Protected Marine Resources on the West Coast of the United States: Assessing current management and opportunities for future research

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I. INTRODUCTION

NMFS manages the listing and recovery of marine species under the Endangered Species Act (ESA) and the protection of marine mammals Marine Mammal Protection act (MMPA). NOAA's West Coast Region, which includes marine resources in California, Oregon, and Washington, is host to 46 ESA listed species (or distinct population segments) and over 30 species of marine mammals protected by the MMPA. Salmon and steelhead (salmonids) are at the forefront of protected resources (PR) management in this Region, where 28 evolutionary significant units of ESA listed salmonids from six species are listed under the ESA. Other ESA listed species in the West Coast Region include killer whales, eulachon, and yelloweye and bocaccio rockfish. The ESA listing process does not permit economic analysis, but it can it can inform recovery planning and management decisions. Furthermore, federal management actions that impact protected resources are subject to regulatory reviews under the National Environmental Policy Act (NEPA), and may involve consideration of costs and benefits under EO12866 and EO 13563.

The ESA recovery planning process involves designating critical habitat (CHD) areas where human uses are limited to facilitate species recovery. Amendments to the ESA allow for exclusion of proposed critical habitat if the economic benefits of exclusion are sufficiently large, and the exclusion will not lead to species extinction. Government researchers and contractors estimate the potential economic costs of proposed CHDs to inform habitat exclusion decisions. Plantinga et al. (2014) concluded that current methodologies used to estimate the costs are sound, but inherent uncertainty makes development of useful estimates difficult. Further, the authors found no evidence that prior CHD economic analyses provided useful information for making exclusion decisions.

PR managers can also be compelled to employ economic analysis when significant federal actions impact listed species. These cases involve a net present value comparison of the costs and benefits of an action in accordance with EO12866 and EO 13563.

Several federal agencies recently collaborated to evaluate the costs and benefits associated with proposed removal of the Klamath River dams. Dam removal would improve habitat conditions for ESA listed Klamath salmon but would also modify ecosystem service flows and the welfare of stakeholders who depend on them. To evaluate the proposed dam removal, federal and federally contracted researchers conducted stated and revealed preference studies to estimate the costs and benefits of the dam removal and associated actions, across stakeholder groups.

Economic analysis has the potential to enrich PR research and inform species recovery planning. Within NOAA, a recent review of the West Coast Protected Fish Species Science Program noted that “The complete lack of discussion of coordination between the natural sciences and economics and other social sciences was noteworthy.” And recommended “more effort should be placed on integrating the relevant social and natural sciences that bear on recovery.” (NOAA 2015).

NOAA economists held a workshop in 2014 to initiate the process of identifying national social science research needs and best practices. A primary recommendation from the workshop was to conduct a high-level analysis that documents and assess species threats and the instruments used to reduce threats. The recommended analysis would also identify information needs for evaluating threats and research needs in PR economics research (NOAA 2014).

This report begins to implement the analysis recommended by the PR Economics Workshop for the West Coast region. Our approach is to assess threats, recovery actions, and information/research needs one protected species at a time. This report reviews the threats, scientific understanding, and recovery instruments associated with each listed West Coast species[1]. The objective of the report is to identify opportunities for economic analysis to contribute to PR management. To that end, the final chapter synthesizes the results across species and discusses opportunities for economic analysis to inform PR management and research.

This draft document applies the approach to Pacific salmon and steelhead, Puget Sound Rockfish, and Eulachon. The draft final chapter outlines emergent themes and economic research opportunities revealed in the preliminary analysis. Assessments of remaining listed fish, invertebrates, marine mammals, and sea turtles, are under development. These assessments and the resulting synthesis will be incorporated into subsequent versions of this report.

