carried out in the Strait of Georgia using either rope trawls or beam trawls. All 5 species of salmon were captured and in this paper preliminary results are reported of the distribution and abundance of chum salmon (O.keta). Chum were not caught in the earliest survey and were not abundant in the samples until late May. Once chum were abundant in all catches, they were distributed throughout the Strait, including the Gulf Islands area. By mid-November, chum were still abundant and had a mean size of 22 cm and ranged from 16-28 cm. A swept volume estimate of abundance indicated there could be approximately 1.3 million juveniles at this time. Depending on the amount of marine mortality that had occurred by November, the juveniles that remained in this relatively small marine ecosystem could contribute significantly to the future catch and escapement. It appears that the occurrence of such large numbers of juveniles in the Strait of Georgia, so late in the year, is a recent phenomena that may be related to natural changes in the Strait of Georgia ecosystem that, in turn, are linked to large scale climate-ocean events in the North Pacific.

TI: A review of size trends among North Pacific salmon (Oncorhynchus spp.)
AU: Bigler, BS; Welch, DW; Helle, JH
AF: Wards Cove Packing Company, Box c-5030, Seattle, WA 98105, USA
SO: Canadian Journal of Fisheries and Aquatic Sciences/Journal Canadien des Sciences Halieutiques et Aquatiques. Ottawa [CAN. J. FISH. AQUAT. SCI./J. CAN. SCI. HALIEUT. AQUAT.], vol. 53, no. 2, pp. 455-465, 1996
IS: 0706-652X
NT: Incl. 35 ref.
AB: The abundance of North Pacific salmon (Oncorhynchus spp.) has nearly doubled during the period 1975-1993. As salmon population numbers have increased, there have been corresponding decreases in average adult size at return (maturity). As nearly all the growth of Pacific salmon occurs in the ocean, the ocean plays an important role in determining salmon abundance. It was found that 45 of 47 North Pacific salmon populations, comprising five species from North America and Asia, are decreasing in average body size. Total salmon production correlated well with environmental trends between 1925 and 1989, but the inverse relationship between population abundance and average size during the period 1975-1993 indicates that there is a limitation to the salmon-sustaining resources of the ocean. The increased ocean survivorship and expansion of enhancement programs in the 1980s and early 1990s are probable factors in the ocean-wide reduced size of salmon.

TI: Physiological Ecology of Pacific Salmon
AU: Groot, C; Margolis, L; Clarke, WC
AF: Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, BC, V9R 5K6
SO: UBC Press, Vancouver, BC, 510 p, 1995

TI: Effect of water temperature on emigration timing and size of Fraser River pink salmon (Oncorhynchus gorbuscha) fry: Implications for marine survival

AU: **Henderson, MA; Diewert, RE; Stockner, JG; Levy, DA**
AF: Dep. Fish. and Oceans, Biol. Sci. Branch, 555 W. Hastings St., Vancouver, BC V6B 5G3, Canada
CA: National Research Counc. of Canada, Ottawa, ON (Canada)
CF: Climate Change and Northern Fish Populations Conf., Victoria, BC (Canada), 19-24 Oct 1992
ED: Beamish, RJ (ed)
SO: CLIMATE CHANGE AND NORTHERN FISH POPULATIONS., 1995, pp. 655-664, Canadian special publication of fisheries and aquatic sciences /Publication speciale canadienne des sciences halieutiques et aquatiques Ottawa ON [CAN. SPEC. PUBL. FISH. AQUAT. SCI./PUBL. SPEC. CAN. SCI. HALIEUT. AQUAT.], no. 121
IS: 0706-6481
IB: 0-660-15780-2
NT: Incl. 64 ref.
AB: The effect of water temperature was evaluated on the date and dispersion of the emigration of Fraser River pink salmon (Oncorhynchus gorbuscha) fry and their size at the time of emigration. Increases in the number of degree-days over the first few weeks of embryo development resulted in an earlier date of emigration and smaller size of fry. However, the number of degree days over the entire period of embryo development had no effect on the date of emigration or fry size. Dispersion of the emigration was not affected by the number of degree-days over the early, late, or entire period of embryo development. Marine survival of pink salmon fry increased as the date of emigration occurred earlier in the year. Fry size at the time of emigration had no effect on marine survival. Warming of the waters of the Fraser River as the result of climate change should result in an earlier date of emigration of pink salmon fry, and as a result, possibly higher marine survival.

