Climate Change and Pacific Salmon

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Multiple Species

Abdul-Aziz, O. I., N. J. Mantua, and K. W. Myers. 2011. Potential climate change impacts on thermal habitats of Pacific salmon (*Oncorhynchus spp.*) in the North Pacific Ocean and adjacent seas. Canadian Journal of Fisheries and Aquatic Sciences 68(9):1660-1680. https://doi.org/10.1139/f2011-079

> Evaluates the effects of natural climate variability and projected changes under three scenarios of future greenhouse gas emissions for six species of Pacific salmon.

Adelfio, L. A., S. M. Wondzell, N. J. Mantua, and Gordon H. Reeves. 2024. Expanded, compressed, or equal? Interactions between spawning window and stream thermal regime generate three responses in modeled juvenile emergence for Pacific salmon. Canadian Journal of Fisheries and Aquatic Sciences. 81(5):573-588. https://doi-org.cbfwl.idm.oclc.org/10.1139/cjfas-2023-0238

> Explores how interactions between spawning timing and stream thermal regimes can drive variability in modeled emergence timing for five species of Pacific salmon.

Alava, J. J., A. M. Cisneros-Montemayor, U. R. Sumaila, and W. W. L. Cheung. 2018. Projected amplification of food web bioaccumulation of MeHg and PCBs under climate change in the Northeastern Pacific. Scientific Reports 8:13460. https://doi.org/10.1038/s41598-018-31824-5

> Examines the bioaccumulation of organic mercury and polychlorinated biphenyls in a Northeastern Pacific marine food web under climate change.

Anderson, S. C., J. W. Moore, M. M. McClure, N. K. Dulvy, and A. B. Cooper. 2015. Portfolio conservation of metapopulations under climate change. Ecological Applications 25(2):559-572. https://doi.org/10.1890/14-0266.1

> Demonstrates how a portfolio approach to managing population diversity can inform metapopulation conservation priorities in climate change scenarios.

Araujo, H. A., W. D. P. Duguid, R. Withler, J. Supernault, A. D. Schulze, J. L. Mckenzie, K. Pellett, T. D. Beacham, K. Jonsen, and A. Gummer. 2021. Chinook and coho salmon hybrids linked to habitat and climatic changes on Vancouver Island, British Columbia. Ecology and Evolution 11(23):16874-16889. https://doi.org/10.1002/ece3.8322

Documents observed naturally occurring hybridization of Chinook and coho salmon on Vancouver Island, British Columbia, and the environmental and climate change factors which may be driving this hybridization.

Beamish, R. J., C. Mahnken. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Progress in Oceanography 49(1-4):423-437. https://doi.org/10.1016/S0079-6611(01)00034-9

Investigates the hypothesis that salmon year class strength is determined in two stages during the first year in the ocean using data from ocean surveys of juvenile salmon and from experimental feeding studies on coho.

Beechie, T. J., C. Fogel, C. Nicol, J. Jorgensen, B. Timpane-Padgham, and P Kiffney. 2023. How does habitat restoration influence resilience of salmon populations to climate change? Ecosphere 14(2): e4402. https://doi.org/10.1002/ecs2.4402

Uses the HARP model to examine the relative importance of various mechanisms for increasing salmon population resilience by comparing projected salmon spawner abundance for seven individual restoration action types under current and projected climates.

Beechie, T., H. Imaki, J. Greene, A. Wade, H. Wu, G. Pess, P. Roni, J. Kimball, J. Stanford, P. Kiffney, and N. Mantua. 2013. Restoring salmon habitat for a changing climate. River Research and Applications 29(8):939-960. https://doi.org/10.1002/rra.2590

Describes a decision support process for adapting salmon recovery plans that incorporates local habitat factors, scenarios of climate change effects on stream flow and temperature, and the ability of restoration actions to ameliorate climate change effects, and increase habitat diversity and salmon population resilience.

Beer, W. N., and J. J. Anderson. 2011. Sensitivity of juvenile salmonid growth to future climate trends. River Research and Applications 27(5):663-669. https://doi.org/10.1002/rra.1390

Explores the impacts on juvenile salmonid growth of possible climate-induced changes to mean annual water temperature and snowpack in four characteristic ecoregions.

Bell, D. A., R. P. Kovach, S. C. Vulstek, J. E. Joyce, and D. A. Tallmon. 2017. Climate-induced trends in predator–prey synchrony differ across life-history stages of an anadromous salmonid. Canadian Journal of Fisheries and Aquatic Sciences 74(9):1431-1438. https://doi.org/10.1139/cjfas-2016-0309

Examines the long-term data from a warming stream with shifting salmonid migration timings to quantify intra-annual migration synchrony between predatory Dolly Varden and Pacific salmon.

Botsford, L. W., M. D. Holland, J. F. Samhouri, J. W. White, and A. Hastings. 2011. Importance of age structure in models of the response of upper trophic levels to fishing and climate change. ICES Journal of Marine Science 68(6):1270-1283. https://doi.org/10.1093/icesjms/fsr042

Illustrates the potential effects of climate on age-structured populations, examining long-term changes in abundance, and variability attributable to cohort resonance. Compares Pacific salmon and cod.

Bryant, M. D. Global climate change and potential effects on Pacific salmonids in freshwater ecosystems of southeast Alaska. 2009. Climatic Change 95:169–193. https://doi.org/10.1007/s10584-008-9530-x

Examines potential responses of the five species of Pacific salmon found in southeast Alaska to climate change, focusing on the freshwater phase of the life cycle of each species.

Cheung, W. W. L., and T. L. Frölicher. 2020. Marine heatwaves exacerbate climate change impacts for fisheries in the northeast Pacific. Scientific Reports 10:6678. https://doi.org/10.1038/s41598-020-63650-z

Combines outputs from a large ensemble simulation of an Earth system model with a fish impact model to simulate responses of major northeast Pacific fish stocks to marine heatwaves.

Chittenden, C. M., R. J. Beamish, and R. S. McKinley. 2009. A critical review of Pacific salmon marine research relating to climate. ICES Journal of Marine Science 66(10):2195–2204. https://doi.org/10.1093/icesjms/fsp174

Review of existing literature on the consequences of climate change in marine environments for Pacific salmon.

Crozier, L. G., A. P. Hendry, P. W. Lawson, T. P. Quinn, N. J. Mantua, J. Battin, R. G. Shaw, and R. B. Huey. 2008. Potential responses to climate change in organisms with complex life histories: evolution and plasticity in Pacific salmon. Evolutionary Applications 1(2):252-270. https://doi.org/10.1111/j.1752-4571.2008.00033.x

Summarizes the likely impacts of climate change on the physical environment of salmon in the Pacific Northwest and discusses the potential evolutionary consequences of these changes, with particular reference to Columbia River Basin spring/summer Chinook and sockeye salmon.

Crozier, L. G. and J. A. Hutchings. 2014. Plastic and evolutionary responses to climate change in fish. Evolutionary Applications 7(1):68-87. https://doi.org/10.1111/eva.12135

Examines the evidence for phenotypic responses to recent climate change in fish. Changes in the timing of migration and reproduction, age at maturity, age at juvenile migration, growth, survival and fecundity were associated primarily with changes in temperature.

Crozier, L. G., M. M. McClure, T. Beechie, S. J. Bograd, D. A. Boughton, M. Carr, T. D. Cooney, J. B. Dunham, C. M. Greene, M. A. Haltuch, E. L. Hazen, D. M. Holzer, D. D. Huff, R. C. Johnson, C. E. Jordan, I. C. Kaplan, S. T. Lindley, N. J. Mantua, P. B. Moyle, J. M. Myers, M. W. Nelson, B. C. Spence, L. A. Weitkamp, T. H. Williams, and E. Willis-Norton. 2019. Climate vulnerability assessment for Pacific salmon and steelhead in the California Current Large Marine Ecosystem. PLoS ONE 14(7):e0217711. https://doi.org/10.1371/journal.pone.0217711

Presents the results of a climate vulnerability assessment that included all anadromous Pacific salmon and steelhead populations listed under the U.S. Endangered Species Act to determine which populations are most at risk and what poses the greatest danger to these units.

Crozier, L. G., and J. E. Siegel. 2023. A comprehensive review of the impacts of climate change on salmon: strengths and weaknesses of the literature by life stage. Fishes 8(6):319. https://doi.org/10.3390/fishes8060319

Systematic literature review of climate impacts on salmon and anadromous trout, compiles a database of these resources and summarizes expected phenotypic and genetic responses and management actions by life stage.

Crozier L. G., J. E. Siegel, L. E. Wiesebron, E. M. Trujillo, B. J. Burke, B. P. Sandford, and D. L. Widener. 2020. Snake River sockeye and Chinook salmon in a changing climate: Implications for upstream migration survival during recent extreme and future climates. PLoS ONE 15(9):e0238886. https://doi.org/10.1371/journal.pone.0238886

Examines several factors affecting survival of endangered sockeye and threatened Chinook salmon as they migrate upstream through eight dams and reservoirs to spawning areas in the Snake River Basin.

Davis, M. J., I. Woo, C. S. Ellings, S. Hodgson, D. A. Beauchamp, G. Nakai, and S. E. W. De La Cruz. 2022. A climate-mediated shift in the estuarine habitat mosaic limits prey availability and reduces nursery quality for juvenile salmon. Estuaries and Coasts 45:1445–1464. https://doi.org/10.1007/s12237-021-01003-3

Employs a spatially explicit bioenergetics model to assess how different climate change scenarios might affect juvenile salmon growth rate potential relative to present day conditions in the Nisqually River Delta, WA.

DeBano, S. J., D. E Wooster, J. R. Walker, L. E. McMullen, and D. A. Horneck. 2016. Interactive influences of climate change and agriculture on aquatic habitat in a Pacific Northwestern watershed. Ecosphere 7(6):e01357. https://doi.org/10.1002/ecs2.1357

Uses temperature and hydrology data in combination with a habitat quality framework developed for Pacific salmon and trout to predict how different levels of climate change stressors and agricultural intensification may impact aquatic habitats in the Umatilla Subbasin.

Dittmer, K. 2013. Changing streamflow on Columbia basin tribal lands—climate change and salmon. Climatic Change 120:627-641. https://doi.org/10.1007/s10584-013-0745-0

Offers a retrospective analysis of changes in tributary streamflow for Columbia Basin tribal lands and ceded areas and suggests how future how habitat and productivity may be altered by climate change.

Donley, E. E., R. J. Naiman, and M. D. Marineau. 2012. Strategic planning for instream flow restoration: a case study of potential climate change impacts in the central Columbia River basin. Global Change Biology 18(10):3071-3086. https://doi.org/10.1111/j.1365-2486.2012.02773.x

Provides a case study prioritizing instream flow restoration activities by sub-basin according to the habitat needs of Endangered Species Act listed salmonids relative to climate change in the central Columbia River basin.

Dunmall, K. M., J. A. Langan, C. J. Cunningham, J. D. Reist, and H. Melling. 2024. Pacific salmon in the Canadian Arctic highlight a range-expansion pathway for sub-Arctic fishes. Global Change Biology 30(6):e17353. https://doi.org/10.1111/gcb.17353

Connects Indigenous and scientific knowledges to explore potential oceanographic mechanisms facilitating ongoing northward expansion of Pacific salmon into the western Canadian Arctic.

Farrell, A. P. 2009. Environment, antecedents and climate change: Lessons from the study of temperature physiology and river migration of salmonids. Journal of Experimental Biology 212:(23)3771-3780. https://doi.org/10.1242/jeb.023671

Analyzes how the temperature dependence of aerobic scope can be used to examine the fundamental temperature niches of salmonids.

Flitcroft, R., K. Burnett, and K. Christiansen. 2013. A simple model that identifies potential effects of sea-level rise on estuarine and estuary-ecotone habitat locations for salmonids in Oregon, USA. Environmental Management 52:196-208. https://doi.org/10.1007/s00267-013-0074-0

Examines the effect of sea-level rise on the availability, complexity, and distribution of estuarine, and low-freshwater habitat for Chinook salmon, steelhead, and coho salmon, along the Oregon Coast under future climate change scenarios.

Fogel C. B., C. L. Nicol, J. C. Jorgensen, T. J. Beechie, B. Timpane-Padgham, P. Kiffney, G. Seixas, and J. Winkowski. 2022. How riparian and floodplain restoration modify the effects of increasing temperature on adult salmon spawner abundance in the Chehalis River, WA. PLoS ONE 17(6):e0268813. https://doi.org/10.1371/journal.pone.0268813

Estimates the effect of future increases in stream temperature due to climate change and the effectiveness of two restoration actions aimed at decreasing stream temperatures.