[1] Salmonids, rockfish, killer whales, other cetaceans, and seals are grouped into single analyses

II. PACIFIC SALMONIDS

CURRENT STATUS

Historically, massive annual runs of anadromous salmonids (genus *Oncorhynchus)* filled the estuaries, rivers, and streams along the U.S. West Coast. Over the past century, however, salmonid runs in the western U.S. have declined markedly due to a myriad of anthropogenic activities. An estimated 29 percent of the 1,400 distinct Pacific salmon populations in Oregon, Washington, and Idaho that existed in 1848 have been extirpated (Lackey, 2017). The remaining populations occupy an estimated 40% of their original range (Ruckelshaus et al., 2002), and most of these populations are less than 5 percent of their historical numbers (Lackey, 2017). Furthermore, half of the remaining salmon populations in the Pacific Northwest are thought be at risk of extinction (Ruckelshaus et al., 2002) and 84 percent of Columbia River salmonid populations are nonviable (McClure et al., 2003).

These declines have led to the listing of six species of Pacific salmonids (chinook, chum, coho, sockeye, and steelhead) under the Endangered Species Act (ESA). These listings afford protections for 28 evolutionarily significant units (ESUs) across Washington, Oregon and California. NOAA Fisheries defines ESUs as a stock of salmon that is substantially reproductively isolated from other population units and represents an important component in the evolutionary legacy of the species (NOAA, 1991). The following sections describe the threats facing West Coast salmonid species and then synthesize the body of scientific literature that seeks to understand the relative importance of those threats and the prioritization of recovery action alternatives.

THREATS FACING PROTECTED WEST COAST SALMONIDS

Salmon scientists have traditionally categorized the anthropogenic threats that affect Pacific salmon into four categories known as the four H's: Habitat, Hydropower, Hatcheries and Harvest. This section broadly reviews each threat category and discusses how the four H classification system fails to capture the true complexity of the situation facing protected salmon on the West Coast.

Rapid development in the West Coast region over the past 150 years led to significant degradation of salmon habitat. The sources of these impacts are diverse, and include agricultural, urban (e.g. residential, commercial, and industrial), waterway (e.g. dredging, channelization) and natural resource (e.g. forestry, mining) development. Moreover, over the course of their lifecycle, anadromous salmon occupy a diverse range of habitats, all of which are subject to modification by human activity. For example, human activity directly affects freshwater habitats that support spawning, rearing of juvenile salmon, and passage to sea. Essential salmon habitat characteristics subject to anthropogenic impacts include water temperature (freshwater and ocean), suitable spawning substrate and water quality (oxygen, toxicity, fine sediment) and water quantity (i.e. in-stream flow).

The second "H", hydropower, refers to the threats Pacific salmon face in freshwater habitats due to hydropower dams. In practice, hydropower is one of many economic benefits of dams. Others include water storage, transportation facilitation, and flood control. While dams provide services for some stakeholders, they also represent a threat to salmonid survival. Dams can impede passage for adult salmon returning to spawn and for juvenile salmon as they migrate to the sea. Dams also modify the habitat of freshwater salmonid environments, creating reservoirs where rivers once existed. These modifications can reduce the quality and quantity of essential fish habitats (e.g. reduce fry capacity of habitats) and modify the ecological communities living in those habitats. In many cases, changing the ecological community can pose additional threats for salmon (e.g. increased predation). Moreover, this discussion illustrates that the four Hs are not independent but rather overlapping and interrelated threats. The threats posed by hydropower, for example, interact and spill over into the threats associated with habitat degradation. The threat that dams pose to salmon in the West Coast Region is still a point of discussion in the scientific literature. For example, Hilborn (2013) notes that literature assessing the threat posed to salmon by the Columbia River dams is mixed. Specifically, he suggests that dams may not be the cause of salmonid decline. Moreover, he concludes that removing inland dams may not significantly improve the status of protected salmonid populations. A better understanding of the relationship between hydropower dams and salmonid population health would facilitate more accurate economic analysis of dam removal for salmon recovery.

Harvest of Pacific salmonid species has long provided value for tribal, recreational, and commercial fishermen. By the mid twentieth century, overharvest of Pacific salmon contributed to significant population declines for many West Coast populations. Today, commercial, recreational, and tribal harvests are a fraction of their historical levels. However, because it is difficult for fishermen to avoid catching weak stocks, and because salmon are a bycatch species in some West Coast fisheries (e.g. Pacific whiting,) harvest still represents a significant source of mortality for protected salmonid stocks.

