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Why Aren't Salmon Responding to Habitat Restoration in the Pacific Northwest?

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ABSTRACT

Declines in Pacific salmon populations (*Oncorhynchus sp.*) in the Pacific Northwest have led to listings under the Endangered Species Act. One objective of current recovery efforts is the restoration of freshwater and estuarine habitats, which had been occurring prior to ESA listing but increased dramatically afterwards. However, few listed populations are improving. We believe that there are five factors contributing to the lack of population response to habitat restoration:

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1. Not enough restoration has been done;
2. We are not doing the right things in the right places at the right times;
3. Ongoing habitat degradation is offsetting restoration benefits;
4. Not enough time has passed; and,
5. Monitoring has been inadequate to detect changes in salmon abundance.

All factors contribute to the disappointing progress on salmon recovery, although their importance varies. Two factors are more consistently significant than the others. Resources available to address habitat damage remain insufficient. The scale of the problem is large, so, the response needs to be correspondingly large to yield desired outcomes. Of equal significance is the failure of restoration programs to identify elements controlling fish production. Implementing the right projects in the right places is key to improving the outcomes of restoration.

INTRODUCTION

The abundance of many populations of Pacific salmon (*Oncorhynchus* spp.) in Washington, Oregon and California has declined dramatically over the last 150 years (Nehlsen et al. 1991; Ford 2022) leading to listing of 28 distinct Evolutionarily Significant Units (ESUs) across five species and hundreds of populations under the Endangered Species Act (ESA) (Fig. 1). The vulnerable status of these populations, and the economic, cultural, and ecological significance of salmon in the Pacific Northwest, have launched a region-wide, decades-long effort to recover Pacific salmon (Katz et al. 2007; Barnas et al. 2015). After almost three decades, however, few of the listed ESUs are improving (Tab. 1; GSRO 2020), raising questions about why we are not seeing better progress.

Many programs have been established to address declining abundances of salmon and steelhead (*O. mykiss*). These programs are conventionally segregated into four major management sectors: harvest, hatcheries, hydropower, and habitat (Nehlsen et al. 1991, NRC 1996, Ruckelshaus et al. 2002). Impacts on salmon abundance from degradation of spawning, rearing, and migration habitats are often considered the most ecologically complex and difficult to manage because of competing societal desires (NRC 1996). Habitat impacts occur across a patchwork of private, state, and federal lands with different management objectives and regulations (Lombard 2006). Addressing impacts through regulatory mechanisms, therefore, has been challenging. Regulatory protections have been augmented by active restoration of degraded freshwater and estuarine habitats. The restoration effort has been supported by a considerable investment; billions of dollars have been dedicated to salmon recovery over the last several decades in the Pacific Northwest (GSRO 2020). Nonetheless, most salmon and

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steelhead populations have shown little response. In Washington, for example, only two listed ESUs are nearing goals established in recovery plans, Hood Canal Summer Chum and Snake River Fall Chinook (Table 1). Among the 12 other listed ESUs in the state only two have made modest progress since listing but are far from meeting recovery goals. The four improving ESUs have been influenced by changes in harvest, hatchery practices and dam operations (for Snake River Fall Chinook Salmon and Snake River Steelhead) in addition to habitat restoration efforts. Thus, it is unclear the extent to which habitat restoration has contributed to improvement. The remaining 10 ESUs have not increased in abundance since listing with three ESUs considered to be "in crisis" (GSRO 2020).

So, why are we not seeing more progress? In this paper we identify 5 factors that help explain why salmon and steelhead populations may not be responding as expected to habitat restoration efforts. It is our hope that by identifying the factors contributing to lack of progress, we can accelerate the development of a practical framework to aid decision makers in sorting through the complexity of this issue and reprioritize habitat restoration strategies and expectations to achieve more tangible results.

WHY ARE WE NOT SEEING PROGRESS? THE FIVE FACTORS AFFECTING HABITAT RESTORATION SUCCESS

Given the effort and resources that have been dedicated towards salmon recovery in the Pacific Northwest over the last several decades, the lack of population response to freshwater and nearshore habitat protection and restoration raises questions about the current approach. We

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believe that there isa set of common factors that are largely responsible for the lack of salmon response to habitat restoration efforts. Better understanding the complex ecological and societal factors limiting salmon recovery (Fig. 2) may help provide a framework to assess the current programs, reprioritize habitat restoration strategies and temper expectations. We suggest five primary factors, which are discussed in detail below:

- Not enough restoration has been done;
- We are not doing the right things in the right places at the right times;
- Ongoing habitat degradation is offsetting restoration benefits;
- Not enough time has passed; and,
- Monitoring has been inadequate to detect changes in salmon abundance.

Not enough restoration has been done

At a population level, the lack of salmon response to restoration may simply be because not enough restoration has occurred to elicit a detectable response . The amount of habitat restoration required to generate a positive fish response depends on initial watershed condition, current rate of habitat degradation, initial abundance of the fish, and the types of projects and their location. It is also influenced by factors outside the watershed, including ocean productivity, fish harvest and hatchery management (Roni and Beechie 2013). Two approaches are generally used to estimate the amount of restoration required to achieve a desired fish response. Models can be used to predict how much restoration would be required in a watershed to achieve desired population responses (Honea et al. 2009; Jorgensen et al. 2021). Life-cycle models that link fish survival, abundance, and other population attributes with habitat conditions are frequently used for this purpose. Commonly applied models in the Pacific Northwest have included the Ecosystem Diagnosis and Treatment (EDT) model (Blair et al. 2009), SHIRAZ (Scheuerell et al. 2006) and HARP (Jorgensen et al. 2021) (see a review of these and other models in Roni et al. (2018)). Several models have also been developed recently that focus more heavily on trophic dynamics (Bellmore et al. 2017). Modeling has limitations, however, particularly the need for detailed data on life-stage-specific fish survival and habitat conditions (Roni and Beechie 2013) and identification and incorporation of all relevant determinants of survival. It is possible that some of the uncertainties of an individual model might be reduced by using multiple analytical tools to help triangulate on the factors that are controlling salmon population performance. However, multiple models are rarely used to identify limiting factors.

Another approach is to use empirical information from intensively monitored watershed (IMW) studies (Bennett et al 2016; Hillman et al. 2019). Generally, these studies compare treatment and reference watersheds, before and after the application of restoration treatments applied at a spatial scale large enough to assess the full life-cycle response of the target fish population. Economically and logistically, this approach is most tractable in small- and medium-sized watersheds where treatments can be applied to a substantial proportion of the stream network accessible to salmon. At least seventeen IMWs have been implemented in the Pacific Northwest (Bennett et al. 2016; Hillman et al. 2019). These studies have provided some insights about system response to current restoration practices (Bilby et al. 2022) and as they

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mature, should improve our ability to estimate the amount of restoration required to generate a detectable fish response.

Collectively, the results from IMWs, models and other studies all suggest that large amounts of restoration may be required to measurably increase salmon populations in a watershed. Based on modeling, Roni et al. (2010) concluded that on average, 20% of floodplain and in-channel habitat would have to be restored to produce a 25% increase in Coho salmon and steelhead smolt production (the minimum level considered detectable by most monitoring programs). This conclusion is supported by results from several studies in the Pacific Northwest, such as in the Chilliwack River, British Columbia, where restoring 157 km^2 of floodplain (about 26% of the total floodplain area) increased Coho Salmon populations by 27- 34% (Ogston et al. 2015). Roni et al. (2010) found that most restoration programs typically affect less than 10% of the salmon habitat in a watershed, making detection of a population level response very difficult.

There are many studies that have documented increased fish abundance or biomass at the scale of an individual project. For example, common restoration actions, such as instream wood placement or creation of off-channel habitat, have often been associated with reach-scale fish responses (Solazzi et al. 2000; Morley et al. 2005; Ogston et al. 2014; Clark et al. 2019; Roni et al. 2008, 2010, 2015; Whiteway et al. 2010). However, there are few examples where a watershed-scale response in fish populations has been associated with habitat restoration. Lack of population-level response may be because most restoration efforts influence only a small proportion of available habitat in a watershed. Concentration of enough restoration projects in a watershed to affect a significant fraction of the available habitat may be required to produce a detectable fish response (Roni and Quinn 2001, Clark et al. 2019).

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We are not doing the right things in the right places at the right times

Regardless of the resources dedicated to restoration, an increase in salmon abundance is unlikely to occur unless the conditions constraining fish production are accurately identified and measures that effectively address these constraints are implemented. Effectiveness of habitat restoration efforts is often hampered by inappropriate project selection. Barnas et al. (2015) compared ecological concerns identified in recovery plans with the subsequent selection of restoration projects in the Pacific Northwest using a database of 36,895 projects, finding that in most watersheds the implemented projects matched ecological concerns no better, and often worse, than would a random selection of prospective projects. This conclusion was supported in two recent studies. A review of results from IMWs across the Pacific Northwest indicated that despite aggressive habitat restoration at all these study sites, less than 50% of the monitored fish population metrics showed improvement (Bilby et al. 2022). Similarly, Jaeger and Scheuerell (2023) found no evidence that investment in habitat restoration in the Columbia Basin has produced an increase in adult, non-hatchery Chinook Salmon.

