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Dataset for the Incorporation of Climate Change into a Multiple Stressor Risk Assessment for the Chinook Salmon (Oncorhynchus tshawytscha) Population in the Yakima River, Washington USA

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Supplemental Information

Table S1. Descriptions and derivation of conditional probability tables (CPTs). CPTs were generated using equations, case learning, and pegging the corners, defined below.

Equations, such as derived from regressions on exposure-response data, can be used to derive conditional probability tables. The use of equations in Netica is described here (https://www.norsys.com/WebHelp/NETICA/X_Equations.htm).

Case learning: Case learning is a machine learning tool used to derive relationships between variables. In the BN-RRM we are using parameter case learning since the causal relationships have already been identified. Details on the methodology in Netica can be found at (https://www.norsys.com/WebHelp/NETICA/X_Learning_from_Cases.htm).

Pegging the corners. When an interaction is indicated and data do not exist to quantify the interaction a 'pegging the corners" technique can be employed (Marcot et al. 2006, Marcot 2017). Pegging the corners sets the extreme cases to the maximum or minimum response possible and then back interpolates the other entries.

Node	Description	Rank Descriptions	Description	Data Source
Spray scenario	Describes the additional amounts of insecticide added given the scenario	None Decrease Present Low Medium High	None-no spraying of these pesticides in the future, Decrease-60 percent decrease in present concentrations, Present-pesticide concentrations as described in Mitchel et al 2021, Low-20 percent increase in pesticide concentrations, Medium-60 percent increase in pesticide concentrations, High-100 increase in pesticide concentrations	Current pesticide concentrations are derived from Ecology 2016a, Tuttle 2014. Distribution is derived from downloaded data for each of the watersheds.
River and Region (Mitchell et al 2021)	Lower Yakima, Upper Yakima, Naches	NA	Study areas	Ecology 2016a, 2016b; Tuttle 2014; WAC 2011a, 2011b. (Landis et al 2020, Mitchell et al 2021)
Season (Landis et al 2020, Mitchell et al 2021)	Time of year	Spring (months 3-< 6), summer (months 6-< 9), fall (months 9-< 12), winter (months 12-< 3)	Captures seasonal variability in water temperature, DO and chlorpyrifos concentrations.	Ecology 2016a, 2016b; Tuttle 2014; WAC 2011a, 2011b.

Water Quality (WQ) Scenario	This node specifies which water quality parameters to use from Ficklin et al (2013.	NA	Selection here populates the DO mod and the Temp mod nodes. When a scenario is selected the appropriate distribution populates each node.	Ficklin et al 2013 is the source of the temperature and DO distributions.
Malathion concentration (Landis et al 2020, Mitchell et al 2021)	Measured concentrations of malathion over a ten-year period in each of the river's major waterways.	0 to 2.6e-5 M, 2.6e-5 to 2.6e-4 M, 2.6e-4 to 5.4e-4 M, 5.4e-4 to 0.001 M, 0.001 to 0.005 M	Ranks based on molar concentrations of malathion. Molar concentrations are adapted from regulatory criteria for OPs (reported in µg/L)	Ecology 2016a, Tuttle 2014. Distribution is derived from downloaded data from each of the watershed. Then we calculated OP concentrations versus probability for each river and season.
Malathion concentration 2	Concentration of malathion by adding the spray scenario amount to that predicted from the River and Region node	0 to 2.6e-5 M, 2.6e-5 to 2.6e-4 M, 2.6e-4 to 5.4e-4 M, 5.4e-4 to 0.001 M, 0.001 to 0.005 M	Ranks based on molar concentrations as above. Derived from the addition of values from Spray Scenario and River and Region.	The percent increases were derived from Table 1.
Diazinon concentration (Landis et al 2020, Mitchell et al 2021)	Measured concentrations of diazinon over a ten-year period in each of the river's major waterways.	0 to 3.04e-5 M, 3.04e-6 to 3.04e-5 M, 3.04e-5 to 1.52e-4 M, 1.52e-4 to 0.001 M, 0.001 – 0.005 M	Ranks based on molar . concentrations of diazinon. Molar concentrations are adapted from regulatory criteria for OPs (reported in µg/L)	Ecology 2016a, Tuttle 2014. Distribution is derived from downloaded data from each of the watershed. Then we calculated OP concentrations versus probability for each river and season
Diazinon concentration 2	Concentration of malathion by adding the spray scenario amount to that predicted from the River and Region node	0 to 3.04e-5 M, 3.04e-6 to 3.04e-5 M, 3.04e-5 to 1.52e-4 M, 1.52e-4 to 0.001 M, 0.001 – 0.005 M	Ranks based on molar concentrations as above. Derived from the addition of values from Spray Scenario and River and Region.	The percent increases were derived from Table 1.
Water Temperature(Landis et al 2020, Mitchell et al 2021)	Measured water temperature over a ten-year period in each of the river's main waterways.	0 to 13, 13 to 16, 16 to 18, 18 to 25, >25 (°C)	Temperature ranges specific to salmonids based on Table 200 (1)(c) Aquatic Life Temperature Criteria in Fresh Water and survival data.	Ecology 2016b, WAC 2011a. Distribution is derived from downloaded data for each of the watersheds. We calculated WT value versus probability for each river and season.
Temp mod	Change of temperature as derived by the climate change model (Ficklin et al 2013)	-13 to-11, -11 to -9, -9 to -7, to -7 to -5, -5 to -3,-3 to -1, -1 to 1, 1 to 3, 5 to 5, 5 to 7, 7 to 9, 9 to 11, 1q to 13, 13 to 15 (°C)C)	Change in temperature as predicted by Ficklin et al 2013.	Ficklin et al 2013
Water Temperature 2	Describes the change in water temperature with climate change introduced.	0 to 13, 13 to 16, 16 to 18, 18 to 25, >25 (°C)	Distribution of temperature ranges as predicted by Ficklin et al 2013.	Derived from the Temperatures of Water Temp node to the Temp mod. Nodes.

