

Cold Water Refugia in Western North American Rivers

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Bagley, A. M. 2019. Evaluating temperature buffering capacity of floodplain side channels to promote refugia for salmonids in the Stillaguamish River basin. Master's Thesis. University of Washington, Seattle, Washington. <http://hdl.handle.net/1773/44348>

Identifies variations in stream temperature, dissolved oxygen, stream type, cover type, and salmonid use of mainstem, side channel, and tributary habitats between five areas and 13 reaches within the Stillaguamish River basin.

Barrett, H. S., and J. B. Armstrong. 2022. Move, migrate, or tolerate: quantifying three tactics for cold-water fish coping with warm summers in a large river. *Ecosphere* 13(6):e4095. <https://doi.org/10.1002/ecs2.4095>

Reports on the use of temperature transmitting radio-tags to track coastal cutthroat trout habitat use across 100 km of the Willamette River to assess how fluvial life histories cope with summer temperatures in mainstem rivers.

Barrett, H., S. Gregory, and J. Armstrong. 2024. Evidence of a temperature–oxygen squeeze within floodplain thermal refuge habitats. *Freshwater Biology* 69(8):1118–1130. <https://doi.org/10.1111/fwb.14294>

Measures temperature and oxygen profiles in six cold-water alcoves on the Willamette River floodplain to characterize potential trade-offs in temperature and oxygen for coastal cutthroat trout.

Benda, S. E., G. P. Naughton, C. C. Caudill, M. L. Kent, and C. B. Schreck. 2015. Cool, pathogen-free refuge lowers pathogen-associated prespawn mortality of Willamette River Chinook salmon. *Transactions of the American Fisheries Society* 144(6):1159–1172. <https://doi.org/10.1080/00028487.2015.1073621>

Determines whether holding fish in constant temperature, pathogen-free conditions prior to spawning increased survival through spawning in 2010 through 2012 using Chinook salmon caught in the lower Willamette River.

Berman, C. H., and T. P. Quinn. 1991. Behavioural thermoregulation and homing by spring Chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), in the Yakima River. *Journal of Fish Biology* 39(3):301–312. <https://doi.org/10.1111/j.1095-8649.1991.tb04364.x>

Studies the patterns of behavioral thermoregulation, habitat preference and movement of 19 adult spring Chinook salmon in the Yakima River.

Bilski R. L., J. M. Wheaton, and J. E. Merz. 2022. Effects of in-channel structure on Chinook salmon spawning habitat and embryo production. *Water* 14(1):83. <https://doi.org/10.3390/w14010083>

Quantifies in-channel structure effects on local hydraulics and hyporheic flow and provide a mechanistic link between these changes and the survival, development, and growth of Chinook salmon embryos.

Brewitt, K. S., and E. M. Danner. 2014. Spatio-temporal temperature variation influences juvenile steelhead (*Oncorhynchus mykiss*) use of thermal refuges. *Ecosphere* 5(7):1-26. <http://dx.doi.org/10.1890/ES14-00036.1>

Combines monitoring of environmental variables with measures of fish temperature (a proxy for refuge use) to quantify juvenile steelhead use of thermal refuges in the Klamath River.

Brewitt, K. S., E. M. Danner, and J. W. Moore. 2017. Hot eats and cool creeks: juvenile Pacific salmonids use mainstem prey while in thermal refuges. *Canadian Journal of Fisheries and Aquatic Sciences* 74(10): 1588-1602. <https://doi.org/10.1139/cjfas-2016-0395>

Utilizes invertebrate drift sampling and fish density surveys to quantify potential in-refuge food limitation, temperature-sensitive radio-tagging studies to quantify thermal habitat use, and isotopic analyses to determine diet sources for juvenile Pacific salmonids using thermal refuges in California's Klamath River.

Campbell E.Y., R. W. Merritt, K. W. Cummins, and M. E. Benbow. 2012. Spatial and temporal variability of macroinvertebrates in spawning and non-spawning habitats during a salmon run in southeast Alaska. *PLoS ONE* 7(6):e39254. <https://doi.org/10.1371/journal.pone.0039254>

Explores how the spatial and temporal distribution of macroinvertebrates changed during a pink salmon spawning run and compared macroinvertebrates in spawning (riffle) and non-spawning (refugia) habitats in an Alaskan stream.

Chiaramonte, L. V., R. A. Ray, R. A. Corum, T. Soto, S. L. Hallett, and J. L. Bartholomew. 2016. Klamath River thermal refuge provides juvenile salmon reduced exposure to the parasite *Ceratonova shasta*. *Transactions of the American Fisheries Society* 145(4):810–820. <https://doi.org/10.1080/00028487.2016.1159612>

Examines how the use of a thermal refuge affects progression of *Ceratonova shasta*-induced enteronecrosis in juvenile Chinook salmon and Coho salmon in the Klamath River.

