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# Empirical evaluation of the conceptual model underpinning a regional aquatic long-term monitoring program using causal modelling

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ABSTRACT

Conceptual models are an integral facet of long-term monitoring programs. Proposed linkages between drivers, stressors, and ecological indicators are identified within the conceptual model of most mandated programs. We empirically evaluate a conceptual model developed for a regional aquatic and riparian monitoring program using causal models (i.e., Bayesian path analysis). We assess whether data gathered for regional status and trend estimation can also provide insights on why a stream may deviate from reference conditions. We target the hypothesized causal pathways for how anthropogenic drivers of road density, percent grazing, and percent forest within a catchment affect instream biological condition. We found instream temperature and fine sediments in arid sites and only fine sediments in mesic sites accounted for a significant portion of the maximum possible variation explainable in biological condition among managed sites. However, the biological significance of the direct effects of anthropogenic drivers on instream temperature and fine sediments were minimal or not detected. Consequently, there was weak to no biological support for causal pathways related to anthropogenic drivers' impact on biological condition. With weak biological and statistical effect sizes, ignoring environmental contextual variables and covariates that explain natural heterogeneity would have resulted in no evidence of human impacts on biological integrity in some instances. For programs targeting the effects of anthropogenic activities, it is imperative to identify both land use practices and mechanisms that have led to degraded conditions (i.e., moving beyond simple status and trend estimation). Our empirical evaluation of the conceptual model underpinning the long-term monitoring program provided an opportunity for learning and, consequently, we discuss survey design elements that require modification to achieve question driven monitoring, a necessary step in the practice of adaptive monitoring. We suspect our situation is not unique and many programs may suffer from the same inferential disconnect. Commonly, the survey design is optimized for robust estimates of regional status and trend detection and not necessarily to provide statistical inferences on the causal mechanisms outlined in the conceptual model, even though these relationships are typically used to justify and promote the long-term monitoring of a chosen ecological indicator. Our application demonstrates a process for empirical evaluation of conceptual models and exemplifies the need for such interim assessments in order for programs to evolve and persist.



## 1. Introduction

Most regional and national monitoring programs are developed upon the same overarching goal of providing natural resource status and trend assessments beyond the local scale (e.g., Bureau of Land Management's Assessment, Inventory and Monitoring Strategy; Forest Service and BLM's Northwest Forest Plan; National Park Service's Vital Signs Program; and PacFish–InFish Biological Opinions Effectiveness Monitoring Program). A key component in the development of such monitoring programs is the creation of conceptual models that identify core ecosystem processes and factors that may impact them directly or indirectly (Fancy et al., 2009; Noon et al., 1997). Conceptual models can be presented in many different forms; for example, stressors and processes could

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be listed in tabular form, as flow charts with boxes and arrows connecting the individual components, or as cartoons (e.g., Gross, 2003; Margolius et al., 2009). The utility of framing monitoring programs around conceptual models is the development of scientifically sound monitoring questions, selection of relevant ecological indicators of resource condition, identification of drivers and stressors, and as a communication and information organization tool (Barrows and Allen, 2007; Fancy et al., 2009; Lindenmeyer and Likens, 2009; Noon et al., 1997; Ringold et al., 1999).

Interestingly, although there is emphasis on creating conceptual models during program development, many times the primary measurable objectives are in terms of status and regional trend assessments ("surveillance monitoring", Nichols and Williams, 2006). Consequently, most initial and interim planning focuses on the choice of sampling design (where and how many sample points are selected), temporal revisit design (frequency of data collection over years), or response design (what and how field measurements are collected) that precisely characterize biological condition (status) and maximize trend detection (e.g., Urquhart et al., 1998; Manley et al., 2004; Sims et al., 2006; Reynolds et al., 2011; Levine et al., 2014). For programs targeting the effects of anthropogenic activities, however, it is imperative to identify and measure land use practices and mechanisms that have led to degraded conditions (i.e., moving beyond simple status and trend estimation). Knowledge of such causal linkages is needed for prescribing appropriate changes in management to reduce stressor(s) and improve resource condition. Here we assess whether data collected as part of a regional aquatic monitoring program, PacFish–Infish Biological Opinions Effectiveness Monitoring Program (PIBO) (PACFISH, 1994), can be used to estimate causal pathways as articulated in the original conceptual model. The PIBO program was developed in response to listing of steelhead (*Oncorhynchus mykiss*) and bull trout (*Salvelinus confluentus)* under the Endangered Species Act with a specific focus on evaluating the status and trends of federally-managed headwater streams in the Interior Columbia River Basin and has since expanded to the upper Missouri River Basin (Fig. 1, Kershner et al., 2004).