Francis, R. C., and N. J. Mantua. 2003. Climatic influences on salmon populations in the Northeast Pacific. Pages 37-76 *in* A. MacCall, and T. Wainwright, editors. Assessing extinction risk for West Coast Salmon: Proceedings of the Workshop, November 1996. National Marine Fisheries Service, NOAA Technical Memorandum NMFS-NWFSC-56. https://purl.fdlp.gov/GPO/LPS121048

Presents results from two analyses: a Pacific Basin-scale perspective and search for linear relationships between climate and salmon-metapopulation variability, and case studies that illustrate complex, nonlinear relationships between climate and salmon population variability.

Fuller, M. R., P. Leinenbach, N. E. Detenbeck, R. Labiosa, and D. J. Isaak. 2022. Riparian vegetation shade restoration and loss effects on recent and future stream temperatures. Restoration Ecology 30(7): e13626. https://doi.org/10.1111/rec.13626

Assesses how manipulating reach shade conditions may affect stream temperature under current and future climate periods at large spatial extents.

Fullerton, A. H., C. E. Torgersen, J. J. Lawler, E. A. Steel, J. L. Ebersole and S. Y. Lee. 2018. Longitudinal thermal heterogeneity in rivers and refugia for coldwater species: effects of scale and climate change. Aquatic Sciences 80. https://doi.org/10.1007/s00027-017-0557-9

Evaluates water temperature patterns at different spatial resolutions, the frequency, size, and spacing of cool thermal patches suitable for Pacific salmon, and potential influences of climate change on availability of cool patches in the Pacific Northwest and northern California.

Goode, J. R., J. M. Buffington, D. Tonina, D. J. Isaak, R. F. Thurow, S. Wenger, D. Nagel, C. Luce, D. Tetzlaff, and C. Soulsby. 2013. Potential effects of climate change on streambed scour and risks to salmonid survival in snow-dominated mountain basins. Hydrological Processes 27(5):750-765. https://doi.org/10.1002/hyp.9728

Presents a general framework for examining the vulnerability of salmonids to climate-driven changes in streambed scour and demonstrates its application in the Salmon River, ID.

Gosselin, J. L., L. G. Crozier, and B. J. Burke. 2021. Shifting signals: Correlations among freshwater, marine and climatic indices often investigated in Pacific salmon studies. Ecological Indicators 121:107167. https://doi.org/10.1016/j.ecolind.2020.107167

Analyzes 43 freshwater, marine, and climate indices associated with 72 river sites and five coastal ecoregions inhabited by Chinook and coho salmon in western US waters to seek correlations among indices.

Grah, O., T. Coe, M. Maudlin, N. Currence, J. Beaulieu, S. Klein, J. Butcher, H. Herron, and T. Beechie. 2016. Qualitative assessment: Evaluating the impacts of climate change on Endangered Species Act recovery actions for the South Fork Nooksack River, WA. EPA/600/R-16/153, Corvallis, Oregon. https://nooksacktribe.org/wp-content/uploads/2021/09/FINAL_QUALITATIVE-ASSESSMENT_JANUARY2017-1.pdf

Provides a comprehensive analysis of climate change impacts on freshwater habitat and Pacific salmon in the South Fork Nooksack River and evaluates the effectiveness of restoration tools that address Pacific salmon recovery.

Grah, O., and J. Beaulieu.2013. The effect of climate change on glacier ablation and baseflow support in the Nooksack River basin and implications on Pacific salmonid species protection and recovery. Climatic Change 120(3):657-670. https://doi.org/10.1007/s10584-013-0747-y

Reviews the decline of Pacific salmonids in the Nooksack River basin and the impact of future reduced summer flows and increased temperatures due to climate change.

MacDonald, B., and S. C. H. Grant. 2023. State of Canadian Pacific salmon: Considerations for Pacific salmon management in a changing climate. Department of Fisheries and Oceans Canada Report 23-2305. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/41213531.pdf

Reviews the conditions and predicted impacts of climate change on Canadian Pacific salmon populations and suggests management actions.

Hanson, K. C., and D. P. Peterson. 2014. Modeling the potential impacts of climate change on Pacific salmon culture programs: An example at Winthrop National Fish Hatchery. Environmental Management 54:433-448. https://doi.org/10.1007/s00267-014-0302-2

Describes and applies a novel deterministic modeling framework to evaluate how climate change may affect hatcheries that rear Pacific salmon.

Hatten, J. R., T. R. Batt, P. J. Connolly, and A. G. Maule. 2014. Modeling effects of climate change on Yakima River salmonid habitats. Climatic Change 124(1-2):427-439. https://doi.org/10.1007/s10584-013-0980-4

Evaluates the potential effects of two climate change scenarios on salmonid habitats in the Yakima River by linking the outputs from a watershed model, a river operations model, a two-dimensional hydrodynamic model, and a geographic information system.

Herbold, B., S. M. Carlson, and R. Henery. 2018. Managing for salmon resilience in California's variable and changing climate. San Francisco Estuary and Watershed Science 16(2):3. https://doi.org/10.15447/sfews.2018v16iss2art3

Assesses the history of management and decline and the ways to promote salmon productivity and persistence in California's changing climate.

Iacarella, J. C., R. Chea, D. A. Patterson, and J. D. Weller. 2024. Projecting exceedance of juvenile salmonid thermal maxima in streams under climate change: A crosswalk from lab experiments to riparian restoration. Freshwater Biology, Online Version of Record before inclusion in an issue. https://doi.org/10.1111/fwb.14300

Describes a thermal maxima experiment on cold-water adapted juvenile Chinook and coho salmon and refit a regionally specific stream temperature model for British Columbia to directly relate to lab-derived thresholds.

Iacarella, J. C., and J. D. Weller. 2024. Predicting favourable streams for anadromous salmon spawning and natal rearing under climate change. Canadian Journal of Fisheries and Aquatic Sciences 81(1):1-13. https://doi.org/10.1139/cjfas-2023-0096

Applies environmental niche models to five Pacific salmon species focusing on freshwater spawning and natal rearing habitat as these are critical to population survival and highly susceptible to climate change.

Irvine, J. R., and M. Fukuwaka. 2011. Pacific salmon abundance trends and climate change. ICES Journal of Marine Science 68(6):1122–1130. https://doi.org/10.1093/icesjms/fsq199

Reviews historical patterns in salmon abundance to understand the role of temperature and climate conditions in the survival of various Pacific salmon species.

Isaak, D. J., C. H. Luce, D. L. Horan, G. L. Chandler, S. P. Wollrab, and D. E. Nagel. 2018. Global warming of salmon and trout rivers in the northwestern U.S.: Road to ruin or path through purgatory? Transactions of the American Fisheries Society 147(3):566-587. https://doi.org/10.1002/tafs.10059

Estimates water temperature trends at 391 sites in the 56,500-km river network of the northwestern United States and assess potential changes in thermal exposure for several species.

Isaak, D. J., S. Wollrab, D. Horan, and G. Chandler. 2012. Climate change effects on stream and river temperatures across the northwest U.S. from 1980–2009 and implications for salmonid fishes. Climatic Change 113:499-524. https://doi.org/10.1007/s10584-011-0326-z

Examines 18 temperature time-series from sites on unregulated and regulated northwest U.S. streams that span the period from 1980–2009 to assess historical trends and potential impacts to salmonids.

Isaak, D. J., and M. K. Young. 2023. Cold-water habitats, climate refugia, and their utility for conserving salmonid fishes. Canadian Journal of Fisheries and Aquatic Sciences. 80(7):1187-1206. https://doi.org/10.1139/cjfas-2022-0302

Addresses the concept and utility of climate refugia, describes technological advances that enable accurate temperature mapping and species distribution modeling in lotic environments, and outlines key uncertainties.

Keefer, M. L., T. S. Clabough, M. A. Jepson, E. L. Johnson, C. A. Peery, and C. C. Caudill. 2018. Thermal exposure of adult Chinook salmon and steelhead: Diverse behavioral strategies in a large and warming river system. PLoS ONE 13(9):e0204274. https://doi.org/10.1371/journal.pone.0204274

Pairs radiotelemetry with archival temperature loggers to construct continuous, spatially-explicit thermal histories for 212 adult Chinook salmon and 200 adult steelhead.

Keister, J. E., B. Herrmann, and J. Bos. 2022. Zooplankton composition links to climate and salmon survival in a northern temperate fjord. Limnology and Oceanography 67(11):2389-2404. https://doi.org/10.1002/lno.12208

Uses a zooplankton time series from the eastern Strait of Juan de Fuca in the Salish Sea to explore its relationships to climate variability and survival of coho and Chinook salmon.

Kovach, R. P., S. C. Ellison, S. Pyare, and D. A. Tallmon. 2015. Temporal patterns in adult salmon migration timing across southeast Alaska. Global Change Biology 21:1821-1833. https://doi.org/10.1111/gcb.12829

Examines five salmonid species in Southeast Alaska to determine long-term changes in salmon migration timing, interannual phenological synchrony, relationships between climatic variation and migratory timing.

Kovach, R. P., J. E. Joyce, J. D. Echave, M. S. Lindberg, and D. A. Tallmon. 2013. Earlier migration timing, decreasing phenotypic variation, and biocomplexity in multiple salmonid species. PLoS ONE 8(1): e53807. https://doi.org/10.1371/journal.pone.0053807

Assesses whether consistent are temporal patterns and drivers of phenology for similar species and alternative life histories, and if shifts in phenology are associated with changes in phenotypic variation.

Kovach, R. P., J. E. Joyce, S. C. Vulstek, E. M. Barrientos, and D. A. Tallmon. 2014. Variable effects of climate and density on the juvenile ecology of two salmonids in an Alaskan lake. Canadian Journal of Fisheries and Aquatic Sciences 71(6):799-807. https://doi.org/10.1139/cjfas-2013-0577

Estimates how temperature and density affected juvenile coho and sockeye salmon using a 31-year census from an Alaskan lake.

Kovach, R. P., C. C. Muhlfeld, R. Al-Chokhachy, J. V. Ojala, and E. K. Archer. 2019. Effects of land use on summer thermal regimes in critical salmonid habitats of the Pacific Northwest. Canadian Journal of Fisheries and Aquatic Sciences 76(5):753-761. https://doi.org/10.1139/cjfas-2018-0165

Quantifies how land management activities such as cattle grazing are related to summer stream temperatures across the Pacific Northwest, which may intensify the effects of climate change.

Langan, J. A., C. J. Cunningham, J. T. Watson, and S. McKinnell. 2024. Opening the black box: New insights into the role of temperature in the marine distributions of Pacific salmon. Fish and Fisheries 25(4):551–568. https://doi.org/10.1111/faf.12825

Uses a database of historical coastal and high-seas salmon survey data (1953–2022) in the North Pacific to fit species distribution models that characterize the marine spatial distribution of Pacific salmon and investigate how species' temperature preferences influence distribution.

Lee, S.-Y., A. H. Fullerton, N. Sun, and C. E. Torgersen. 2020. Projecting spatiotemporally explicit effects of climate change on stream temperature: A model comparison and implications for coldwater fishes. Journal of Hydrology 588:125066. https://doi.org/10.1016/j.jhydrol.2020.125066.

Uses stream temperature projections to assess the vulnerability of Pacific salmon and trout to changes in the spatial distribution of cold-water habitats during August by the 2080s.

Litzow, M. A., L. Ciannelli, P. Puerta, J. J. Wettstein, R. R. Rykaczewski, and M. Opiekun. 2018. Non-stationary climate-salmon relationships in the Gulf of Alaska. Proceedings of the Royal Society B 285(1890):20181855. https://doi.org/10.1098/rspb.2018.1855

Evaluates the implications of non-stationary relationships among physical variables for climate regulation of salmon populations in the Gulf of Alaska.

Litzow, M. A., M. J. Malick, N. A. Bond, C. J. Cunningham, J. L. Gosselin, and E. J. Ward. 2020. Quantifying a novel climate through changes in PDO-climate and PDO-salmon relationships. Geophysical Research Letters 47(16):e2020GL087972. https://doi.org/10.1029/2020GL087972

Investigates climate change impacts to the Pacific Decadal Oscillation index as it relates to salmonid survival.

Mantua, N., I. Tohver, and A. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102:187-223. https://doi.org/10.1007/s10584-010-9845-2

Evaluates the sensitivity of Washington State's freshwater habitat to climate change, focusing on summertime stream temperatures, seasonal low flows, and changes in peak and base flows.