Dissolved Oxygen (Landis et al 2020, Mitchell et al 2021)	Measured oxygen concentrations over a ten-year period in each of the river's main waterways.	0 to 3.5, 3.5 to 5, 5 to 6.5, 6.5 to 8, 8 to 9.5, 9.5 to 11, 11 to 15, 15 to 22.39 (mg dissolved oxygen/L)	Ranges specific to salmonids based on Table 200 (1)(d) Aquatic Life Temperature Criteria in Fresh Water and survival data. Distribution is based on downloaded data from each of the watersheds	Ecology 2016b, WAC 2011b. Distribution is derived from downloaded data from each of the watersheds calculate DO value versus probability for each river and season.
DO mod	Change of temperature as derived by the climate change model (Ficklin et al 2013)	1.6 to 1.8, 1.4 to 1.6, 1.2 to 1.4, 1 to 1.2, 0.8 to 1, 0.6 to 0.8, 0.4 to 0.6, 0.2 to 0.4, 0 to 0.2, -0.2 to 0, -0.4 to -0.2, -0.6 to -o.4, -0.8 to -0.6, -0.6 to -0.4, -0.8 to -0.6, -1 to -0.8, -1.2 to -1, -1.4 to -1.2,-1.6 to -1.4, -1.8 to -1.6, -2 to -1.8 (mg dissolved oxygen/L)	Amount of change in DO concentration with climate change introduced.	Ficklin et al 2013
Dissolved Oxygen 2	Describes the distribution in dissolved oxygen with predicted changes.	0 to 3.5, 3.5 to 5, 5 to 6.5, 6.5 to 8, 8 to 9.5, 9.5 to 11, 11 to 15, 15 to 22.39 (mg dissolved oxygen/L)	Resulting change in DO concentration with climate change introduced.	Ficklin et al 2013.
Simulation year (Landis et al 2020, Mitchell et al 2021)	Year of simulation results.	Years 1, 5, 10, 20, 50	The maximum model simulation year is 50.	Plots summarized by describing results for years 1, 5, 10, 20 and 50 from the metapopulation model simulations.
AChE activity (Landis et al 2020, Mitchell et al 2021)	AChE activity in salmonids exposed to OP concentrations dissolved in water.	0 to 25, 25 to 50, 50 to 75, 75 to 100, 100 to 125, 125 to 200 milli optical density (mOD) per minute per gram	This describes the relationship between the malathion and diazinon concentrations and the change in AChE activity as determined by curve fitting.	Laetz et al. 2009. Curve fitted from the dataset kindly supplied by NOAA via C. Laetz using the drc package in R.
Toxicological Effects-Percent Mortality (Landis et al 2020, Mitchell et al 2021)	Mortality due to AChE activity	0, 10, 20, 50, 90	AChE values that were 5-20% as published by Fulton and Key (2005) was linked to mortality	Coppage et al. 1975, Duangsawasdi 1977, Weiss 1961, Wheelock et al. 2005, Fulton and Key (2001).