The PIBO program has been implemented for over a decade, making it ideal for employing causal models to rigorously evaluate whether the original conceptual model of drivers and stressors is supported by the available monitoring data. We describe our process of translating the ecological information within the tabular conceptual model into a causal graph. The linkage structure portrayed in the graph is inherently a complex causal hypothesis and can be considered as a series of working hypotheses for how structure and function of an ecological system responds to various anthropogenic stressors and natural environmental gradients (Grace et al., 2012; Shipley 2009). Some of the advantages of utilizing these models for analyses include tests of mediation (see Burdon et al., 2013; Cubaynes et al., 2012; Gimenez et al., 2012; Riseng et al., 2011), estimation of cumulative and indirect effects (e.g., Clough, 2012), and accounting for context dependency and mitigating factors as commonly encountered with probabilistically sampled data collected across large spatial domains (brief introduction to causal models in

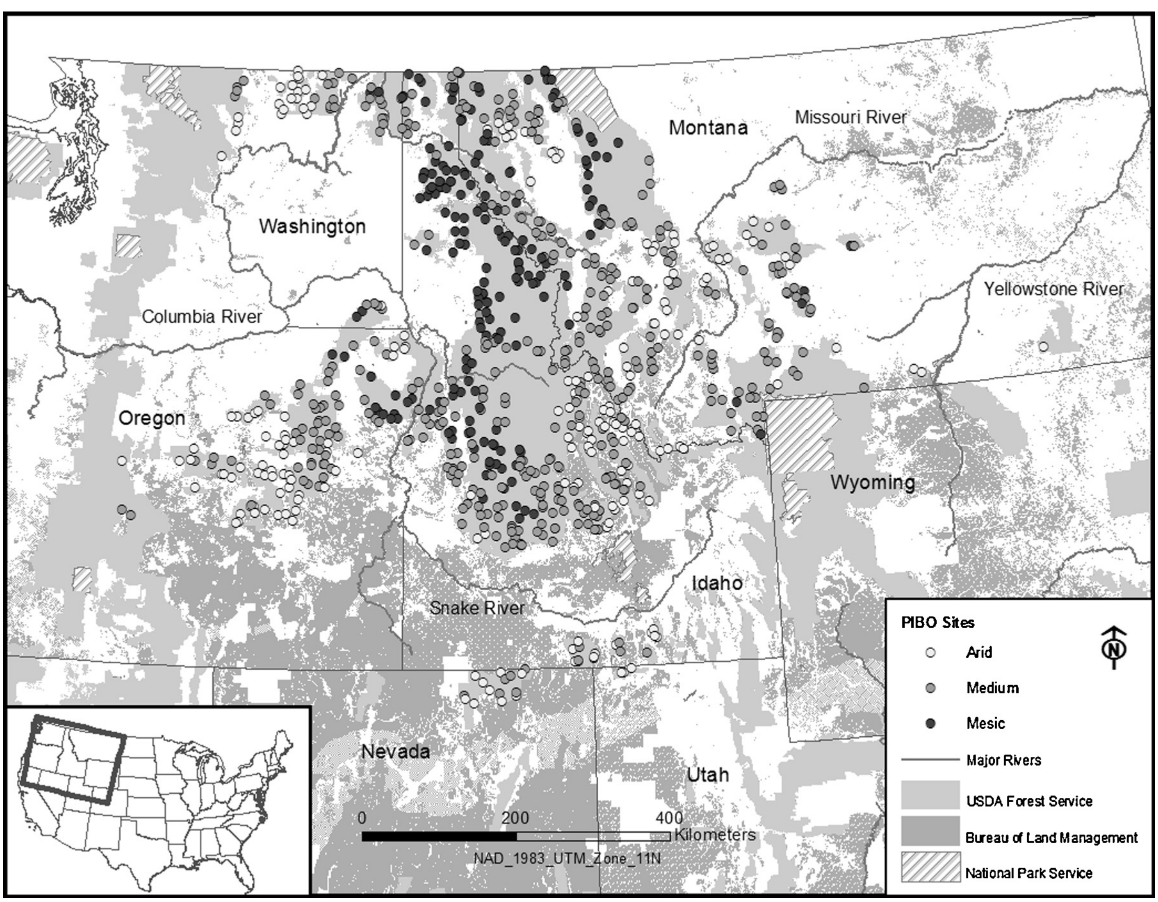


**Fig. 1.** Spatial distribution of landownership and PIBO sample sites within each of the three precipitation groups (arid [ppt ≤ 0.66 m yr$^{-1}$], medium [0.66 < ppt < 1.05 m yr$^{-1}$], and mesic sites [ppt ≥ 1.05 m yr$^{-1}$]) sampled throughout the Interior Columbia and Upper Missouri River Basins.