TI: Recent changes in age and size of chum salmon (Oncorhynchus keta) in the North Pacific Ocean and possible causes.
AU: **Ishida, Y; Ito, S; Kaeriyama, M; McKinnell, S; Nagasawa, K**
AF: Natl. Res. Inst. Far Seas Fish., 5-7-1 Orido, Shimizu 424, Japan
SO: Canadian Journal of Fisheries and Aquatic Sciences [CAN. J. FISH. AQUAT. SCI.], vol. 50, no. 2, pp. 290-295, 1993
IS: 0706-652X
NT: Incl. bibliogr.: 17 ref.
AB: Changes in age composition and size of adult chum salmon (Oncorhynchus keta) from rivers in Japan, Russia, and Canada were examined based on body weight and scale measurement data collected from 1953 to 1988. A significant increase in mean age was found in Japanese and Russian stocks after 1970 when the number of Japanese chum salmon began to increase exponentially, but not in the Canadian stock. Significant decreases in mean body weight, mean scale radius, and mean width of the third-year zones of age 4 chum salmon also occurred in Japanese and Russian stocks after 1970. Results suggest that density dependence is one of the possible causes for the recent changes in age and size of chum salmon in the North Pacific Ocean.

TI: Potential influence of North Pacific sea-surface temperatures on increased production of chum salmon (Oncorhynchus keta) from Japan
AU: **Ishida, Y; Welch, DW; Ogura, M**
AF: Natl. Res. Inst. Far Seas Fish., Fish. Agency Japan, 5-7-1, Orido, Shimizu, Shizuoka 424, Japan
CA: National Research Counc. of Canada, Ottawa, ON (Canada)
CF: Climate Change and Northern Fish Populations Conf., Victoria, BC (Canada), 19-24 Oct 1992
ED: Beamish, RJ (ed)

SO: CLIMATE CHANGE AND NORTHERN FISH POPULATIONS., 1995, pp. 271-275, Canadian special publication of fisheries and aquatic sciences /Publication speciale canadienne des sciences halieutiques et aquatiques Ottawa ON [CAN. SPEC. PUBL. FISH. AQUAT. SCI./PUBL. SPEC. CAN. SCI. HALIEUT. AQUAT.], no. 121
IS: 0706-6481
IB: 0-660-15780-2
AB: We examined the potential influence of changes in sea-surface temperature (SST) in the North Pacific Ocean on Japanese chum salmon (Oncorhynchus keta) adult return rates and growth rates. SST near the Kuril Islands in July and SST in the Central North Pacific in winter and spring showed significant decreasing trends from 1947 to 1988. Average return rate after the mid-1960s was higher than that occurring before the mid-1960s, when most juveniles were not fed prior to release. Return rate was negatively correlated with SST near the Kuril Islands and in the Central North Pacific after the mid-1960s, but not before. Growth was positively correlated with spring SST in the Central North Pacific. The present results and previously reported negative correlations between growth and fish density suggest that chum salmon production is enhanced in Japan by hatchery technology but that yields have been reduced by declining growth rates caused by decreasing SST and increasing fish density in the central North Pacific.

TI: Synopsis of the parasites of fishes of Canada: Supplement (1978-1993)
AU: McDonald, TE; Margolis, L
CA: Department of Fisheries and Oceans, Nanaimo, BC (Canada). Biological Sciences Branch
SO: Canadian special publication of fisheries and aquatic sciences /Publication speciale canadienne des sciences halieutiques et aquatiques Ottawa ON [CAN. SPEC. PUBL. FISH. AQUAT. SCI./PUBL. SPEC. CAN. SCI. HALIEUT. AQUAT.], 1995, no. 122, 269 pp
IS: 0706-6481
NT: NTIS-Accession Number: MIC-95-03749.
AB: Information on the parasites of Canadian fishes published between the years 1978 and 1993, inclusive, is assembled as Parasite-Host and Host-Parasite lists. The 925 named species of parasites are distributed among higher taxa as follows: Apicomplexa - 34; Ciliophora - 20; Mastigophora - 16; Microspora - 9; Myxozoa - 122; Cnidaria - 2; Udonellidea - 1; Trematoda - 184; Monogenea - 183; Cestoda - 94; Nematoda - 76; Acanthocephala - 29; Annelida - 27; Mollusca - 4; Branchiura - 7; Copepoda - 112; Amphipoda - 3; and Isopoda - 2. Additionally, there are many records of parasites not identified to species level, including a genus of Rhizopoda and 2 genera of Acarina. Of the 1102 species of Canadian fishes listed by McAllister (1990), parasites are reported for 292 species, including 2 hybrid forms. This list includes 18 species of Apicomplexa, 12 species of Ciliophora, 6 species of Mastigophora, 3 species of Microspora, 73 species of Myxozoa, 2 species of Cnidaria, 62 species of Trematoda, 67 species of Monogenea, 25 species of Cestoda, 28 species of Nematoda, 6 species of Acanthocephala, 13 species of Annelida, 2 species of Mollusca, 1 species of Branchiura, 44 species of Copepoda, 3 species of Amphiphoda, 1 species of Isopoda, and parasite records for 80 species of Canadian fishes not found in the Synopsis of the Synopsis of the Parasites of Fishes of Canada by Margolis and Arthur (1979).

