Integrating Salish Sea Climate Change Stressors and Human Health and Well-Being into Ecological Risk Assessment

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Abstract

Climate change is expected to have widespread impacts on ecosystem services in the Salish Sea. In this ongoing research, we focused on the question of how stressors generated by climate change affect contaminant toxicity to species in the Skagit River watershed. Specifically we assessed how those combined effects potentially influence risks to the river's ecosystem services that, in turn, impact human health and well-being. To answer this question, we are conducting an ecological risk assessment using the Bayesian network Relative Risk Model (BN-RRM). It is a quantitative, probability-based model that calculates complex relationships between ecological variables to provide estimates of risk to valued receptors (endpoints). The Skagit River study area contains important habitats for native salmon species and bald eagles (*Haliaeetus leucocephalus*). These species provide numerous ecological, economic, cultural, and spiritual benefits to humans. Its floodplains also provide fertile, highly productive croplands, making it an important agricultural center in the region. Pesticide use on croplands in the watershed currently pose risks to these non-target species that may increase in severity with climate change. Increasing water temperature, decreasing dissolved oxygen levels, and changes in seawater pH are of particular concern, as are changing river and stream flows, increasing storm event frequency and intensity, and sea level rise. These stressors have potential to impact human health and well-being endpoints such as human health, water quality, salmon fisheries, tribal cultural and community health indicators, recreation areas, tourism, agriculture, boating, fishing, and shellfish harvesting. The BN-RRM will enable us to calculate the risks posed by various stressors on these select endpoints in the Skagit River watershed due to climate change. Once constructed the BN-RRM can also serve as a useful tool for resource managers and decision-makers as part of an adaptive management process and to direct future research efforts in the watershed, as well as in other watersheds in the Salish Sea region.

Objectives

- Conduct a risk assessment of the Skagit River Watershed for impacts to human health and well-being by climate change and other physical and chemical stressors.
- Develop a tool to serve as part of an adaptive management process for ecological resources in the Skagit River Watershed.

Study Area – Lower Skagit River Watershed

- The Skagit River Watershed was chosen due to the multitude of stressors and ecological services present. It has also been studied extensively, producing bountiful sources of quality data.
- Skagit River Watershed is largest in the Puget Sound, covering about 5013 km^2 (Lee and Hamlet 2011).
- Inhabited by Native American tribes for thousands of years. Extensive development by European-American setters starting in the mid-19th century.
- Skagit River Delta is agriculturally important – over 90 crops including blueberries, raspberries, strawberries, tulips, daffodils, apples, potatoes, and cucumbers.
- Skagit River watershed provides habitat for many wildlife species such as all six native salmonid species, shellfish species, bald eagles, snow geese, and trumpeter swans, providing cultural, economic, and spiritual benefit to humans.
- Study area located in the Lower Skagit River Watershed and divided into 5 tentative risk regions based on sub-basins covering a total of 2800 km^2.
- Potential Skagit endpoints related to human health and well-being: water quality, salmon fisheries, tribal cultural and community health indicators, recreation areas, tourism, birdwatching, agriculture, boating, fishing, and shellfish harvesting.

Figure 1. Skagit River delta farmland featuring daffodil field. Photo by Linda Landis.