Appropriate assessments are critical to diagnosing the habitat elements limiting salmon production and identifying potential remedies. Recovery plans developed from assessments in the 1990s and early 2000s guided much of the habitat restoration for ESA-listed salmonid in the Pacific Northwest for more than a decade thereafter. Most early assessments were based on evaluation of nine habitat elements: fish access, floodplains, riparian areas, sedimentation, large woody debris, pools, water quality, and high and low flows (Smith 2005). These assessments were often augmented with application of a model (Blair et al. 2009; Jorgensen et al. 2021). These models employed quantitative data on habitat condition, where available. However, complete habitat information is available for very few systems in the Pacific Northwest, necessitating estimation of habitat attributes for many locations. These evaluations were useful but were not adequate to consistently identify the factors that control salmon population performance, partly due to incomplete habitat data. Another deficiency is that these assessments typically focused only on major physical habitat elements, like wood abundance and pool frequency. They cannot accurately identify constraints on salmon production if the assessment omits the habitat attributes that are limiting fish production, if habitat relationships to salmon life history are poorly understood, or if the assessment scale is too coarse to match habitat constraints to a critical life stage (Booth et al. 2016).

Restoration science over the last two decades has emphasized the importance of restoring ecosystem processes rather than manipulating channel features (Beechie and Bolton 1999, Simenstad et al. 2006; Beechie et al. 2010; Roni and Beechie 2013). One of the processes that has been largely ignored in limiting factors assessments and restoration planning is food web dynamics (Bellmore et al. 2017). Trophic system dynamics likely have a much greater influence on salmonids than currently appreciated by most restoration practitioners (Bellmore et al 2017; Benjamin et al. 2022). Kaylor and Warren (2017) found that physical habitat features traditionally assessed in restoration planning explained very little of the among stream variation in cutthroat trout (*O. clarki)* biomass, whereas several measures of trophic productivity were closely related to trout biomass (Fig. 3). Appreciation of the significance of trophic processes in controlling salmon and trout abundance is not a recent development (Murphy and Hall 1981; Bilby and Bisson 1992). In the 1980s, nutrient additions to streams in

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coastal British Columbia were found to enhance trophic system productivity and produced increases in growth of juvenile Steelhead and Coho Salmon (Johnston et al. 1990). The generality of this result is difficult to assess because the effect of food web linkages and energy flow on salmonid production has been evaluated in relatively few studies. Nonetheless, available results clearly indicate that an increased emphasis on trophic processes in limiting factor assessments, restoration planning, and project selection is warranted. Restoration projects that slow nutrient transport in streams (Newbold et al. 1982) or increase terrestrial insect production from riparian area (Benjamin et al. 2022) are two restoration options for enhancing trophic productivity.

In some cases, factors other than habitat condition may be limiting salmon or steelhead productivity. Periods of low ocean productivity, overharvest of fish, hatchery practices and hydropower all can reduce adult salmon returns (NRC 1996, Welch et al. 2020). If severe enough, these impacts can result in insufficient abundance of juvenile fish to occupy available habitat. Therefore, actions that simply increase habitat availability may generate very little fish response.

Water pollution can also limit salmon response to restoration in some watersheds. While the effects of some pollutants on salmon are understood, there are many compounds found in waters of the Pacific Northwest for which the ecological impacts are not fully understood (Wong 2021). Some of these compounds may be detrimental to salmon and, therefore, impact potential fish response to habitat restoration. Recently, a compound, which is an oxidation product of an additive used to prevent tire damage from ozone (6PPD-quinone), was found to

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be highly toxic to Coho salmon (Tian et al. 2022). Therefore, the response by Coho salmon to habitat restoration in a stream reach that receives runoff from highways would be limited.

In summary, all factors must be considered in identifying constraints on salmon production and setting reasonable expectations for fish responses to habitat restoration. Coordinating measures to improve habitat condition with actions to address other factors impacting salmon abundance will be required to recover salmon populations. Regularly improving assessments of factors controlling fish production, rather than relying on findings that are decades old, is essential for ensuring that the right restoration actions occur in the right places.

Fortunately, the variety of assessment tools, models and decision support protocols have greatly expanded and improved in the last two decades (Roni et al. 2018, Table 2). Some of these new tools address factors previously underappreciated, such as trophic system dynamics and climate change (Penaluna et al. 2015; Benjamin and Bellmore 2016). Because different models approach the identification of limiting factors differently, the application of multiple models can provide a more comprehensive limiting factor assessment. Application of these increasingly sophisticated tools may be challenging for many restoration programs due to limited funding and lack of technical expertise in modelling. However, the cost of conducting these detailed analyses is usually much less than the cost of implementing a large, but ultimately unsuccessful, restoration program.

Ongoing habitat degradation is offsetting restoration benefits

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To achieve a net improvement in salmon habitat, the quantity and quality of habitat lost must be less than the amount of habitat being restored. Although regulations have slowed the degradation of salmon habitat from human activities, impacts still occur (Bilby and Mollot 2008; Bartz et al. 2015; PSP 20219). An ever-increasing human population occurring in concert with impacts from climate change, will continue to degrade aquatic habitat (Crozier et al. 2008; Crozier et al. 2019). The population of Washington increased 4.5-times from 1940 to 2020 and is expected to increase another 30% by 2050 (Fig. 4). Although Washington has implemented growth management policies designed to focus new housing within urban boundaries, expansion of residential development in rural and wildland areas continues (Robinson et al. 2005; Bartz et al. 2015). For example, improved regulations have slowed the annual rate of conversion of forest and farmland in the Puget Sound region from 0.36% to 0.15% (PSP 2021). Nonetheless, ecologically important locations are still being developed (Bartz et al. 2015). Once an area is developed, opportunities to recover habitat and fish populations are limited because stream restoration becomes difficult and expensive due to the diversity and intensity of impacts that result from commercial, industrial and residential development, and the constraints imposed by existing land uses and property ownership (Paul and Meyer 2001; Booth and Bledsoe 2009). Beyond the reach of land-use regulations, climate change is reducing the capacity of freshwater and marine habitats to support salmon and this impact is expected to intensify over the coming decades (Crozier et al. 2008; Crozier et al. 2019). In many locations, the combined effects of development and climate change may overwhelm the contributions habitat restoration can make to achieving salmon recovery goals.

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Not enough time has passed

Restoring ecological processes is fundamental to successful restoration (Beechie and Bolton 1999, Simenstad et al. 2006; Beechie et al. 2010; Booth et al. 2016). Ecological processes have highly variable response times to restoration treatments and some responses can be lengthy. Therefore, even after project execution, considerable time may be required before the full benefits of a project on habitat and the target fish population are expressed (Roni and Beechie 2013). The slow response of some ecosystem processes to restoration actions can lead to a premature conclusion that a project has been ineffective.

Some projects can take many decades to have the desired effect on ecosystem conditions. For example, riparian plantings are typically done to improve water temperature, reduce bank erosion and provide a future source of large wood to provide fish habitat. All three of these objectives require trees to grow to substantial size. Effective shading requires trees tall enough to block sunlight and bank erosion protection requires the development of extensive root systems in the stream bank and riparian area. Development of these properties can take a decade for small streams (D’Souza et al. 2011) and longer for larger channels (Welty et al. 2002). Approximately 80 years is required for riparian stands to begin contributing large wood to stream channels in the coastal Pacific Northwest (Beechie et al. 2000; Welty et al. 2002; Meleason et al. 2003). Even projects that are intended to directly impact channel form (e.g., in-channel wood placement) may need several large storm flows to occur before wood causes changes to the channel (Roni and Beechie 2013). These factors suggest that monitoring over a decade or more may be required to discern any meaningful trends in either physical or biological response to restoration.

Monitoring has been inadequate to detect changes in salmon abundance

Assessing the contribution that habitat restoration makes to salmon recovery requires monitoring of fish populations and habitat conditions. Furthermore, the habitat and fish population measurements must be collected in a manner that enables habitat changes due to restoration to be linked to demographic changes in salmon (Reeves et al. 1991). Habitat and fish monitoring programs have expanded rapidly in the Pacific Northwest since salmon were listed under the ESA. However, fish and habitat data collection programs often are not coordinated, making it difficult to draw meaningful inferences about fish response to habitat changes.

Habitat data are collected by a mix of local and regional programs managed by tribes, counties, non-governmental organizations, and state and federal agencies (Reeves et al. 2004; Anlauf et al. 2011; NWIFC 2020). Fish monitoring programs in the region are mostly conducted by state agencies and tribes. These programs collect data on adult salmon abundance for many Washington watersheds, although sampling effort and/or sampling program design does not support accurate estimation of watershed-level abundance for many locations (Table 3).