TI: Interannual variability of the zooplankton community off southern Vancouver Island
AU: Mackas, DL
AF: Inst. Ocean Sci., Biol. Sci. Branch, Dep. Fish. and Oceans, Sidney, BC V8L 4B2, Canada
CA: National Research Counc. of Canada, Ottawa, ON (Canada)
CF: Climate Change and Northern Fish Populations Conf., Victoria, BC (Canada), 19-24 Oct 1992
ED: Beamish, RJ (ed)

SO: CLIMATE CHANGE AND NORTHERN FISH POPULATIONS., 1995, pp. 603-615, Canadian special publication of fisheries and aquatic sciences /Publication speciale canadienne des sciences halieutiques et aquatiques Ottawa ON [CAN. SPEC. PUBL. FISH. AQUAT. SCI./PUBL. SPEC. CAN. SCI. HALIEUT. AQUAT.], no. 121
IS: 0706-6481
IB: 0-660-15780-2
NT: Incl. 39 ref.
AB: Time series of zooplankton anomalies (deviations from the long-term average seasonal cycle) are calculated from 1985-92 records of log-transformed biomass for dominant zooplankton taxa off the southwest coast of British Columbia. Statistically significant anomalies occur in all of the major taxa. Average persistence of the anomalies ranges from less than a year for gelantinous zooplankton, to 1-2 yr for the common copepods, to 3 yr or more for chaetognaths and euphausiids. Significant zooplankton anomalies occur throughout the time series; they are not confined to transient episodes such as the 1987 and 1992 El Nino events. Because of the long persistence of most of the anomalies, the length of the time series is still too short to permit stand-alone statistical proof of a linkage between environmental and zooplankton fluctuations. However, coincidence of timing suggests an association of local zooplankton and environmental anomalies with the 1988 change in winter-season atmospheric pressure patterns in the North Pacific Ocean.

TI: Physical, biological and fisheries oceanography of a large ecosystem (west coast of Vancouver Island) and implications for management
AU: McFarlane, GA; Ware, DM; Thomson, RE; Mackas, DL; Robinson, CLK
AF: Pacific Biological Station, Hammond Bay Road, Nanaimo, British Columbia, V9R 5K6, Canada
ED: Castel, J (eds)
SO: [LONG-TERM CHANGES IN MARINE ECOSYSTEMS.] LES CHANGEMENTS A LONG TERME DANS LES ECOSYSTEMES MARINS., GAUTHIERS-VILLARS, PARIS (FRANCE), 1997, pp. 191-200, Oceanologica acta. Paris [OCEANOL. ACTA], vol. 20, no. 1
IS: 0399-1784
PB: GAUTHIERS-VILLARS, PARIS (FRANCE)
AB: The west coast of Vancouver Island is one of the most productive fishing grounds off western North America. In 1985, a multi-disciplinary study was initiated to provide long-term physical and biological data from this large marine ecosystem that could be used in the development of management strategies for commercial fish stocks. In this paper we review the physical, biological and fisheries oceanography of this system. We use this information to examine the linkages between these components, particularly changes in abundance of major fish species in relation to physical and biological oceanography. In addition, we present an overview of a model developed to synthesize our current knowledge about this ecosystem and the relative importance of climate conditions and predator-prey relationships in determining interannual and longer-term variation in productivity.

TI: Age-specific effects of sockeye abundance on adult body size of selected British Columbia sockeye stocks
AU: McKinnell, S
AF: Pac. Biol. Stn., Dep. Fish. and Oceans, Nanaimo, BC V9R 5K6, Canada
SO: Canadian Journal of Fisheries and Aquatic Sciences/Journal Canadien des Sciences Halieutiques et Aquatiques. Ottawa [CAN. J. FISH. AQUAT. SCI./J. CAN. SCI. HALIEUT. AQUAT.], vol. 52, no. 5, pp. 1050-1063, 1995
IS: 0706-652X
AB: Annual mean body lengths of adult sockeye salmon (Oncorhynchus nerka) covary systematically from year to year in major northern and central British Columbia stocks

(Nass River, Skeena River, and Rivers Inlet). These positive correlations are greatest between sexes within rivers, followed by age-classes among rivers. A common factor or factors affecting sockeye length in the North Pacific Ocean is suggested. The mean length of age 1.3 sockeye salmon but not age 1.2 sockeye caught annually in these B.C. fisheries was negatively correlated with the magnitude of Bristol Bay (western Alaska) sockeye catches. During the spring of maturation, age 1.3 sockeye from these B.C. stocks were farther from their natal streams, and likely subject to more intense competition with Bristol Bay sockeye than age 1.2 sockeye. The pattern of annual marine growth measured from Skeena River sockeye scales collected during the 1960s provides additional evidence that the length of age 1.3 sockeye was related to Bristol Bay sockeye abundance in the year of maturation. No such correlation was evident in scales collected from age 1.2 sockeye. These results suggest that sockeye populations have more systematic distributions in the North Pacific Ocean than has been previously reported.