Cline, T. J., D. E. Schindler, T. E. Walsworth, D. W. French, and P. J. Lisi. 2020. Low snowpack reduces thermal response diversity among streams across a landscape. *Limnology and Oceanography Letters* 5(3):254-263. <https://doi.org/10.1002/lol2.10148>

Analyses how summer stream temperatures across a complex river basin in southwest Alaska show that loss of snowpack has disproportionate effects on water temperatures in streams that are cold under typical conditions, thereby homogenizing stream temperatures across the landscape during low snow conditions.

Cordoleani, F., C. C. Phillis, A. M. Sturrock, M. Willmes, G. Whitman, E. Holmes, P. K. Weber, C. Jeffres, and R. C. Johnson. 2024. Restoring freshwater habitat mosaics to promote resilience of vulnerable salmon populations. *Ecosphere* 15(3):e4803. <https://doi.org/10.1002/ecs2.4803>

Examines the impact of a large, connected mosaic of aquatic habitats across modified landscapes, such as cold water refugia and floodplains on the abundance and climate resilience of the three remaining core natural spring-run Chinook salmon populations in the California Central Valley.

Davis, M. J., I. Woo, and S. E. De La Cruz. 2025. Estuarine tidal cycles may preserve thermal refugia as global temperatures increase. *Estuaries and Coasts* 48(4). <https://doi.org/10.1007/s12237-025-01510-7>

Examines spatiotemporal patterns in estuarine water temperature and thermal refugia given current estimates of climactic change.

Deitch, M. J., M. Van Docto, M. Obedzinski, S. P. Nossaman, and A. Bartshire. 2018. Impact of multi-annual drought on streamflow and habitat in coastal California salmonid streams. *Hydrological Sciences Journal* 63(8):1219–1235. <https://doi.org/10.1080/02626667.2018.1492722>

Reports on changes in stream conditions and habitat availability for Coho salmon in North Central California coastal streams over three years of drought, 2012-2015.

Dominguez, L. G., S. P. Cramer, and S. Duery. 2010. Temperature characteristics of Herman Creek Cove and its function as a cool-water refuge for adult salmon and steelhead in the Columbia River. Report to Nestlé Water North America. https://www.researchgate.net/publication/264761201_TEMPERATURE_CHARACTERISTICS_OF_HERMAN_CREEK_COVE_AND_ITS_FUNCTION_AS_A_COOL-WATER_REFUGE_FOR_ADULT_SALMON_AND_STEELHEAD_IN_THE_COLUMBIA_RIVER

Aims to determine the temperatures and spatial extent of the cool-water plume from Herman Creek as it enters the Columbia River during peak use by adult steelhead and Chinook salmon.

Dzara, J. R., B. T. Neilson, and S. E. Null. 2019. Quantifying thermal refugia connectivity by combining temperature modeling, distributed temperature sensing, and thermal infrared imaging. *Hydrology and Earth System Sciences* 23(7):2965–2982. <https://doi.org/10.5194/hess-23-2965-2019>

Utilizes distributed temperature sensing to observe small-scale stream temperature variability, measured as a temperature range through space and time, within two 400 m reaches in summer 2015 in Nevada's East Walker and mainstem Walker rivers.

Ebersole, J. L. 1994. Stream habitat classification and restoration in the Blue Mountains of northeast Oregon. Master's Thesis. Oregon State University, Corvallis, Oregon. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/08612r02r

Describes potential habitat refugia for aquatic organisms in the Joseph Creek basin in the Blue Mountains of northeast Oregon utilizing four key steps: identification of the historic patterns of habitat development; protection of the developmental diversity that remains; local application of specific knowledge about suppressive factors; classification of sensitive, critical or refugium habitats; release of anthropogenic suppression; and monitoring of biotic response to habitat change.

Ebersole, J. L. Heterogeneous thermal habitat for northeast Oregon stream fishes. Doctoral Dissertation. Oregon State University, Corvallis, Oregon.

https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/zg64tq270

Focuses on heterogeneity in stream water temperatures as influenced by local influx of cooler subsurface waters, using field thermal probes and recording thermistors to identify cold water patches potentially serving as thermal refugia for cold water fishes.

Ebersole, J. L., W. J. Liss, and C. A. Frissell. 2001. Relationship between stream temperature, thermal refugia and rainbow trout *Oncorhynchus mykiss* abundance in arid-land streams in the northwestern United States. *Ecology of Freshwater Fish* 10(1):1-10.

