NPAFC

Doc. No. 558

Rev. No._____

Canadian Research Results, 1999-2000: Report on the Canadian Workplans

by

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submitted to the

NORTH PACIFIC ANADROMOUS FISH COMMISSION

by

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September 2001

This paper may be cited in the following manner:
D.J. Noakes and C.G. Wallace. Canadian research results, 1999-2000: Report on the Canadian workplans (NPAFC Doc. No. 558). 18 p. Dept. of Fisheries and Oceans, Sciences Branch - Pacific Region, Pacific Biological Station, Nanaimo, B.C. Canada. V9R 5K6

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 1999-2000. 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: Chapter 5 Fisheries Climatology: understanding decadal scale processes that naturally regulate British Columbia fish populations.

AU: Beamish, RJ, McFarlane, GA and King, JR

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

SO: Fisheries Oceanography An Integrated approach to fisheries ecology and management, department of earth and ocean sciences, University of British Columbia, Canada,

PB: Blackwell Science Ltd.

AB: Traditional fisheries science theory proposes that all unexploited populations have a surplus yield that can be removed by fishing. This basic assumption implies that fishing unexploited populations is always possible*, albeit* at varying levels. This theory was developed when fish populations were less threatened and the relationship between climate and fish population dynamics was unknown. We believe that climate fluctuations have always affected fish abundance, but in the distant past the confounding effects of fishing were not present. Thus, while species of commercial interest survived natural fluctuations in climate-ocean environment before being fished, there is no guarantee that they can survive future extremes, particularly with the poor understanding of the interactions of these species and their ecosystem. Therefore, it is important to rethink how to assess the impacts of fishing. It is also important to think of the impact of fishing on the ecosystem in the context of evolutionary processes. When species are removed continuously, how is the carrying capacity for the species affected? Is it correct to assume that the interrelationships among species remain the same? Does the fishery become an extreme factor that results in the natural selection of the traits of the species that are best adapted to the new habitat conditions that include the impact of fishing? We should always remember that plants and animals respond to extreme change by changing themselves. Extreme change is actually a common event over evolutionary time. We need to at least consider the possibility that fishing is an extreme change. Will other human impacts such as global warming be an extreme change? Considering that the future of fisheries science will be complicated by global climate change, it is appropriate to emphasize the linkage between our climate, the ocean ecosystem and fish population dynamics.

In this chapter, we introduce the major climate and ocean systems of the North Pacific. We review several indices that characterize the nature of climate and ocean conditions within regimes and that exhibit regime shifts in their time series. The changes in climate-ocean states in the North Pacific translate into changes in regional weather and ocean conditions and we present some examples of regional environmental variables. Next we will focus on the consequences that these changes in climate-ocean systems have for fish populations, specifically the impact on commercial fisheries of British Columbia. The regime shifts exhibited by the climate-ocean systems are mirrored in catch and abundance patterns in fish populations. We believe that the synchronicity of changes in climate-ocean states and fish abundance points to a direct link between these systems. In order to emphasize the need to understand and incorporate relationships between

climate, ocean ecosystems and fish population dynamics into fisheries management, new studies linking climates and fisheries could be called fisheries climatology.

TI: Trends in coho marine survival in relation to the regime concept
AU: Beamish, R; Noakes, D; Mcfarlane, G; Pinnix, W; Sweeting, R; King, J
AF: Department of Fisheries and Oceans, Sciences Branch, Pacific Biological Station, Nanaimo, BC, Canada V9R 5K6
SO: Fisheries Oceanography [Fish. Oceanogr.], vol. 9, no. 1, pp. 114-119, Mar 2000
IS: 1054-6006
PB: Blackwell Science Ltd
AB: There was a synchronous and significant decrease in marine survival of coho salmon in the Strait of Georgia, Puget Sound, and off the coast from California to Washington after 1989. This large-scale, synchronous change indicates that trends in coho marine survivals were linked over the southern area of their distribution in the north-east Pacific, and that these linkages were associated with a common event. Indicators of large-scale climate change (the Aleutian Low Pressure Index) and of recent regional climate change (the April flows from the Fraser River) also changed abruptly about the same time. The synchrony of trends in marine survival of aggregates of coho stocks from three distinct marine areas and trends in climate indices implies that climate/ocean changes can have profound impacts on the population dynamics of coho salmon. The trend towards low marine survival may persist as long as the trends in the climate indicators do not change.

TI: Recent declines in the recreational catch of coho salmon (Oncorhynchus kisutch) in the Strait of Georgia are related to climate
AU: Beamish, RJ; McFarlane, GA; Thomson, RE
AF: Biological Sciences Branch, Department Fisheries Oceans Nanaimo, BC V9R 5K6 Canada; E-mail:beamishr@dfo-mpo.gc.ca
SO: Canadian journal of fisheries and aquatic sciences/Journal canadien des sciences halieutiques et aquatiques. Ottawa ON [Can. J. Fish. Aquat. Sci./J. Can. Sci. Halieut. Aquat.], vol. 56, no. 3, pp. 506-515, 1999
IS: 0706-652X
AB: Wild and hatchery-reared coho salmon (Oncorhynchus kisutch) from streams and rivers that flow into the Strait of Georgia are caught in the Strait of Georgia and off the west coast of Vancouver Island. The percentage of coho caught in either of these two areas varies from year to year. The variation is associated with the flow of freshwater from the Fraser River and became more extreme in the 1990s. In four of eight years in the 1990s and in the past three years, most coho have been caught outside the Strait of Georgia. The dramatic decline in the sport catch in the Strait is related to ocean conditions in the Strait. The change in ocean conditions is related to an increase in the number of days of zonal (westerly) winds in October, November, and December and to an increase in relative sea level height. The climate change about 1989 that affected the pattern of winter winds and the circulation in the Strait of Georgia was associated with changes in other global climatic indices, demonstrating the impact that global climate events can have on the dynamics of regional salmon stocks.

TI: Large-scale climate-related changes in the carrying capacity in the Strait of Georgia and Northern Pacific ecosystems
AU: Beamish, RJ; Neville CM
AF: Department Fisheries Oceans, Pacific Biological Station 3190 Hammond Road, Nanaimo, BC V9R 5K6 Canada;
SO: Large Marine Ecosystems of the Pacific Rim: Assessment, Sustainability, and Management. P 27-41. 1999
ED: Sherman, K and Tang, Q.