TI: Population-specific aggregations of steelhead trout (Oncorhynchus mykiss) in the North Pacific Ocean

AU: McKinnell, S; Pella, JJ; Dahlberg, ML

AF: Science Branch, Department Fisheries Oceans, Hammond Bay Road, Nanaimo, BC V9R 5K6, Canada

SO: Canadian Journal of Fisheries and Aquatic Sciences/Journal Canadien des Sciences Halieutiques et Aquatiques. Ottawa [Can. J. Fish. Aquat. Sci./J. Can. Sci. Halieut. Aquat.], vol. 54, no. 10, pp. 2368-2376, 1997

IS: 0706-652X

AB: The distribution of North American hatchery-origin steelhead (Oncorhynchus mykiss) in the North Pacific Ocean varied by age and hatchery location. Columbia River steelhead were more abundant south of the Aleutian Islands at an earlier age than steelhead from the Georgia Basin (Georgia Strait, Puget Sound, and waters connecting with the open Pacific). Between 1984 and 1989, there were eight independent and coincident recoveries of coded-wire-tagged steelhead, where individuals released from hatcheries as juveniles at similar times and locations were recovered together on the high seas up to 3 years later. A statistical test was developed to determine whether these coincident recoveries should be expected if individual steelhead within populations traveled in the North Pacific in an uncoordinated manner. The overall test suggested that some tagged steelhead populations traveled together in a significantly coordinated manner on the high seas.

TI: Associations of species caught in the Japanese large scale pelagic squid driftnet fishery in the central North Pacific Ocean: 1988-1990

AU: McKinnell, S; Waddell, B

AF: Dep. Fish. Oceans, Biol. Sci. Branch, Nanaimo, BC V9R 5K6, Canada

CF: Symp. on Biology, Distribution and Stock Assessment of Species Caught in the High Seas Driftnet Fisheries in the North Pacific Ocean, Tokyo (Japan), 4 Nov 1991

ED: Ito, J; Shaw, W; Burgner, RL (eds)

SO: BIOLOGY, DISTRIBUTION AND STOCK ASSESSMENT OF SPECIES CAUGHT IN THE HIGH SEAS DRIFTNET FISHERIES IN THE NORTH PACIFIC OCEAN. 1. DRIFTNET FISHERIES OF THE NORTH PACIFIC OCEAN. 2. OCEANOGRAPHY -- BIOLOGY -- ECOLOGY (ALL SPECIES). 3. CATCH AND FISHERY IMPACT (ALL SPECIES)., 1993, pp. 91-109, INPFC BULL., vol. 53

AB: In the central North Pacific Ocean, many epipelagic species are susceptible to capture in monofilament driftnets. From 1988 to 1991, scientific observers of the Japanese large scale pelagic squid driftnet fishery recorded catches of target species and the bycatch of fish, birds, mammals, cephalopods, and turtles (data collected in 1991 were not available for analysis). Principal component analyses of species correlation matrices, stratified by month, in each of three years, produce meaningful ordinations of species. The ordination

patterns are consistent over the months and years examined and they are often significantly correlated with fishing locations and sea surface temperature.

TI: Review of the Japanese landbased driftnet salmon fishery in the western North Pacific Ocean and the continent of origin of salmonids in this area.
AU: Myers, KW; Harris, CK; Ishida, Y; Margolis, L; Ogura, M
CA: International North Pacific Fisheries Comm., Vancouver, B.C. (Canada)
SO: I.N.P.F.C. BULL., no. 52, 1993, 86 pp
NT: Incl. bibliogr.: 165 ref. INPFC was replaced Feb. 21, 1993 by the North Pacific Anadromous Fish Commission.
AB: Since 1978, much new information on the biology, distribution, abundance, and continent of origin of salmonids in the former fishing area of the Japanese landbased drifnet salmon fishery has been acquired. Research results have generally been submitted in the form of INPFC Documents. The purpose of this report is to summarize information reported to the Commission through 1991. The report includes a description of the salmonid resource in the area southwest of 48 degree N, 175 degree W, a review of the Japanese landbased driftnet salmon fishery, a summary of information on continent of origin of salmonids in the area, a review of estimates of interceptions of Asian and North American salmonids by the fishery, and a discussion of the effect of Convention changes on landbased fishery catches.