<https://doi.org/10.1034/j.1600-0633.2001.100101.x>

Assesses the abundance and utilization of thermal refugia by Rainbow trout (*Oncorhynchus mykiss*) within 12 northeast Oregon stream reaches was inversely correlated with mean ambient maximum stream temperatures.

Ebersole, J. L., W. J. Liss, and C. A. Frissell. 2003. Thermal heterogeneity, stream channel morphology, and salmonid abundance in northeastern Oregon streams. *Canadian Journal of Fisheries and Aquatic Sciences*. 60(10):1266-1280. <https://doi.org/10.1139/f03-107>

Assesses the relationship between heterogeneity in stream water temperatures created by local influx of cooler subsurface waters into geomorphically complex stream channels and increased abundance of rainbow trout and Chinook salmon in northeastern Oregon.

Ebersole, J. L., W. J. Liss, and C. A. Frissell. 2003. Cold water patches in warm streams: physicochemical characteristics and the influence of shading. *Journal of the American Water Resources Association* 39(2):355-368. <https://doi.org/10.1111/j.1752-1688.2003.tb04390.x>

Focuses on reach scale heterogeneity in water temperatures as influenced by local influx of cooler subsurface waters within alluvial valleys of the Grande Ronde basin in northeastern Oregon.

Ebersole, J. L., R. M. Quiñones, S. Clements, and B. H. Letcher. 2020. Managing climate refugia for freshwater fishes under an expanding human footprint. *Frontiers in Ecology and the Environment* 18(5): 271-280. <https://doi.org/10.1002/fee.2206>

Evaluates recent climate-refugia management associated with water use and landscape modification by comparing efforts in the US states of Oregon and Massachusetts to propose tools and principles which can be applied more broadly.

Ebersole, J. L., P. J. Wigington, Jr., S. G. Leibowitz, R. L. Comeleo, and J. Van Sickle. 2015. Predicting the occurrence of cold-water patches at intermittent and ephemeral tributary confluences with warm rivers. *Freshwater Science* 34(1):111-124. <https://doi.org/10.1086/678127>

Uses random forest analysis to model occurrence of cold-water patches at tributary confluences as a function of watershed and climatic characteristics and tested predictive performance with a 2-y data set of 68 tributary–mainstem confluence zones in northeastern Oregon.

Everett, R. A., and G. M. Ruiz. 1993. Coarse woody debris as a refuge from predation in aquatic communities. *Oecologia* 93(4):475–486. <https://doi.org/10.1007/BF00328954>

Experimental demonstration of how coarse woody debris can provide refugia in aquatic environments.

Fausch, K. D. 1993. Experimental analysis of microhabitat selection by juvenile steelhead (*Oncorhynchus mykiss*) and coho salmon (*O. kisutch*) in a British Columbia stream. *Canadian Journal of Fisheries and Aquatic Sciences*. 50(6):1198-1207. <https://doi.org/10.1139/f93-136>

Tests the relative importance of velocity refuge, visual isolation, and overhead cover to microhabitat selection by steelhead (*Oncorhynchus mykiss*) parr and age-0 coho salmon.

Forney, W. M., C. E. Soulard, and C. C. Chickadel. 2013. Salmonids, stream temperatures, and solar loading--modeling the shade provided to the Klamath River by vegetation and geomorphology. USGS Scientific Investigations Report 2013-5022, Reston, Virginia. <https://doi.org/10.3133/sir20135022>

Develops a conceptual model and methodological techniques to quantify the change in solar insolation load to the Klamath River caused by riparian and floodplain vegetation, the morphology of the river, and the orientation and topographic characteristics of its watersheds.

Frissell, C. A. 1992. Cumulative effects of land use on salmon habitat in southwest Oregon coastal streams. Doctoral dissertation. Oregon State University, Corvallis, Oregon. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/dn39x468d

Defines ten classes of fluvial and lacustrine habitats at the scale of valley segments based on geomorphic, geologic criteria and land use in Southern Oregon streams.

Fullerton, A. H., C. E. Torgersen, J. J. Lawler, E. A. Steel, J. L. Ebersole, and S. Y. Lee. 2017. Longitudinal thermal heterogeneity in rivers and refugia for coldwater species: effects of scale and climate change. *Aquatic Sciences* 80:3. <https://doi.org/10.1007/s00027-017-0557-9>

Uses high-resolution remotely sensed water temperature data to characterize summer thermal heterogeneity patterns for 11,308 km of second–seventh-order rivers throughout the Pacific Northwest and northern California.