PB: Blackwell Science Ltd

AB: Changes in the ecosystem in the Strait of Georgia are linked to changes in the ecosystem in the northern North Pacific Ocean. The intensification of the Aleutian low pressure system that began in the late 1970s was associated with a decrease in snowpack, a decrease in total annual discharge from the Fraser River, and an increase in the water temperatures in the Strait. The changes in the northern North Pacific were associated with an intensification of the Aleution Low, a cooling of the mid-Pacific, and an increased plankton production, possibly as a consequence of mid-ocean upwelling. Increases in salmon production occurred in the mid-Pacific, whereas the changes in the Strait of Georgia appear to be associated with decreases in production of chinook salmon and decreases in the survival of hatchery-reared chinook and coho salmon. The apparent opposite effects of large-scale climate shift on salmon survival in a coastal and mid-ocean ecosystem highlight the importance of understanding the linkages between marine ecosystems and salmon production when attempting to manage fisheries for these species.

TI: The regime concept and natural trends in the production of Pacific salmon

AU: Beamish, RJ; Noakes, DJ; McFarlane, GA; Klyashtorin, L; Ivanov, VV; Kurashov, V

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

SO: Canadian journal of fisheries and aquatic sciences/Journal canadien des sciences halieutiques et aquatiques. Ottawa ON [Can. J. Fish. Aquat. Sci./J. Can. Sci. Halieut. Aquat.], vol. 56, no. 3, pp. 516-526, 1999

IS: ISSN 0706-652X

AB: Large fluctuations in the trends of Pacific salmon (Oncorhynchus) production in this century have been linked to trends in climate in the Pacific that are in turn associated with climate trends throughout the Northern Hemisphere. The close correspondence in the persistence of climate trends and the synchrony of the changes is evidence that a common event may cause the regime shifts. The trends or regimes can be characterized by stable means in physical data series or multiyear periods of linked recruitment patterns in fish populations. The regime concept is important in fisheries management because the natural shifts in abundance may be large and sudden, requiring that these natural impacts be distinguished from fishing effects. An equally important consideration is that biological and physical mechanisms may change when regimes shift, resulting in conditions that may not be characterized in the earlier part of the data series. Fluctuations in Pacific salmon abundance in this century were synchronous with large fluctuations in Japanese sardine abundance, which can be traced back to the early 1600s. The synchrony in the fluctuations suggests that Pacific salmon abundance may have fluctuated for centuries in response to trends in climate. The concept of regimes and regime shifts stresses the need to improve understanding of the mechanisms that regulate the dynamics of fish and their ecosystems.

TI: Land use, fishing, climate change, and the decline of Thompson River, British Columbia, coho salmon

AU: Bradford, MJ; Irvine, JR

AF: Fisheries and Oceans Canada and Cooperative Resource Management Institute, Simon Fraser University Burnaby, BC V5A 1S6 Canada; E-mail: mbradfor@sfu.ca

SO: Canadian Journal of Fisheries and Aquatic Sciences [Can. J. Fish. Aquat. Sci./J. Can. Sci. Halieut. Aquat.], vol. 57, no. 1, pp. 13-16, 2000

IS: 0706-652X

AB: This study investigates a recent, major decline in the abundance of a large aggregate of coho salmon (Onchorynchus kisutch) spawning in the Thompson River, British Columbia, watershed. It was found that the decline could be attributed to a declining trend in productivity likely related to changing ocean conditions, overfishing, and freshwater

habitat alteration. Among individual watersheds, rates of decline in adult coho salmon abundance were correlated with agricultural land use, road density, and a qualitative measure of stream habitat status but not with the proportion of land recently logged. The recovery of these populations will require the prudent regulation of fishing, the restoration of salmon producing watersheds, and an improvement in ocean conditions.

TI: Have there been recent changes in climate? Ask the fish

AU: McFarlane, GA; King, JR; Beamish, RJ

AF: Fisheries and Oceans Canada, Pacific Biological Station Nanaimo, BC V9R 5K6 Canada; E-mail: noakesd@pac.dfo-mpo.gc.ca

SO: Progress in Oceanography [Prog. Oceanogr.], vol. 47, no. 2-4, pp. 147-169, 2000

AB: It is generally accepted that a climate shift occurred about 1977 that affected the dynamics of North Pacific marine ecosystems. Agreement on the possibility of climate shifts in 1989 and 1997 is not widely accepted. However, there have been some changes in the dynamics of key commercial fishes that indicate changes in their environment occurred in the early 1990's and possibly around 1996/97. One method of measuring climate change is to observe the dynamics of species that could be affected.

Several studies have described decadal-scale changes in North Pacific climate-ocean conditions. Generally, these studies focus on a single index. Using principal components analysis, we use a composite index based on three aspects of climate ocean conditions: the Aleutian Low Pressure Index, the Pacific Atmospheric Circulation Index and the Pacific Interdecadal Oscillation Index. We link this composite index (Atmospheric Forcing Index) to decadal-scale changes in British Columbia salmon and other fish populations. Around 1989 there was a change from intense Aleutian Lows, above average south-westerly and westerly circulation patterns and warming of coastal sea surface temperatures to average Aleutian Lows, less frequent south-westerly and westerly circulation and slightly cooler coastal sea surface temperatures in winter. These climate-ocean changes were associated with changes in the abundance and ocean survival of salmon (*Oncorhynchus spp*.), distribution and spawning behaviour of hake (*Merluccius productus*) and sardines (*Sardinops sagax*) and in recruitment patterns of several groundfish species.

TI: Changing the balance: Interactions between hatchery and wild Pacific coho salmon in the presence of regime shifts.

AU: Noakes, DJ; Beamish, RJ; Sweeting, R; King, J

AF: Fisheries and Oceans Canada, Pacific Biological Station Nanaimo, BC V9R 5K6 Canada; E-mail: noakesd@pac.dfo-mpo.gc.ca

CA: North Pacific Anadromous Fish Comm., Vancouver, BC (Canada)

ED: Helle, JH (ed); Ishida, Y(ed); Noakes, D(ed); Radchenko, V(ed)

SO: NPAFC Bulletin Number 2: Recent changes in ocean production of Pacific salmon., 2000, no. 2, pp. 155-163, Bull. Npafc

IS: 1028-9127

AB: Nearly 5 billion salmon are released from enhancement projects on an annual basis into the Pacific Ocean by Canada, Japan, Russia, and the United States. Although these large-scale enhancement programs contribute substantially to salmon fisheries in the North Pacific, there is growing evidence to suggest that these hatchery fish may negatively affect wild salmon stocks both from a genetic and ecological perspective. There is also some evidence that hatchery fish have replaced wild fish particularly chinook (Oncorhynchus tshawytscha) and coho (Oncorhynchus kisutch) stocks. The percentage of hatchery fish in the waters off southern British Columbia, marine survival and climate trends, and hatchery policies and practices are used to examine potential interactions between hatchery and wild stocks. Shifts to lower productivity regimes such

as those that occurred in 1989/90 may amplify the negative interactions. Decisive management action such as significantly reducing harvest pressure and protecting freshwater habitat may reduce these effects, but longer-term solutions are a possibility only if enhancement activities are viewed in a broader ecological context.