The Skagit River Watershed

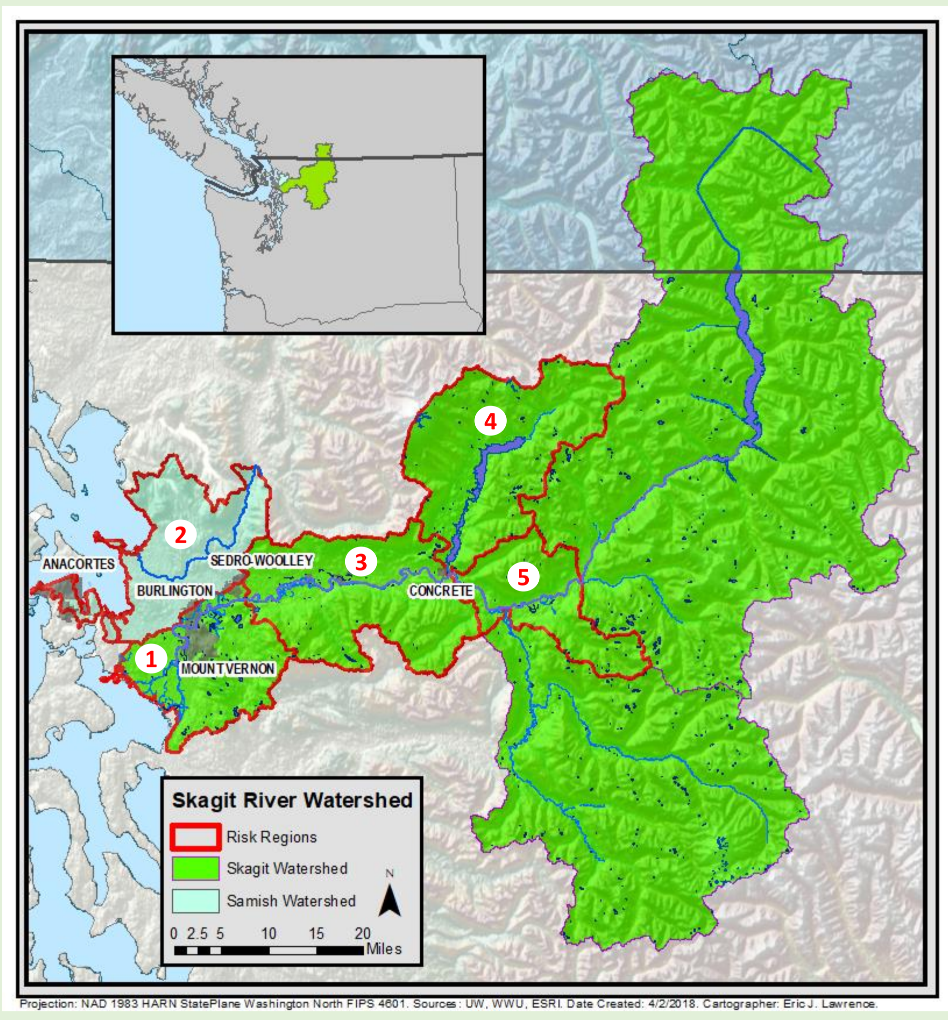

Figure 2. Skagit River Watershed with tentative risk regions.

The Bayesian Network Relative Risk Model (BN-RRM)

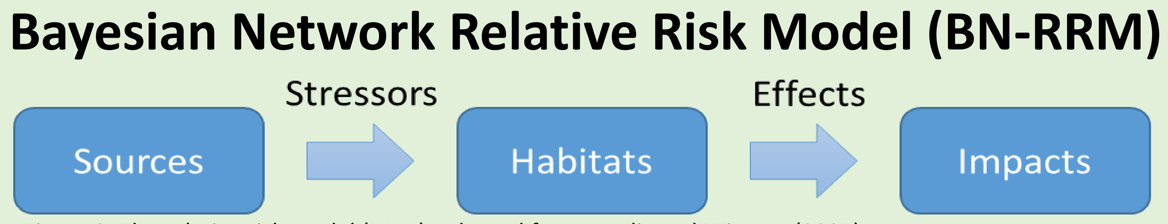

Figure 3. The relative risk model (RRM), adapted from Landis and Wiegers (2005).

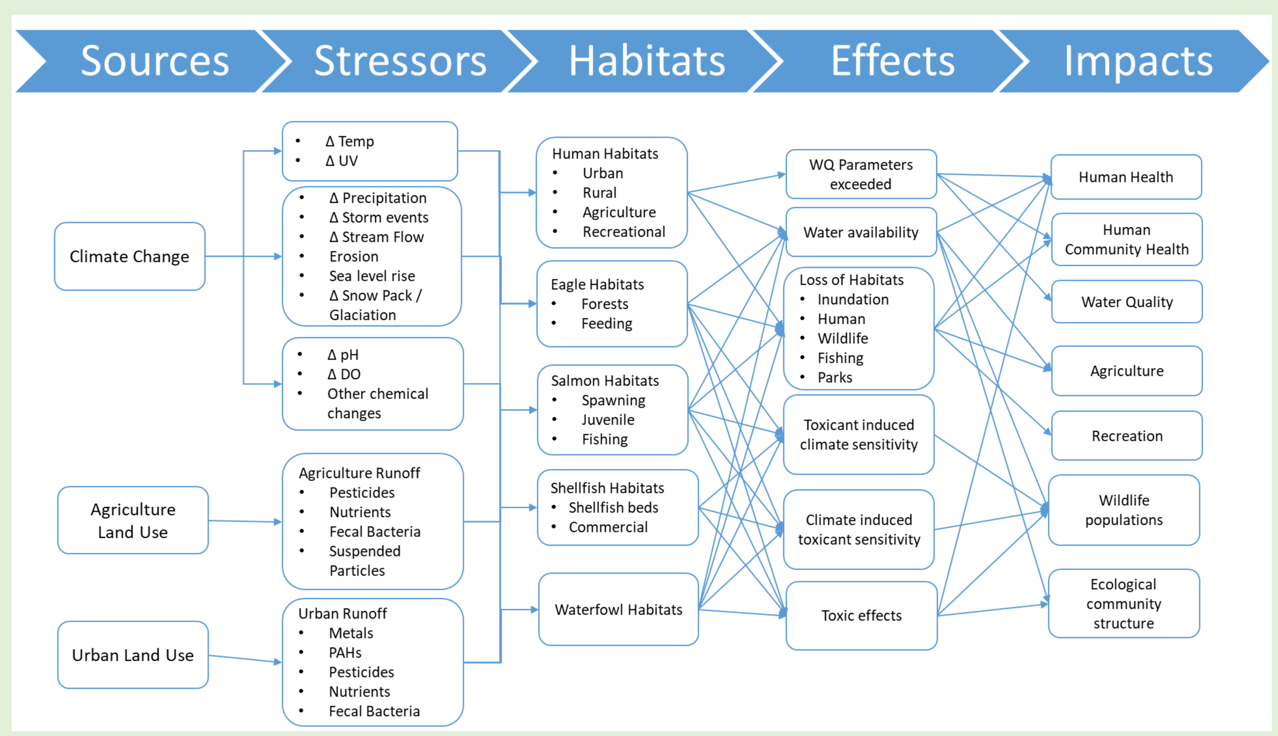

Figure 4 . Preliminary conceptual model for the risk assessment of the Skagit River.