Gendaszek, A. 2014. Hydrogeologic framework and groundwater/surface-water interactions of the South Fork Nooksack River Basin, northwestern Washington: U.S. Geological Survey Scientific Investigations Report 2014–5221. <http://dx.doi.org/10.3133/sir20145221>

Describes a hydrogeologic framework of the South Fork (SF) Nooksack River Basin in northwestern Washington and characterizes the groundwater-flow system and its interaction with surface-water features.

Gibson, D. J., H. E. Kuder, and S. B. Fey. 2026. What environmental features give rise to thermal refuges? A systematic review. *Oikos* 2026(1):e11582. <https://doi.org/10.1002/oik.11582>

Systematic literature review focused on contemporary, cold thermal refuges to 1) assess how commonly studies have identified determinants of thermal refuges, 2) determine patterns in the definitions, focal organisms, biomes, and geographic regions of thermal refuge research, and 3) identify the major features that promote cold thermal refuges across ecosystems.

Gombert, C. E., S. T. Lancaster, G. E. Grant, and R. L. Flitcroft. 2022. Novel dimensionless index for physically based assessment of thermal refugia characterizes off-channel habitat on gravel bed river. *Journal of the American Water Resources Association* 59(4):615–634. <https://doi.org/10.1111/1752-1688.13096>

Presents a dimensionless index for assessment of thermal refugia on the upper Willamette River.

Goniaea, T. M., M. L. Keefer, T. C. Bjornn, C. A. Peery, D. H. Bennett, and L. C. Stuehrenberg. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook salmon in response to

high Columbia River water temperatures. *Transactions of the American Fisheries Society* 135(2):408-419. <https://doi.org/10.1577/T04-113.1>

Studies the relationships between lower Columbia River water temperatures and migration rates, temporary tributary use, and run timing of adult fall Chinook salmon by combining historical counts at dams and radiotelemetry data.

Greer G., S. Carlson, and S. Thompson. 2019. Evaluating definitions of salmonid thermal refugia using in situ measurements in the Eel River, Northern California. *Ecohydrology*. 12(5):e2101. <https://doi.org/10.1002/eco.2101>

Uses high resolution thermal data from two cold-water zones created at the confluence of tributaries with a warm main channel of the South Fork Eel River in Northern California to demonstrate that the characteristics of cold zones identified as thermal microrefugia are not robust to the choice of microrefugium definition.

Hess, M. A., J. E. Hess, A. P. Matala, R. A. French, C. A. Steele, J. C. Lovtang, and S. R. Narum. 2016. Migrating adult steelhead utilize a thermal refuge during summer periods with high water temperatures. *ICES Journal of Marine Science* 73(10):2616–2624. <https://doi.org/10.1093/icesjms/fsw120>

Combines parentage-based tagging with mixed stock analyses to test whether steelhead use a non-natal tributary as a thermal refuge and if this migratory behavior is associated with stock-specific run-timing.

Howell, P. J., J. B. Dunham, and P. M. Sankovich. 2010. Relationships between water temperatures and upstream migration, cold water refuge use, and spawning of adult bull trout from the Lostine River, Oregon, USA. *Ecology of Freshwater Fish* 19(1):96–106. <https://doi.org/10.1111/j.1600-0633.2009.00393.x>

Employs a combination of archival temperature tags, radio tags, and thermographs to describe spatial and temporal patterns of thermal habitat use by migratory adult bull trout that spawn in the Lostine River.

Isaak, D. J., M. K. Young, C. H. Luce, S. W. Hostetler, S. J. Wenger, E. E. Peterson, J. M. Ver Hoef, M. C. Groce, D. L. Horan, and D. E. Nagel. 2016. Slow climate velocities of mountain streams portend their role as refugia for cold-water biodiversity. *Proceedings of the National Academy of Sciences* 113(16):4374–4379. <https://doi.org/10.1073/pnas.1522429113>

Uses large stream temperature and biological databases to show that thermal habitat in mountain streams is highly resistant to temperature increases and that many populations of cold-water species exist where they are well-buffered from climate change.

Isaak, D. J., M. K. Young, D. E. Nagel, D. L. Horan, and M. C. Groce. 2015. The cold-water climate shield: Delineating refugia for preserving salmonid fishes through the 21st century. *Global Change Biology* 21(7):2540–2553. <https://doi.org/10.1111/gcb.12879>

Couples crowd-sourced biological datasets with high-resolution stream temperature scenarios to delineate network refugia across >250 000 stream km in the Northern Rocky Mountains for two bull trout and cutthroat trout.