TI: Comparison of parameter estimation methods for detecting climate-induced changes in productivity of Pacific salmon (Onchorynchus spp.)
AU: Peterman, RM; Pyper, BJ; Grout, JA
AF: School of Resource and Environmental Management, Simon Fraser University, Burnaby, BC V5A 1S6, Canada; E-mail: peterman@sfu.ca
SO: Canadian Journal of Fisheries and Aquatic Sciences [Can. J. Fish. Aquat. Sci./J. Can. Sci. Halieut. Aquat.], vol. 57, no. 1, pp. 181-191, 2000
IS: 0706-652X
AB: Pacific salmon (Oncorhynchus spp.) populations can experience persistent changes in productivity, possibly due to climatic shifts. Management agencies need to rapidly and reliably detect such changes to avoid costly suboptimal harvests or depletion of stocks. Given the inherent variability of salmon populations, it is difficult to detect changes quickly, let alone forecast them. Therefore, three methods of annually updating estimates of stock recruitment parameters were compared: standard linear regression, Walters' bias-corrected regression, and a Kalman filter. Monte Carlo simulations were used that hypothesized a wide range of future climate-induced changes in the Ricker a parameter of a salmon stock. Then each parameter estimation method was used on the simulated stock and recruitment data and escapement targets and harvest goals were set accordingly. In these situations with a time-varying true Ricker a parameter, Kalman filter estimation resulted in greater mean cumulative catch than was produced by the standard linear regression approach, Walters' bias correction method, or a fixed harvest rate policy. This benefit of the Kalman filter resulted from its better ability to track changing parameter values, thereby producing escapements closer to the optimal escapement each year. However, errors in implementing desired management actions can significantly reduce benefits from all parameter estimation techniques.

TI: New Developments in Ocean Salmon Research
AU: Welch, DW
AF: Fisheries and Oceans Canada, Pacific Biological Station Nanaimo, BC V9R 5K6 Canada; E-mail: welchd@pac.dfo-mpo.gc.ca
SO: EEZ tech. 4: (Exclusive Economic Zones: Technology) pp. 203-210, 1999.
AB: The stocks of Pacific salmon form some of the most valuable fisheries in the world. In this article I describe some of the basic scientific research directed at salmon, and relate these efforts to understanding why the oceans are currently changing in the 1990s. There are unprecedented and fundamental changes occurring in both our understanding of how and why salmon use the ocean, and also in our growing appreciation of the effects of ocean climate on salmon. In particular, very rapid and large scale changes in ocean climate occurring in the 1990s may now be having devastating effects on the marine survival of many species of salmon, seriously affecting the sustainability of existing fisheries. Long-term impacts from global warming may also prove to have major implications for sustainability. In each case, a fundamental requirement is to develop a better scientific understanding of how fish species use the ocean and fit into the marine food chain. This will involve increasing use of new technologies such as archival tags to supplement traditional scientific methods

2. Stock Identification

TI: **Microsatellite DNA variation and estimation of stock composition of sockeye salmon, Oncorhynchus nerka, in Barkley Sound, British Columbia**

AU: Beacham, TD; Le, KD; Raap, MR; Hyatt, K; Luedke, W; Withler, RE

AF: Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, British Columbia, Canada V9R 5K6; E-mail: beachamt@pac.dfo-mpo.gc.ca

SO: Fishery Bulletin [Fish. Bull.], vol. 98, no. 1, pp. 14-24, Jan 2000

IS: 0090-0656

AB: Microsatellite DNA variation at six microsatellite loci (Omy77, Ots3, Ots100, Ots103, Ots107, and Ots108) was examined in approximately 900 sockeye salmon, Oncorhynchus nerka, collected between 1987 and 1995 from three stocks on the west coast of Vancouver Island, British Columbia, Canada. Variation in allele frequencies among stocks was, on average, about 12 times greater than temporal variation within stocks. Individual locus F sub(ST) estimates ranged from 0.013 to 0.107 among stocks, with an overall value of 0.056. Analysis of simulated mixed-stock samples indicated that data from four to six of the microsatellite loci surveyed would enable relatively accurate and precise estimates of stock composition for mixtures composed of fish from the three stocks. Application of the mixture analysis to 1100 fish sampled in Barkley Sound and Alberni Inlet fisheries during 1997 indicated that sockeye salmon from Great Central Lake constituted about 70% of the commercial catch. The later time of return of sockeye salmon from Henderson Lake than of those from Great Central or Sproat Lake as previously indicated by analysis of parasite frequencies was confirmed in the 1997 fishery sampling. Stock composition of catches varied among gears, presumably owing to gear selectivity.

TI: **Microsatellite DNA population structure and stock identification of steelhead trout (*Oncorhynchus mykiss*) in the Nass and Skeena Rivers in northern British Columbia.**

AU: Beacham, TD; Pollard, S, and Le, KD.

AF: Pacific Biological Station, Department of Fisheries and Oceans, Nanaimo, British Columbia, Canada V9R 5K6; E-mail: beachamt@pac.dfo-mpo.gc.ca

SO: Marine Biotechnology, pp587-600, 2000

AB: Population structure and the application to genetic stock identification for steelhead (Oncorhynchus mykiss) in the Nass and Skeena rivers in northern British Columbia was examined using microsatellite markers. Variation at eight microsatellite loci (Oki200, Omy77, Ots1, Ots3, Ssa85,Ots100, Ots103, and Ots108) was surveyed for approximately 930 steelhead from 7 populations in the Skeena River drainage, and 850 steelhead from 10 populations in the Nass River drainage, as well as 1,550 steelhead from test fisheries conducted near the mouth of each river. Differentiation among populations within rivers accounted for about 1.9 times the variation observed among years within populations, with differences between drainages less than variation among populations within drainages. In the Nass River, winter-run populations formed a distinct group from the summer-run populations. Winter-run populations were not assessed in the Skeena River watershed. Simulated mixed-stock samples suggested that variation at the eight microsatellite loci surveyed should provide relatively accurate and precise estimates of stock composition for fishery management applications within drainages. In the Skeena River drainage in 1998, Babine River (27%) and Bulkley drainage populations (31%) comprised the main components of the returns. For the Nass River in 1998, steelhead returning to Bell-Irving River were estimated to have comprised 39% of the fish sampled in the test fishery, with an additional 27% of the returns estimated to be derived from Cranberry River. The survey of microsatellite variation did not reveal enough differentiation between Nass River and Skeena River populations to be applied confidently in estimation of stock composition in marine fisheries at this time.