TI: Spatial variations in feeding and condition of juvenile pink and chum salmon off Vancouver Island, British Columbia
AU: Perry, RI; Hargreaves, NB; Waddell, BJ; Mackas, L
AF: Dep. Fish. and Oceans, Pacific Biol. Stn., Nanaimo, BC, Canada V9R 5K6
SO: Fisheries Oceanography [FISH. OCEANOGR.], vol. 5, no. 2, pp. 73-88, 1996
IS: 1054-6006
AB: Spatial variations in feeding and condition of juvenile pink (Oncorhynchus gorbuscha) and chum (Oncorhynchus keta) salmon, and their implications for growth, were examined on the Vancouver Island continental shelf in early summer 1992. Juvenile pink salmon off northern Vancouver Island had more material in their stomachs, were in better condition, and had higher potential growth rates (from a bioenergetics model) than pink salmon off southern Vancouver Island. These variations were consistent with spatial differences in zooplankton biomass, there being more plankton in the northern region. There was a significant positive relationship between condition of pinks and the amount of material in their stomachs, suggesting a positive feedback on feeding success. Juvenile chum in the north also had more material in their stomachs than chum to the south. However, condition factor was not significantly different between southern and northern regions nor was there a significant relationship between condition factor and the weight of stomach contents for chum on the southern shelf. A bioenergetics model suggests that chum in the south were food limited. Stable carbon isotope data also indicated different feeding histories for some chum in the southern region, which may have been recent migrants onto the continental shelf from near-shore areas, or possibly a nearby hatchery. Estimation of the energy required by juvenile salmon to migrate north in a continental shelf area with low zooplankton biomass and a weak northerly current (inner shelf), compared with an area with higher zooplankton biomass but a strong southerly current (outer shelf), indicated sufficient surplus energy only in the inner shelf, consistent with observations of northward migrations predominantly through this area. Spatial variations in current velocity and zooplankton biomass can affect feeding, condition, and potential growth of juvenile pink and chum salmon off Vancouver Island.

TI: Food web theory, marine food webs, and what climate change may do to northern marine fish populations

AU: Rice, J

AF: Dep. Fish. and Oceans, Biol. Sci. Branch, Pac. Biol. Stn., Nanaimo, BC V9R 5K6, Canada

CA: National Research Counc. of Canada, Ottawa, ON (Canada)

CF: Climate Change and Northern Fish Populations Conf., Victoria, BC (Canada), 19-24 Oct 1992

ED: Beamish, RJ (ed)

SO: CLIMATE CHANGE AND NORTHERN FISH POPULATIONS., 1995, pp. 561-568, Canadian special publication of fisheries and aquatic sciences /Publication speciale canadienne des sciences halieutiques et aquatiques Ottawa ON [CAN. SPEC. PUBL. FISH. AQUAT. SCI./PUBL. SPEC. CAN. SCI. HALIEUT. AQUAT.], no. 121

IS: 0706-6481

IB: 0-660-15780-2

NT: Incl. 64 ref.

AB: Many marine fish and invertebrates feed at progressively higher trophic positions as they grow larger. Many marine food webs, particularly in boreal and subboreal seas, have "waists"; that is, a single taxon in a middle trophic position passes most of the food or energy from lower trophic levels to all higher predators. Life-history omnivory and waists have profound effects on system dynamics. These effects seem not to depend on the details of the dynamic equations linking predators and prey. If the features are present in the real food web, any plausible representations of them in models are likely to dominate model dynamics. The abundances of many key species in marine food webs are conjectured to increase, decrease, or become more variable under climate change scenarios.

TI: Cycles of abundance among Fraser River sockeye salmon (Oncorhynchus nerka)

AU: Ricker, WE

AF: Department Fisheries Oceans, Pacific Biological Station, Nanaimo, BC V9R 5K6, Canada

SO: Canadian Journal of Fisheries and Aquatic Sciences/Journal Canadien des Sciences Halieutiques et Aquatiques. Ottawa [CAN. J. FISH. AQUAT. SCI./J. CAN. SCI. HALIEUT. AQUAT.], vol. 54, no. 4, pp. 950-968, 1997

IS: 0706-652X

AB: In some but not all populations of sockeye salmon (Oncorhynchus nerka) that mature mainly at age 4, there has been a persistently `subdominant' line about 10-25% as large, and two weak lines having less than 1% as many fish as the dominant line. Suggested causes of this phenomenon that have been shown to be wrong or inadequate are the presence of a few sockeye of ages 3 and 5 in the spawning stocks and a somewhat larger rate of harvest of the nondominant lines. The only plausible type of explanation that has been suggested so far involves interaction between the dominant line and the others, and the only specific example involves a 4-year cycle of abundance of a predacious fish at Shuswap Lake. Other types of interactions are possible, but have not been documented. The magnitudes of the instantaneous interaction mortality rates at Shuswap Lake are estimated as about 0.78 per generation for the subdominant line out of a 7.65 total, and 1.11 out of 7.94 for the weak line 3, line 4 being similar.