Abundance of smolts is often considered a key parameter for evaluating fish response to restoration because improving smolt production is often the primary focus of habitat restoration programs. Detecting changes in smolt production that might be caused by habitat restoration requires that fish data be collected at an appropriate spatial scale in the right locations, capture relevant life-history stages, and include adequate sampling intensity over

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enough years (Reeves et al. 1991). Although smolt production is measured at many watersheds in the Pacific Northwest (Table 3), smolt counts are often aggregates of multiple natal populations, which means the abundance trends can be difficult or impossible to associate with habitat changes caused by restoring a specific stream reach.

The large interannual variability in salmon abundances caused by factors such as changes in ocean productivity, fish harvest, hatchery management, and the effects of weather patterns on freshwater habitats means that even a good monitoring program can take decades to detect statistically significant changes in salmon abundance (Bennett et al. 2016). Several western Washington IMWs have estimated that between 7 and 12 years of monitoring after restoration has been completed are required to statistically detect a change in smolt production of 30% (Anderson et al. 2015). Detecting changes in smolt production less than this would require correspondingly longer monitoring.

Demographic parameters of salmon populations other than abundance can be influenced by habitat changes, including productivity, diversity (variation in life history), and spatial structure (distribution of fish in a watershed) (McElhaney et al. 1999). Goals for these population attributes are often included in recovery plans for salmon and steelhead populations. Most monitoring efforts have been directed towards estimating abundance and productivity, as discussed above. However, monitoring of spatial structure and diversity are increasingly being recognized as equally important aspects of salmon response to habitat restoration. Most monitoring programs would require some modification to accurately assess these attributes. These population attributes may be especially responsive to the ongoing efforts by states, counties, local governments, and private landowners to remove tens of thousands of blockages impeding salmon migration.

Although monitoring effort in the region has expanded since ESA listing of salmon ESUs, monitoring programs generally are not sufficiently coordinated to take full advantage of the information being collected. Organizations involved in habitat and fish population monitoring often have different objectives and use different protocols. In addition, there is relatively little communication between local, tribal, non-governmental organization, state, and federal monitoring programs. Because organizations that conduct monitoring are often unaware of other monitoring efforts in their area of interest, exchange of data and other important information often doesn't occur. Better communication among monitoring practitioners, and perhaps establishment of a central clearinghouse where monitoring organizations can store and share data and other types of information would enhance the value of monitoring efforts.

DISCUSSION

The success of habitat restoration depends on multiple, complex, interacting socio-ecological factors. When the results of restoration efforts do not result in expected population level responses, decision-makers and funders want to know why and what should be changed. The authors of this paper believe that distilling this complexity into the five major factors discussed in this paper can help decision-makers identify more realistic expectations, reassess past strategies, and reprioritize their efforts.

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The relative importance of the five factors and how they interact, however, is not straightforward. Impact of these factors on project effectiveness will vary depending on conditions prior to restoration, innate productive capacity of the habitats being restored and other elements. However, a few of the factors are likely more consistently significant than the others. We believe that there is compelling evidence that the two factors of greatest significance in the limited fish response to restoration are (1) not enough restoration has been done; and (2) we are not doing the right things in the right places at the right times. The lack of sufficient resources to address the scope and magnitude of the problem and) failure to accurately identify the key elements constraining fish production and focus restoration on these constraints are the major factors contributing to the lack of progress that has been made in salmon recovery.

Other factors may be locally important but do not provide an explanation for the consistent lack of fish population response. Although time is required for the effects of a project to fully manifest, this factor is not likely of regional significance in the lack of progress. Many restoration projects have been in place for decades, providing sufficient time to generate a fish response, if one were going to occur. Habitat degradation continues to occur in many locations in the Pacific Northwest. This problem tends to be particularly acute in locations undergoing rapid growth in human population. Continuing loss of habitat in these locations may well play a significant role in poor fish population response to restoration. While ongoing habitat damage is likely an important factor impacting fish response at some locations, it is not a key factor in situations with limited, recent human impact, such as on U.S Forest Service lands. . . It also seems unlikely that a failure to adequately monitor fish and habitat conditions has prevented us from detecting a fish response. Better coordination between current efforts to assess habitat conditions and salmon population status would provide a clearer indication of the effectiveness of restoration efforts. However, monitoring of salmon population status is comprehensive enough that it should be sufficient to detect changes in abundance and productivity for many populations (Table. 2).

PRIORITY RECOMMENDATIONS

Do more restoration

Increasing investment in ecosystem recovery is essential if we wish to see positive responses from salmon. The scale of the problem, after nearly 150 years of habitat degradation, is very large, and so the response needs to be correspondingly large to have the desired effect. Despite the money being spent, salmon recovery plans remain underfunded relative to the magnitude of the problem and existing restoration plans have not been fully implemented anywhere in the region. Coordinating agencies, tribes, and other organizations engaged in habitat restoration to better integrate the responsibilities, actions, and knowledge of the various organizations engaged in this effort can increase overall efficiency (Rieman et al. 2015), but no amount of coordination can fully compensate for an inadequate investment of resources.

Do the right things in the right places at the right times Implementing the right projects in the right places is key to improving the effectiveness of restoration efforts. Even though lack of

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restoration funding constrains restoration effort, more success could be achieved if restoration resources were focused in areas with the greatest potential to generate a fish population response. The consistent failure to do this stems from not accurately identifying the factors constraining salmon production, the tendency to emphasize treatment of localized symptoms rather than the underlying causes of impairment (Beechie and Bolton 1999; Booth et al. 2016), bias towards less expensive projects because of limited funding, and opportunism (Barnas et al. 2015). Historically, assessments to identify limiting factors focused on physical habitat elements, like channel form or riparian shade. Over the last two decades, however, scientists have emphasized the importance of restoring the ecosystem processes responsible for creation and maintenance of salmon habitat (Beechie et al. 2010). Most focus has been on processes that determine physical habitat characteristics. However, processes like trophic dynamics and nutrient cycling also are significant factors in salmon productivity (Benjamin et al. 2022) and should receive equal attention. Restoration programs also need to incorporate impacts from factors beyond the watershed, including fish harvest, impacts from hatchery operations and climate change. Coordination of efforts to address all the factors affecting salmon populations will be required for successful recovery of these fishes.

Improving the methods now being used to identify locations where restoration actions would have the greatest chance of generating a positive fish response would enhance effectiveness of restoration programs. Productive potential for salmon varies greatly among locations because of watershed features like geology, channel gradient and floodplain topography (Pess et al. 2002; Burnett et al. 2007). Identification of the locations with the greatest underlying potential to support high levels of salmon production, and focusing restoration efforts at these locations, would greatly enhance the probability of restoration actions generating a positive fish response. At present, significant constraints to implementing the right projects in the right places are the practical aspects of land ownership, property access, permitting, legal, and economic considerations. Especially in landscapes where land is held in small parcels by many owners, selection of the most effective projects is influenced by both ecological and social factors (Knight et al. 2013). Restoration planning and implementation could be greatly improved if frameworks that explicitly incorporate these factors as part of a socio-ecological system were employed (Ban et al. 2013). The social sciences offer a variety of analytical tools, such as mapping social and human dimensions of conservation opportunity, which can bring more structure to this element of restoration planning and decision making (Knight et al. 2013; Ban et al. 2013).

ADDITIONAL RECOMMENDATION

Protect quality habitat

Habitat degradation is occurring rapidly enough in some watersheds to offset or mask benefits associated with restoration. Identifying and protecting high quality habitat, therefore, is an essential component of any restoration program (Roni et al. 2002). A variety of tools exist for protecting habitat, including acquisitions, conservation easements, and regulations. Acquisitions and conservation easements are mostly applicable at a local scale, whereas zoning and other land-use regulations can provide broader protection. The continuing development of land across the range of salmon in the Pacific Northwest indicates that regulations will need to

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change to accommodate both salmon and human needs. Comprehensive assessments of regulatory effectiveness are needed to do this, but this task is complicated because processes to assess regulatory effectiveness are either absent or scattered among different geographies, agency jurisdictions and funding sources.

Recognize time required for effects of restoration to be expressed

Although lack of time alone is insufficient to explain the lack of fish population response to restoration efforts regionally, it clearly is contributing to the perceived lack of progress in some situations, especially for recently implemented projects. Many restoration actions require years or decades to be fully functional, considering the potential lags in geomorphic, biogeochemical, biological, and demographic processes. Therefore, determining restoration effectiveness is a long-term proposition. Developing realistic expectations about the length of time required for the benefits of a restoration project to be fully expressed should be an element of every project design.