TI: **Application of microsatellite DNA variation to estimation of stock composition and escapement of Skeena River Sockeye salmon (*Oncorhynchus nerka*).**

AU: Beacham, TD; Wood, CC; Withler, RE; Le, KD; Miller, KM

AF: Department of Fisheries and Oceans, Pacific Biological Station Nanaimo, BC V9R 5K6 Canada; E-mail: beachamt@pac.dfo-mpo.gc.ca

CA: North Pacific Anadromous Fish Comm., Vancouver, BC (Canada)

ED: Helle, JH (ed); Ishida, Y(ed); Noakes, D(ed); Radchenko, V(ed)

SO: NPAFC Bulletin Number 2: Recent changes in ocean production of Pacific salmon., 2000, no. 2, pp. 263-276, Bull. Npafc

IS: 1028-9127

AB: Microsatellite loci can be used to estimate spawning escapements of individual Pacific salmon populations returning to remote spawning locations throughout large river systems by analysis of appropriately weighted samples from test fisheries near the river mouth. Variation at six microsatellite loci was surveyed from approximately 1,700 sockeye salmon (Oncorhynchus nerka) from 17 populations in the Skeena River drainage in northern British Columbia, as well as from 1,400 fish in test fisheries conducted in the lower river during 1996-1999. Simulated mixed-stock samples suggested that the six microsatellite DNA loci should enable relatively accurate and precise estimates of stock composition when utilized for fishery management applications within the river. Analysis of the test fishery samples indicated that sockeye salmon from Babine Lake comprised a substantial portion of the returning fish. Population structure of sockeye salmon was also compared from both the Skeena and Nass rivers. Simulated and actual mixed-stock samples suggested that accurate estimates of stock composition of sockeye salmon from these two major production areas in northern British Columbia should be obtained in analysis of samples from mixed-stock marine fisheries.

TI: **Population Structure and Stock Identification of Steelhead in Southern British Columbia, Washington, and the Columbia River Based on Microsatellite DNA Variation**

AU: Beacham, TD; Pollard, S; Le, KD

AF: Department of Fisheries and Oceans, Science Branch, Pacific Biological Station, Nanaimo, British Columbia V9R 5K6, Canada; E-mail: beachamt@pac.dfo-mpo.gc.ca

SO: Transactions of the American Fisheries Society [Trans. Am. Fish. Soc.], vol. 128, no. 6, pp. 1068-1084, Nov 1999

IS: 0002-8487

AB: The purpose of this study was to describe population structure and determine the potential for genetic stock identification for steelhead Oncorhynchus mykiss in British Columbia using microsatellite DNA markers. Variation at eight microsatellite DNA loci (Oki200, Omy77, Ots1, Ots3, Ssa85, Ots100, Ots103, and Ots108) was surveyed in approximately 1,500 steelhead from 22 populations in southern British Columbia, Washington, and the Columbia River drainage as well as in more than 450 steelhead from two commercial salmon fisheries conducted off the southwest coast of Vancouver Island. Nine populations were sampled for two or more years, and variation in allele frequencies among populations and regions was, on average, about 3.7 times greater than annual variation within populations. Regional structuring of populations was apparent, with Thompson River, upper Fraser River, and Columbia River populations forming distinct groups. Significant differences in allele frequencies were observed among regional stock groups at all loci. After variation within populations was accounted for, variation among regions was the greatest source of the remaining variation (4.4%), followed by variation among populations within regions (3.1%) and variation among years within populations (2.0%). The overall classification accuracy of single individuals to five regional groups using a jackknifed discriminant analysis was 80%. Simulated mixed-stock samples suggested that variation at the eight microsatellite DNA loci surveyed should provide relatively accurate and precise estimates of stock composition for fishery management applications. Analyses of commercial marine fisheries samples indicated

that during 1994-1996 more than 85% of the steelhead sampled in a directed chum salmon fishery off the mouth of the Nitinat River originated in the Fraser River drainage with the majority of steelhead from the Thompson River. However, in 1997, steelhead of U.S. origin were estimated to have composed 60% of the samples, and the Canadian component was largely of Fraser River steelhead, possibly reflecting anomalies associated with climatic variation. Estimated stock composition of samples from the 1997 sockeye salmon fishery in Barkley Sound indicated that the majority (71%) of steelhead was of Vancouver Island origin with the remainder being of U.S. origin.

TI: Genetic differentiation in gill raker number and length in sympatric anadromous and nonanadromous morphs of sockeye salmon, *Oncorhynchus nerka*

AU: Foote, CJ; Moore, K; Stenberg, K; Craig, KJ; Wenburg, JK; Wood, CC

AF: School of Fisheries, Box 357980, University of Washington Seattle, WA 98195 USA; E-mail: cfoote@fish.washington.edu

SO: Environmental biology of fishes. The Hague [Environ. Biol. Fish.], vol. 54, no. 3, pp. 263-274, 1999

IS: 0378-1909

AB: The genetic and environmental basis for polymorphism in gill raker number and length in sympatric anadromous and nonanadromous morphs of sockeye salmon, Oncorhynchus nerka, was investigated. Analysis of 30 full sib families involving pure types and reciprocal hybrids revealed that the variation was partitioned significantly among families within cross types and among cross types in both traits. As in the wild, kokanee displayed more gill rakers than sockeye; reciprocal hybrids displayed intermediate counts. Gill raker length also varied markedly among cross types, with pure sockeye displaying 19% longer gill rakers than comparable sized kokanee. This difference was in the opposite direction predicted, given the common positive association between gill raker number and length in sympatric morphs of the same species in fishes. Gill raker number and length were generally not correlated within cross types, suggesting independent divergence of the traits. The results are discussed in relation to genetic and trophic divergence of the morphs and to factors selecting for differentiation in the two gill raker traits.