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 and opportunities.

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.

Lichatowich, J. A., G. R. Rahr, S. M. Whidden, and C. R. Steward. 2000. Sanctuaries for Pacific salmon. Pages 675-686 *in* E. E. Knudsen and D. McDonald, editors. *Sustainable fisheries management: Pacific salmon*. CRC Press, Boca Raton, Florida.

Traces the history of the fish refuge concept over the last century, explores its application to current salmonid recovery efforts, and examines the challenges of implementation.

Ligon, F. K., R. J. Nakamoto, B. C. Harvey, and P. F. Baker. 2016. Use of streambed substrate as refuge by steelhead or rainbow trout *Oncorhynchus mykiss* during simulated freshets. *Journal of Fish Biology* 88(4):1475-1485. <https://doi.org/10.1111/jfb.12925>

Employs a flume to estimate the carrying capacity of streambed substrates for juvenile steelhead or rainbow trout seeking refuge from simulated freshets.

Magoulick, D. D., and R. M. Kobza. 2003. The role of refugia for fishes during drought: A review and synthesis. *Freshwater Biology* 48(7):1186–1198. <https://doi.org/10.1046/j.1365-2427.2003.01089.x>

Reviews available literature on aquatic refugia for fishes to synthesize current knowledge and provide suggestions for needed research.

Marcoe, K., C. Collins, C. Corbett, M. Burke, M. Schwartz, P. Kolp, and A. Hanson. 2018. Lower Columbia River thermal refuge study, 2015–2018. Report to U.S. Environmental Protection Agency. https://www.estuarypartnership.org/sites/default/files/resource_files/LCEP%20Lower%20Columbia%20Thermal%20Refuge%20Report%20FINAL_small.pdf

Describes a multi-year, three phase study to document the extent and quality of cold-water inputs to the lower Columbia River which are, or potentially could be, utilized by summer migrating salmonid species for thermal respite from warm Columbia River mainstem water.

Mathes, M.T., S. G. Hinch, S. J. Cooke, G.T. Crossin, D. A. Patterson, A.G. Lotto, and A. P. Farrell. 2010. Effect of water temperature, timing, physiological condition, and lake thermal refugia on migrating adult Weaver Creek sockeye salmon (*Oncorhynchus nerka*). *Canadian Journal of Fisheries and Aquatic Sciences*. 67(1):70-84. <https://doi.org/10.1139/F09-158>

Combines physiological biopsy and positional telemetry to examine survival to reach spawning grounds in relation to water temperature, timing, physiological condition, and holding location in adult migrating sockeye salmon.

Matsubu, W., C. A. Simenstad, and G. E. Horton. 2017. Juvenile steelhead locate coldwater refugia in an intermittently closed estuary. *Transactions of the American Fisheries Society* 146(4):680–695. <https://doi.org/10.1080/00028487.2017.1301993>

Uses acoustic telemetry to infer water quality exposure by linking the temperature of individually tagged fish with water quality profiles collected in close proximity.

McIntosh, B. A., D. M. Price, C. E. Torgersen, and H. W. Li. 1994. Distribution, habitat utilization, movement patterns, and the use of thermal refugia by spring Chinook in the Grande Ronde, Imnaha, and John Day basins. Progress Report to Bonneville Power Administration, Project 88-108. <https://docs.cbfwl.org/biblio42645.pdf>

Examines factors that affect habitat quality of holding areas for adult spring Chinook salmon in eastern Oregon, especially cold water refugia.

Mejia, F. H., V. Ouellet, M. A. Briggs, S. M. Carlson, R. Casas-Mulet, M. Chapman, M. J. Collins, S. J. Dugdale, J. L. Ebersole, D. M. Frechette, A. H. Fullerton, C.-A. Gillis, Z. C. Johnson, C. Kelleher, B. L. Kurylyk, R. Lave, B. H. Letcher, K. M. Myrvold, T.-L. Nadeau, H. Neville, H. Piégay, K. A. Smith, D. Tonolla, C. E. Torgersen. Closing the gap between science and management of cold-water refuges in rivers and streams. *Global Change Biology* 29(19):5482-5508. <https://doi.org/10.1111/gcb.16844>

Reviews current understanding of cold-water refuges, identify gaps between science and management, and evaluate policies aimed at protecting thermally sensitive species.