Meyer, B. E., M. S. Wipfli, E. R. Schoen, D. J. Rinella, and J. A. Falke. 2023. Landscape characteristics influence projected growth rates of stream-resident juvenile salmon in the face of climate change in the Kenai River watershed, south-central Alaska. Transactions of the American Fisheries Society 152(2):169-186. https://doi.org/10.1002/tafs.10397

Combines bioenergetics models with temperature sensitivity models for streams across the Kenai River watershed to the potential influence of climate warming on juvenile Chinook and Coho summer growth rates.

Munsch, S. H., C. M. Greene, N. J. Mantua, and W. H. Satterthwaite. 2022. One hundred-seventy years of stressors erode salmon fishery climate resilience in California's warming landscape. Global Change Biology 28(7):2183-2201. https://doi.org/10.1111/gcb.16029

Examines the industrial era (post 1848) of California's Central Valley, chronicling the decline of a diversified, functional portfolio of salmon habitats and life histories and investigates for empirical evidence of lost climate resilience in its fishery.

Murdoch A., C. Mantyka-Pringle, and S. Sharma. 2020. Impacts of co-occurring environmental changes on Alaskan stream fishes. Freshwater Biology 65(10):1685–1701. https://doi.org/10.1111/fwb.13569

Examines the potential combined and interacting effects of climate change, current weather, habitat, land use, and fire on two community-level metrics (species richness, relative abundance), and on the distributions of three Alaskan fish species.

Nicol, C. L., J. C. Jorgensen, C. B. Fogel, B. Timpane-Padgham, and T. J. Beechie. 2022. Spatially overlapping salmon species have varied population response to early life history mortality from increased peak flows. Canadian Journal of Fisheries and Aquatic Sciences 79(2):342-351. https://doi.org/10.1139/cjfas-2021-0038

Assesses the impacts of predicted increases in peak flows due to climate change on four salmonid populations in the Chehalis River basin.

Nielsen, J. L., G. T. Ruggerone, and C. E. Zimmerman. 2013. Adaptive strategies and life history characteristics in a warming climate: Salmon in the Arctic? Environmental Biology of Fishes 96:1187-1226. https://doi.org/10.1007/s10641-012-0082-6

Reviews the recent history of salmon in the Arctic and explores various patterns of climate change that may influence range expansions and future sustainability of salmon in Arctic habitats.

Northwest Fisheries Science Center. Impacts of climate change on salmon of the Pacific Northwest: a review of the scientific literature published in [Year]. NOAA, Seattle, Washington. 2015 2017 2018 2019

Annual reports on scientific literature published in the specified year relevant to climate change and Pacific salmon.

Petersen, J. H., and J. F Kitchell. 2001. Climate regimes and water temperature changes in the Columbia River: bioenergetic implications for predators of juvenile salmon. Canadian Journal of Fisheries and Aquatic Sciences. 58(9):1831-1841. https://doi.org/10.1139/f01-111

Examines how climatic regime shifts may affect predation rates on juvenile Pacific salmonids by northern pikeminnow, smallmouth bass, and walleye in the Columbia River.

Pitman, K. J., J. W. Moore, M. Huss, M. R. Sloat, D. C. Whited, T. J. Beechie, R. Brenner, E. W. Hood, A. M. Milner, G. R. Pess, G. H. Reeves, and DE. Schindler. 2021. Glacier retreat creating new Pacific salmon habitat in western North America. Nature Communications 12:6816. https://doi.org/10.1038/s41467-021-26897-2

Projects future gains in Pacific salmon freshwater habitat by linking a model of glacier mass change for 315 glaciers, forced by five different Global Climate Models, with a simple model of salmon stream habitat potential.

Railsback, S. F. 2022. What we don’t know about the effects of temperature on salmonid growth. Transactions of the American Fisheries Society 151(1):3-12. https://doi.org/10.1002/tafs.10338

Identifies conflicts between management assumptions and models about temperature effects and examines them in light of the available evidence.

Ray, R. A., R. A. Holt, and J. L. Bartholomew. 2012. Relationship between temperature and *Ceratomyxa shasta*-induced mortality in Klamath River salmonids. Journal of Parasitology 98(3):520-526. https://doi.org/10.1645/jp-ge-2737.1

Reviews the effects of water temperature on the mortality of Klamath River Chinook and coho salmon infected with *Ceratomyxa shasta*.

Ruesch, A. S., C. E. Torgersen, J. J. Lawler, J. D. Olden, E. E. Peterson, C. J. Volk, and D. J. Lawrence. 2012. Projected climate-induced habitat loss for salmonids in the John Day River network, Oregon, U.S.A.. Conservation Biology 26(5):873-882. https://doi.org/10.1111/j.1523-1739.2012.01897.x

Applies a geostatistical network model of stream temperature to forecast potential climate induced changes in the availability of thermal habitat for three salmonid species.

Schoen, E. R., M. S. Wipfli, E. J. Trammell, D. J. Rinella, A. L. Floyd, J. Grunblatt, M. D. McCarthy, B. E. Meyer, J. M. Morton, J. E. Powell, A. Prakash, M. N. Reimer, S. L. Stuefer, H. Toniolo, B. M. Wells, and F. D. Witmer. 2017. Future of pacific salmon in the face of environmental change: lessons from one of the world’s remaining productive salmon regions. Fisheries 42(10):538–553. https://doi.org/10.1080/03632415.2017.1374251

Examines changes in climate, hydrology, land cover, salmon populations, and fisheries over the past 30–70 years in the Gulf of Alaska region with a focus on the Kenai River, where Chinook salmon populations have noticeably declined.

Shanley, C. S., and D. M. Albert. 2014. Climate change sensitivity index for Pacific salmon habitat in Southeast Alaska. PLoS ONE 9(8):0104799. https://doi.org/10.1371/journal.pone.0104799

Describes a watershed-scale hydroclimatic sensitivity index to assess the impacts of hydrologic changes associated with climate change in Southeast Alaska.

Sloat, M. R., G. H. Reeves, and K. R. Christiansen. 2017. Stream network geomorphology mediates predicted vulnerability of anadromous fish habitat to hydrologic change in southeast Alaska. Global Change Biology 23(2):604-620. https://doi.org/10.1111/gcb.13466

Combines field measurements and model simulations to estimate the potential influence of future flood disturbance on geomorphic processes controlling the quality and extent of coho, chum, and pink salmon spawning habitat in over 800 southeast Alaska watersheds.

Snyder, M. N., N. H. Schumaker, J. B. Dunham, J. L. Ebersole, M. L. Keefer, J. Halama, R. L. Comeleo, P. Leinenbach, A. Brookes, B. Cope, J. Wu, and J. Palmer. 2022. Tough places and safe spaces: can refuges save salmon from a warming climate? Ecosphere 13(11):e4265. https://doi.org/10.1002/ecs2.4265

Employs a spatially explicit, individual-based model to investigate the potential for thermal refuges to benefit upstream-migrating Pacific salmonids in the Pacific Northwest.

Spanjer, A. R., A. S. Gendaszek, E. J. Wulfkuhle, R. W. Black, and K. L. Jaeger. 2022. Assessing climate change impacts on Pacific salmon and trout using bioenergetics and spatiotemporal explicit river temperature predictions under varying riparian conditions. PLOS ONE 17(5):e0266871. https://doi.org/10.1371/journal.pone.0266871

Develops a spatiotemporal model to assess how riparian canopy and vegetation preservation and addition could influence river temperatures under future climate predictions in the Quinault River, Washington.

Sydeman, W. J., J. A. Santora, S. A. Thompson, B. Marinovic, and E. Di Lorenzo. 2013. Increasing variance in North Pacific climate relates to unprecedented ecosystem variability off California. Global Change Biology 19:1662-1675. https://doi.org/10.1111/gcb.12165

Investigates whether recent high variability in demographic attributes of salmon and seabirds off California is related to increasing variability in remote, large-scale forcing in the North Pacific operating through changes in local food webs.

Vehanen, T., T. Sutela, and A. Huusko. 2023. Potential impact of climate change on salmonid smolt ecology. Fishes 8(7):382. https://doi.org/10.3390/fishes8070382

Reviews the effects of climate change on smolt ecology from the growth of juveniles in fresh water to early post-smolts in the sea to identify the potential effects of climate change on migratory salmonid populations during this period in their life history.

von Biela, V. R., C. J. Sergeant, M. P. Carey, Z. Liller, C. Russell, S. Quinn-Davidson, P. S. Rand, P. A. H. Westley, and C. E. Zimmerman. 2022. Premature mortality observations among Alaska's Pacific salmon during record heat and drought in 2019. Fisheries 47(4):157-168. https://doi.org/10.1002/fsh.10705

Evaluates whether observed Pacific salmon premature mortalities in in Alaska in 2019 were due to atmospheric conditions.

Wobus C., R. Prucha, D. Albert, C. Woll, M. Loinaz, and R. Jones. 2015. Hydrologic alterations from climate change inform assessment of ecological risk to pacific salmon in Bristol Bay, Alaska. PLoS ONE 10(12):e0143905. https://doi.org/10.1371/journal.pone.0143905

Incorporates climate change scenarios into a hydrologic model to evaluate how hydrologic regimes and stream temperatures might change in a future climate, and to summarize indicators of hydrologic alteration that are relevant to salmon habitat ecology and life history.

Zhang, X., H.-Y. Li, Z. D. Deng, L. R. Leung, J. R. Skalski, and S. J. Cooke. 2019. On the variable effects of climate change on Pacific Salmon. Ecological Modelling 397(1):95–106. https://doi.org/10.1016/j.ecolmodel.2019.02.002

Investigates the impacts of climate change and water management practices on Chinook and steelhead smolts in the Columbia River Basin using an integrated earth system model and a multiple regression model.

Chinook (Oncorhynchus tshawytscha)

Austin, C. S., T. E. Essington, and T. P. Quinn. 2021. In a warming river, natural-origin Chinook salmon spawn later but hatchery-origin conspecifics do not. Canadian Journal of Fisheries and Aquatic Sciences 78(1):68-77. https://doi.org/10.1139/cjfas-2020-0060

Investigates if timing of spawning by Chinook salmon populations is related to temperature with increasing temperature, if spawning will occur later in the year when temperatures increase, and if spawning in the hatchery would show no trend or a trend in the opposite direction.

Battin, J., M. W. Wiley, M. H. Ruckelshaus, R. N. Palmer, E. Korb, K. K. Bartz, and H. Imaki. 2007. Projected impacts of climate change on salmon habitat restoration. Proceedings of the National Academy of Sciences of the United States of America 104(16):6720-6725. https://doi.org/10.1073/pnas.0701685104

Investigates the impacts of climate change on the effectiveness of proposed habitat restoration efforts designed to recover depleted Chinook salmon populations in the Snohomish River basin.

Beechie, T. J., A. Goodman, M. Lowe, O. Stefankiv, B. Timpane-Padgham, and J. Jorgensen. 2023. Evaluating effects of climate change, restoration scenarios, and hatchery effects on Chinook Salmon in the Stillaguamish River Basin with the HARP Model. NOAA Contract Report NMFS-NWFSC-CR-2023-09. https://doi.org/10.25923/963j-pd86

Uses the HARP Model to evaluate potential effects of climate change on Stillaguamish Chinook salmon, identify restoration actions that will increase spawner abundance and resilience to climate change, and evaluate if hatchery practices could help ameliorate climate change effects.

Beer, W. N., and J. J. Anderson. 2013. Sensitivity of salmonid freshwater life history in western US streams to future climate conditions. Global Change Biology 19(8):2547-2556. https://doi.org/10.1111/gcb.12242

Investigates projected effects of mid-21st century climate on the early life growth of Chinook salmon and steelhead in western United States streams.

Beer, W. N., and E. A. Steel. 2018. Impacts and implications of temperature variability on Chinook salmon egg development and emergence phenology. Transactions of the American Fisheries Society 147(1):3-15. https://doi.org/10.1002/tafs.10025

Uses a mechanistic model of the relationship between temperature and development to better understand laboratory results on the primary effects of temperature variability leading to emergence.

Bowerman, T. E., M. L. Keefer, and C. C. Caudill. 2021. Elevated stream temperature, origin, and individual size influence Chinook salmon prespawn mortality across the Columbia River Basin. Fisheries Research 237:105874. https://doi.org/10.1016/j.fishres.2021.105874

Examines annual estimates of female Chinook salmon prespawn mortality relative to individual fish traits and reach-scale variables in 49 study reaches from 41 streams throughout the Columbia River Basin.