Learn from monitoring

Monitoring of salmon and salmon habitat has expanded greatly in the last several decades. In many regions of the Pacific Northwest monitoring of salmon population status is comprehensive enough to provide a clear indication of trends in abundance of adults and smolts (Table 2). However, there are many opportunities to improve fish and habitat monitoring. Expansion of monitoring to include salmon life-history diversity and spatial structure would give a more complete picture of restoration effectiveness. Improved habitat monitoring is required to determine the net gain or loss of habitat, so that we can understand how well protection and restoration strategies are working. Expansion, or modification of existing fish monitoring programs to better align with habitat monitoring would provide more opportunities to link habitat restoration to salmon survival and production.

The need and opportunity exist for improving and making better use of the expanding suite of tools that facilitate investigation of the link between restoration actions, changes in habitat condition, and fish response. More complete habitat and juvenile life-history data are required to improve the reliability of models that link habitat condition to salmon productivity (Hall et al. 2018). IMWs are generating some of the information required to meet this need. However, most of these studies have focused on small watersheds and have evaluated only a limited number of restoration treatments (Hillman et al 2019; Bilby et al. 2022). In addition, many IMWs in the region are sunsetting after several decades and opportunities for initiating new projects are becoming more limited. As a result, ensuring that monitoring infrastructure is sufficient to adaptively improve restoration programs should be a regional priority.

CONCLUSIONS

Salmon recovery represents one of the most complex conservation challenges in North America. Addressing this issue with the limited resources that have been available to date has made success even more difficult. However, unless tangible progress towards salmon recovery can be demonstrated, the resources now being dedicated to this problem could be reduced. We believe that identifying and acknowledging the underlying reasons for the lack of progress

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can help create more effective restoration strategies and ultimately demonstrate that mitigating past and preventing future habitat damage to freshwater and estuarine ecosystems is a key to achieving salmon recovery.

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Table 1: Staus of ESA listed salmon and steelhead ESUs in Washington. The "Current Condition" ratings taken from GSRO (2020). ESUs considered to be "In Crisis" are at low abundance relative to recovery goals and have decreased in abundance since listing. ESUs rated as "Not Keeping Pace" are more abundant than those ESUs "In Crisis" but have not exhibited any increase in abundnace since listing. Those ESUs rated as "Making Progress" have exhibited some increase in abundance since listing but have not achieved recovery goals. Two ESUs have increased to near the established recovery goal and are rated "Approaching Goal."

ESU	ESA Status	Current Conditilon
	Chinook Salmon	
Upper Columbia Spring	Endangered	In Crisis
Lower Columbia	Threatened	Not Keeping Pace
Puget Sound	Threatened	In Crisis
Snake River Fall	Threatened	Approaching Goal
Snake River Sping/Summer	Threatened	In Crisis
	Coho Salmon	
Lower Columbia	Threatened	Not Keeping Pace
	Chum Salmon	
Columbia River	Threatened	Not Keeping Pace
Hood Canal Summer	Threatened	Approaching Goal
	Sockeye Salmon	

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Ozette Lake	Threatened	In Crisis
	Steelhead	
Lower Columbia	Threatened	Making Progress
Middle Columbia	Threatened	Not Keeping Pace
Puget Sound	Threatened	In Crisis
Snake River	Threatened	Making Progress
Upper Columbia	Threatened	Not Keeping Pace

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Table 2. Applications of different kinds of salmon recovery diagnosis and planning tools (developed from Roni et al. (2018), which contains examples and literature references).

Tools	**Set Goals**	**Assess Condition**	**Identify Problems & Actions**	**Select Restoration Techniques**	**Prioritize Actions & Projects**	**Design & Monitoring**
Models						
Limiting factors	X		X			
Life-cycle	X		X			
Ecosystem Diagnosis & Treatment	X		X		X	
Intrinsic potential	X	X				
Climate change	X	X		X	X	
Food web	X			X	X	
Watershed Assessments						
Sediment budget	X	X	X	X	X	X
Hydrology	X	X	X	X		X
Water Quality/Nutrients	X	X	X	X		
Riparian mapping	X	X	X	X	X	
Floodplain condition	X	X	X	X	X	X
Connectivity	X	X	X	X	X	
BOR reach assessment		**X**	**X**			X
HEC River Analysis System						X
Habitat Suitability Index						X
Habitat assessment	X	X	X			
Spawner surveys		X	X			
Juvenile fish surveys		X	X			
Effectiveness monitoring				X	X	X
Decision Support						
Multi-attribute utility theory	X			X	X	X
Structured decision making	X			X	X	X
Analytical hierarchy/network process	X			X	X	X

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Table 3. Salmon monitoring efforts for adult and smolt Chinook salmon and Steelhead in the Puget Sound region. The populations listed are all monitored for adults. However, in some watersheds these data are not collected in a manner that enables an estimate of the abundance of natural-origin, naturally spawning fish. The site of smolt monitoring is provided for locations where this metric is measured. In several cases, smolts generated by several populations are sampled at a single location. Populations without smolt monitoring are indicated by "none". The information in this table was provided by J. Anderson and J. Cram of the Washington Department of Fish and Wildlife.

ESU	Population	Smolts	Adults (X = natural-origin, naturally-spawning abundance available)
Puget Sound Chinook (ESA listed 1999)	Nooksack spring	Mainstem Nooksack	X
	Upper Skagit summer		X
	Lower Skagit fall	Mainstem Skagit	X
	Lower Sauk summer		X
	Upper Sauk spring		X
	Suiattle spring		X
	Cascade spring		X
	N.F. Stillaguamish summer	Mainstem	X
	S.F. Stillaguamish fall	Stillaguamish	X
	Skykomish summer/fall	Skykomish	X
	Snoqualmie fall	Snoqualmie	X
	White River spring	None	X
	Puyallup fall	Puyallup	Abundance of entire population not reported (just a subset of the population monitored)
	Cedar summer/fall	Cedar	X
	Sammamish summer/fall	Bear Cr.	Abundance of entire population not reported (just a subset of the population monitored)

	Green R. summer/fall	Green	X
	Nisqually R. summer/fall	Nisqually	X
	Skokomish summer/fall	None	X
	Mid Hood Canal summer/fall	Duckabush	Data represent a composite of natural + hatchery-origin fish
	Dungeness spring/summer	Dungeness	X
	Elwha summer/fall	Elwha	X
Puget Sound Steelhead (ESA listed 2007)	Drayton Harbor tributaries winter	None	Not monitored
	Samish winter	None	X
	Nooksack winter	None	X
	S.F. Nooksack summer	None	Not monitored
	Skagit summer/winter	Mainstem Skagit	X
	Baker summer/winter		X
	Sauk summer/winter		X
	Nookachamps winter		X
	Stillaguamish winter	Mainstem Stillaguamish	Abundance of entire population not reported (just a subset of the population monitored)
	Deer Cr. Summer		Not monitored
	Canyon Cr. Summer		Not monitored
	Pilchuck R. winter		X
	Snohomish/Skykomish winter	Mainstem	X
	N.F. Skykomish summer	Skykomish	Not monitored
	Snoqualmie winter	Mainstem	X
	Tolt R. summer	Snoqualmie	X
	N. Lake Washington/Sammamish winter	Bear Cr.	Not monitored
	Cedar R. winter	Cedar	Abundance of entire population not reported (just a subset of the population monitored)
	Green R. winter	Green	Data represent a composite of natural + hatchery-origin fish
	Puyallup/Carbon winter	Puyallup	Abundance of entire population not reported (just a subset of the population monitored)
	White R. winter	None	X
	Nisqually R. winter	Nisqually	X

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South Puget Sound tributaries winter	None	
East Kitsap winter	None	Not monitored
East Hood Canal winter	Big Beef Cr. Dewatto R.	Data represent a composite of natural + hatchery-origin fish
South Hood Canal winter	Tahuya R.	X
Skokomish winter	Skokomish	Not monitored
West Hood Canal winter	Duckabush R. Little Quilcene R.	Data represent a composite of natural + hatchery-origin fish
Sequim and Discovery Bay tributaries winter	Snow Cr. Jimmycomelately Cr. Bell Cr.	Abundance of entire population not reported (just a subset of the population monitored)
Dungeness winter	Dungeness R. Mattrioti Cr.	X
Strait of Juan de Fuca tributaries winter	McDonald Cr. Siebert Cr. Ennis Cr.	Abundance of entire population not reported (just a subset of the population available)
Elwha winter and summer	Elwha	Abundance of entire population not reported (just a subset of the population monitored)

Figure Captions

Figure 1. Locations of salmon and Steelhead recovery regions in the western U.S.A. and the number of evolutionarily significant units (ESUs) and species listed under the Endangered Species Act in each region. (from https://www.fisheries.noaa.gov/resource/document/status-esa-listings-and-critical-habitat-designations-west-coast-salmon-and)

Figure 2. Factors affecting the success of salmon recovery organized as a Driver-Pressure-State-Impact-Response conceptual model (Leemans and De Groot 2003). Impacts are expressed as changes in ecosystem services. Arrows indicate interactions among model elements and arrowed loops indicate multiple interactions of attributes within an element.