Mejia, F. H., C. E. Torgersen, E. K. Berntsen, J. R. Maroney, J. M. Connor, A. H. Fullerton, J. L. Ebersole, and M. S. Lorang. 2020. Longitudinal, lateral, vertical, and temporal thermal heterogeneity in a large impounded river: implications for cold-water refuges. *Remote Sensing* 12(9):1386. <https://doi.org/10.3390/rs12091386>

Studies the median water temperature and probability of occurrence of cool-water areas using generalized additive models at reach and subcatchment scales, and we evaluates potential cold-water refuge occurrence in relation to these patterns.

Moore, J. W., M. E. Ulaski, K. L. Wilson, T. G. Martin, S. D. Kuiper, S. J. Peacock, D. C. Braun, S. M. Naman, K. J. Pitman, A. J. Reid, J. S. Rosenfeld, N. C. Sainsbury, S. M. Wilson, and B. J. Zdasiuk. 2025a. A safe operating space for salmon watersheds under rapid climate change. *Fish and Fisheries* 26(6):1213–1228. <https://doi.org/10.1111/faf.70027>

Offers a synthetic perspective on the downscaled application of the safe operating space concept to inform the stewardship of watersheds in this time of rapid climate change, with particular focus on watersheds that support coldwater migratory fishes such as Pacific salmon.

Moravek, J. A., T. Soto, J. S. Brashares, and A. Ruhí. 2024. Restored off-channel pond habitats create thermal regime diversity and refuges within a Mediterranean-climate watershed. *Restoration Ecology* 32(4):e14110. <https://doi.org/10.1111/rec.14110>

Applies multivariate autoregressive time series models of fine-scale temperature data from ponds, tributaries, and the mainstem Klamath River to assess how off-channel ponds contributed to thermal regime diversity and thermal refuge habitat in the Klamath riverscape.

Naman, S. W. 2005. Thermal refugia use by salmonids in response to an experimental release of water on the Trinity River, California 2004. Yurok Tribal Fisheries Program Technical Memorandum, Hoopa, California. <https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=54aa427007d876a5ce4c200bff115be94e9f412c>

Investigates fish use of thermal refugia on the Trinity River as it relates to river flow, water temperature and time, and documents the effects of a Proactive Flow Release of water from Lewiston Dam on the use of two thermal refugia by fish.

Naughton, G. P., M. L. Keefer, T. S. Clabough, M. J. Knoff, T. J. Blubaugh, C. Sharpe, and C. C. Caudill. 2018. Reservoir provides cool-water refuge for adult Chinook salmon in a trap-and-haul reintroduction program. *Marine and Freshwater Research* 69(12):1995. <https://doi.org/10.1071/MF18124>

Uses biotelemetry to assess the potential benefits of releasing transported adult Chinook salmon into a cold-water reservoir v. a relatively warm-water tributary before spawning.

Nielsen, J. L., T. E. Lisle, and V. Ozaki. 1994. Thermally stratified pools and their use by steelhead in Northern California streams. *Transactions of the American Fisheries Society* 123(4) 613-626. [https://doi.org/10.1577/1548-8659\(1994\)123%3C0613:TSPATU%3E2.3.CO;2](https://doi.org/10.1577/1548-8659(1994)123%3C0613:TSPATU%3E2.3.CO;2)

Studies the use of thermally stratified pools as refuges for young-of-the-year, yearling, and adult steelhead in marginal river habitats where stream temperatures reach upper incipient lethal levels.

Oregon Department of Environmental Quality, Division of Water Quality Standards and Assessment. 2020. Lower Willamette River cold-water refuge narrative criterion implementation study. Report to National Marine Fisheries Service, Portland, Oregon. <https://www.oregon.gov/deq/wq/Documents/lowwillCWRreportD.pdf>

Discusses a cold-water refuge study for the lower 50 miles of the Willamette River in order to interpret the narrative criterion and evaluate whether there is sufficient cold-water refuge and identify what regulatory or voluntary actions could be taken, should DEQ find that the narrative is not being met.

Railsback, S. F., and B. C. Harvey. 2023. Can thermal refuges save salmonids? Simulation of cold-pool benefits to salmonid populations. *Transactions of the American Fisheries Society* 152(4):383–396. <https://doi.org/10.1002/tafs.10411>

Addresses how refuge availability and characteristics affect population abundance and persistence under warming.

Reid, I. S. 2007. Influence of motorboat use on thermal refuges and implications to salmonid physiology in the lower Rogue River, Oregon. *North American Journal of Fisheries Management* 27(4):1162–1173. <https://doi.org/10.1577/M06-061.1>

Uses maps and thermal imagery to locate refuges, and continuous temperature monitors, behavioral observations, and bioenergetics models (including Q10) to quantify effects of motorboat use on salmonids in the lower Rogue River, Oregon.