TI: Isotopic composition of otoliths as a chemical tracer in population identification of sockey salmon (*Onchorynchus nerka*)

AU: Gao, YW; Beamish, RJ

AF: Department of Fisheries and Oceans, pacific Biological Station 3190 Hammond Bay Road, Nanaimo, BC V9R 5K6 Canada; E-mail: gaoy@dfo-mpo.gc.ca

SO: Canadian Journal of Fisheries and Aquatic Sciences [Can. J. Fish. Aquat. Sci./J. Can. Sci. Halieut. Aquat.], vol. 56, no. 11, pp. 2062-2068, 1999

IS: 0706-652X

AB: The feasibility of stable oxygen and carbon isotope ratio (delta super(18)O and delta super(13)C) analyses in sagittal otoliths of sockeye salmon (Oncorynchus nerka) was tested by analyzing the seasonal and annual otolith zones of 44 samples collected from different localities in the Northeast Pacific coast. The delta super(18)O and delta super(13)C values of these otoliths ranged from -14.23 to +1.62% and from -15.18 to -3.17%, respectively. The delta super(18)O variations can be divided into two stages from freshwater (-14.2 to -2.5%) to marine (2.5 to +1.6%) that were consistent with the life history of sockeye salmon from juvenile to adult stages. The transition occurred after age 1, during which the timing of seaward migration of smolts was different. The marine component of the isotope variation in sockeye salmon otoliths (ages > 2) was uniform but showed a consistent and strong shift towards oceanic changes around 1996. Thus, delta super(18)O and delta super(13)C values of otoliths can be potentially used as a chemical tracer in population identification, and their marine portions can be used in the study of ocean environmental changes.

TI: Population structure of Fraser River chinook salmon (*Oncorhynchus tshawytscha*): an analysis using microsatellite DNA markers

AU: Nelson, RJ; Small, MP; Beacham, TD; Supernault, KJ

AF: SeaStar Biotech Inc., 32056-3749 Shelbourne St., Victoria, British Columbia, V8P 5S2 Canada; E-mail: jnelson@seastarbio.com

SO: Fishery Bulletin [Fish. Bull.], vol. 99, no. 1, pp. 94-107, Jan 2001

IS: 0090-0656

AB: Microsatellite DNA analysis was applied in a genetic study of 20 chinook salmon populations from four regions within the Fraser River drainage of British Columbia, Canada. Twelve populations were represented by samples collected in different years. A total of 2612 fish were examined at three microsatellite loci. Each locus was highly polymorphic, with 30 alleles at Ots101, 28 alleles at Ots100, and 35 alleles at Ots102. Average observed heterozygosities were 86%, 88%, and 71%, respectively. In a dendrogram analysis of pairwise genetic distances, four geographically based groups were observed consisting of the lower Fraser River, the middle Fraser River, the upper Fraser River, and the Thompson River. An analysis of molecular variance showed that 97.57% of the genetic variance was within populations and 1.80% of the genetic variance was partitioned among populations. We detected significantly different allele frequencies among populations within regional groupings and temporal stability in allele frequencies in populations for which multiple years of samples were analyzed. Regional divergence may reflect colonization patterns following the last ice age, and divergence among populations within regions may reflect local adaptation. The elucidation of population structure of chinook salmon of the Fraser River watershed will be useful information for management designed to conserve genetic biodiversity.

TI: Biological characteristics of Skeena River sockeye salmon (Oncorhynchus nerka) and their utility for stock composition analysis of test fishery samples.

AU: Rutherford, DT; Wood, CC; Cranny, M. and Spilsted, B.

SO: Can. Tech. Rep. Fish. Aquat. Sci. 2295: 48p., 1999

AB: Sockeye salmon (Oncorhynchus nerka) were collected from principal spawning sites and a test fishery within the Skeena River to evaluate the potential for estimating stock composition using genetic and other biological characteristics. Samples from spawning sites were examined for age and length composition, prevalence of the parasites Myxobolus arcticus and Philonema oncorhynchi, and electrophoretic variation at up to 39 loci. Significant variation in biological characteristics was detected among most rearing lakes but not among sites within lakes. Estimation of stock composition in the test fishery catches using biological characteristics appears to be a valuable tool for enumerating sockeye runs in the Skeena River. Simulations demonstrated that mixing proportions could be estimated reliably for 7 stocks corresponding to the major lake systems examined (Alastair, Lakelse, Kitsumkalum, McDonell, Morice, Swan, Babine-Nilkitkwa, Motase, Bear and Sustut-Johanson). However, fish from spawning sites within these lake systems could not be distinguished reliably. The overall proportion of Babine fish in the test fishery averaged 76% over the 11 years. Escapement estimates generated from stock composition of the test fishery imply larger escapements to non-Babine sites than observed using visual techniques.

TI: Managing fisheries using genetic data: Case studies from four species of Pacific salmon

AU: Shaklee, JB; Beacham, TD; Seeb, L; White, BA

AF: Washington Department of Fish and Wildlife, 600 Capitol Way N, Olympia, WA 98501, USA; E-mail: shakljbs@dfw.wa.gov

CF: Stock Identification -- Its Role in Stock Assessment and Fisheries Management Symp. Presented at the 128. Annu. Meet. of the American Fisheries Society -- Challenges for the

New Millennium: Shaping the Future of Fisheries Science and the Fisheries Profession, Hartford, CT (USA), 23-27 Aug 1998

SO: Fisheries Research (Amsterdam) [Fish. Res.], vol. 43, no. 1-3, pp. 45-78, Oct 1999

IS: 0165-7836

NT: Special Issue: Stock Identification -- Its Role in Stock Assessment and Fisheries Management.

PB: Elsevier Science B.V., P.O. Box 211 Amsterdam 1000 AE Netherlands

AB: Pacific salmon exhibit complex patterns of population subdivision and undergo substantial marine migrations that result in stock intermixing. Stock assessment, fishery management, and conservation of salmon are all complicated by stock multiplicity and intermingling in fishing areas. Genetic data have been successfully used by several agencies in the Pacific Northwest for over a decade to address assessment, management, and conservation needs. Four case studies are described to document the design, implementation, results, and benefits of genetic analysis. These consist of: (1) the chinook salmon winter gill-net fishery in the lower Columbia River (allozymes), (2) commercial pink salmon fisheries in British Columbia (allozymes), (3) chum salmon fisheries in Alaska (allozymes, mtDNA, and microsatellites) and, (4) the recreational coho salmon fishery off Vancouver Island (microsatellite and MHC genes). Estimates of stock group and/or individual stock contributions to harvests are obtained using maximum likelihood methods. Simulations indicate that estimates are often within 5-10% of the true contributions and are quite precise (plus or minus 2-10%) with sample sizes of 100-400. Genetic results have been used both in-season and post-season to determine fishery openings and closures to provide harvest benefits or meet conservation needs, to address catch allocation and equity issues among user groups and between countries, to provide data for in-season run-size updates, and to investigate migration patterns and timing.