Carvalho, P. G., W. H. Satterthwaite, M. R. O'Farrell, C. Speir, and E. P. Palkovacs. 2023. Role of maturation and mortality in portfolio effects and climate resilience. Canadian Journal of Fisheries and Aquatic Sciences 80(6):924-941. https://doi.org/10.1139/cjfas-2022-0171

Explores the population dynamics of Sacramento River fall-run Chinook salmon under different age structure scenarios and tests whether age structure promotes resilience to drought.

Connor, W. P., K. F. Tiffan, J. A. Chandler, D. W. Rondorf, B. D. Arnsberg, and K. C. Anderson. 2019. Upstream migration and spawning success of Chinook salmon in a highly developed, seasonally warm river system. Reviews in Fisheries Science & Aquaculture 27(1):1-50. https://doi.org/10.1080/23308249.2018.1477736

Summarizes what is known about the influence of water temperature and velocity on the migration and spawning success of an inland population of Chinook salmon and uses models to illustrate how migration and spawning success might change in future climate scenarios.

Cordoleani, F., C. C. Phillis, A. M. Sturrock, A. M. FitzGerald, A. Malkassian, G. E. Whitman, P. K. Weber, and R. C. Johnson. 2021. Threatened salmon rely on a rare life history strategy in a warming landscape. Nature Climate Change 11:982–988. https://doi.org/10.1038/s41558-021-01186-4

Examines genetic markers and genetic diversity within Chinook salmon and how this may relate to adaptations that could help Chinook populations survive droughts and ocean heatwaves.

Crozier, L. G., B. J. Burke, B. E. Chasco, D. L. Widener, and R. W. Zabel. 2021. Climate change threatens Chinook salmon throughout their life cycle. Communications Biology 4:222. https://doi.org/10.1038/s42003-021-01734-w

Evaluates climate impacts at all life stages and modeled future trajectories forced by global climate model projections on eight populations of Chinook salmon.

Crozier, L.G., and R. W. Zabel. 2006. Climate impacts at multiple scales: evidence for differential population responses in juvenile Chinook salmon. Journal of Animal Ecology 75(5):1100-1109. https://doi.org/10.1111/j.1365-2656.2006.01130.x

Explores differential population responses to climate in 18 populations of Chinook salmon in the Salmon River basin, Idaho.

Crozier, L. G., R. W. Zabel, and A. F. Hamlet. 2008. Predicting differential effects of climate change at the population level with life-cycle models of spring Chinook salmon. Global Change Biology 14(2):236-249. https://doi.org/10.1111/j.1365-2486.2007.01497.x

Explores potential differential responses of four Chinook salmon populations to changes in streamflow and temperature that might result from climate change and if habitat diversity can help buffer species from the impacts of climate change.

Cunningham, C. J., P. A. H. Westley, and M. D. Adkison. 2018. Signals of large scale climate drivers, hatchery enhancement, and marine factors in Yukon River Chinook salmon survival revealed with a Bayesian life history model. Global Change Biology 24(9):4399-4416. https://doi.org/10.1111/gcb.14315

Estimates the effect of factors in marine and freshwater environments on Chinook salmon survival.

Daly E. A., and R. D. Brodeur. 2015. Warming ocean conditions relate to increased trophic requirements of threatened and endangered salmon. PLoS ONE 10(12):e0144066. https://doi.org/10.1371/journal.pone.0144066

Utilizes a long-term study of salmon feeding and condition to investigate three possible mechanisms to explain lower survival of Chinook salmon during warmer ocean regimes.

Del Rio, A. M., B. E. Davis, N. A. Fangue, and A. E. Todgham. 2019. Combined effects of warming and hypoxia on early life stage Chinook salmon physiology and development. Conservation Physiology 7(1): coy078. https://doi.org/10.1093/conphys/coy078

Investigates how elevated temperature and hypoxia as individual and combined stressors affected the survival, physiological performance, growth, and development of Chinook salmon.

Del Rio, A. M., G. N. Mukai, B. T. Martin, R. C. Johnson, N. A. Fangue, J. A. Israel, and A. E. Todgham. 2021. Differential sensitivity to warming and hypoxia during development and long-term effects of developmental exposure in early life stage Chinook salmon. Conservation Physiology 9(1):coab054. https://doi.org/10.1093/conphys/coab054

Tests the impacts of warm water temperature and hypoxia as individual and combined developmental stressors on late fall-run Chinook salmon embryos.

Eiler, J. H., M. M. Masuda, and A. N. Evans. 2023. Swimming depths and water temperatures encountered by radio-archival-tagged Chinook salmon during their spawning migration in the Yukon River basin. Transactions of the American Fisheries Society 152(1)51-74. https://doi.org/10.1002/tafs.10386

Documents the migratory patterns of Chinook salmon in relation to the environmental conditions encountered to assess the impact of climate change.

Feddern, M. L., E. R. Schoen, R. Shaftel, C. J. Cunningham, C. Chythlook, B. M. Connors, A. D. Murdoch, V. R. von Biela, and B. Woods. 2023. Kings of the North: Bridging disciplines to understand the effects of changing climate on Chinook salmon in the Arctic–Yukon–Kuskokwim Region. Fisheries 48(8):331-343. https://doi.org/10.1002/fsh.10923

Synthesizes perspectives shared at a workshop on Chinook salmon declines in the AYK region and suggests pathways forward to integrate different types of information and build relationships among communities, academic partners, and fishery management agencies.

FitzGerald, A. M., S. N. John, T. M. Apgar, N. J. Mantua, and B. T. Martin. 2021. Quantifying thermal exposure for migratory riverine species: Phenology of Chinook salmon populations predicts thermal stress. Global Change Biology 27(3):536-549. https://doi.org/10.1111/gcb.15450

Links temperature predictions with data on the distribution and phenology of Chinook salmon to estimate thermal exposure and assesses thermal stress for each life stage based on nearness to upper thermal limits.

Fullerton, A. H., B. J. Burke, J. J. Lawler, C. E. Torgersen, J. L. Ebersole, and S. G. Leibowitz. 2017. Simulated juvenile salmon growth and phenology respond to altered thermal regimes and stream network shape. Ecosphere 8(12):e02052. https://doi.org/10.1002/ecs2.2052

Investigates if changes in growth and timing of life history events due to climate alteration can be moderated in topologically complex stream networks where opportunities to thermoregulate are readily available.

Fullerton, A. H., N. Sun, M. J. Baerwalde, B. L. Hawkins, and H. Yan. 2022. Mechanistic simulations suggest riparian restoration can partly counteract climate impacts to juvenile salmon. Journal of the American Water Resources Association 58(4):525-546. https://doi.org/10.1111/1752-1688.13011

Examines how a threatened population of Chinook salmon may respond to climate change and whether riparian restoration could reduce climate effects using a process-based modeling system.

Garzke, J., I. Forster, C. Graham, D. Costalago, and B. P. V. Hunt. 2023. Future climate change-related decreases in food quality may affect juvenile Chinook salmon growth and survival. Marine Environmental Research 191:106171. https://doi.org/10.1016/j.marenvres.2023.106171

Assesses the effects of food quality on juvenile Chinook salmon body and nutritional condition to better understand predicted increases in prey availability and lower prey nutritional quality in marine ecosystems.

Giroux, M., J. Gan, and D. Schlenk. 2019. The effects of bifenthrin and temperature on the endocrinology of juvenile Chinook salmon. Environmental Toxicology and Chemistry 38(4):852-861. https://doi.org/10.1002/etc.4372

Studies the potential interaction between temperature and pesticide exposure on Chinook salmon development in the alevin and fry stages.

Goertler, P., K. Jones, J. Cordell, B. Schreier, and T. Sommer. 2018. Effects of extreme hydrologic regimes on juvenile Chinook salmon prey resources and diet composition in a large river floodplain. Transactions of the American Fisheries Society 147(2):287-299. https://doi.org/10.1002/tafs.10028

Examines juvenile Chinook salmon prey resources and feeding in response to extreme drought and flood events flood in the Yolo Bypass, California.

Gross, P. L., J. C. L. Gan, D. J. Scurfield, C. Frank, C. Frank, C. McLean, C. Bob, and J. W. Moore. 2023. Complex temperature mosaics across space and time in estuaries: Implications for current and future nursery function for Pacific Salmon. Frontiers in Marine Science 10:1278810. https://doi.org/10.3389/fmars.2023.1278810

> Investigates spatial and temporal patterns of water temperature across two contrasting estuaries on Vancouver Island, BC, and uses this data to simulate juvenile Chinook salmon growth potential under both present conditions and a simplified scenario of climate warming.

Hawkins, B. L., A. H. Fullerton, B. L. Sanderson, and E. A. Steel. 2020. Individual-based simulations suggest mixed impacts of warmer temperatures and a nonnative predator on Chinook salmon. Ecosphere 11(8):e03218. https://doi.org/10.1002/ecs2.3218

> Investigates how the independent and combined impacts of climate change and largemouth bass predation can affect the early life history of a Chinook salmon in the Snoqualmie River, Washington.

Honea, J. M., M. M. McClure, J. C. Jorgensen, and M. D. Scheuerell. 2016. Assessing freshwater life-stage vulnerability of an endangered Chinook salmon population to climate change influences on stream habitat. Climate Research 71(2):127-137. https://doi.org/10.3354/cr01434

> Connects a set of climate, hydrology, landscape, and fish population models to estimate the relative influence of freshwater habitat variables on the abundance of a population of endangered stream-type Chinook salmon responding to a warming climate.

Howard, K. G., and V. von Biela. 2023. Adult spawners: A critical period for subarctic Chinook salmon in a changing climate. Global Change Biology 29(7):1759-1773. https://doi.org/10.1111/gcb.16610

> Utilizes existing production and environmental data to understand which life history stages link environmental conditions to production in Yukon River Chinook salmon.

Huntsman, B. M., M. L. Wulff, N. Knowles, T. Sommer, F. V. Feyrer, and L. R. Brown, L.R. 2024. Estimating the benefits of floodplain restoration to juvenile Chinook salmon in the upper San Francisco Estuary, United States, under future climate scenarios. Restoration Ecology e14238 Online Version of Record before inclusion in an issue https://doi.org/10.1111/rec.14238

> Investigates whether improved connectivity between a floodplain and river could limit negative climate change effects on salmon populations.

Jacobs, G. R., R. F. Thurow, J. M. Buffington, D. J. Isaak, and S. J. Wenger. 2021. Climate, fire regime, geomorphology, and conspecifics influence the spatial distribution of Chinook salmon redds. Transactions of the American Fisheries Society 150(1):8-23. https://doi.org/10.1002/tafs.10270

Examines which covariates best predict the spawning occurrence of Chinook salmon and how shifts under a changing climate might affect habitat availability.

Jones, L. A., E. R. Schoen, R. Shaftel, C. J. Cunningham, S. Mauger, D. J. Rinella, and A. St. Saviour. 2020. Watershed-scale climate influences productivity of Chinook salmon populations across southcentral Alaska. Global Change Biology 26(9):4919-4936. https://doi.org/10.1111/gcb.15155

Analyzes the effects of precipitation, streamflow, and stream temperature on Chinook salmon, in the Cook Inlet Basin, Alaska.

Jorgensen, J .C., M. M. McClure, M. B. Sheer, and N. L. Munn. 2013. Combined effects of climate change and bank stabilization on shallow water habitats of Chinook salmon. Conservation Biology 27(6):1201-1211. https://doi.org/10.1111/cobi.12168

Examines anticipated effects on shallow water over low-sloped beaches to natural variability, climate change, and human activity in the lower Willamette River, Oregon.

Justice, C., S. M. White, D. A. McCullough, D. S. Graves, and M. R. Blanchard. 2017. Can stream and riparian restoration offset climate change impacts to salmon populations? Journal of Environmental Management 188:212-227. https://doi.org/10.1016/j.jenvman.2016.12.005

Investigates potential thermal benefits of riparian reforestation and channel narrowing to Chinook salmon populations using a deterministic water temperature model.

Kuehne, L. M., J. D. Olden, and J. J. Duda. 2012. Costs of living for juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in an increasingly warming and invaded world. Canadian Journal of Fisheries and Aquatic Sciences. 69(10):1621-1630. https://doi.org/10.1139/f2012-094

Tests the separate and interactive effects of water temperature and predation by non-native smallmouth bass on the lethal (mortality) and sublethal (behavior, physiology, and growth) effects for juvenile Chinook salmon in seminatural stream channel experiments.