Toxicological Effects- Change in Swimming rate (Landis et al 2020, Mitchell et al 2021)	Decreased AChE activity in salmonids exposed to OP concentrations dissolved in water. Change is swimming due to AChE activity	0 to 25, 25 to 50, 50 to 75, 75 to 100, 100 to 150, 150 to 250	AChE inhibition affects swimming,	Results based on Sandahl et al. 2005 with Coho salmon as the surrogate. Ranking is set as equal intervals up until 100%. >100% indicates a faster swimming speed. The exposure-response curve is based upon the dataset as kindly supplied by NOAA via C. Laetz using the drc package in R.
Toxicological Effects-Summing mortality and the change in swimming rate (Landis et al 2020, Mitchell et al 2021)	Summation of toxicological effects due to acute mortality and change in swimming rate.	None, 10, 20, 50, 90 percent change	Conditional probability table based on a "peg the corners" approach Marcot (2017).	The CPT was compiled using an extrapolation (peg the corners) approach for the Yes Mortality. The CPT was constructed using a peg the corners approach due to lack of data in the literature, with the highest (100%) probability of effect set at 270 (the summed maximum percent in each of the three nodes (90+90+90= 270)). to cause a 90% reduction in juvenile survival.
Water Quality Effects - Juvenile Salmonids (Mitchell et al 2021)	Effects specific to juvenile salmonid survivorship due to water quality in the Yakima.	0, 10, 20, 50, 90 percent	Combines the effects of DO and temperature.	Water quality effects was compiled using a case file based the Literature (Brett 1952, Carter 2005, 2008).
Water Quality Effects - Egg to emergence (Landis et al 2020, Mitchell et al 2021)	Effects specific to eggs and larval salmonids, specifically the decline in survivorship of eggs to hatch due to water quality effects.	0, 10, 20, 50, 90 percent	Combines the effects of DO and temperature.	This CPT was completed using the literature (our expert judgement).References to support current CPT include: Carter 2005, 2008. Geist et al. 2006; Jager 2011; McCullough 1999; McCullough et al. 2001; Richter and Kolmes 2005.
Juvenile % Reduction in Survival (Landis et al 2020, Mitchell et al 2021)	Reduction in juvenile salmonid survivorship due to all effects.	0, 10, 20, 50, 90 percent	Combines the ecological and toxicological pathways that affect juvenile survival.	A pegging the corners approach was used. The sum of each combination % 10, 20, 50, 90 was calculated. 90+90+90= 270 was the highest probability of risk and was calculated as 100% probability of 90% reduction.
Adult % Reduction in Survival (Landis et al 2020, Mitchell et al 2021)	Reduction in adult salmonid survivorship due to all effects.	0, 10, 20, 5 percent	Combines the ecological and toxicological pathways that affect adult survival.	This CPT was completed using the literature (our expert judgement) and case file learning. Carter 2005, 2008; Jager 2011;

				McCullough 1999, McCullough et al. 2001; Richter and Kolmes 2005; Peery 2010.
Metapopulation (Mitchell et al 2021)	CESRF (hatchery), Upper Yakima, Naches, American.	NA	Specifies the subpopulation to the Yakima River metapopulation of Chinook salmon.	Based on characterizations of the Spring Chinook salmon populations in the Yakima River Basin Fast et al. 1991, Busack and Marshall 1991).
Chinook Pop. Size (Landis et al 2020, Mitchell et al 2021)	The probability distribution of subpopulation size.	0 to 1e5, 1e5 to 5e5, 5e5 to 1e6, 1e6 to 5e6, 5e6 to 1e7, 1e7 to 2.14748e9 (# fish in subpopulation)	The probability distributions were derived from the metapopulation model outputs (subpopulation abundance) for the combinations of inputs and 200 simulations of each condition.	This CPT compiled from case file learning using the Netica software to derive the probabilities for each cause and effect combination as determined by the model output. The inputs are from nodes Adult %Reduction in survival and Juvenile % reduction in survival. The nodes simulation year and metapopulation specify the length of the simulation and the segment of the metapopulation respectively. See Mitchell et al 2021 for additional details on the population modeling.

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Summary of methods used in the BN from Mitchell et al (2021).

Mitchell et al. (2021) constructed four age-based matrix population models representing each spring Chinook subpopulation in the Yakima River Basin, WA. The study focused on direct effects, and not the indirect effects that may be caused by changes to benthic communities and water flows. The transition matrices were based on stream-type Chinook salmon life history graphs and had a maximum age of 5 years. Matrix transition values (survival and reproduction) and dispersal rates were estimated from subpopulation-specific life history information described in detail in the Supplemental Data of Mitchell et al. (2021). The matrices used baseline models representing metapopulation dynamics prior to impact from pesticides and ecological stressors. An equation for diazinon-malathion synergistic mixture toxicity was derived using the drc package in R (Ritz et al. 2015) to model a log logistic 3 parameter model of the pesticide toxicity data from Laetz et al. (2013). Diazinon and malathion concentrations were converted to toxic units (TU) in the equation for this model by normalizing measured concentrations with EC50s calculated from individual diazinon and malathion dose-response curves (Laetz et al. 2009, 2013).