TI: Intact genetic structure and high levels of genetic diversity in bottlenecked sockeye salmon (*Oncorhynchus nerka*) populations of the Fraser River, British Columbia, Canada.

AU: Withler, RE; Le, KD; Nelson, RJ; Miller, KM; Beacham, TD

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SO: Canadian journal of fisheries and aquatic sciences/Journal canadien des sciences halieutiques et aquatiques. Ottawa ON [Can. J. Fish. Aquat. Sci./J. Can. Sci. Halieut. Aquat.], vol. 57, no. 10, pp. 1985-1998, 2000

IS: 0706-652X

AB: Analysis of six microsatellite loci in 5800 sockeye salmon (Oncorhynchus nerka) from 29 Fraser River populations provided little evidence of genetic bottlenecks or mass straying in upper Fraser sockeye salmon resulting from reduced abundances following 1913-1914 rockslides in the Fraser canyon and successive decades of high exploitation. Upper Fraser populations were not characterized by a paucity of rare alleles, a sensitive indicator of populations in which effective size has been recently reduced. Heterozygosity and allelic diversity did not differ consistently between lower and upper Fraser populations. Throughout the watershed, early-migrating populations had lower allelic diversity and a lower proportion of rare alleles than did late-migrating ones. Genetic differentiation between upper and lower Fraser populations and heterogeneity among lower Fraser populations supported the suggestion that Fraser sockeye salmon are descendants of at least two postglacial "races". Variation among lakes within regions was the strongest component of genetic structure, accounting for five times the variation among populations within lakes and more than two times the variation among regions. Extensive historical transplants of eggs and juveniles apparently resulted in little gene flow among regions, but three populations were reestablished or rebuilt as the result of more recent transplants.

3. Biology, Physiology and Ecology of Pacific Salmon

TI: Estimating the Abundance of Juvenile Coho Salmon in the Strait of Georgia by Means of Surface Trawls

AU: Beamish, RJ; McCaughran, D; King, JR; Sweeting, RM; McFarlane, GA

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SO: North American Journal of Fisheries Management [N. Am. J. Fish. Manage.], vol. 20, no. 2, pp. 369-375, May 2000

IS: 0275-5947

AB: A fixed survey design with a randomized depth component and a large rope trawl that fished surface waters at a speed of approximately 5 knots was used to estimate the abundance of juvenile coho salmon Oncorhynchus kisutch in the Strait of Georgia. The estimates of 4.2 million juveniles in September 1996, 3.0 million in September 1997, and 3.0 million in September 1998 were minimal because the catchability of the net was probably lower than that used in the analysis. In 1997, by using hatchery-marking percentages, we estimated that 3.4 million wild coho salmon smolts entered the Strait of Georgia from Canadian rivers. The estimates of juvenile abundance made in September 1997 were considerably larger than the estimated total returns in 1998, indicating that the marine mortality in fall and winter is an important component of the total marine mortality determining the final strength of the brood year. The use of surveys for estimating juvenile coho salmon abundance is a contribution to the understanding of the processes that regulate salmon abundance naturally and can potentially provide management information well in advance of any fishery.

TI: The ecology, distribution, and abundance of midwater fishes of the Subarctic Pacific gyres

AU: Beamish, RJ; Leask, KD; Ivanov, OA; Balanov, AA; Orlov, AM; Sinclair, B

AF: Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, Canada

SO: Progress in Oceanography [Prog. Oceanogr.], vol. 43, no. 2-4, pp. 399-442, 1999

IS: 079-6611

NT: Ecosystem Dynamics in the Eastern and Western Gyres of the Subarctic Pacific.

AB: We describe the distribution and abundance of the midwater fish community, between 200 m and 500 m, in the North Pacific. The main area of interest was the Subarctic Pacific gyres, but we include species from the Bering Sea and the Sea of Okhotsk. There were 196 species identified in each gyre, 38 of which were common to both gyres. The most abundant species belong to the family Myctophidae and the most ecologically important myctophid probably is Stenobrachius leucopsarus. This species could have a biomass of approximately 21 million tonnes (t) in the Subarctic Pacific (including the Bering Sea and Sea of Okhotsk). S. leucopsarus is a small (about 8 cm maximum length) fish that lives up to 7 years. It is prey for a variety of other fishes, birds and mammals and may migrate into the mixing layer each evening where it feeds mainly on euphausiids and copepods. The total abundance of midwater fishes appears to be large relative to total catches of other fish in the same areas. The vertical migratory behaviour of some of the residents provides a mechanism to transfer production out of the mixing layer. The movement into the surface layer by some fishes at night indicates that dynamic changes occur in the midwater community between the day and night, and the ecosystem dynamics in the surface layer are different in the day and in the night. This behaviour and the huge biomass relative to commercial species means that the dynamics of fish communities in the Subarctic Pacific are complex and need to be studied over a 24 hour period. The large biomasses may eventually attract commercial interest, thus it is important to establish international, cooperative programs now to learn more about the dynamics of these populations and the relationships with other species.

TI: **Epipelagic nekton of the North Pacific Subarctic and Transition Zones**
AU: Brodeur, R; McKinnell, S; Nagasawa, K; Pearcy, W; Radchenko, V; Takagi, S
AF: Northwest Fisheries Science Center, NMFS, Newport, OR 97365 USA
SO: Progress in Oceanography [Prog. Oceanogr.], vol. 43, no. 2-4, pp. 365-397, 1999
IS: 0079-6611
NT: Ecosystem Dynamics in the Eastern and Western Gyres of the Subarctic Pacific.
AB: During the 1980s and 1990s, scientific research cruises and commercial gillnet operations with scientific observers aboard were conducted throughout much of the Subarctic and Transition Zones of the North Pacific Ocean. These studies produced one of the most extensive databases ever collected on the relative species composition and trophic structure of epipelagic nekton of the Subarctic and Transition Zones in the North Pacific Ocean. Data from Japanese high-seas gillnet research surveys (1981-1991) were examined using multivariate analytical techniques to analyse community structure of nektonic cephalopods, elasmobranchs, and teleosts in the North Pacific Subarctic and Transition Zones during the summer months, emphasizing differences between the eastern and western Subarctic Gyres. Species diversity generally increased going from west to east, which was apparently associated with the greater range of temperatures in the east. Discriminant analysis was able to correctly classify about half the catch locations into their respective regions. Catches from multinational drift gillnet commercial fisheries operations in 1990-1991 mainly in the Transition Zone were also examined. Classification techniques were employed to determine species associations and multivariate analyses were used to examine relationships of these assemblages to environmental data. We found that some species are often captured in the same gillnet sets and form species associations that are distinct in ordination space, but these associations are loose and may vary appreciably from year to year. We review recent studies on the feeding habits and daily ration of the dominant species and construct food webs for the eastern and western Subarctic and Transition Zone systems emphasizing the role that nekton play in these pelagic ecosystems.