TI: Ocean Station 'Papa' detailed zooplankton data: 1956-1980

AU: Waddell, BJ; McKinnell, S

CA: Department of Fisheries and Oceans, Nanaimo, BC (Canada). Sci. Branch

SO: Canadian technical report of fisheries and aquatic sciences/Rapport technique canadien des sciences halieutiques et aquatiques. Imprint varies [CAN. TECH. REP. FISH. AQUAT. SCI./RAPP. TECH. CAN. SCI. HALIEUT. AQUAT.], 1995, no. 2056, 25 pp

IS: 0706-6457

AB: Zooplankton samples were collected at Ocean Station "P" (50 degree N, 145 degree W) from 1956 to 1980, and were analyzed to various levels of taxonomic resolution over the years. Although summaries of these data have been previously published by LeBrasseur (1965) and Fulton (1978, 1983), the detailed species data have never been published. We have reformatted the detailed data, corrected any errors we discovered, and added extra information to produce one complete dataset for the whole sampling period. This dataset contains total zooplankton wet weights/m super(3) for the whole period 1956 to 1980, as well as densities (numbers/m super(3)) for five major taxa (copepods, chaetognaths, euphausiids, amphipods, and Aglantha) from 1964 to 1967, and species identifications, counts and lengths for many samples collected between 1968 to 1980. The purpose of this document is to make the detailed data available to the scientific community in electronic format, and to provide a convenient reference for citing the detailed data. A diskette is enclosed that contains the complete, "corrected", detailed zooplankton data, both of the original data files, and a dataset with other variables for samples collected from 1956 to 1964. The document contains information on the methods used to collect and process the data, and describes our version of the dataset, along with descriptions of a number of fairly minor points about the data that we were unable to resolve. It also describes, in detail, the format of the original data files, the corrections/changes we made to these files in creating our version, and how these errors affect what was published in Fulton (1983). (DBO)

TI: Anatomical Specialization in the Gut of Pacific Salmon (*Oncorhynchus*): Evidence for Oceanic Limits to Salmon Production?

AU: Welch, DW

AF: Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, BC V9R 5K6

SO: Canadian Journal of Zoology [CAN. J. ZOOL.], vol. 75, no. 6, pp. 936-942, 1997

AB: The stomach (but not intestine) of chum salmon (*Oncorhynchus keta*) is greatly enlarged relative to other species of Pacific salmon. This permits the exploitation of gelatinous zooplankton (jellyfish, ctenophores, and salps) as a major food source, an abundant but low energy prey unused by other species of salmon. The unique gut structure of chum therefore allows efficient feeding on a little-exploited branch of the food web and reduces inter-specific trophic competition. The development of this remarkable anatomical specialization suggests that salmon abundances were previously high enough that the resulting trophic competition led to evolutionary selection to reduce trophic competition. As total salmon abundances in the north Pacific are now probably the highest of this century, the carrying capacity of the ocean rather than freshwater could limit overall salmon production if abundances are once again approaching pre-exploitation levels.

TI: Upper thermal limits on the oceanic distribution of Pacific salmon (Oncorhynchus spp.) in the spring

AU: Welch, DW; Chigirinsky, AI; Ishida, Y

AF: Dep. Fish. and Oceans, Biol. Sci. Branch, Nanaimo, BC V9R 5K6, Canada

SO: Canadian Journal of Fisheries and Aquatic Sciences/Journal Canadien des Sciences Halieutiques et Aquatiques. Ottawa [CAN. J. FISH. AQUAT. SCI./J. CAN. SCI. HALIEUT. AQUAT.], vol. 52, no. 3, pp. 489-503, 1995

IS: 0706-652X

AB: Pacific salmon (Oncorhynchus spp.) are normally thought to be distributed throughout the Subarctic Pacific, an area where they form the dominant fish fauna. A series was used of generalized additive models to show that salmon exhibit a sharp step-function response to temperature in the oceanic eastern North Pacific in spring. The critical temperature defining the southern boundary varied by species: 10.4 degree C for pink and chum salmon, 9.4 degree C for coho salmon, and 8.9 degree C for sockeye salmon. These thermal limits occur well to the north of the southern boundary of the Transition Zone, at widely separated geographic positions within the Subarctic Domain, and at temperatures

much lower than the lethal upper limit for each species. The sharp decline in abundance with temperature, and the remarkably low temperatures at which the response occurs, suggests that thermal barriers form an effective limit to the offshore distribution of salmon in spring, and can limit the distribution of Pacific salmon to a relatively small area of the Subarctic Pacific.