Measured organophosphate concentrations (malathion and diazinon in µg/L), water temperature 7-day average of the daily maxima (°C), and dissolved oxygen (DO) data (mg/L) were downloaded from the Washington Department of Ecology's Environmental Integrated Management (EIM) database (WDOE 2020) using search filters “Lower Yakima” and “fresh/surface waters” for the monitoring period of 2006 to 2016. The resulting frequency distributions of the data were discretized into bins and incorporated into conditional probability tables (CPTs) dependent on the season. For pesticide data, non-detects (“U” -qualified) and data detected below the reporting limit (“J”-qualified) were captured in the lowest pesticide concentration bins in the Bayesian network. The lowest pesticide concentration bins were parameterized as 0 µg/L to the US Environmental Protection Agency (USEPA) aquatic life criteria for diazinon (0.17 µg/L) or malathion (0.1 µg/L) (USEPA 2020) and were associated with no toxic effect (no effect on AChE activity) in the model. Additional details can be found in Mitchell et al. (2021) and the associated Supplemental Information.

The Puget Sound Partnership’s (PSP’s) recovery goal for Chinook salmon is “no net loss” of population abundance (PSP 2020). This metric was used to define risk to Chinook in the present study and has previously been used to define risk by Landis et al. (2020) and Mitchell et al. (2021).The initial abundance for all subpopulation models was set to 500 000 fish, which approximates a typical salmon population’s spawner abundance under a stable age distribution for the region. Risk was defined as the probability that the resultant metapopulation size is below the initial abundance of 500 000 fish.

The sensitivity of the Bayesian network Chinook population size endpoint to various nodes was calculated using Netica's “Sensitivity to findings” function to calculate percent mutual information (Norsys 2014).

Supplemental Information Tables

SI Table 1. Modifications (additions) to the temperature and dissolved oxygen distributions for seasons and climate change scenarios. All modification (mod) distributions are normal distributions with the mean and standard deviation indicated below. Modifications adapted from Ficklin et al. (2013) percentile and standard deviation ensemble model statistics across the Sierra Nevada for the 2050s and 2080s for spring and summer. Low=25th percentile; medium = 50th percentile; high = 75th percentile of SWAT model simulations forced with 16 general circulation models.