A main function of salmon hatcheries is to supplement harvest to offset declining wild fish runs. Today, salmon hatchery objectives may include providing additional fish for harvest, supplementing weak stocks, and recolonizing areas where salmon have been extirpated. However, mounting scientific evidence suggests that hatchery fish can interfere with the viability of protected wild stocks through ecological (e.g. competition, increased predation of wild stocks) and genetic interactions (e.g. domestication through spawning) (Naish et al., 2007). Buhle et al. (2009) found that increased hatchery operations are associated with lower wild run productivity. Moreover, supplementation programs in the Pacific Northwest have largely proven ineffective at recolonizing rivers with viable salmonid runs (Waples et al., 2007)

Hatchery stocks affect wild populations through at least three pathways. First, hatchery salmonids can affect the viability of wild stocks through ecological interactions. Most notably, hatchery fish can compete with wild fish for habitat, food and other resources (Naish et al., 2007). Hatchery releases may also impact the predation rates of wild stocks by other salmonid and non-salmonid species (Naish et al., 2007). Genetic interactions are a second pathway by which hatchery fish impact wild salmonids. When hatchery fish interact genetically with wild runs, there can be negative consequences for the evolutionary trajectory and population viability of wild runs (McClure et al., 2008). This occurs because hatchery fish tend to possess lower fitness compared to wild fish (e.g. Araki et al., 2007). The lower fitness of hatchery fish is related to genetic changes that quickly occur after fish are domesticated. Christie et al. (2016) found that significant genetic changes occur within a single generation after domestication. Finally, hatchery operations can exacerbate the threat of harvest to wild stocks. Specifically, hatchery stocks can be sustainably harvested at higher rates compared to wild populations. Because commercial and tribal fishermen cannot effectively target wild vs. hatchery fish, harvesting hatchery fish at a sustainable rate may lead to overharvest of wild stocks (Naish et al., 2007).

While the four Hs provide a starting point for understanding the threats facing protected Pacific salmonids, these four categories have significant overlap and interdependencies. For example, hydropower projects can reduce available salmon habitat and lead to ecological shifts that increase salmon predation. Likewise, hatcheries can affect the quantity of habitat available to wild salmon (through competition) and the threat posed by salmon harvests. The threats described by the four Hs also interact with dynamic processes such as changes in climate and ocean conditions, and trends in human population growth and economic development (Maas-Hebner et al., 2016). Understanding the interdependencies among threats, and how external processes affect the severity of threats, is a challenging but essential question for salmon scientists moving forward.

EVALUATION AND ASSESMENT OF THREATS

As documented in the previous section, Pacific salmonids face an interconnected and dynamic array of threats. Furthermore, the threats facing salmonids vary significantly across populations. This section describes the criteria NOAA Fisheries uses to determine the viability of salmonid populations and then reviews literature evaluating the relative impact of threats on population viability.

NOAA's unit for endangered salmonid ESA listings is Evolutionary Significant Units (ESUs), which represent reproductively isolated groups of significant populations that share distinct evolutionary histories. Within ESUs, major population groups are defined based on their genetics, habitat (e.g. elevation), and life histories (e.g. timing, age at return). The viability of individual populations within these groups is evaluated by NOAA scientists based on their abundance (i.e. number of spawners over generations), productivity (i.e. growth rate of population), spatial structure[2], and diversity[3] (McElhany et al., 2000). NOAA assesses the viability of ESUs based on their resilience to catastrophic risk, facilitation of meta-population process, and maintenance of among-population diversity.