TI: **Mesozooplankton community characteristics in the NE subarctic Pacific**
AU: Goldblatt, RH; Mackas, DL; Lewis, AG
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SO: Deep-Sea Research (Part 2, Topical Studies in Oceanography) [Deep-Sea Res. (2 Top. Stud. Oceanogr.)], vol. 46, no. 11-12, pp. 2619-2644, 1 Nov 1999
IS: 967-0645
PB: lsevier Science Ltd., Pergamon
AB: Mesozooplankton biomass, species composition, abundance, and vertical distribution were determined along a transect from the continental slope off the west coast of Canada to Ocean Station Papa (OSP) in the open-ocean waters of the NE subarctic Pacific as part of the Canadian Joint Global Ocean Flux Study of this area. All of these measurements had distinct seasonal patterns. At OSP biomass peaked in spring, coincident with the annual biomass maximum of large copepods of the genus Neocalanus. Early copepodites of these copepods were present in surface waters at all stations along the transect in winter, but N. plumchrus and N. flemingeri copepodites were only at the offshore stations in spring. This indicated that these large copepods had completed the growth phase of their life cycle slower in the open ocean than closer to shore where they had already descended to deep water by May or June. Summer biomass was low compared to the spring peak. The summer mesozooplankton abundance was similar to the springtime abundance, but the composition had changed from large-bodied copepods in the spring to small copepods and fewer non-copepod taxa in the summer, which accounts for the reduction in total biomass. Winter biomass was the lowest of the year. Winter species composition was similar to summer except for the appearance of juvenile stages of the genera Neocalanus and Calanus. Diel changes in

biomass in the upper 150 m were found in summer but not in winter or spring. Vertical distributions of copepods were often distinct, with closely related species occupying different depth strata. Measurements of wet weight at OSP were higher than the long-term mean wet weight during winter and spring, and lower during summer.

TI: Diet comparisons indicate a competitive interaction between ocean age-0 chum and coho salmon.

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CA: North Pacific Anadromous Fish Comm., Vancouver, BC (Canada)

ED: Helle, JH (ed); Ishida, Y(ed); Noakes, D(ed); Radchenko, V(ed)

SO: NPAFC Bulletin Number 2: Recent changes in ocean production of Pacific salmon., 2000, no. 2, pp. 65-74, Bull. Npafc

IS: 1028-9127

AB: Systematic trawl surveys were conducted within the Strait of Georgia in June/July and September of 1997 and 1998. Stomachs of 2230 coho (Oncorhynchus kisutch) and 1558 chum (Oncorhynchus keta) ocean age-0 salmon were analysed. A large hatchery marking program was conducted for coho but not for chum salmon allowing a comparison of diets of hatchery-marked and unmarked coho throughout the seasons of both years. The seasonal patterns in diet composition illustrate that in early summer chum are potential competitors of coho in the Strait of Georgia. By late summer chum are still competitors but they begin to feed upon gelatinous zooplankton. The implications of all diet comparisons are that chum and hatchery-reared coho are competitors of non-hatchery coho during their first marine summer. In the Strait of Georgia, the catch per unit effort indicates that chum salmon is two to four times more abundant than coho. If coho final brood year strength is determined via first summer growth and winter mortality (according to the critical-size-and critical-period hypothesis), then the high abundance of chum and the overlap in chum and coho diets could explain, at least in part, the recent increase in natural marine mortality of coho.

TI: Horizontal flux of nutrients and plankton across and along the British Columbia continental margin

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SO: Deep-Sea Research (Part 2, Topical Studies in Oceanography) [Deep-Sea Res. (2 Top. Stud. Oceanogr.)], vol. 46, no. 11-12, pp. 2941-2967, 1 Nov 1999

IS: 0967-0645

PB: Elsevier Science Ltd., Pergamon

AB: We report rate estimates for the horizontal transport of realized and potential "new" production across and along the Vancouver Island continental margin. Measurements consisted of three summer-season surveys (1993--1995) of water properties, chlorophyll and dissolved nutrient concentrations, zooplankton biomass and community composition. Sampling was done along paired 350-km station lines extending parallel to and approximately 25 km seaward of the shelf break. Horizontal transport of nutrients and plankton biomass was estimated from cross-products of concentration fields with cross-shore and alongshore geostrophic velocity fields and with space- and time-averaged estimates of Ekman volume transport. Because concentrations of nutrients and phytoplankton were low in the upper 30--50 m, their horizontal flux within the Ekman layer was relatively small (order 10% of geostrophic transport). Geostrophic, transport was strongly localized and was correlated vertically with concentration gradients, and horizontally with eddies and meanders of the alongshore geostrophic currents. Net geostrophic transport was a small difference between larger localized seaward and

shoreward components. Upper layer (0--50 m) transports of nutrients and phytoplankton biomass were of roughly similar magnitude. Both were much larger than transport of zooplankton biomass. Total cross-shore flux was a small fraction (< 10%) of the estimated total productivity shoreward of the sampling lines. Direction and magnitude varied among survey periods, but for all 1990s surveys appear to have been weaker than in the mid-1980s, when summer-season averaged upwelling-favorable winds were stronger and the shelf-break current was faster.

TI: Mesozooplankton in the eastern and western subarctic Pacific: community structure, seasonal life histories, and interannual variability

AU: Mackas, DL; Tsuda, A

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SO: Progress in Oceanography [Prog. Oceanogr.], vol. 43, no. 2-4, pp. 335-363, 1999

IS: 0079-6611

NT: Ecosystem Dynamics in the Eastern and Western Gyres of the Subarctic Pacific.

AB: The zooplankton community of the subarctic Pacific is relatively simple, and contains a similar set of major species in all deep water areas of the subarctic Pacific. Their role in the food web varies considerably between coastal and offshore locations. In the oceanic gyres, microzooplankton and other mesozooplankton taxa replace phytoplankton as the primary food source for the dominant mesozooplankton species. Micronekton and larger zooplankton probably replace pelagic fish as major direct predators. Productivity and upper ocean biomass concentrations are intensely seasonal, in part because of seasonality of the physical environment and food supply, but also because of life history patterns involving seasonal vertical migrations (400-2000 m range) and winter dormancy. During the spring-summer season of upper ocean growth, small scale horizontal and vertical patchiness is intense. This can create local zones of high prey availability for predators such as planktivorous fish, birds, and marine mammals. On average, the cores of the subarctic gyres have lower biomass and productivity than the margins of the gyres. There is also some evidence that the Western Gyre is more productive than the Alaska Gyre, but more research is needed to confirm whether this east-west gradient is permanent. There is increasing evidence that the pattern of zooplankton productivity is changing over time, probably in response to interdecadal ocean climate variability. These changes include 2-3 fold shifts in total biomass, 30-60 day shifts in seasonal timing, and 10-25% changes in average body length.