Ritter, T. D., A. V. Zale, G. Grisak, and M. J. Lance. 2020. Groundwater upwelling regulates thermal hydrodynamics and salmonid movements during high-temperature events at a montane tributary confluence. *Transactions of the American Fisheries Society* 149(5):600-619. <https://doi.org/10.1002/tafs.10259>

Uses integrated networks of temperature loggers, PIT tag antenna stations, and in situ temperature mapping to investigate the thermal hydrodynamics and associated movements of PIT-tagged salmonids at the confluence of a major, unaltered coldwater tributary of the Smith River.

Rojas, I. M., M. K. Jennings, E. Conlisk, A. D. Syphard, J. Mikesell, A. M. Kinoshita, K. West, D. Stow, E. Storey, M. E. De Guzman, D. Foote, A. Warneke, A. Pairis, S. Ryan, L. E. Flint, A. L. Flint, and R. L. Lewison. 2021. A landscape-scale framework to identify refugia from multiple stressors. *Conservation Biology* 36(1):e13834. <https://doi.org/10.1111/cobi.13834>

Devises a new conceptual approach, the domains of refugia, for assessing refugial capacity that identifies areas where exposure to multiple stressors is low.

Sedell, J. R., G. H. Reeves, F. R. Hauer, J. A. Stanford, and C. P. Hawkins. 1990. Role of refugia in recovery from disturbances: modern fragmented and disconnected river systems. *Environmental Management* 14(5):711–724. <https://doi.org/10.1007/BF02394720>

Proposes a spatial hierarchy of different physical components of a drainage network to provide a context for different refugia.

Sheibley, R. W., M. Appel, R. Little, and J. R. Foreman. 2024. Extent and duration of cold-water areas associated with side channels and tributaries of the lower Yakima River, Washington, September 2018–20. U.S. Geological Survey Scientific Investigations Report 2023–5140. <https://doi.org/10.3133/sir20235140>

Provides new information on spatial and temporal dynamics of cold-water areas on the lower Yakima River, which might provide cold-water habitat for migrating fishes in the future.

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 simulation model to evaluate the buffering potential of cold-water thermal refuges for anadromous salmon and trout migrating upstream through a warm river corridor.

Snyder, M. N., N. H. Schumaker, J. B. Dunham, M. L. Keefer, P. Leinenbach, A. Brookes, J. Palmer, J. Wu, D. Keenan, and J. L. Ebersole. 2020. Assessing contributions of cold-water refuges to reproductive migration corridor conditions for adult salmon and steelhead trout in the Columbia River, USA. *Journal of Ecohydraulics* 7(2):111–123. <https://doi.org/10.1080/24705357.2020.1855086>

Describes a spatially explicit simulation model that integrates complex individual behaviors of fall Chinook salmon and summer steelhead during migration, responds to variable habitat conditions over a large extent of the Columbia River, and links migration corridor conditions to fish condition outcomes.

Soto, P. A., and D. A. Reid. 2026. Characterizing stream temperature to support habitat restoration – a review of methods and best practices. Department of Fisheries and Oceans Canada, Pacific Region. Vancouver, British Columbia. <https://doi.org/10.60825/dzqf-mt21>

Provides an overview of temperature monitoring approaches organized into three broad categories - spatial, temporal and hybrid (a combination of both).

Stevens, B. S., and J. M. DuPont. 2011. Summer use of side-channel thermal refugia by salmonids in the North Fork Coeur d'Alene River, Idaho. *North American Journal of Fisheries Management* 31(4):683–692. <https://doi.org/10.1080/02755947.2011.611037>

Reports on observed aggregations of westslope cutthroat trout, mountain whitefish, and rainbow trout moving into cold side channels in the North Fork Coeur d'Alene River during the summer of 2007.

Strange, J. S. 2011. Salmonid use of thermal refuges in the Klamath River: 2010 annual monitoring study. Yurok Tribal Fisheries Program, Hoopa, California. https://www.waterboards.ca.gov/waterrights/water_issues/programs/hearings/marblemountain/exhibits/nat_marine_fs_exhibits/nmfs_44.pdf

Focuses on the role of thermal refuges to sustain salmonid populations, both during discrete time periods and locations in addition to whole river systems over longer time scales.

Sullivan, C. J., J. C. Vokoun, A. M. Helton, M. A. Briggs, and B. L. Kurylyk. 2021. An ecohydrological typology for thermal refuges in streams and rivers. *Ecohydrology* 14(5):e2295. <https://doi.org/10.1002/eco.2295>

Contends that lexical differences resulting from divergent scholarly training hinder holistic understanding of thermal refuges and that existing studies would benefit from a structured framework for thermal refuge conceptualization.