Landis, W. G., C. J. Mitchell, J. D. Hader, R. Nathan, and E. E. Sharpe. 2024. Incorporation of climate change into a multiple stressor risk assessment for the Chinook salmon (*Oncorhynchus tshawytscha*) population in the Yakima River, Washington, USA. Integrated Environmental Assessment and Management 20(2):419-432. https://doi.org/10.1002/ieam.4878

Integrates selected direct and indirect effects of climate change on the Chinook salmon population in the Yakima River Basin into an existing Bayesian network previously used for ecological risk assessment.

Lawrence, D. J., B. Stewart-Koster, J. D. Olden, A. S. Ruesch, C. E. Torgersen, J. J. Lawler, D. P. Butcher, and J. K. Crown. 2014. The interactive effects of climate change, riparian management, and a nonnative predator on stream-rearing salmon. Ecological Applications 24(4):895-912. https://doi.org/10.1890/13-0753.1

Applies a framework to forecast the interactive effects of climate change, riparian management, and nonnative species on stream-rearing salmon and to evaluate the capacity of restoration to mitigate these effects in the Columbia River basin.

Levin, P. S. 2003. Regional differences in responses of Chinook salmon populations to large-scale climatic patterns. Journal of Biogeography 30(5):711-717. https://doi.org/10.1046/j.1365-2699.2003.00863.x

Explores the extent to which many different populations of the same species respond cohesively to a common large-scale climatic trend in the Columbia River basin.

Muñoz, N. J., A. P. Farrell, J. W. Heath, and B. D. Neff. 2014. Adaptive potential of a Pacific salmon challenged by climate change. Nature Climate Change 5(2):163–166. https://doi.org/10.1038/nclimate2473

Reports on the physiological and genetic capacities of Chinook salmon to increase their thermal tolerance in response to rising temperatures.

McCann, K. S, L. W Botsford, and A. Hasting. 2003. Differential response of marine populations to climate forcing. Canadian Journal of Fisheries and Aquatic Sciences. 60(8):971-985. https://doi.org/10.1139/f03-078

Demonstrates how the response of populations to variable recruitment changes with the degree of overcompensation using models of two species with similar age structure but different density-dependent recruitment, Chinook salmon and Dungeness crab.

Munsch, S. H., C. M. Greene, R. C. Johnson, W. H. Satterthwaite, H. Imaki, and P. L. Brandes. 2019. Warm, dry winters truncate timing and size distribution of seaward-migrating salmon across a large, regulated watershed. Ecological Applications 29:14. https://doi.org/10.1002/eap.1880

Examines the phenology of juvenile Chinook salmon in the Sacramento River watershed, quantifying environmental conditions and juvenile salmon responses.

Naik, P. K., and D. A. Jay. 2011. Human and climate impacts on Columbia River hydrology and salmonids. River Research and Applications 27(10):1270-1276. https://doi.org/10.1002/rra.1422

Describes methods to distinguish the human and climate-induced contributions to Columbia River hydrologic processes relevant to the crucial seaward spring migration of juveniles through the tidal river and estuary.

Nobriga, M. L., C. J. Michel, R. C. Johnson, and J. D. Wikert. 2021. Coldwater fish in a warm water world: Implications for predation of salmon smolts during estuary transit. Ecology and Evolution 11(15):10381-10395. https://doi.org/10.1002/ece3.7840

Assesses the impact of warming waters on intensifying predation of juvenile Chinook salmon by striped and largemouth bass.

Reeder, W. J., F. Gariglio, R. Carnie, C. Tang, D. Isaak, Q. Chen, Z. Yu, J. A. McKean, and D. Tonina. 2021. Some (fish might) like it hot: Habitat quality and fish growth from past to future climates. Science of The Total Environment 787:147532. https://doi.org/10.1016/j.scitotenv.2021.147532

Investigates the effects of recorded climate conditions on Chinook salmon spawning and rearing habitats and growth responses to the local climate and compares those conditions to predicted responses to a climate change.

Sabal, M. C., K. Richerson, P. Moran, T. Levi, V. J. Tuttle, and M. Banks. 2023. Warm oceans exacerbate Chinook salmon bycatch in the Pacific hake fishery driven by thermal and diel depth-use behaviours. Fish and Fisheries 24(6):910–923. https://doi.org/10.1111/faf.12775

Examines whether thermal and diel depth-use behaviors influenced bycatch of Chinook in the Pacific hake with annual consequences in a warming ocean.

Scheuerell, M. D., and J. G. Williams. 2005. Forecasting climate-induced changes in the survival of Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*). Fisheries Oceanography 14(6):448-457. https://doi.org/10.1111/j.1365-2419.2005.00346.x

Predicts changes in the ocean survival of Snake River spring/summer Chinook salmon from indices of coastal ocean upwelling with a high degree of certainty using a Bayesian time-series model.

Shelton, A.O., G. H. Sullaway, E. J. Ward, B. E. Feist, K. A. Somers, V. J. Tuttle, J. T. Watson, and W.H. Satterthwaite. 2021. Redistribution of salmon populations in the northeast Pacific Ocean in response to climate. Fish and Fisheries. 22(3):503-517. https://doi.org/10.1111/faf.12530

Estimates the ocean distribution of all major fall-run Chinook salmon stocks from California to British Columbia over 40 years by using a new spatio-temporal model.

Siegel, J. E., M. V. McPhee, and M. D. Adkison. 2017. Evidence that marine temperatures influence growth and maturation of western Alaskan Chinook salmon. Marine and Coastal Fisheries 9(1):441-456. https://doi.org/10.1080/19425120.2017.1353563

Investigates the influence of sea surface temperatures on the life history of western Alaskan Chinook salmon.

Steel, E. A., A. Marsha, A. H. Fullerton, J. D. Olden, N. K. Larkin, S.-Y. Lee, and A. Ferguson. 2019. Thermal landscapes in a changing climate: biological implications of water temperature patterns in an extreme year. Canadian Journal of Fisheries and Aquatic Sciences. 76(10):1740-1756. https://doi.org/10.1139/cjfas-2018-0244

Applies spatial stream network models to data collected at 42 sites on the Snoqualmie River to compare water temperature patterns, summarized with relevance to particular life stages of native and nonnative fishes, in 2015 with more typical conditions (2012–2014).

Strange, J. S. 2012. Migration strategies of adult Chinook salmon runs in response to diverse environmental conditions in the Klamath River Basin. Transactions of the American Fisheries Society 141(6):1622-1636. https://doi.org/10.1080/00028487.2012.716010

Investigates Chinook salmon migration behaviors in response to temperature within the context of run timing strategies.

Tolimieri, N., and P. Levin. 2004. Differences in responses of Chinook salmon to climate shifts: Implications for conservation. Environmental Biology of Fishes 70:155-167. https://doi.org/10.1023/B:EBFI.0000029344.33698.34

Examines the response of Chinook salmon from 9 evolutionary significant units to climate regime shifts.

Tonina, D., J. A. McKean, D. Isaak, R. M. Benjankar, C. Tang, and Q. Chen. 2022. Climate change shrinks and fragments salmon habitats in a snow-dependent region. Geophysical Research Letters 49(12):e2022GL098552. https://doi.org/10.1029/2022GL098552

Investigates how climate-induced summer flow declines during historical and future periods cause complex local changes in Chinook salmon habitats for juveniles and spawning adults in Bear Valley Creek, Idaho.

Walters, A.W., K. K. Bartz, and M. M. McClure. 2013. Interactive effects of water diversion and climate change for juvenile Chinook salmon in the Lemhi River basin (U.S.A.). Conservation Biology 27(6):1179-1189. https://doi.org/10.1111/cobi.12170

Examines the potential effects of water diversion and climate change on juvenile Chinook salmon by using models to project juvenile survival and habitat carrying capacity for diversion and climate-change scenarios.

von Biela, V. R., L. Bowen, S. D. McCormick, M. P. Carey, D. S. Donnelly, S. Waters, A. M. Regish, S. M. Laske, R. J. Brown, S. Larson, S. Zuray, and C. E. Zimmerman. 2020. Evidence of prevalent heat stress in Yukon River Chinook salmon. Canadian Journal of Fisheries and Aquatic Sciences 77:1878-1892. https://doi.org/10.1139/cjfas-2020-0209

Assesses the proportion of Yukon River Chinook salmon exhibiting evidence of heat stress to assess the potential that high temperatures contribute to freshwater adult mortality in a northern Pacific salmon population.

Ward, E. J., J. H. Anderson, T. J. Beechie, G. R. Pess, and M. J. Ford. 2015. Increasing hydrologic variability threatens depleted anadromous fish populations. Global Change Biology 21(7):2500-2509. https://doi.org/10.1111/gcb.12847

Evaluates potential responses of anadromous fish populations to an increasingly variable climate using a hierarchical analysis of 21 Chinook salmon populations from the Pacific Northwest.

Warkentin, L., C. K. Parken, R. Bailey, and J. W. Moore. 2022. Low summer river flows associated with low productivity of Chinook salmon in a watershed with shifting hydrology. Ecological Solutions and Evidence 3(1):e12124. https://doi.org/10.1002/2688-8319.12124

Investigates how river flow regimes affect the productivity of Chinook salmon in a British Columbia watershed which exemplifies cumulative effects of human activities and climate change.

Yasumiishi, E. M., E. V. Farley, J. Maselko, K. Y. Aydin, K. A. Kearney, A. J. Hermann, G. T. Ruggerone, K. G. Howard, and W. W. Strasburger. 2020. Differential north-south response of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) marine growth to ecosystem change in the eastern Bering Sea, 1974-2010. Ices Journal of Marine Science 77(1):216-229. https://doi.org/10.1093/icesjms/fsz166

Assesses the differential influence of climatic and oceanic conditions on the growth of juvenile Chinook salmon in the north and southeastern Bering Sea.

Yates, D., H. Galbraith, D. Purkey, A. Huber-Lee, J. Sieber, J. West, S. Herrod-Julius, and B. Joyce. 2008. Climate warming, water storage, and Chinook salmon in California's Sacramento Valley. Climatic Change 91:335-350. https://doi.org/10.1007/S10584-008-9427-8

Reviews the state of Chinook salmon populations in the Sacramento River, California, and potential risks posed by climate change on temperature regime and drought conditions.

Zabel, R. W., M. D. Scheuerell, M. M. McClure, and J. G. Williams. 2006. The interplay between climate variability and density dependence in the population viability of Chinook salmon. Conservation Biology, 20(1):190-200. https://doi.org/10.1111/j.1523-1739.2005.00300.x

Examines the relationship of freshwater recruitment of juveniles to density of spawners, and third-year survival in the ocean to monthly indices of broad-scale ocean and climate conditions.

Zillig, K. W., A. M. FitzGerald, R. A. Lusardi, D. E. Cocherell, and N. A. Fangue. 2023. Intraspecific variation among Chinook salmon populations indicates physiological adaptation to local environmental conditions. Conservation Physiology 11(1). https://doi.org/10.1093/conphys/coad044

Tests for local adaptation and counter gradient variation by assessing interpopulation variation among six populations of fall-run Chinook Salmon from the western United States to better predict Chinook responses to climate change.

Sockeye (Oncorhynchus nerka)

Akbarzadeh, A., D. T. Selbie, L. B. Pon, and K. M. Miller. 2021. Endangered Cultus Lake sockeye salmon exhibit genomic evidence of hypoxic and thermal stresses while rearing in degrading freshwater lacustrine critical habitat. Conservation Physiology 9(1):coab089. https://doi.org/10.1093/conphys/coab089

Investigates markers of hypoxic and thermal stress on endangered Cultus Lake sockeye salmon to better understand the response of sockeye to these stressors.

Armstrong, J. B., D. E. Schindler, K. L. Omori, C. P. Ruff, and T. P. Quinn. 2010. Thermal heterogeneity mediates the effects of pulsed subsidies across a landscape. Ecology 91(5):1445-1454. https://doi.org/10.1890/09-0790.1

Studies how spatial variation in water temperature regulates the potential for juvenile coho salmon to exploit a seasonal pulsed subsidy of eggs produced by anadromous sockeye salmon.

Atlas, W. I., K. M. Seitz, J. W. N. Jorgenson, B. Millard-Martin, W. G. Housty, D. Ramos-Espinoza, N. J. Burnett, M. Reid, and J. W. Moore. 2021. Thermal sensitivity and flow-mediated migratory delays drive climate risk for coastal sockeye salmon. FACETS 6(1):71-89. https://doi.org/10.1139/facets-2020-0027

Evaluates the potential vulnerability of coastal sockeye salmon to shifting hydrology and warming waters in a remote and undeveloped watershed.