Figure 3. Relationship between wood and cutthroat trout (*Oncorhynchus clarki*) biomass and invertebrate biomass and trout biomass for 18 stream reaches in the Oregon Cascade Mountain. Drawn from data presented in Kaylor and Warren (2017). This study found that physical habitat features explained very little of the among-stream variation in trout biomass but measures reflecting food web processes were strongly related to biomass. Regression for invertebrate biomass versus trout biomass: trout biomass = 1.751(invertebrate biomass) + 0.895; R^2 = 0.71.

Figure 4. Population of Washington state from 1940 through 2020 and projections for future population through 2050 (data from Washington Office of Financial Management, Olympia, WA).

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Figure 1

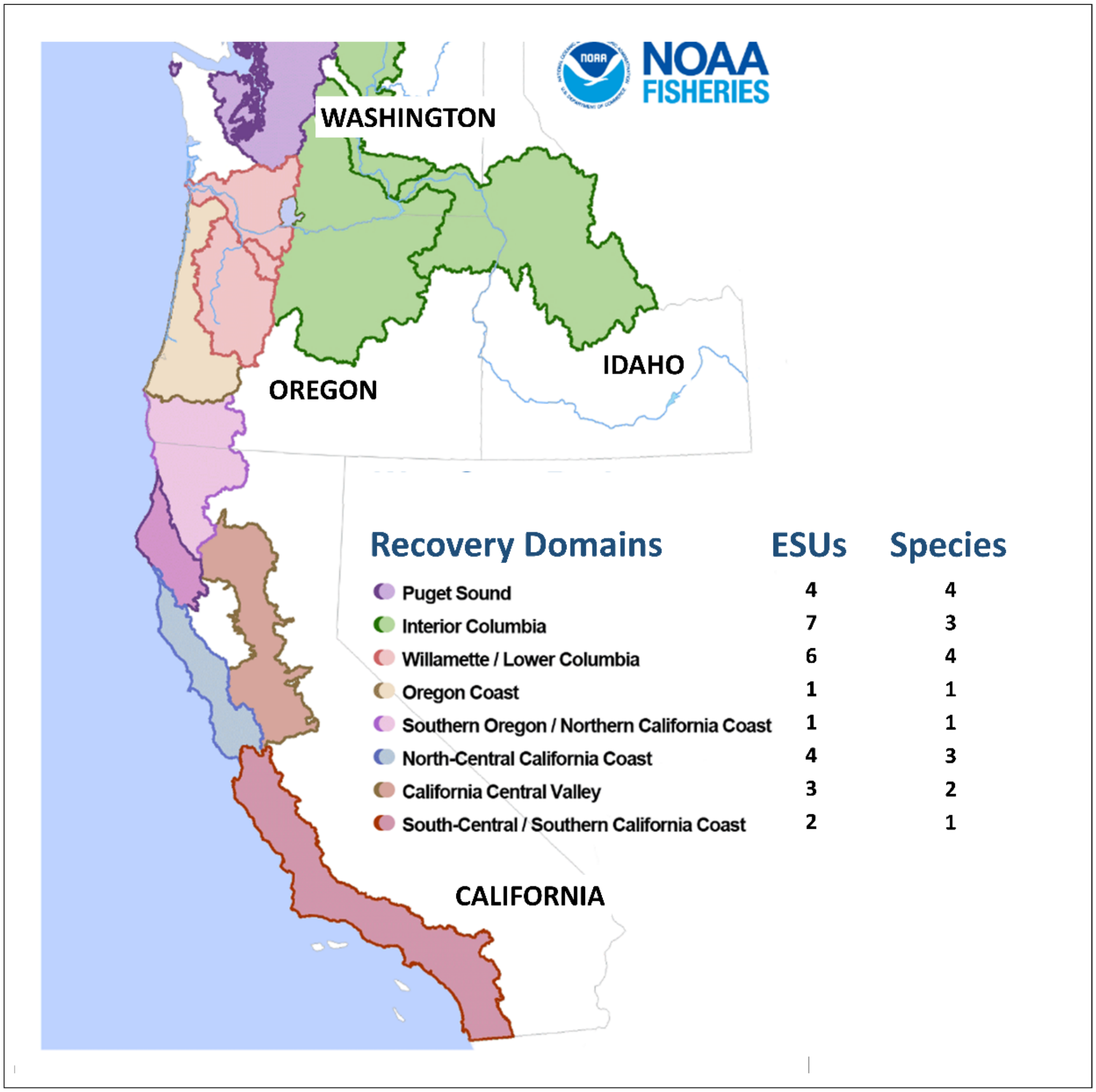

Figure 2

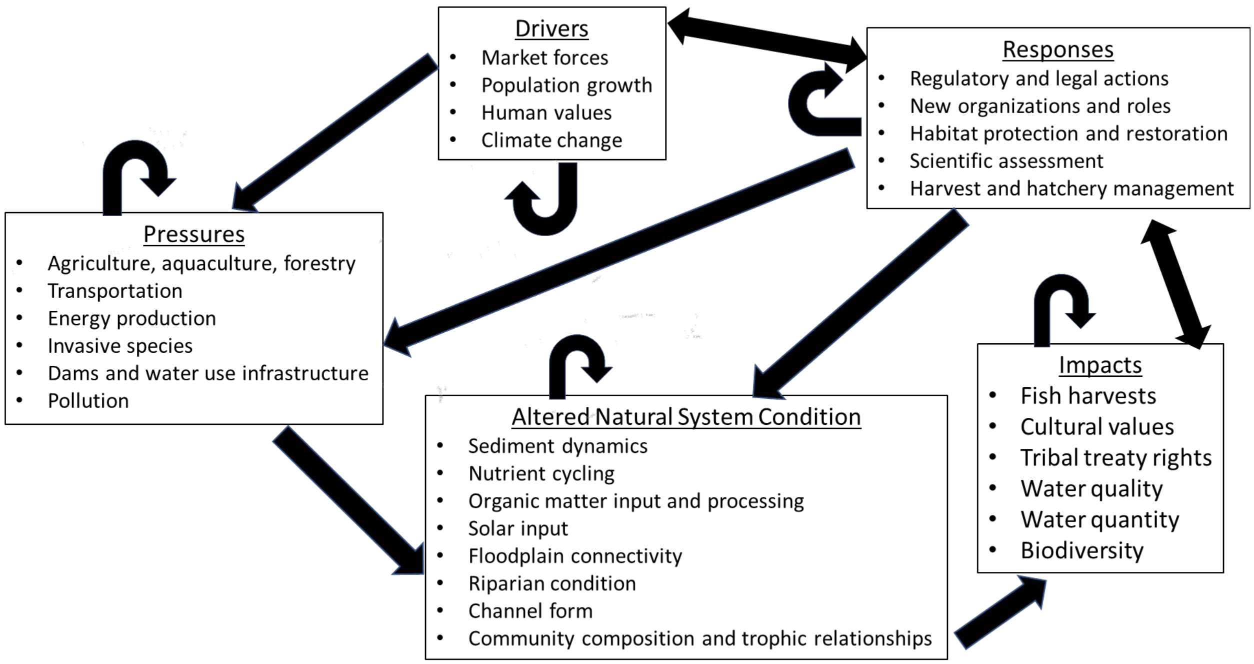

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Figure 3

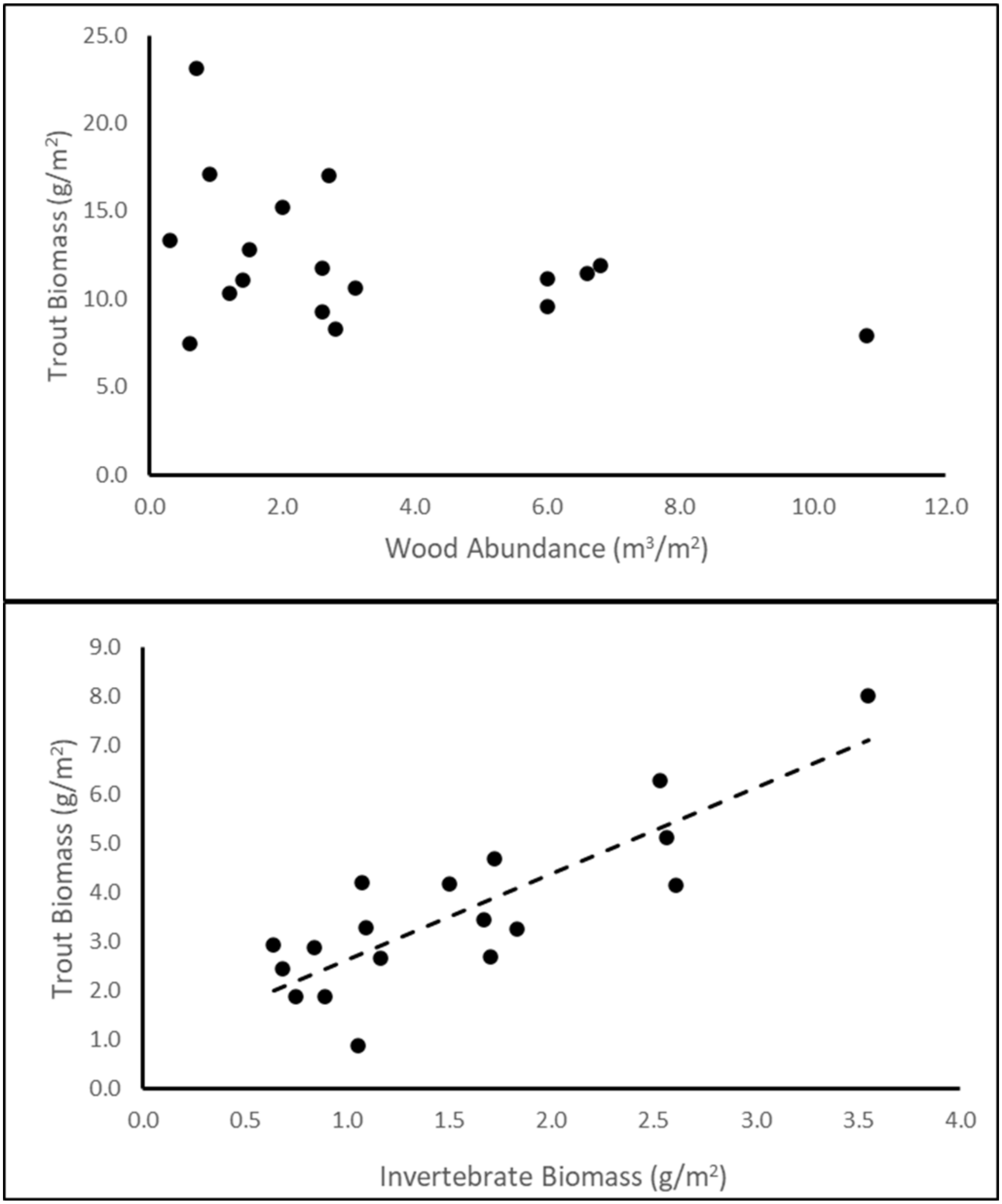