Sutton, R. J., M. L. Deas, S. K. Tanaka, T. Soto, and R. A. Corum. 2007. Salmonid observations at a Klamath River thermal refuge under various hydrological and meteorological conditions. *River Research Applications* 23(7):775-785. <https://doi.org/10.1002/rra.1026>

Studies the Beaver Creek confluence with the main-stem Klamath River to assess salmonid use in a thermal mixing zone under various summer hydrological and meteorological conditions.

Sutton, R., and T. Soto. 2010. Juvenile coho salmon behavioural characteristics in Klamath river summer thermal refugia. *River Research and Applications* 28(3):338–346. <https://doi.org/10.1002/rra.1459>

Summarizes results from coho salmon thermal refugia studies conducted 2006-2010 in the Klamath River.

Torgersen, C., J. Ebersole, and D. Keenan. Primer for identifying cold-water refuges to protect and restore thermal diversity in riverine landscapes. Environmental Protection Agency EPA 910-C-12-001, Washington, D. C.

<https://nepis.epa.gov/Exe/ZyPDF.cgi/P100E45N.PDF?Dockey=P100E45N.PDF>

Provides a summary with easily referenced information and illustrations on the scientific advances and management applications of research on cold-water refuges and can be used as a 'roadmap' for identifying cold-water refuges and learning more about processes that create thermal diversity in riverine landscapes.

Torgersen, C. E., D. M. Price, H. W. Li, and B. A. McIntosh. 1999. Multiscale thermal refugia and stream habitat associations of Chinook salmon in northeastern Oregon. *Ecological Applications* 9(1):301–319. [https://doi.org/10.1890/1051-0761\(1999\)009\[0301:MTRASH\]2.0.CO;2](https://doi.org/10.1890/1051-0761(1999)009[0301:MTRASH]2.0.CO;2)

Quantifies distribution and behavior of adult spring Chinook salmon related to patterns of stream temperature and physical habitat at channel-unit, reach-, and section-level spatial scales in a wilderness stream and a disturbed stream in the John Day River basin.

U. S. Environmental Protection Agency, Region 10. 2021. Columbia River cold water refuges plan. EPA-910-R-21-001. <https://www.epa.gov/columbiariver/columbia-river-cold-water-refuges-plan>

Describes available cold water refuges (CWR) in the Lower Columbia River, characterizes how salmon and steelhead use CWR, assesses the amount of CWR needed to attain Oregon's Clean Water Act CWR narrative water quality standard, identifies actions to protect and restore CWR, and recommends future CWR studies.

Van Kirk, R. W., B. A. Contor, C. N. Morrisett, S. E. Null, and A. S. Loibman. 2020. Potential for managed aquifer recharge to enhance fish habitat in a regulated river. *Water* 12(3):673.

<https://doi.org/10.3390/w12030673>

Uses an existing aquifer model, water temperature data, and analysis of water administration to assess potential benefits of managed aquifer recharge to cold-water fisheries in the Snake River.

Wang T., S. J. Kelson, G. Greer, S. E. Thompson, 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>

Quantifies use of two tributary confluence plumes by juvenile steelhead throughout the summer, including how trout positioned themselves in relation to temperature within confluence plumes.

Walters, A. W., N. G. Clancy, T. P. Archdeacon, S. Yu, J. S. Rogosch, and E. A. Rieger. 2024. Refuge identification as a climate adaptation strategy to promote fish persistence during drought. *Fish and Fisheries* 25(6):997–1008. <https://doi.org/10.1111/faf.12860>

Synthesizes literature on drought refuges and proposes a framework to identify and manage functional refuges that incorporate species physiological tolerances, behaviors and life-history strategies.

Washington Department of Fish and Wildlife. 2022. Fishery management in Columbia River cold water refuge for salmonids. Washington Department of Fish and Wildlife, Olympia. <https://wdfw.wa.gov/sites/default/files/publications/02336/wdfw02336.pdf>

Provides recommendations for fishery management within tributary cold-water refuges throughout the Columbia River.

Willms, T. A. 2024. Identification and characterization of stream thermal refuges and associated habitat use by juvenile pacific salmon (*Oncorhynchus SPP.*) and steelhead (*O. mykiss*). Doctoral dissertation. University of Northern British Columbia, Prince George, British Columbia. <https://doi.org/10.24124/2024/59567>

Employs a three-phased approach to identify and classify thermal refuges in streams, characterize their environmental conditions during critical rearing periods, and monitor diel migration patterns of juvenile salmonids in response to environmental covariates.