Bentley, K. T., and R. L. Burgner. 2011. An assessment of parasite infestation rates of juvenile sockeye salmon after 50 years of climate warming in southwest Alaska. Environmental Biology of Fishes 92:267-273. https://doi.org/10.1007/s10641-011-9830-2

Examines the relationship between summer temperature and average infestation rates in Sockeye salmon over the previous 50 years.

Carey, M. P., C. E. Zimmerman, K. D. Keith, M. Schelske, C. Lean, and D. C. Douglas. 2017. Migration trends of sockeye salmon at the northern edge of their distribution. Transactions of the American Fisheries Society 146(4):791-802. https://doi.org/10.1080/00028487.2017.1302992

Explores relationships between interannual variability and annual migration timing of sockeye salmon in a subarctic watershed with environmental conditions at broad, intermediate, and local spatial scales.

Cline, T. J., J. Ohlberger, and D. E. Schindler. 2019. Effects of warming climate and competition in the ocean for life-histories of Pacific Salmon. Nature Ecology & Evolution 3(6):935–942. https://doi.org/10.1038/s41559-019-0901-7

Utilizes multivariate time-series models to quantify changes in the prevalence of different life-history strategies of sockeye salmon from Bristol Bay, Alaska over 50 years.

Connors, B., M. J. Malick, G. T. Ruggerone, P. Rand, M. Adkison, J. R. Irvine, R. Campbell, and K. Gorman. 2020. Climate and competition influence sockeye salmon population dynamics across the Northeast Pacific Ocean. Canadian Journal of Fisheries and Aquatic Sciences 77(6):943-949. https://doi.org/10.1139/cjfas-2019-0422

Studies data from 47 North American sockeye salmon populations to assess climate and competition effects across their distribution.

Crossin, G. T., S. G. Hinch, S. J. Cooke, D. W. Welch, D. A. Patterson, S. R. M. Jones, A. G. Lotto, R. A. Leggatt, M. T. Mathes, J. M. Shrimpton, G. Van der Kraak, and A. P. Farrell. 2008. Exposure to high temperature influences the behaviour, physiology, and survival of sockeye salmon during spawning migration. Canadian Journal of Zoology 86(2):127-140. https://doi.org/10.1139/Z07-122

Investigates the cause of Fraser River sockeye salmon early migrations and high mortality rates during these migrations.

Crozier, L. G., M. D. Scheuerell, and R. W. Zabel. 2011. Using time series analysis to characterize evolutionary and plastic responses to environmental change: A case study of a shift toward earlier migration date in sockeye salmon. American Naturalist 178(6):755-773. https://doi.org/10.1086/662669

Assesses the causes of earlier sockeye salmon runs in the Columbia Rive and the extent to which an estimated selection differential explained observed variation better than environmental factors alone.

Dorner, B., K. R. Holt, R. M. Peterman, C. Jordan, D. P. Larsen, A. R. Olsen, and O. I. Abdul-Aziz. 2013. Evaluating alternative methods for monitoring and estimating responses of salmon productivity in the North Pacific to future climatic change and other processes: a simulation study. Fisheries Research 147:10-23. https://doi.org/10.1016/j.fishres.2013.03.017

Examines how reliably alternative monitoring designs and fish stock assessment methods can distinguish between changes in density-dependent versus density-independent components of productivity and identify the relative contribution of a climate-driven covariate.

Eliason, E. J., T. D. Clark, M. J. Hague, L. M. Hanson, Z. S. Gallagher, K. M. Jeffries, M. K. Gale, D. A. Patterson, S. G. Hinch, and A. P. Farrell. 2011. Differences in thermal tolerance among sockeye salmon populations. Science 332(6025):109-112. https://doi.org/10.1126/science.1199158

Suggests that physiological adaptation occurs at a very local scale, with population-specific thermal limits set by physiological limitations in aerobic performance, possibly due to cardiac collapse at high temperatures.

Farley, E. V., A. Starovoytov, S. Naydenko, R. Heintz, M. Trudel, C. Guthrie, L. Eisner, and J. R. Guyon. 2011. Implications of a warming eastern Bering Sea for Bristol Bay sockeye salmon. ICES Journal of Marine Science 68(6):1138-1146. https://doi.org/10.1093/icesjms/fsr021

Examines overwinter survival of Bering Sea sockeye salmon to better understand how a warming ocean will affect overwinter survival.

Griffiths, J. R., and D. E. Schindler. 2012. Consequences of changing climate and geomorphology for bioenergetics of juvenile sockeye salmon in a shallow Alaskan lake. Ecology of Freshwater Fish 21(3):349-362. https://doi.org/10.1111/j.1600-0633.2012.00555.x

Uses output from a hydrodynamics model of lake thermal structure and a bioenergetics model to assess how alternative scenarios of climate change, geomorphic evolution and habitat restoration in a shallow Alaskan lake may affect juvenile sockeye salmon.

Griffiths, J. R., D. E. Schindler, G. T. Ruggerone, and J. D. Bumgarner. 2014. Climate variation is filtered differently among lakes to influence growth of juvenile sockeye salmon in an Alaskan watershed. Oikos 123(6):687-698. https://doi.org/10.1111/j.1600-0706.2013.00801.x

Assesses the response of sockeye salmon growth during their juvenile life phase to single and integrated measures of climate within a watershed between 1950 and 2010.

Hague, M. J., M. R. Ferrari, J. R. Miller, D. A. Patterson, G. L. Russell, A. P. Farrell, and S. G. Hinch. 2011. Modelling the future hydroclimatology of the lower Fraser River and its impacts on the spawning migration survival of sockeye salmon. Global Change Biology 17(1):87-98. https://doi.org/10.1111/j.1365-2486.2010.02225.x

Evaluates the impact of climate warming on the frequency of exceeding thermal thresholds associated with salmon migratory success in the Fraser River.

Healey, M. 2011. The cumulative impacts of climate change on Fraser River sockeye salmon (*Oncorhynchus nerka*) and implications for management. Canadian Journal of Fisheries and Aquatic Sciences 68(4):718-737. https://doi.org/10.1139/f2011-010

Uses a qualitative model to characterize the vulnerability of Fraser River sockeye salmon to future climate change at all ages of the life cycle.

Henderson, M. A., D. A. Levy, and J. S. Stockner. 1992. Probable consequences of climate change on freshwater production of Adams River sockeye salmon (*Oncorynchus nerka*). GeoJournal 28:51-59. https://doi.org/10.1007/BF00216406

Combines information on the influence of temperature on the thermal physiology, growth, and survival of sockeye salmon with projections of temperature change to determine the effect of climate change on two freshwater life history stages of sockeye salmon.

Hinch, S. G, M. C. Healey, R. E. Diewert, M. A. Henderson, K. A. Thomson, R. Hourston, and F. Juanes. 1995. Potential effects of climate change on marine growth and survival of Fraser River sockeye salmon. Canadian Journal of Fisheries and Aquatic Sciences 52(12):2651-2659. https://doi.org/10.1139/f95-854

Evaluates the probable consequences of changes in sea surface temperature and food availability to the adult recruitment and weight of Fraser River sockeye.

Hyatt, K. D., M. M. Stockwell, and D P. Rankin. 2003. Impact and adaptation responses of Okanagan River sockeye salmon (*Oncorhynchus nerka*) to climate variation and change effects during freshwater migration: stock restoration and fisheries management implications. Canadian Water Resources Journal 28(4):689-713. https://doi.org/10.4296/cwrj2804689

Summarizes existing knowledge on behavioral and physiological responses of Okanagan sockeye salmon adults to annual and seasonal variations in aquatic thermal regimes during migration.

Jacob, C., T. McDaniels, and S. Hinch. 2010. Indigenous culture and adaptation to climate change: Sockeye salmon and the St'at'imc people. Mitigation and Adaptation Strategies for Global Change 15:859-876. https://doi.org/10.1007/s11027-010-9244-z

Discusses a recent synthesis of expert views on the effects of climate change on sockeye salmon, the limited options available to mitigate or adapt to the effects of climate change on sockeye salmon, and the implications or viability of these options for the St'át'imc people.

Jeffries, K. M., S. G. Hinch, T. Sierocinski, T. D. Clark, E. J. Eliason, M. R. Donaldson, S. R. Li, P. Pavlidis, and K. M. Miller. 2012. Consequences of high temperatures and premature mortality on the transcriptome and blood physiology of wild adult sockeye salmon (*Oncorhynchus nerka*). Ecology and Evolution 2(7):1747-1764. https://doi.org/10.1002/ece3.274

Assesses the effects of elevated water temperatures on the gill transcriptome and blood plasma variables in wild-caught sockeye salmon.

Martins, E. G., S. G. Hinch, S. J. Cooke, and D. A. Patterson. 2012. Climate effects on growth, phenology, and survival of sockeye salmon (*Oncorhynchus nerka*): a synthesis of the current state of knowledge and future research directions. Reviews in Fish Biology and Fisheries 22:887-914. https://doi.org/10.1007/s11160-012-9271-9

Reviews existing research evaluating the effects of climate on sockeye salmon growth, phenology, and survival.

Litzow, M. A., M. J. Malick, T. Kristiansen, B. M. Connors, and G. T. Ruggerone. 2023. Climate attribution time series track the evolution of human influence on North Pacific sea surface temperature. Environmental Research Letters 19(1):014014. https://doi.org/10.1088/1748-9326/ad0c88

Applies climate attribution techniques to sea surface temperature time series from five regional North Pacific ecosystems to track the growth in human influence on ocean temperatures from 1950-2022 using the Gulf of Alaska sockeye salmon fishery.

Martins, E. G., S. G. Hinch, D. A. Patterson, M. J. Hague, S. J. Cooke, K. M. Miller, M. F. Lapointe, K. K. English, and A. P. Farrell. 2011. Effects of river temperature and climate warming on stock-specific survival of adult migrating Fraser River sockeye salmon (*Oncorhynchus nerka*). Global Change Biology 17(1):99-114. https://doi.org/10.1111/j.1365-2486.2010.02241.x

Tracks and investigates the effect of freshwater thermal experience on spawning migration survival of four distinct stocks of Fraser River sockeye salmon.

Martins, E. G., S. G. Hinch, D. A. Patterson, M. J. Hague, S. J. Cooke, K. M. Miller, D. Robichaud, K. K. English, and A. P. Farrell. 2012. High river temperature reduces survival of sockeye salmon (*Oncorhynchus nerka*) approaching spawning grounds and exacerbates female mortality. Canadian Journal of Fisheries and Aquatic Sciences 69(2):330-342. https://doi.org/10.1139/f2011-154

Investigates whether river thermal conditions differentially influence spatial patterns of survival for sockeye salmon along a stretch of migration and survival of the sexes.

McDaniels, T., S. Wilmot, M. Healey, and S. Hinch. 2010. Vulnerability of Fraser River sockeye salmon to climate change: a life cycle perspective using expert judgments. Journal of Environmental Management 91(12):2771-2780. https://doi.org/10.1016/j.jenvman.2010.08.004

Assesses the vulnerability of Fraser River sockeye salmon to future climate change throughout their lifecycle, reviews existing literature and proposes efforts to mitigate impacts on Fraser River sockeye.

McKinnell, S. 2008. Fraser River sockeye salmon productivity and climate: a re-analysis that avoids an undesirable property of Ricker's curve. Progress in Oceanography 77(2-3):146-154. https://doi.org/10.1016/j.pocean.2008.03.014

Examines the factors affecting sockeye salmon productivity in the Fraser River watershed, identifying artificial spawning channels, density-dependent mortality, carryover mortality, and climate as contributing factors to lower productivity.

Price, M. H. H., J. W. Moore, S. McKinnell, B. M. Connors, and J. D. Reynolds. 2024. Habitat modulates population-level responses of freshwater salmon growth to a century of change in climate and competition. Global Change Biology 30(1):e17095. https://doi.org/10.1111/gcb.17095

Examines the influence of habitat on the growth of sockeye salmon in nursery lakes of Canada's Skeena River watershed over a century of change in regional temperature and intraspecific competition.

Rand, P. S., S. G. Hinch, J. Morrison, M. G. G. Foreman, M. J. MacNutt, J. S. Macdonald, M. C. Healey, A. P. Farrell, and D. A. Higgs. 2006. Effects of river discharge, temperature, and future climates on energetics and mortality of adult migrating Fraser River sockeye salmon. Transactions of the American Fisheries Society 135(3):655-667. https://doi.org/10.1577/T05-023.1

Evaluates the effects of past and future trends in temperature and discharge in the Fraser River on the migratory performance of the early Stuart population of sockeye salmon.