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Figure 4

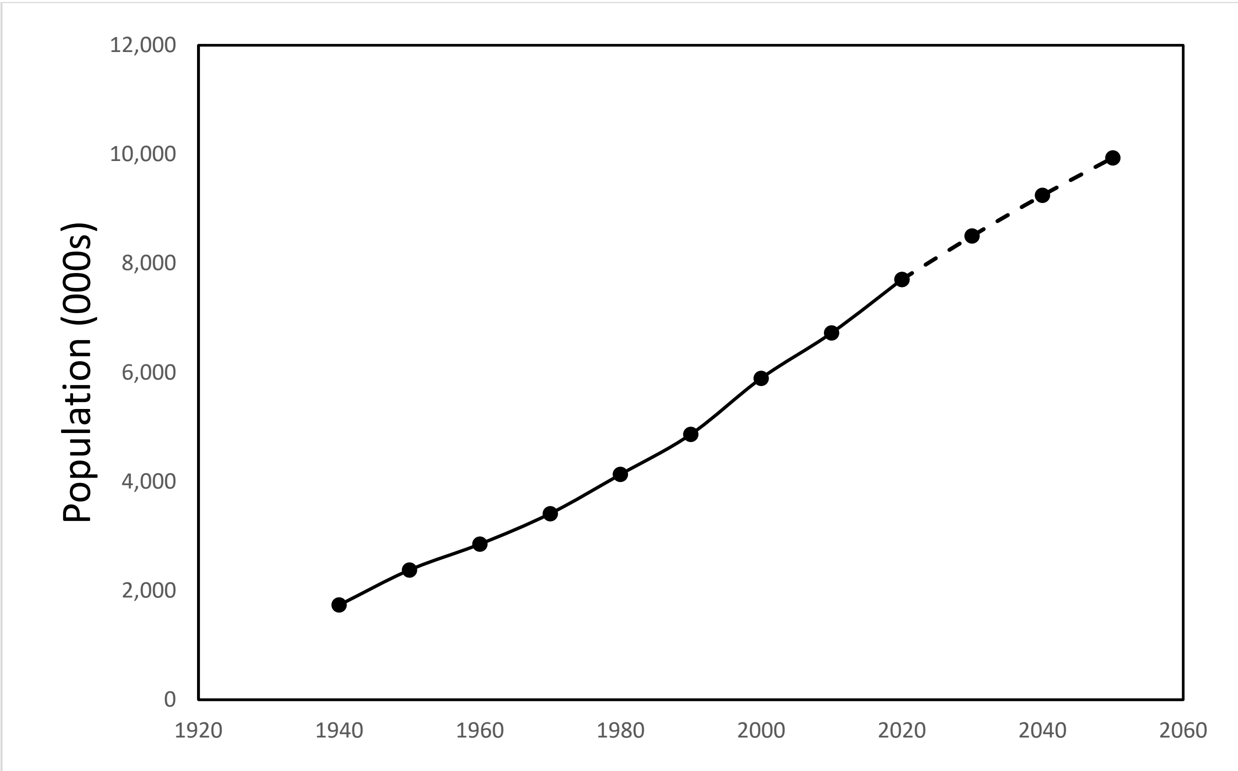

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Figure 1

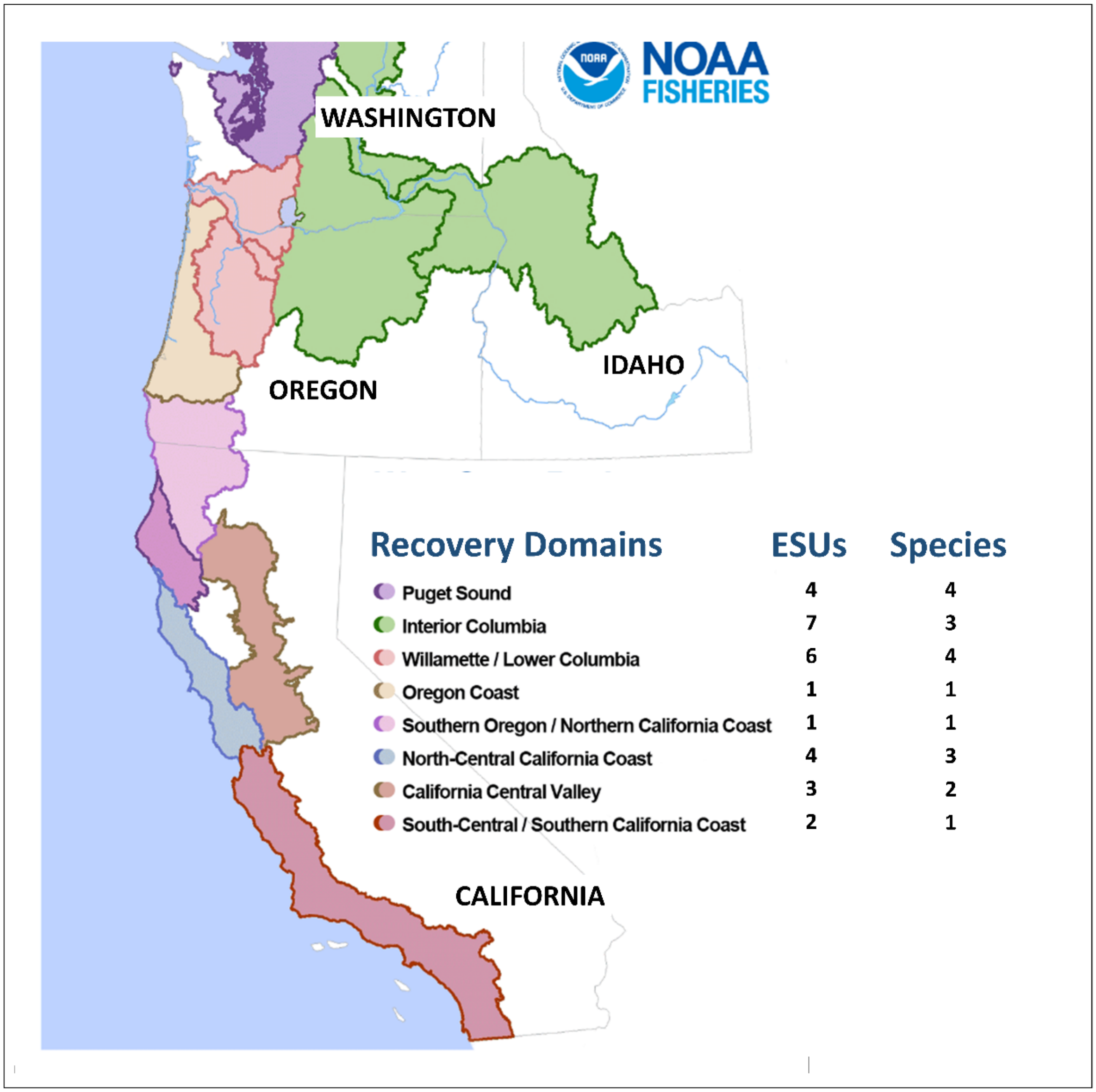

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Figure 2

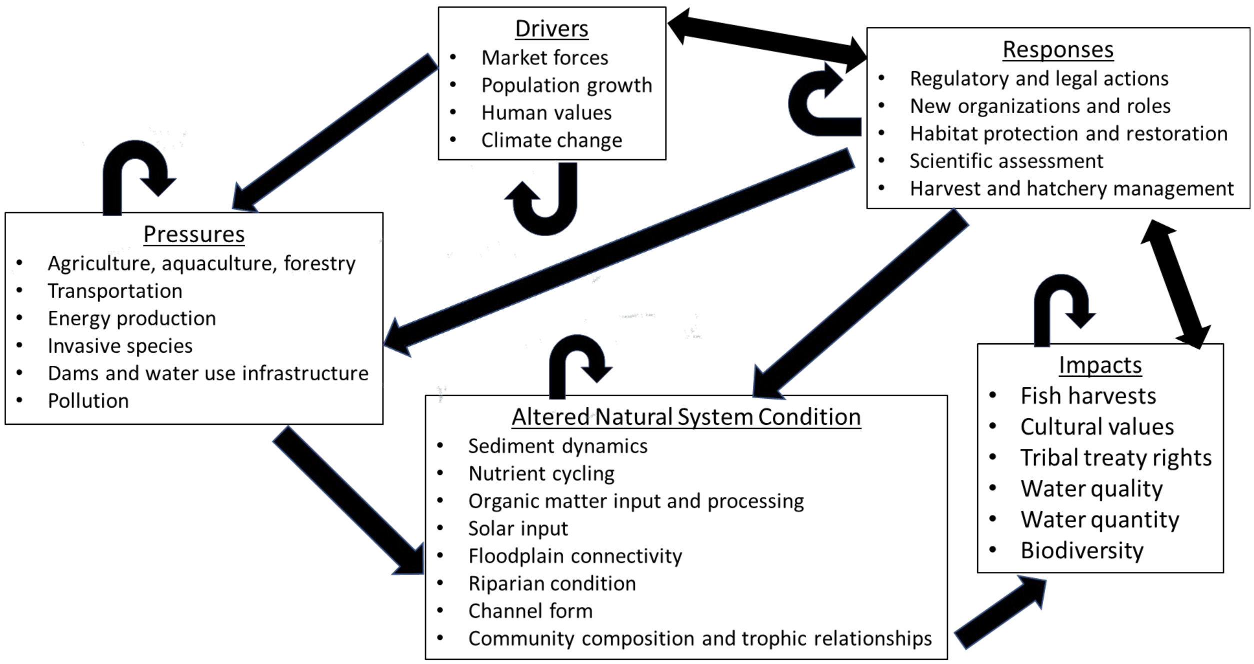

Figure 3

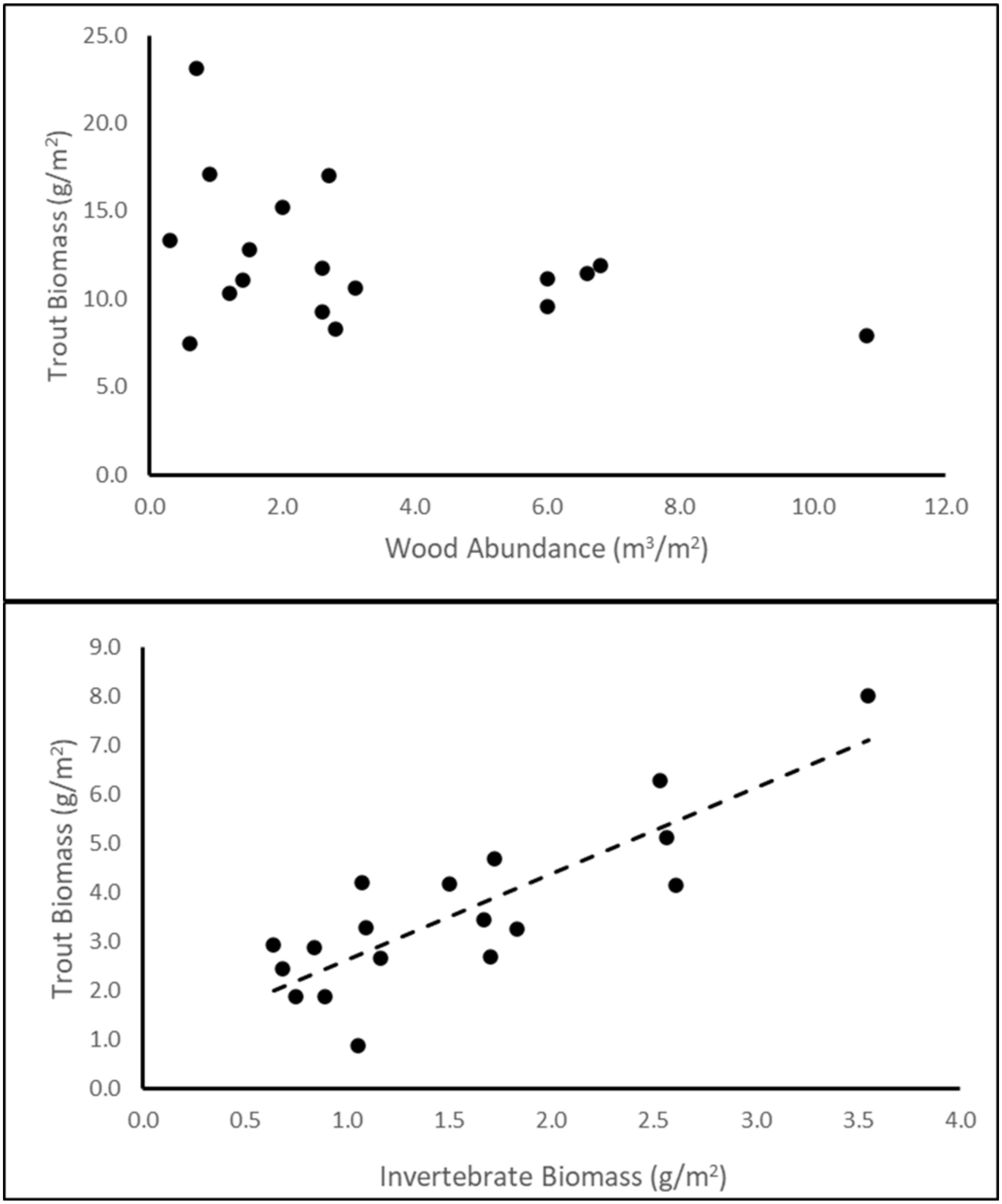

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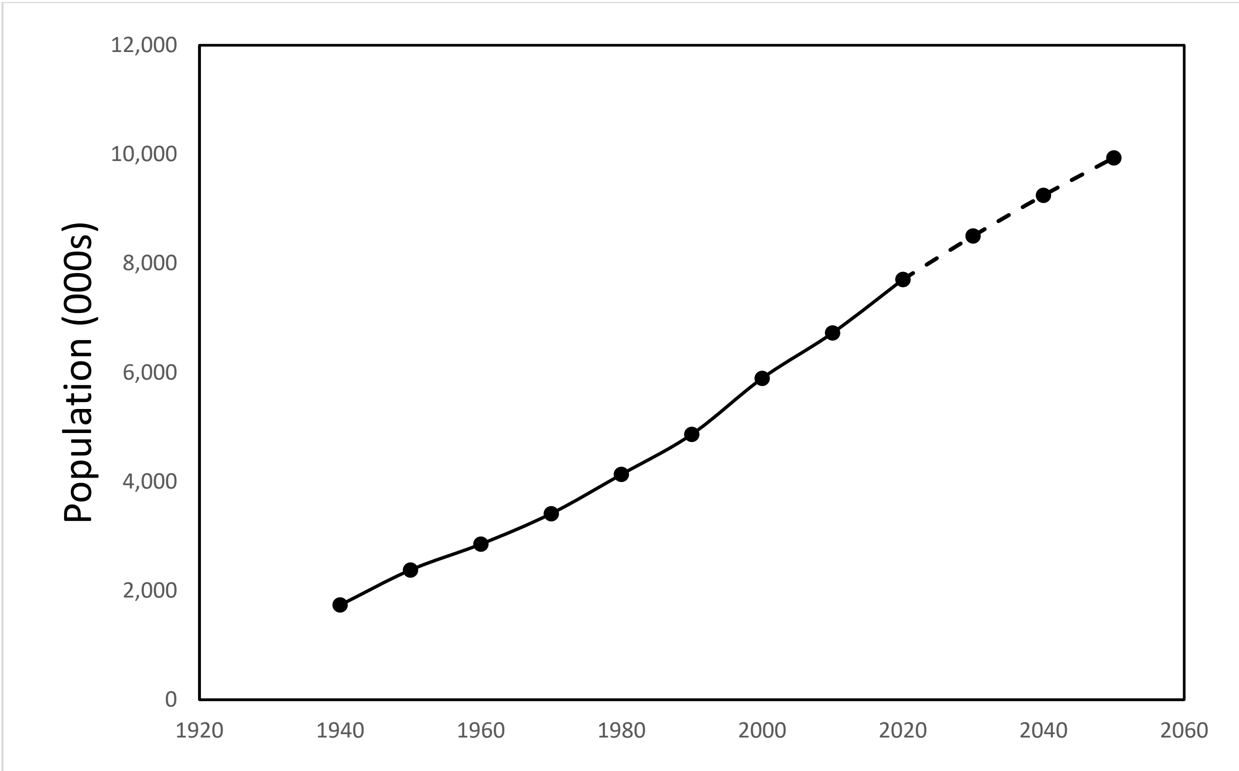
Figure 4