While scientists generally agree on the criteria for determining population viability, there is less consensus regarding how to model viability, and how threats influence viability. Many studies in the literature focus on linking a single threat or threat category to the viability of a single population or population group. These studies are important for understanding threats, but they often ignore the spatial heterogeneity and interdependencies of threats across the West Coast region. Studies that model multiple, interrelated threats, and weigh the relative impact of the threats, are especially useful for guiding more efficient population recovery plans. However, such models are difficult to develop and require data inputs that are often not available. Moreover, the diffuse nature of climate change, population growth, and other threats facing salmonids make understanding the relative influence of threats on populations especially difficult. Despite these challenges, a number of studies consider the influence of multiple salmonid threats simultaneously and assessed their relative effects on population viability (Fullerton et al., 2011; Hoekstra et al., 2007; Lawrence et al., 2014; Scheuerell et al., 2006) ; Fullerton et al. 2011). The results of these studies are largely context-specific, but they provide methodological foundations for future applications in new areas and contexts.

INSTRUMENTS OF RECOVERY AND THEIR RELATIVE EFFECTIVENESS

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[2] The geographic distribution of a population and the processes supporting that distribution. Rationale is to have multiple spawning reaches within a population and allow high-production "source" areas to supplement other population segments. Protects against catastrophic events and periods of low survival.

[3] considers life histories and traits, genetic characteristics, dispersal and gene flows

A myriad of threats face protected Pacific salmonid populations. Likewise, a number of ongoing programs are in place to facilitate fish passage and to increase propagation and survival rates. For example, fish ladder systems act as supplementary transportation of fish around challenging migration impediments, and have at least been modestly successful in mitigating the effect of dams on salmon populations. This section reviews literature on the effectiveness of recovery actions. We first describe available recovery actions and then review literature examining the relationship between recovery actions and salmon population outcomes. Finally, we review studies that apply economic analysis to evaluate and prioritize recovery actions.

Actions with the potential to promote recovery of protected salmonid populations include harvest reductions, reductions in hatchery releases, supplemental hatchery operations, predator management, and habitat restoration. Of these alternatives, a large share of recovery resources have been allocated to habitat restoration. One reason for this focus is that hatchery, harvest, or hydropower related recovery actions are likely to face opposition from entrenched stakeholders. (e.g. commercial and recreational fishermen, electric utilities, restoration specialists).

Habitat restoration falls into two categories: habitat quality restoration and habitat quantity expansion. For habitat quality, modifications are made to the in-stream or surrounding landscape (e.g. riparian tree planting, road decommissioning, and bank stabilization) to improve the quality of salmon habitat. Habitat quantity expansion occurs through removing barriers (e.g. dams, culverts) blocking access to upstream habitat or through construction of additional habitat capacity (e.g. side channels). Restoration actions can also include market-based strategies that provide incentives for landowners to conserve habitat or incentives that discourage further degradation. Examples include leasing water to provide fish with additional in-stream flows and compensating timber companies to not harvest in environmentally sensitive areas.

Scientists have developed biological models to understand the relationship between habitat features and salmon biological outcomes. These models can predict the biological response associated with habitat restoration. The scale of modeled biological responses range from population level to predicting meta-population impacts including connectivity and resilience. Some efforts also quantify the degree of uncertainty on the impacts of climate change on the biological response. Modeling can also predict the impact of climate change on restoration effectiveness, both in terms of improving habitat conditions and recovering species. Studies in the literature analyze the impact of alternative human disturbance scenarios on salmon metapopulation connectivity and resilience. Modeling can also predict the biological impact of installing technologies (e.g. fish ladders, fish-friendly tidal gates) that reduce the impact of grey infrastructure on fish passage (Greene et al., 2012).

The literature also suggests an increased focus on food webs in salmon habitat restoration and management (Naiman et al., 2012). One recovery action that explicitly considers food webs is predator management. In many cases, Pacific salmonids face predation from non-native species that thrive in modified habitats. For example, juvenile salmon face predation from introduced brook trout in upland streams and from walleye in lower river reaches, particularly in the reservoirs created by hydroelectric dams (Levin et al., 2002; Sanderson et al., 2009). However, predator management can be difficult when the predators are important recreational species (e.g. walleye in the Columbia) or when the predators are also protected species (e.g. protected sea lions at Bonneville dam).