TI: An assessment of light-based geoposition estimates from archival tags

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SO: Canadian journal of fisheries and aquatic sciences/Journal canadien des sciences halieutiques et aquatiques. Ottawa ON [Can. J. Fish. Aquat. Sci./J. Can. Sci. Halieut. Aquat.], vol. 56, no. 7, pp. 1317-1327, 1999

IS: 0706-652X

AB: Archival tags record information about the environment of tagged animals over long periods of time (months to years). In theory, position can be estimated from a record of changes in light intensity with time. Two approaches are described to estimating geoposition based on estimating either the time of maximal rate of change in light intensity or the time that a reference light intensity is reached. Digital signal processing is investigated as a method of increasing the signal-to-noise ration of the light record. Test data suggest that the daily position of a tagged animal can potentially be estimated within an average error of about 140 km (SD's of 0.9 degree of longitude and 1.2 degree of latitude), approaching the resolution of the best eddy-resolving physical oceanographic models of ocean currents. The source of the remaining large-scale errors in geoposition

appears to be extrinsic to the tags and may be related to large-scale weather systems. The accuracy of current archival tags is sufficient to permit an assessment of the open-ocean migration pathways of animals such as maturing salmon and may be sufficient for use in some parts of the continental shelf as well.

TI: Assessing the northern diversion of sockeye salmon returning to the Fraser River, BC

AU: Mckinnell, S; Freeland, HJ; Groulx, SD

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SO: Fisheries Oceanography [Fish. Oceanogr.], vol. 8, no. 2, pp. 104-114, Jun 1999

IS: 1054-6006

AB: We examine the oft-quoted relationship between the migration of Fraser River sockeye salmon around the northern end of Vancouver Island and sea surface temperatures. We examine the methods used to estimate the northern diversion and conclude that the estimates have a sufficiently low expected error to form a useful representation of sockeye salmon behaviour. The well-known relationship with Kains Island sea surface temperature is explored and problems are pointed out. In particular, we explore why Kains Island temperatures are good predictors of salmon behaviour in May when the sockeye can be over 1000 km away, but the coastal temperatures are poor predictors in July to September when the salmon are actually close by. We show that a more robust predictor can be developed using open ocean temperature fields and we show why Kains Island fails as a predictor during the summer months. Finally, we show by cross-validation that the northern diversion is predictable with an r.m.s. error of about 0.1.

TI: Variability in upper-ocean water properties in the NE Pacific Ocean

AU: Whitney, FA; Freeland, HJ

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SO: Deep-Sea Research (Part 2, Topical Studies in Oceanography) [Deep-Sea Res. (2 Top. Stud. Oceanogr.)], vol. 46, no. 11-12, pp. 2351-2370, 1 Nov 1999

IS: 0967-0645

PB: Elsevier Science Ltd., Pergamon

AB: A review of oceanographic properties in the vicinity of Ocean Station Papa (OSP) is presented, using data collected over the past 42 years. Average annual signals at OSP and seasonal characteristics along Line P represent variability on a large scale in the Gulf of Alaska. Between winter and summer, the upper ocean mixed layer varies between 120 and 40 m, monthly average winds decrease from 12 m/s in winter to 7 m/s in July, seawater temperatures warm from lows of 6 degree C to highs >12 degree C, waters freshen slightly in summer, and macronutrients are partially depleted by phytoplankton growth (removal of 7.8 mu M NO sub(3) in 1970s and 6.5 mu M NO sub(3) in 1990s). El Nino events influence this area by transporting heat northward. During the prolonged El Nino of the early 1990s, warming persisted at OSP through 1994, resulting in a reduced macronutrient supply during winter mixing. Changes in water properties over the four decades of observations are evident. There are trends towards warmer and less saline surface waters, lower winter nitrate and silicate levels, and less macronutrient utilization in the 1990s compared to the 1970s. We speculate that these changes must be reducing the productivity of NE subarctic Pacific waters.

TI: Sporadic silicate limitation of phytoplankton productivity in the subarctic NE Pacific

AU: Wong, CS; Matear, RJ

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SO: Deep-Sea Research (Part 2, Topical Studies in Oceanography) [Deep-Sea Res. (2 Top. Stud. Oceanogr.)], vol. 46, no. 11-12, pp. 2539-2555, 1 Nov 1999
IS: 0967-0645
PB: Elsevier Science Ltd., Pergamon
AB: A time series (1970--1980) of silicate concentrations in the surface mixed layer at Ocean Station P (OSP, 50 degree N, 145 degree W) in the subarctic NE Pacific Ocean in high-nutrient and low-chlorophyll (HNLC) waters shows nearly total depletion of silicate (<1 mu mol/kg) in the summers of 1972, 1976 and 1979. From a mixed-layer model for the spring--summer period, we calculated silicate and nitrate utilization. The silicate utilization (Delta SiO sub(4)) during the growing season displays large interannual variations, suggesting that diatom production would experience similar fluctuations. The years 1972 and 1979 had both high-silicate utilization (Delta SiO sub(4)) and high-nitrate utilization (Delta NO sub(3)). During these two high-production years, the lack of available silicate appeared to limit diatom production. For 1972 and 1979, the ratio of Delta SiO sub(4) to Delta NO sub(3) was 1.4 and 2.5, respectively. The 1979 ratio supports the conclusion that high-nutrient utilization in the mixed layer is dominated by diatoms. The 1972 ratio is consistent with the average value calculated from the time-series data and suggests that the high-nutrient utilization resulted from a combination of diatom and non-siliceous production. A time series of particle fluxes (1980--1994) collected in deep-moored sediment traps at OSP showed that the averaged monthly flux ratio of opal to particulate organic nitrogen (PON) remained constant except during two high-PON flux periods.

Appendix 1: Description of Abbreviations

TI: Title
AU: Author
AF: Author Affiliation
CF: Conference
CA: Corporate Author
SO: Source
IS: ISSN
NT: Notes
ED: Editor
PB: Publisher
AB: Abstract