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Our responses to each of the Science Editors suggestions are in red below. We greatly appreciate the thoroughness and thoughtfulness of this review and feel that these changes have greatly enhanced the readability of the paper. The suggestion to simplify the titles used for the 5 factors impeding salmon recovery and apply this terminology consistently throughout the manuscript, was particularly valuable. We incorporated all the editor's suggestions except one (highlighted in yellow).

Science Editor
Comments to the Author:
I want to thank the authors for their revision of the manuscript that is now entitled, Why aren't salmon responding to habitat restoration in the Pacific Northwest? I have reviewed both the revised manuscript and the authors' comments regarding the revision. As their revision was substantial and generally satisfied the concerns of earlier reviewers, I did not send the manuscript out for another round of reviews. Instead, after my review of the revised manuscript, I recommend it for publication pending minor edits noted below.

One of the major recommendations I want to make is to be consistent in the language used for the "five primary factors." The exact wording differs from the abstract and lines 94 – 104, and then again as the section headings throughout the manuscript, and then again in the discussion (lines 368 – 370). I found myself constantly referring to the bullets of the introduction to determine where I was within the authors' initial listing as I read. For example, the subheading at line 253 does not have the same wording as either the bullets in the abstract or introduction. Personally, I suggest that the authors use: 1) Not enough restoration has been done; 2) We are not doing the right things in the right places at the right times; 3) Ongoing habitat degradation is offsetting restoration benefits; 4) Not enough time has passed; and, 5) Monitoring has been inadequate to detect changes in salmon abundance.
In some cases, the authors do a great job of keeping the reader focused when describing each of the factors above; but, other times, I found myself lost in how the wording related to the subheading itself because some of these primary factors overlap conceptually. I made specific suggestions on improvement by line number, below.

- We have made the suggested change in the wording of the 5 factors and used this terminology consistently throughout the manuscript.

Please also review literature cited for formatting consistency. For example, use a space after the colon or not, between volume number and page numbers, but be consistent. Capitalize "Island Press." Bennett et al.'s reference should not have a comma following the issue number; also note, issue numbers are not necessary.

- We have reviewed and corrected the Literature Cited section for the noted inconsistencies.

Use a consistent font throughout the manuscript. Note that the Table 3 legend appears to have a different font.

Line 47. Do not italicize "sp." and use "spp."

- Done

Line 57. As you had for Pacific salmon, provide genus and/or species nomenclature for steelhead, "steelhead (Onchorhyincus mykiss)."

- Done

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Line 78. Delete one of the "that"

- Done

Line 116. Use a semi-colon to separate references.

- Done

Line 126. Delete one of the "by"

- Done

Line 146. Insert "in" behind "such as…"

- Done

Line 148. Note the difference in font between sentences; please use consistent font throughout.

- The font throughout the manuscript is now consistent.

Line 173. Delete the comma behind "that"

- Done

Line 190. Insert "production" behind "salmon."

- Done

Line 217. Insert "of a restoration site" following "habitat condition".

- This sentence refers to general habitat condition in a watershed including both restored and unrestored locations. This paragraph indicates that salmon production is influenced by habitat condition as well as several other factors – like ocean productivity, hatchery impacts, etc. So, we are not addressing only restoration sites.

Line 259. For clarity, consider using "4.5-times its size from 1940…"

- Done

Line 260. Replace "Washington" with "Washington State" to be consistent with reference in line 259; or simply use "Washington" throughout.

- We have used "Washington" throughout the paper.

Line 262. As authors state that "…expansion of residential development…continues," can they provide a more recent reference than Robinson et al. (2005)?

- Added Batz et al. 2015.

Line 272. Please try to reference this section to the subheading by adding a line, something like… "The combined effects of developing watersheds and climate change can eclipse the potential benefits from restoration, making evidence of progress more clandestine."

- We have added the following sentence to the end of this paragraph "In many locations, the combined effects of development and climate change may limit the contributions habitat restoration can make to achieving salmon recovery goals."

Line 279. The authors note that project times can vary by location, conditions, and natural climate variation, but also indicate these factors can be modeled (lines 108 – 111) to help determine how much

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restoration is necessary to yield a satisfactory result in time. As that seems to overlap with the language here, I wonder if the authors would consider here also noting that there are factors that may not be predictable and affect the timeline of success. These could include understudied, complex species interactions or unknown environmental gradients. Without acknowledging some aspect of the unknowns and the unknowables, I think that the concerns of this section are largely redundant with those of the first section.

- We agree that the sentence noted is somewhat off subject. In this section we are trying to indicate that the time required for habitat and fish response to some restoration treatments can be lengthy. This sentence has been modified to simply indicate that response to restoration can take considerable time and that evaluations that do not persist long enough may come to an erroneous conclusion that the project has not been successful.

Line 309. Use a semi-colon to separate references.

- Done

Line 312. For consistency, use “Washington State;” or simply use “Washington” throughout.

- We have used “Washington” throughout the manuscript.

Line 313. Use “Table” and not “Tab.”

- Done.

Line 314. Should this be another paragraph?

- Yes. Done.

Line 315. Remove comma.

- Done

Line 327. For consistency, use “Washington State;” or simply use “Washington” throughout.

- Used Washington throughout.

Line 327. To improve readability, use “…that between 7 and 2 years of monitoring…”

- Done.

Line 336. Be specific with the word “diversity.” Do you mean genetic diversity, species or taxonomic diversity, or both?

- ESA recovery standards for salmon include criteria for abundance, population productivity, spatial structure (distribution of fish in a watershed) and diversity (phenotypic diversity like timing of adult returns or timing of juvenile emigration to salt water). These terms are defined in the McElhany et al. (1999) paper that is cited in this paragraph. We have added a brief explanation of the meaning of diversity in the context of salmon recovery.

Line 347. Spell-out Non-Governmental Organization; I did not see NGO referenced earlier in manuscript.

- Done.

Line 350. Use “Better communication among monitoring” and remove the “s.”

- Done.

Lines 368 – 370. The first factor should be, “not enough restoration has been done” and the second factor should be, “we are not doing the right things in the right places at the right times.”

- Done.

Lines 379 – 381. I suggest deleting these lines, “however, many restoration efforts have been…. anticipated fish responses” because this seems to contradict earlier statements in paragraph and in fact, could plague any of the five factors noted by the authors…thought I think the most likely is, “not enough time has passed.”

- Much of this text has been removed, as suggested. The sentence has been rewritten to emphasize that restoration in locations where there is little ongoing habitat degradation often fails to generate the desired fish response. So, while ongoing habitat damage is likely an important factor impacting fish response in some locations, it is not a factor everywhere.

Lines 388-389. I recommend deleting this statement, “We believe that there are several opportunities…” and replacing it with a section title in Bold, “Priority Recommendations”.

- Done.

Line 391. I recommend rephrasing as, “Do more restoration,” or otherwise use similar language as the first factor.

- Done.

Line 402. I recommend rephrasing as, “Do the right things in the right places at the right times” or something similar to relate directly to the language of the second factor.

- Done.

Line 440. I recommend adding another bolded section title, “Additional Recommendations” as these are not prioritized, but are still important.

- Done.

Line 468. Use “Table” and not “Tab.”

- Done.

Line 483. Insert space between “more” and “limited”

- Done.

Line 486. Use a section title in bold, “Conclusion”

- Done.

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