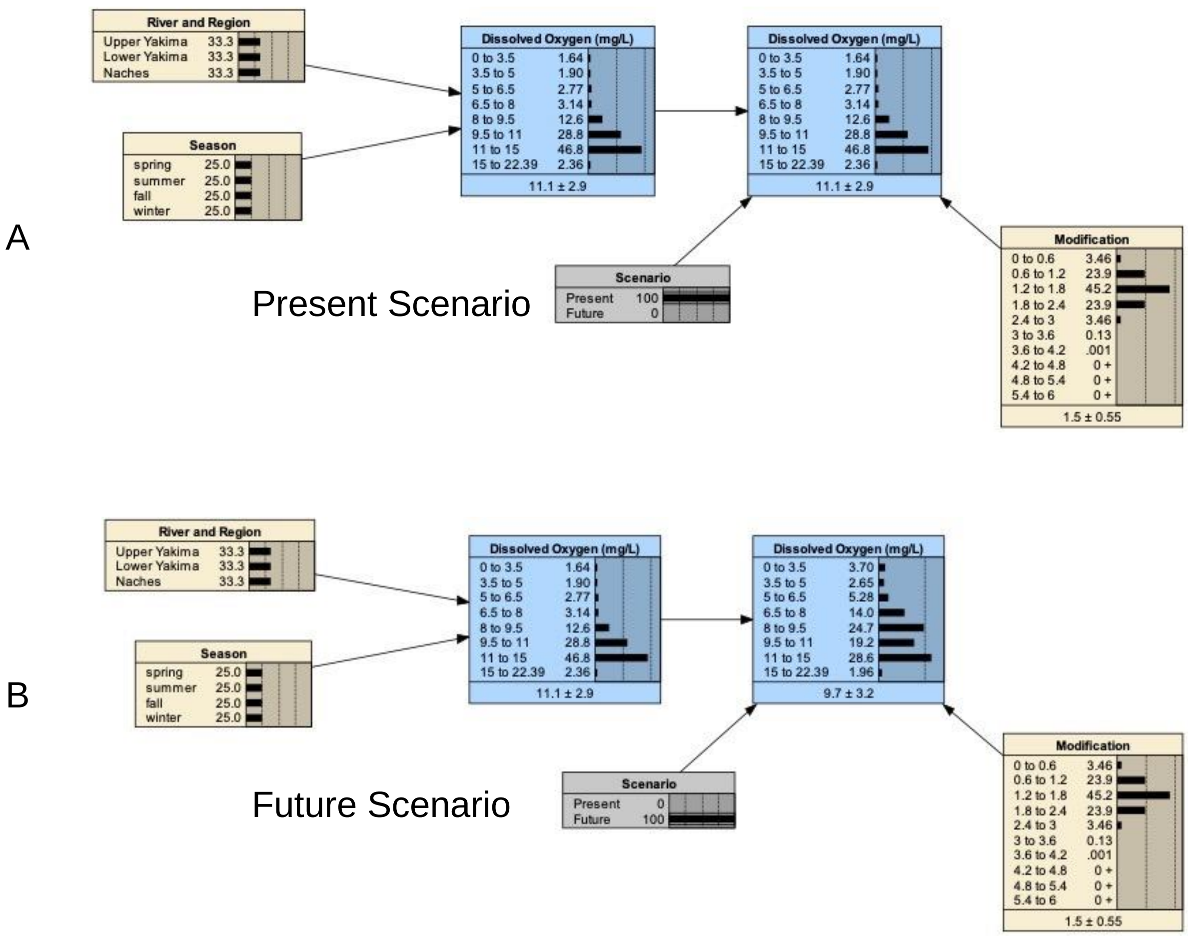
Node	Scenario states	Season	Mean (standard deviation)
Temp mod (25th percentile)	Low_2050	Spring	0.9 (0.2)
	Low_2050	Summer	1.5 (0.5)
	Low_2050	Fall	1 (1)
	Low_2050	Winter	1 (1)
	Low_2080	Spring	2.1 (0.4)
	Low_2080	Summer	3.1 (0.7)
	Low_2080	Fall	1 (1.4)
	Low_2080	Winter	1 (1.4)
Temp mod (50th percentile)	Med_2050	Spring	1.9 (0.3)
	Med_2050	Summer	2.5 (0.6)
	Med_2050	Fall	1 (1.2)
	Med_2050	Winter	1 (1.2)
	Med_2080	Spring	3.2 (0.5)
	Med_2080	Summer	4.4 (0.9)
	Med_2080	Fall	1 (1.8)
	Med_2080	Winter	1 (1.8)
Temp mod (75th percentile)	High_2050	Spring	2.9 (2.5)
	High_2050	Summer	3.4 (0.6)
	High_2050	Fall	1 (5.0)
	High_2050	Winter	1 (5.0)
	High_2080	Spring	4.4 (0.6)
	High_2080	Summer	5.5 (0.8)

	High_2080	Fall	1 (1.6)
	High_2080	Winter	1 (1.6)
DO mod (25^{th} percentile)	Low_2050	Spring	-0.8 (0.1)
	Low_2050	Summer	-1.2 (0.3)
	Low_2050	Fall	-0.1 (0.6)
	Low_2050	Winter	-0.1 (0.6)
	Low_2080	Spring	-1.4 (0.3)
	Low_2080	Summer	-1.6 (0.5)
	Low_2080	Fall	-0.1 (1)
	Low_2080	Winter	-0.1 (1)
DO mod (50^{th} percentile)	Med_2050	Spring	-0.6 (0.5)
	Med_2050	Summer	-0.9 (1.0)
	Med_2050	Fall	-0.1 (2.0)
	Med_2050	Winter	-0.1 (2.0)
	Med_2080	Spring	-1.3 (0.5)
	Med_2080	Summer	-1.3 (1.0)
	Med_2080	Fall	-0.1 (2.0)
	Med_2080	Winter	-0.1 (2.0)
DO mod (75^{th} percentile)	High_2050	Spring	-0.3 (0.1)
	High_2050	Summer	-0.6 (0.2)
	High_2050	Fall	-0.1 (0.4)
	High_2050	Winter	-0.1 (0.4)
	High_2080	Spring	-0.6 (0.1)
	High_2080	Summer	-0.9 (0.2)
	High_2080	Fall	-0.1 (0.4)
	High_2080	Winter	-0.1 (0.4)