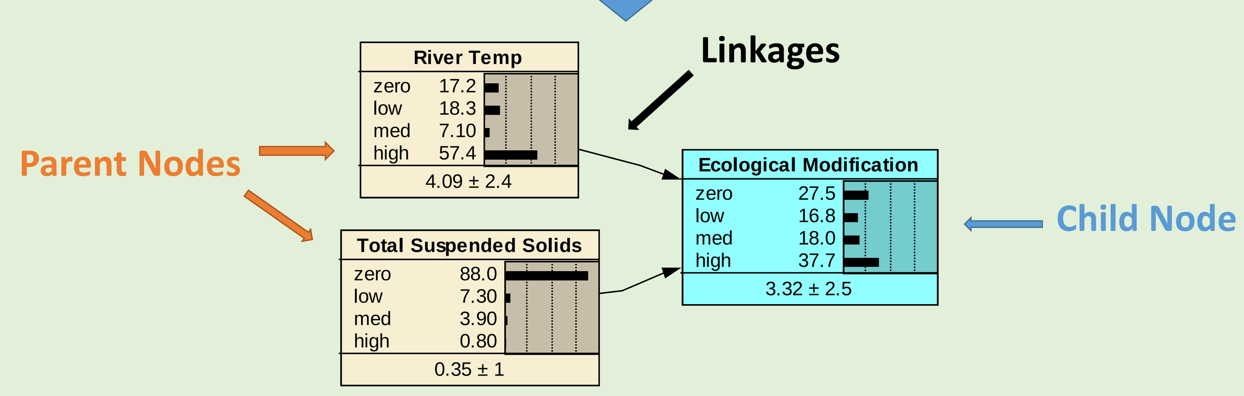

Figure 5. Example Bayesian network. Adapted from Landis et al. (2015)

Human Health and Well-Being Endpoints

Figure 5. Endpoints for ecosystem health determined by the Puget Sound Partnership. http://www.psp.wa.gov/images/vitalsigns_wheel.png

Methods

- **Risk** is the probability actual or relative of an effect to a receptor (endpoint) judged by society to be important (Ayre and Landis 2012).
- **Ecological risk assessment** is a science for characterizing risk to endpoints from a variety of stressors (Landis and Wiegers 2005).
- The **relative risk model (RRM)** method for carrying out ecological risk assessment allows for regional scale modeling, grouping stressors by sources, and being spatially explicit (Figure 3, Wiegers et al. 1998, Landis and Wiegers 2005).

Step 1. Gather Data – Make a Map

- Gather data on sources, stressors and habitats that will be mapped out to determine risk regions (Figure 2).
- Determine human health and well-being endpoints based on importance to stakeholders such as tribes, workers, farmers, businesses, etc. (Figure 5, Donatuto et al. 2016).

Step 2. Conceptual Model

- A **conceptual model** is used to link ecological variables in a cause and effect chain using the structure of the RRM (Figure 4).

Step 3. Construct Bayesian Network

- The conceptual model is used to construct the **Bayesian network** using Netica software (Figure 5).
- Bayesian networks are models that relate ecological variables based on probabilistic calculations generated from conditional probability tables.
- Risk to endpoints is calculated as a probability distribution over discrete states.
- Benefits of the BN-RRM: it is quantitative at every step and explicit about uncertainty, different data types can be related through probability-based calculations, and they are easily updated as new data become available (Ayre and Landis 2012).

Step 4. Incorporate Regional Climate Change Predictions

- Regionally downscaled general circulation models (GCM) will be used to predict future climate scenarios for temperature, precipitation, and snowpack.
- The BN-RRM will be re-run for each risk region for each climate prediction to see how risk is changed.
- Interactions between toxicant and climate stressors can be related through adverse outcome pathways (AOPs) in terms of toxicant-induced climate sensitivity or climate-induced toxicant sensitivity (Hooper et al. 2013).

Step 5. Sensitivity and Uncertainty Analysis

- Sensitivity of endpoints to various stressors is tested by manually altering starting conditions and endpoint distributions (Marcot 2012).
- Linguistic and epistemic uncertainty from known lack of data is evaluated qualitatively by discussion of input parameters included or not included.

Potential Benefits from Research

- Identification of what ecosystem services are most at risk due to climate change caused effects in the Lower Skagit River Watershed.
- Identification of which stressors and stressor interactions are most important to address as part of an adaptive management process.
- Results may be instructive to risk assessment for the wider Salish Sea region.

Next Steps

- Continue gathering data on ecological variables and regionally downscaled climate model predictions.
- Refine conceptual model.
- Construct Bayesian network.
- Run BN-RRM for each risk region and for each climate prediction and compare results.
- Sensitivity and uncertainty analysis.
- Publication and presentation of results at conferences.

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Sources

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