Reed, T. E., D. E. Schindler, M. J. Hague, D. A. Patterson, E. Meir, R. S. Waples, and S. G. Hinch. 2011. Time to evolve? Potential evolutionary responses of Fraser River sockeye salmon to climate change and effects on persistence. PloS ONE 6:e20380. https://doi.org/10.1371/journal.pone.0020380

Explores potential evolutionary changes in migration timing and the consequences for population persistence in sockeye salmon in the Fraser River, Canada, under scenarios of future climate warming.

Rich, H. B., T. P. Quinn. M. D. Scheuerell, and D. E. Schindler. 2009. Climate and intraspecific competition control the growth and life history of juvenile sockeye salmon (*Oncorhynchus nerka*) in Iliamna Lake, Alaska. Canadian Journal of Fisheries and Aquatic Sciences. 66(2):238-246. https://doi.org/10.1139/F08-210

Uses long-term data (1962–2006) on juvenile sockeye salmon in Iliamna Lake to determine the relative roles of climate and density in controlling growth and the life history transition to the smolt stage.

Schindler, D. E., D. E. Rogers, M. D. Scheuerell, and C. A. Abrey. 2005. Effects of changing climate on zooplankton and juvenile sockeye salmon growth in southwestern Alaska. Ecology 86(1):198-209. https://doi.org/10.1890/03-0408

Explores the effects of density-dependence and changing climate on growth of juvenile sockeye salmon and the densities of their zooplankton prey in the Wood River system of southwestern Alaska.

Selbie, D. T., J. N. Sweetman, P. Etherton, K. D. Hyatt, D. P. Rankin, B. P. Finney, and J. P. Smol. 2011. Climate change modulates structural and functional lake ecosystem responses to introduced anadromous salmon. Canadian Journal of Fisheries and Aquatic Sciences 68(4):675-692. https://doi.org/10.1139/f2011-006

Explores the effects and interactions of climate warming and sockeye salmon introductions on northern lake ecology.

Sparks, M. M., J. A. Falke, T. P. Quinn, M. D. Adkison, D. E. Schindler, K. Bartz, D. Young, and P. A. H. Westley. 2019. Influences of spawning timing, water temperature, and climatic warming on early life history phenology in western Alaska sockeye salmon. Canadian Journal of Fisheries and Aquatic Sciences 76(1):123-135. https://doi.org/10.1139/cjfas-2017-0468

Explores current patterns and potential responses of early life history phenology of sockeye salmon in western Alaska to warming water temperatures.

Sparks, M. M., P. A. H. Westley, J. A. Falke, and T. P. Quinn. 2017. Thermal adaptation and phenotypic plasticity in a warming world: Insights from common garden experiments on Alaskan sockeye salmon. Global Change Biology 23(12):5203-5217. https://doi.org/10.1111/gcb.13782

Studies the developmental rate, survival, and body size at hatching in two populations of sockeye salmon that overlap in timing of spawning but incubate in contrasting natural thermal regimes.

Tigano, A., T. Weir, H. G. Ward, M. K. Gale, C. M. Wong, E. J. Eliason, K. M. Miller, S. G. Hinch, and M. A. Russello. 2023. Genomic vulnerability of a freshwater salmonid under climate change. Evolutionary Applications 17(2). https://doi.org/10.1111/eva.13602

Assesses the climate vulnerability of Kokanee salmon using analyses of standing genetic variation, genotype-environment associations, and climate modeling.

Tillotson, M. D., H. K. Barnett, M. Bhuthimethee. M. E. Koehler, and T. P. Quinn. 2019. Artificial selection on reproductive timing in hatchery salmon drives a phenological shift and potential maladaptation to climate change. Evolutionary Applications 12(7):1344–1359. https://doi.org/10.1111/eva.12730

Investigates the drivers behind spawn timing of sockeye salmon in the Cedar River, Washington and how the fitness costs of early spawning may be exacerbated by future warming.

Tillotson M. D., and T. P. Quinn. 2016. Beyond correlation in the detection of climate change impacts: Testing a mechanistic hypothesis for climatic influence on sockeye salmon (*Oncorhynchus nerka*) productivity. PLoS ONE 11(4) e0154356. https://doi.org/10.1371/journal.pone.0154356

Uses a multi-step approach to test the hypothesis that warming waters and the earlier age at juvenile migration are resulting in reduced productivity of Kvichak River sockeye.

Tillotson, M. D., and T. P. Quinn. 2017. Climate and conspecific density trigger pre-spawning mortality in sockeye salmon (*Oncorhynchus nerka*). Fisheries Research 188:138-148. https://doi.org/10.1016/j.fishres.2016.12.013

Investigates pre-spawn mortality, identifies stream flow and spawning density as primary drivers of oxygen availability, and anticipates that lower stream flows related to climate change will lead to higher rates of pre-spawn mortality.

Ulaski, M. E., H. Finkle, A. H. Beaudreau, and P. A. H. Westley. 2021. Climate and conspecific density inform phenotypic forecasting of juvenile Pacific salmon body size. Freshwater Biology 67(2): 404-415. https://doi.org/10.1111/fwb.13850

Uses a four-decade time series of smolt length from archives of returning adult scales to quantify population-specific responses to climate and conspecific density in a small watershed.

Welch, D. W, Y. Ishida, and K. Nagasawa. 1998. Thermal limits and ocean migrations of sockeye salmon (*Oncorhynchus nerka*): long-term consequences of global warming. Canadian Journal of Fisheries and Aquatic Sciences 55(4):937-948. https://doi.org/10.1139/f98-023

Demonstrates that thermal boundaries limited the distribution of sockeye salmon in the Pacific Ocean and adjacent seas over 40 years and that future temperature increases may severely restrict the overall area of the marine environment that sockeye can utilize.

Westley, P. A. H., D. E. Schindler, T. P. Quinn, G. T. Ruggerone, and R. Hilborn. 2010. Natural habitat change, commercial fishing, climate, and dispersal interact to restructure an Alaskan fish metacommunity. Oecologia 163:471-484. https://doi.org/10.1007/s00442-009-1534-3

Investigates the synergistic effects of naturally declining lake volume, climate variation, fishery management, and dispersal on sockeye salmon community composition.

Whitney, C. K., S. G. Hinch, and D. A. Patterson. 2013. Provenance matters: Thermal reaction norms for embryo survival among sockeye salmon Oncorhynchus nerka populations. Journal of Fish Biology 82(4):1159-1176. https://doi.org/10.1111/jfb.12055

Studies differences in thermal tolerance during embryonic development in Fraser River sockeye salmon in nine populations.

Whitney, C. K., S. G. Hinch, and D. A. Patterson. 2014. Population origin and water temperature affect development timing in embryonic sockeye salmon. Transactions of the American Fisheries Society 143(5):1316-1329. https://doi.org/10.1080/00028487.2014.935481

Assesses hatch timing and offspring size of Sockeye salmon in relation to egg size, population origin, and temperature.

Coho (Oncorhynchus kisutch)

Adelfio, L. A., S. M. Wondzell, N. J. Mantua, and G. H. Reeves. 2019. Warm winters reduce landscape-scale variability in the duration of egg incubation for coho salmon (*Oncorhynchus kisutch*) on the Copper River Delta, Alaska. Canadian Journal of Fisheries and Aquatic Sciences. 76(8):1362-1375. https://doi.org/10.1139/cjfas-2018-0152

Examines how winter climate conditions affect water temperature using surface and shallow streambed water-temperature monitoring data collected at coho salmon spawning sites on the Copper River Delta.

Beamish, R. J., G. A. McFarlane, and R. E. Thomson. 1999. Recent declines in the recreational catch of coho salmon (*Oncorhynchus kisutch*) in the Strait of Georgia are related to climate. Canadian Journal of Fisheries and Aquatic Sciences 56(3):506-515. https://doi.org/10.1139/f98-195

Describes how a change in climate is associated with change in salmon behavior that caused a collapse in the sport fishery for coho in the Strait of Georgia in the 1990s.

Beamish, R., D. Noakes, G. MacFarlane, W. D. Pinnix, R. Sweeting, and J. King. 2000. Trends in coho marine survival in relation to the regime concept. Fisheries Oceanography 9(1):114-119. https://doi.org/10.1046/j.1365-2419.2000.00126.x

Investigates the 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 that coincided with large-scale climate change.

Beebe, B. A., K. T. Bentley, T. W. Buehrens, R. W. Perry, and J. B. Armstrong, J.B. 2021. Evaluating fish rescue as a drought adaptation strategy using a life cycle modeling approach for imperiled coho salmon. North American Journal of Fisheries Management 41(1):3-18. https://doi.org/10.1002/nafm.10532

Describes a simulation model that explore how drought-induced fragmentation and seasonal fish rescue interact to affect salmonid population dynamics.

Bellmore, J. R., J. B. Fellman, E. Hood, M. R. Dunkle, and R. T. Edwards 2022. A melting cryosphere constrains fish growth by synchronizing the seasonal phenology of river food webs. Global Change Biology 28(16):4807-4818. https://doi.org/10.1111/gcb.16273

Uses a food web simulation model to explore how the distinct physicochemical properties of glacier-, snow-, and rain-fed streams influence seasonal resource dynamics and the capacity of watersheds to support coho growth.

Bellmore, J. R., C. J. Sergeant, R. A. Bellmore, J. A. Falke, and J. B. Fellman. 2023. Modeling coho salmon (*Oncorhynchus kisutch*) population response to streamflow and water temperature extremes. Canadian Journal of Fisheries and Aquatic Sciences 80(2):243–260. https://doi.org/10.1139/cjfas-2022-0129

Presents a process-based life cycle model that links coho salmon abundance to daily streamflow and thermal regimes to assess salmon abundance with short-term variations in streamflow and temperature, and how temporal resolution of flow and temperature data influence responses.

Kastl, B., M. Obedzinski, S. M. Carlson, W. T. Boucher, and T. E. Grantham. 2022. Migration in drought: receding streams contract the seaward migration window of endangered salmon. Ecosphere 13(12): e4295. https://doi.org/10.1002/ecs2.4295

Investigates how drought affects the seaward migration of coho salmon near the southern extent of their range in California.

Kock, T. J., T. L. Liedtke, D. W. Rondorf, J. D. Serl, M. Kohn, and K. A. Bumbaco. 2012. Elevated streamflows increase dam passage by juvenile coho salmon during winter: implications of climate change in the Pacific Northwest. North American Journal of Fisheries Management 32(6):1070-1079. https://doi.org/10.1080/02755947.2012.720645

Determines the proportion of juvenile coho salmon passing Cowlitz Falls Dam in winter over a four year period and how elevated streamflows due to climate change could result in increased winter passage.

Leppi, J. C., D. J. Rinella, R. R. Wilson, and W. M. Loya. 2014. Linking climate change projections for an Alaskan watershed to future coho salmon production. Global Change Biology 20(6):1808-1820. https://doi.org/10.1111/gcb.12492

Links climate, hydrology, and habitat models within a coho salmon population model to assess how projected climate change could affect survival at each freshwater life stage and, in turn, production of coho salmon smolts in the Chuitna River watershed, Alaska.

Ohlberger J., T. W. Buehrens, S. J. Brenkman, P. Crain, T. P. Quinn, and R. Hilborn. 2018. Effects of past and projected river discharge variability on freshwater production in an anadromous fish. Freshwater Biology 63(4):331-340. https://doi.org/10.1111/fwb.13070

Investigates the hypothesis that more frequent extreme conditions as projected under future climates significantly reduces freshwater production and the harvest that can be sustained in a population of coho salmon.

Wainwright, T. C., and L. A. Weitkamp. 2013. Effects of climate change on Oregon Coast Coho Salmon: Habitat and life-cycle interactions. Northwest Science 87(3):219–242. https://doi.org/10.3955/046.087.0305

Summarizes regional climate change studies to predict future climate patterns affecting terrestrial forests, freshwater rivers and lakes, estuaries, and the ocean and the ecological pathways by which these changes could affect Oregon populations of coho salmon.

Steelhead (Oncorhynchus mykiss)

Atcheson, M. E., K. W. Myers, D. A. Beauchamp, and N. J. Mantua. 2012. Bioenergetic response by steelhead to variation in diet, thermal habitat, and climate in the North Pacific Ocean. Transactions of the American Fisheries Society 141(4):1081-1096. https://doi.org/10.1080/00028487.2012.675914

Simulates interannual variation in prey consumption and growth efficiency of steelhead using a bioenergetics model to evaluate the temperature-dependent growth response of steelhead to past climate events and to estimate growth potential under future climate scenarios.