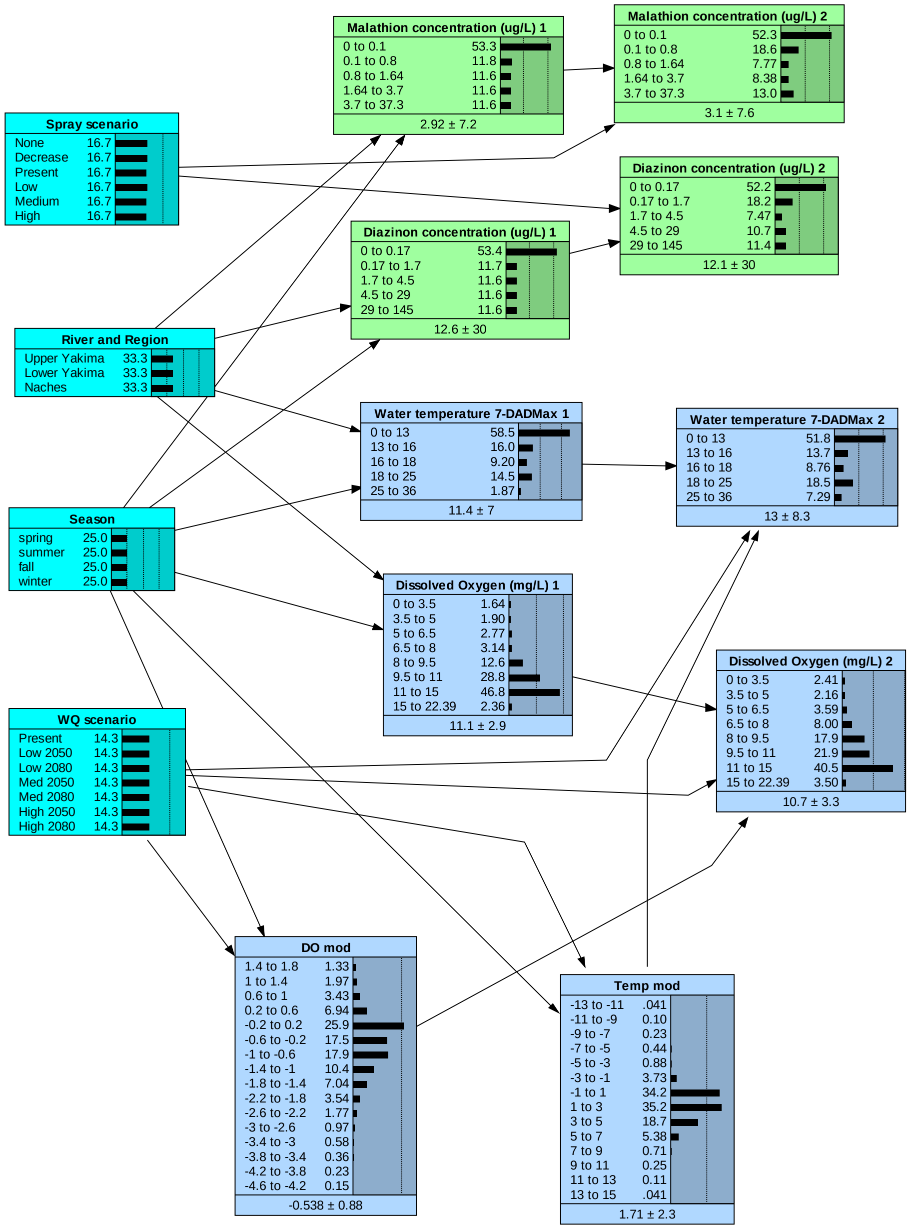
SI Table 2. Scenarios explored in the amended Bayesian network model from Mitchell et al (2021) for the lower Yakima metapopulation. Present = original distributions from Mitchell et al. (2021) model. See Tables 1 and 2 and text for additional explanation of scenarios.

Scenario #	Spray scenario	Season	WQ Scenario
1a	None	Summer	Present
1b	None	Spring	Present
2a	None	Summer	High 2050
2b	None	Spring	High 2050
3a	None	Summer	High 2080
3b	None	Spring	High 2080
4a	Present	Summer	Present
4b	Present	Spring	Present
5a	Present	Summer	High 2050
5b	Present	Spring	High 2050
6a	Present	Summer	High 2080
6b	Present	Spring	High 2080
7a	High	Summer	Present
7b	High	Spring	Present
8a	High	Summer	High 2050
8b	High	Spring	High 2050
9a	High	Summer	High 2080
9b	High	Spring	High 2080
10a	High	Summer	Low 2050
10b	High	Spring	Low 2050
11a	Present	Summer	Low 2080
11b	Present	Spring	Low 2080
12a	High	Summer	Low 2080
12b	High	Spring	Low 2080
13a	None	Summer	Low 2080
13b	None	Spring	Low 2080
14a	None	Summer	Low 2050
14b	None	Spring	Low 2050
15a	Present	Summer	Low 2050
15b	Present	Spring	Low 2050