TI: On the statistical distribution of salmon in the sea: Application of the negative binomial distribution, and the influence of sampling effort.
AU: Welch, DW; Ishida, Y
AF: Dep. Fish. and Oceans, Pacific Biol. Stn., Nanaimo, BC V9R 5K6, Canada
SO: Canadian Journal of Fisheries and Aquatic Sciences [CAN. J. FISH. AQUAT. SCI.], vol. 50, no. 5, pp. 1029-1038, 1993
IS: 0706-652X
NT: Incl. bibliogr.: 26 ref.
AB: We examined the sampling statistics of Pacific salmon (Oncorhynchus spp.) caught in a series of experimental gillnet sets on the high seas and demonstrate how the reliability of the catch statistics varies with the amount of sampling effort. Our analysis indicates that the replicate catches, which were made under essentially identical conditions, are adequately described by the negative binomial distribution. We also extend the utility of this distribution for describing catch statistics by showing that (1) the shape parameter of the distribution can be directly interpreted as the number of degrees of freedom (df) associated with each observation of catch and (2) the df are related to the amount of sampling effort used and the size of the biological aggregation being encountered by the gear. For salmon caught on the high seas, approximately 1 df is obtained per 15 m of gill net used.

TI: Thermal limits on the ocean distribution of steelhead trout (Oncorhynchus mykiss)
AU: Welch, DW; Ishida, Y; Nagasawa, K; Eveson, JP
AF: Department Fisheries Oceans, Pacific Biological Station, Nanaimo, BC V9R 5K6, Canada
CA: North Pacific Anadromous Fish Comm., Vancouver, BC [Canada]
SO: NPAFC Bulletin Number 1: Assessment and status of Pacific Rim salmonid stocks., 1998, no. 1, pp. 396-404, Bull. NPAFC, no. 1
IS: 1028-9127
AB: Sharp thermal limits to the ocean distribution of steelhead trout (Oncorhynchus mykiss) are described which restrict the distribution of steelhead to only a small fraction of the area of the North Pacific otherwise available for grazing. Maximum likelihood estimates indicate that: 1) steelhead exhibit a strong response to temperature in all regions of the North Pacific and in all seasons of the year; 2) both the upper and lower thermal thresholds exist; 3) although the thermal limits have been largely stable over the last 40 years, the temperature defining the southern edge of the steelhead distribution exhibits statistically significant fine-scale differences between regions and between decades. As a result of this strong thermal control, steelhead are distributed in a narrow north-south band stretching across much of the width of the Pacific. Projections of the degree of ocean warming resulting from greenhouse gas induced climate change suggest that the ocean distribution of steelhead may shift far enough north under a 2xCO sub(2) climate that large areas of currently occupied ocean habitat could lie outside the range of these thermal limits by the middle of the next century. This paper reports on an extensive analysis based on essentially all available survey data useful for describing the sharp relationship between distribution of ocean temperatures and marine distribution of steelhead trout.

TI: Entrainment of nitrate in the Fraser River Estuary and its biological implications. 1. Effects of the salt wedge

AU: Yin, K; Harrison, PJ; Pond, S; Beamish, RJ

AF: Dep. Oceanogr., Univ. British Columbia, Vancouver, BC V6T 1Z4, Canada

SO: Estuarine, Coastal and Shelf Science [ESTUAR. COAST. SHELF SCI.], vol. 40, no. 5, pp. 505-528, 1995

IS: 0272-7714

AB: A series of high-resolution vertical profiles of temperature, salinity, NO sub(3) and fluorescence were taken along a transect of the Fraser River estuary to investigate entrainment of NO sub(3). In late spring and summer, the NO sub(3)-poor estuarine plume was found to invade the river with the advancing salt wedge on the flood tide and to form a middle layer between the river water and the NO sub(3)-rich deep seawater in the salt wedge, forming a three-layered system. Thus, during entrainment the upward flux of salt into the riverine plume does not necessarily result in an upward flux of NO sub(3) due to the entrainment of low NO sub(3) estuarine plume water. Therefore, the amount of the entrained NO sub(3) was determined by the amount of the entrained deep water. Entrainment was affected by the tides, with more entrainment occurring during spring than neap tides. At lower low water during a spring tide, the river outflow was stronger and it pushed the estuarine plume water seaward more effectively. Thus, the outflowing freshwater entrained more NO sub(3)-rich deep water during spring tides. There was a chlorophyll maximum located at the bottom of the interface between the estuarine plume and the deep water. The maximum was advected into the river with the invasion of the incoming salt wedge on flood tides and entrained into the outflowing riverine plume on tidal ebbs. The chlorophyll maximum under the riverine plume was often below the euphotic zone and little uptake of nutrients occurred in the dark in samples taken from it at the time of sampling. However, when the samples were incubated under different irradiances, uptake of nutrients increased with increasing irradiance. Thus the phytoplankton in the chlorophyll maximum could serve as a potential seed population for blooms in regions further seaward beyond the river mouth when they were entrained into a zone with improved irradiance and entrained nutrients.