Benjamin, J. R., P. J. Connolly, J. G. Romine, and R. Perry. 2013. Potential effects of changes in temperature and food resources on life history trajectories of juvenile *Oncorhynchus mykiss*.

Transactions of the American Fisheries Society 142(1):208-220. https://doi.org/10.1080/00028487.2012.728162

Explores how water temperature in Beaver Creek, Washington, may increase under four climate scenarios, how these thermal changes may alter steelhead life history trajectory, and how changes in food quality or quantity might interact with increasing temperatures.

Boughton, D. A., M. Gibson, R. Yedor, and E. Kelley. 2007. Stream temperature and the potential growth and survival of juvenile *Oncorhynchus mykiss* in a southern California Creek. Freshwater Biology 52(7):1353-1364. https://doi.org/10.1111/j.1365-2427.2007.01772.x

Assesses whether an increase in food supply increases the ability of steelhead populations to withstand climate warming.

Brewitt, K. S., and E. M. Danner. 2014. Spatio-temporal temperature variation influences juvenile steelhead (*Oncorhynchus mykiss*) use of thermal refuges. Ecosphere 5(7):1353-1364. https://doi.org/10.1890/ES14-00036.1

Combines monitoring of environmental variables with measures of fish temperature to quantify juvenile steelhead use of thermal refuges in the Klamath River basin.

Cooper, S. D., S. W. Wiseman, B. P. DiFiore, and K. Klose. 2024. Trout and invertebrate assemblages in stream pools through wildfire and drought. Freshwater Biology 69(2):300-320. https://doi.org/10.1111/fwb.14212

Examines relationships among the distribution of steelhead, environmental factors, and stream invertebrate resources and assemblage impacted by climate change induced disturbances.

Friedland, K. D., B. R. Ward, D. W. Welch, and S. A. Hayes. 2014. Postsmolt growth and thermal regime define the marine survival of steelhead from the Keogh River, British Columbia. Marine and Coastal Fisheries 6(1):1-11. https://doi.org/10.1080/19425120.2013.860065

Evaluates how post-smolt growth and thermal regimes contributed to the pattern of marine survival of Keogh River steelhead over the period corresponding to smolt years 1977–1999.

Giroux, M., and D. Schlenk. 2021. The effects of temperature and salinity on the endocrinology in two life stages of juvenile rainbow/steelhead trout (*Oncorhynchus mykiss*). Journal of Fish Biology 99(2):513-523. https://doi.org/10.1111/jfb.14741

Examines the interactive effects of salinity and temperature on alevin and fry stages of salmonids.

Hand, B. K., C. C. Muhlfeld, A. A. Wade, R. P. Kovach, D. C. Whited, S. R. Narum, A. P. Matala, M. W. Ackerman, B. A. Garner, J. S. Kimball, J. A. Stanford, and G. Luikart. 2016. Climate variables explain neutral and adaptive variation within salmonid metapopulations: the importance of replication in landscape genetics. Molecular Ecology 25(3):689-705. https://doi.org/10.1111/mec.13517

Uses riverscape genetics modelling to assess whether climatic and habitat variables are related to neutral and adaptive patterns of genetic differentiation within five metapopulations of steelhead trout in the Columbia River Basin.

Hardiman, J. M., and M. G. Mesa. 2014. The effects of increased stream temperatures on juvenile steelhead growth in the Yakima River Basin based on projected climate change scenarios. Climatic Change 124(1-2):413-426. https://link.springer.com/article/10.1007/s10584-012-0627-x

Employs a bioenergetics model to assess the impacts of changing stream temperatures-resulting from different climate change scenarios-on growth of juvenile steelhead in the Yakima River Basin.

Isaak, D. J., C. H. Luce, B. E. Rieman, D. E. Nagel, E. E. Peterson, D. L. Horan, S. Parkes, and G. L. Chandler. 2010. Effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network. Ecological Applications 20(5): 1350-1371. https://doi.org/10.1890/09-0822.1

Explores the influence of recent climate trends and wildfires on stream temperatures and thermal habitat distributions for two salmonid species with contrasting thermal tolerances.

Kelson, S. J., and S. M. Carlson. 2019. Do precipitation extremes drive growth and migration timing of a Pacific salmonid fish in Mediterranean-climate streams? Ecosphere 10(3):e02618. https://doi.org/10.1002/ecs2.2618

Reports how extreme wet and dry years, from 2015 to 2018, affected stream flow patterns in two tributaries to the South Fork Eel River, California and the impacts on growth, body condition, and timing of out-migration in steelhead.

Matala, A. P., M. W. Ackerman, M. R. Campbell, and S. R. Narum. 2014. Relative contributions of neutral and non-neutral genetic differentiation to inform conservation of steelhead trout across highly variable landscapes. Evolutionary Applications 7(6):682-701. https://doi.org/10.1111/eva.12174

Investigates patterns of neutral genetic variation in contrast to non-neutral (putatively adaptive) genetic variation and how non-neutral differentiation in relation to climate change may improve our understanding of population viability.

McCarthy, S. G., J. J. Duda, J. M. Emlen, G. R. Hodgson, and D. A. Beauchamp. 2009. Linking habitat quality with trophic performance of steelhead along forest gradients in the South Fork Trinity River watershed, California. Transactions of the American Fisheries Society 138(3):506-521. https://doi.org/10.1577/T08-053.1

Investigates the potential effect of climate change on steelhead growth by running three climate change scenarios.

Myrvold, K. M., and B. P. Kennedy. 2018. Increasing water temperatures exacerbate the potential for density dependence in juvenile steelhead. Canadian Journal of Fisheries and Aquatic Sciences 75(6):897-907. https://doi.org/10.1139/cjfas-2016-0497

Examines the potential effects of predicted climate change on the energetic demands of juvenile steelhead and their consequences for local population size and structure in Lapwai Creek, Idaho watershed.

Timm R. K., L. Caldwell, A. Nelson, C. Long, M. B. Chilibeck, M. Johnson, K. Ross, A. Muller, and J. M. Brown. 2019. Drones, hydraulics, and climate change: Inferring barriers to steelhead spawning migrations. WIREs Water. 6(6):e1379. https://doi.org/10.1002/wat2.1379

Determines range of discharges that create velocity that exceed a steelhead's swimming ability and evaluates hydrologic model outputs to determine the potential effect of future climate scenarios on the expected timing and duration of barrier-forming flows.

Wade, A. A., T. J. Beechie, E. Fleishman, N. J. Mantua, H. Wu, J. S. Kimball, D. M. Stoms, and J. A. Stanford. 2013. Steelhead vulnerability to climate change in the Pacific Northwest. Journal of Applied Ecology 50(5):1093-1104. https://doi.org/10.1111/1365-2664.12137

Demonstrates a spatially explicit method for assessing salmon vulnerability to projected climatic changes (scenario for the years 2030–2059), applied to steelhead salmon across the entire Pacific Northwest.

Wade, A .A., B. K. Hand, R. P. Kovach, G. Luikart, D. C. Whited, and C. C. Muhlfeld. 2017. Accounting for adaptive capacity and uncertainty in assessments of species' climate-change vulnerability. Conservation Biology 31(1):136-149. https://doi.org/10.1111/cobi.12764

Applies a climate-change vulnerability assessment (CCVA) that incorporates exposure, sensitivity, and capacity to adapt to climate change to steelhead and bull trout in the Columbia River Basin.

Wang T., S. J. Kelson, G. Greer, S. E. Thompson, and S. M. Carlson. 2020. Tributary confluences are dynamic thermal refuges for a juvenile salmonid in a warming river network. River Research and Applications 36(7):1076-1086. https://doi.org/10.1002/rra.3634

Investigates the use of tributary confluences as thermal refuges by steelhead trout in the South Fork Eel River in northern California.

Pink (Oncorhynchus gorbuscha)

Clark, T. D., K. M. Jeffries, S. G. Hinch, and A. P. Farrell. 2011. Exceptional aerobic scope and cardiovascular performance of pink salmon (*Oncorhynchus gorbuscha)* may underlie resilience in a warming climate. Journal of Experimental Biology 214(18):3074-3081. https://doi.org/10.1242/jeb.060517

Investigates whether the continuing success of pink salmon may be linked with exceptional cardiorespiratory adaptations and thermal tolerance of adult fish during their spawning migration.

Frommel, A. Y., J. Carless, B. P. V. Hunt, and C. J. Brauner. 2020. Physiological resilience of pink salmon to naturally occurring ocean acidification. Conservation Physiology 8(1):coaa059. https://doi.org/10.1093/conphys/coaa059

Investigates the physiological response of out-migrating wild juvenile pink salmon to higher CO_2 levels and additional stressors associated with climate change.

Kovach, R. P., A. J. Gharrett, and D. A. Tallmon. 2013. Temporal patterns of genetic variation in a salmon population undergoing rapid change in migration timing. Evolutionary Applications 6(5):795-807. https://doi.org/10.1111/eva.12066

Tests whether temporal trends toward earlier migration timing and a corresponding loss of phenotypic variation would decrease genetic divergence based on migration timing.

Manhard, C. V., J. E. Joyce, and A. J. Gharrett. 2017. Evolution of phenology in a salmonid population: a potential adaptive response to climate change. Canadian Journal of Fisheries and Aquatic Sciences 74(10):1519-1527. https://doi.org/10.1139/cjfas-2017-0028

Demonstrates that changes in pink salmon migration time were caused by directional selection against the late-migrating phenotype during the oceanic phase of the salmonid life cycle, and that the selective event appears to be higher ocean temperatures.

Ohlberger, J., E. J. Ward, R. E. Brenner, M. E. Hunsicker, S. B. Haught, D. Finnoff, M. A. Litzow, T. Schwoerer, G. T. Ruggerone, and C. Hauri. 2021. Non-stationary and interactive effects of climate and competition on pink salmon productivity. Global Change Biology 28(6):2026-2040. https://doi.org/10.1111/gcb.16049

Investigates the joint effects of changes in ocean conditions and competition on the productivity of wild pink salmon.

Taylor, S. G. 2008. Climate warming causes phenological shift in pink salmon, *Oncorhynchus gorbuscha*, behavior at Auke Creek, Alaska. Global Change Biology 14(2):229-235. https://doi.org/10.1111/j.1365-2486.2007.01494.x

Demonstrates how warming waters cause earlier run timing of pink salmon in Auke Creek, Alaska.

Chum (Oncorhynchus keta)

Debertin, A. J., J. R. Irvine, C. A. Holt, G. Oka, and M. Trudel. 2017. Marine growth patterns of southern British Columbia chum salmon explained by interactions between density-dependent competition and changing climate. Canadian Journal of Fisheries and Aquatic Sciences 74(7):1077-1087. https://doi.org/10.1139/cjfas-2016-0265

Evaluates the effects of competition, oceanographic drivers, and climate change on chum salmon growth while accounting for individual heterogeneity.

Dunmall, K. M., D. G. McNicholl, C. E. Zimmerman, S. E. Gilk-Baumer, S. Burril, and V. R. von Biela. 2022. First juvenile chum salmon confirms successful reproduction for Pacific Salmon in the North American arctic. Canadian Journal of Fisheries and Aquatic Sciences 79(5):703–707. https://doi.org/10.1139/cjfas-2022-0006

Examines changes in chum salmon distributional extent into the North American arctic, to clarify the status of Pacific salmon as a potentially emerging fishery in the arctic.

Farley Jr, E., E. Yasumiishi, J. Murphy, W. Strasburger, F. Sewall, K. Howard, S. Garcia, and J. Moss. 2024. Critical periods in the marine life history of juvenile western Alaska chum salmon in a changing climate. Marine Ecology Progress Series 726:149–160. https://doi.org/10.3354/meps14491

Reports on time-series observations from 2003-2019 of sea surface temperatures and juvenile chum salmon size, diet, energy density, and relative abundance.

Weinheimer, J., J. H. Anderson, M. Downen, M. Zimmerman, and T. Johnson, T. 2017. Monitoring climate impacts: Survival and migration timing of summer chum salmon in Salmon Creek, Washington. Transactions of the American Fisheries Society 146(5):983-995. https://doi.org/10.1080/00028487.2017.1321580

Investigates how flow and incubation temperatures influenced juvenile survival and timing of chum salmon in Salmon Creek between 2008 and 2016.