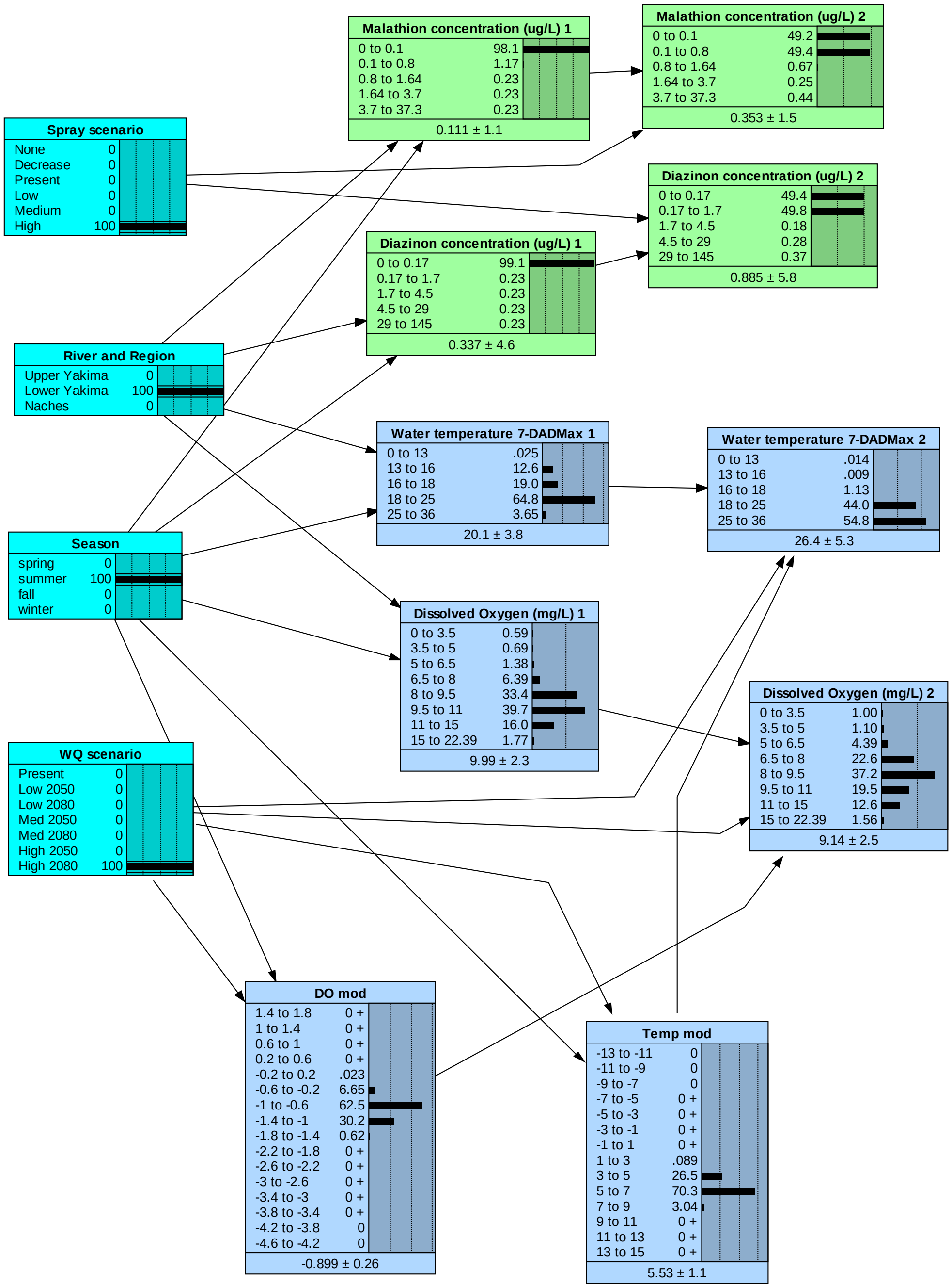
Supplemental Information Figures



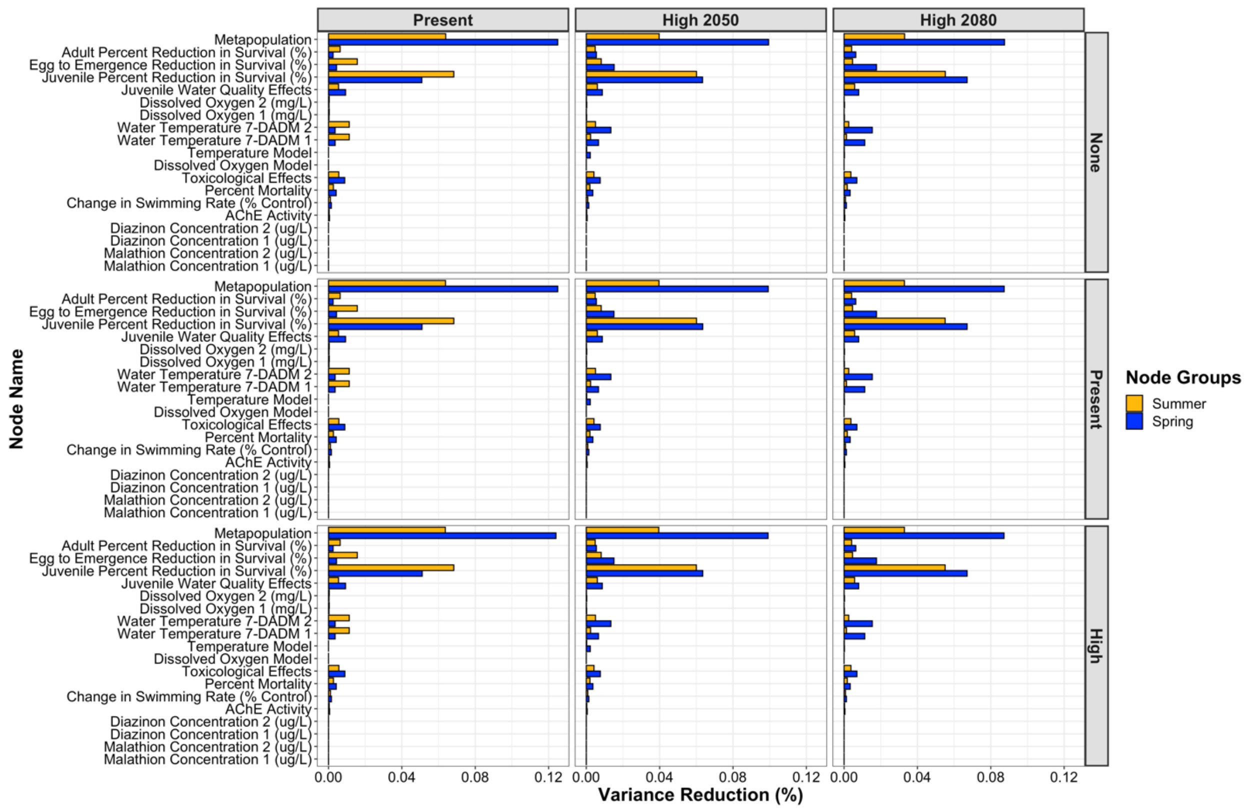
SI Figure 1. Conceptual flow for modifying monitoring concentration distribution nodes from Mitchell et al. (2021) for dissolved oxygen. (a) “Present” state selected in *Scenario* with no resulting change to the original *Dissolved Oxygen (mg/L)* distribution so both *Dissolved Oxygen (mg/L)* nodes contain the same distributions, (b) “Future” state selected in *Scenario* so the distribution in the parent *Dissolved Oxygen (mg/L)* is subtracted from the distribution in the modification node to create a modified distribution in the child *Dissolved Oxygen (mg/L)*. A similar modification was made for the Water *Temperature 7-DADMax* distribution. Pesticide distributions were modified through percent additions or subtractions.



SI Figure 2. Adjustment network for the malathion, diazinon, water temperature, and dissolved oxygen monitoring nodes. Nodes are grouped into pesticides (green); scenarios (bright blue); and water quality (dark blue). Mod=modification factor; DO= dissolved oxygen; temp = temperature. Pesticide concentration distributions are reduced or increased by percentages based on hypothetical futures in the *Spray scenario* node. Water quality nodes are adjusted by adding their corresponding “mod” nodes based on scenario projections.



SI Figure 3. Scenario example for summertime monitoring data in the Lower Yakima with a high 2080 projected adjustment to water quality (temperature and dissolved oxygen) and a high spray scenario. Note the changes in the values of the nodes compared to SI Figure 2.



SI Figure S4. Sensitivity analysis to population node for the present, 2050, and 2080 year scenarios with none, present, and high pesticide loads using mutual information (%). Note the differences in the contributions as measured by mutual information for the spring (yellow) compared to summer (blue). Note the importance of the metapopulation node is in summer compared to the spring.