TI: Entrainment of nitrate in the Fraser River estuary and its biological implications. 2. Effects of spring vs. neap tides and river discharge

AU: Yin, K; Harrison, PJ; Pond, S; Beamish, RJ

AF: Dep. Oceanogr., Univ. British Columbia, Vancouver, BC V6T 1Z4, Canada

SO: Estuarine, Coastal and Shelf Science [ESTUAR. COAST. SHELF SCI.], vol. 40, no. 5, pp. 529-544, 1995

IS: 0272-7714

AB: A 24-h time series of high-resolution vertical profiles of salinity, temperature, NO sub(3) and fluorescence were taken during spring and neap tides at an anchored station (station 2) in the Strait of Georgia, 8 km seaward of the mouth of the Fraser River in order to estimate entrainment of NO sub(3) resulting from the outflowing riverine plume. The time series confirmed that more NO sub(3) was entrained during the spring tide (24 mmol m super(-2)) than during the neap tide (17 mmol m super(-2)). The contribution of the entrained NO sub(3) was 2.3 and 1.6 times that of the river-borne NO sub(3) during spring and neap tides, respectively. We hypothesize that spring tides cause stronger bottom stirring which results in higher NO sub(3) concentrations in the deep seawater which is the source of NO sub(3) that is entrained upward. The results from the times series taken during days of different river discharge show that during higher river discharge (9000 m super(3) s super(-1)) more NO sub(3) (72 mmol m super(-2)) was entrained than during lower (6720 m super(3) s super(-1)) river discharge (32 mmol m super(-2)). The entrained NO sub(3) was 5.4 times that of the river-borne NO sub(3) during the higher river discharge and 3.3 times during the lower discharge. The mechanism which explains the greater NO sub(3) entrainment is that greater river

discharge pushes the estuarine plume seaward, further from the river mouth, and therefore there is a larger area of deep seawater (with higher NO sub(3) concentrations) exposed directly to the riverine plume for entrainment.

TI: Entrainment of nitrate in the Fraser River Estuary and its biological implications. 3. Effects of winds

AU: Yin, K; Harrison, PJ; Pond, S; Beamish, RJ

AF: Dep. Oceanogr., Univ. British Columbia, Vancouver, BC V6T 1Z4, Canada

SO: Estuarine, Coastal and Shelf Science [ESTUAR. COAST. SHELF SCI.], vol. 40, no. 5, pp. 545-558, 1995

IS: 0272-7714

AB: Two 24-h time series of vertical profiles of velocity, salinity, temperature, fluorescence and NO sub(3) were conducted during weak and strong winds (2.2 and 7.3 m/s, respectively) to demonstrate wind effects on entrainment of NO sub(3) near the mouth of the Fraser River. The results showed that wind-induced entrainment of NO sub(3) was mainly responsible for the increased NO sub(3) concentrations in the upper layer because shear velocities between the upper and lower layers were great enough to break down the pycnocline and allow diapycnal mixing to occur. Strong shear was indicated by Richardson numbers less than 0.25 near the depth at which flows in the upper and lower layers moved opposite to each other. As a result of wind-induced entrainment and mixing, the NO sub(3) minimum in the water column was gradually eroded and disappeared at the end of the time series during the strong wind event. The amount of entrained NO sub(3) under windy conditions (44 mmol m super(-) super(2)) was almost three times that (16 mmol m super(-2)) under weak winds. The high ratios of the amount of entrained NO sub(3) to river-borne NO sub(3) (12 under windy conditions and 5.6 under weak winds) indicates that wind-induced entrainment of NO sub(3) in summer is particularly important for new production. Because turbulent energy came from winds, mixing started at the surface and moved downward. Thus, phytoplankton cells remained in the surface mixed layer, and responded to the entrained nutrients and grew rapidly. Phytoplankton biomass and primary production in the water column increased at the end of the time series, compared to the beginning.

TI: Differences in otolith microstructure between hatchery-reared and wild chinook salmon (Oncorhynchus tshawytscha)

AU: Zhang, Z; Beamish, RJ; Riddell, BE

AF: Dep. Fish. and Oceans, Pac. Biol. Stn., Nanaimo, BC V9R 5K6, Canada

SO: Canadian Journal of Fisheries and Aquatic Sciences/Journal Canadien des Sciences Halieutiques et Aquatiques. Ottawa [CAN. J. FISH. AQUAT. SCI./J. CAN. SCI. HALIEUT. AQUAT.], vol. 52, no. 2, pp. 344-352, 1995

IS: 0706-652X

AB: Otolith microstructure exhibited some characteristic differences between hatchery-reared and wild chinook salmon (Oncorhynchus tshawytscha) from the Cowichan River. Daily growth increments that formed in the otoliths of the hatchery-reared chinook salmon after exogenous feeding were more regular in width and contrast than those in the otoliths of wild chinook salmon. In addition, otoliths from hatchery-reared individuals frequently produced a check when the fish were released from the hatchery. Eighty-nine percent of a sample of 67 chinook smolts that had been coded-wire tagged in hatcheries and later captured in the Strait of Georgia were correctly identified as originating from hatcheries based on otolith microstructure. These tagged fish originated from at least 17 different hatcheries, indicating that the method could be used to identify chinook salmon originating from other hatcheries.