Limiting commercial or recreational harvest is another alternative action to promote recovery of protected Pacific salmonids. However, this action can be difficult to implement. The tribes hold legal rights to harvest returning fish, and federal agencies are jointly tasked with the contradictory goals of recovering endangered fish while promoting salmon harvest (Lackey, 2017). In fact, protected Pacific salmon are the only ESA-listed species that many individuals are permitted to harvest (Lackey, 2017). Harvest of wild fish is generally prohibited in recreational fisheries. Anglers can identify wild fish through the presence of an adipose fin, and are compelled to release these fish. Past efforts have analyzed the impact of harvest policies on salmonid population viability. Specifically, Ford et al. (2007) estimated the level of exploitation that is consistent with population survival and recovery for Lower Columbia Chinook.

Conservation hatcheries and reductions to hatchery releases[4] are additional recovery action alternatives. Conservation hatcheries are hatchery operations aimed at restoring wild salmon populations and reducing the threat of extirpation. Conservation hatcheries fall into two categories. One category is supplementation programs, which introduce hatchery fish to increase the number of reproducing fish in a population. Supplementation is often undertaken to mitigate losses in declining or threatened populations (Fraser, 2008). The effectiveness of supplementation programs is unclear as some studies have found negative impacts for wild populations (e.g. Christie et al., 2012) while others have found supplementation programs can increase wild populations (e.g. Hess et al., 2012). In a review of 22 supplementation programs in the Pacific Northwest, Waples et al. (2007) do not identify a single case where supplementation led to a self-sustaining natural population. The second category is captive breeding programs, where endangered or extirpated populations are recolonized with captive-reared broad stock. A recent review of captive breeding programs (Fraser, 2008) found that they are largely ineffective, but may be more effective if implemented in concert with recovery actions that address the root causes of decline (e.g. habitat restoration). Mobrand et al. (2005) offer guidance for hatchery

[4] In cases where hatchery fish negatively affect wild stocks

reform in Washington State, emphasizing the importance of defining hatchery goals, making scientifically defensible policies, and adaptive management strategies.

Hydropower dam operations can be modified to facilitate salmon survival. For example, hydroelectric operations can allow water to spill over dams during high migration periods to facilitate survival of migrating juvenile salmon. Likewise, many dams are equipped with fish ladders to make passage possible for migrating adult salmon. In some cases, salmonids are captured and transported around dams to improve their chances of survival. Dam removal is another potential action that can promote recovery of protected salmonid populations. Dam removal can expand the quantity and improve the quality of salmon habitat. Recent removals of dams on the Elwha and White Salmon rivers in Washington State, and the approved removal of dams on the Klamath River, illustrate the emerging importance of dam removal as a salmon recovery action. The influence of dams on salmon survival, and consideration of dam removal as a recovery action is receiving increasing attention from policy makers. For example, a federal judge recently rejected NOAA's plan for protecting Columbia River salmon, stating that the influence of dams on salmon survival, and the possibility of dam removal should be more carefully considered.

There are an increasing number of ESA-listed Pacific salmonid populations and a limited budget for the recovery of those populations. From the perspective of resource managers, the question becomes: "for a particular population, which feasible recovery actions will most effectively reduce threats and improve population viability?" A number of prior efforts have addressed prioritization of recovery actions for Pacific salmon based on the anticipated biological response. Beechie et al. (2008) developed a qualitative decision framework to guide prioritization of habitat restoration actions. Fullerton et al. (2009) examined alternative futures simulations that predict biological response to restoration actions.

Holistic modeling approaches exist for evaluating recovery actions across habitat and non-habitat recovery alternatives. For example, the aforementioned Shiraz model (see Scheuerell et al., 2006) is a modeling tool that can inform prioritization across alternative habitat and non-habitat recovery actions.

Another branch of research focuses on incorporating the effectiveness uncertainty associated with climate change and economic development. S. C. Anderson et al. (2015) present a portfolio-based conservation approach to buffer against climate uncertainty. Seavy et al. (2009) suggest adapting current habitat restoration methods to be robust to climate change. Beechie et al. (2013) present a framework for habitat restoration under climate change. Battin et al. (2007) predict that climate change will reduce salmon habitat restoration effectiveness to a greater extent in high elevation areas, where little restoration is possible. The authors suggest that lower elevation salmon habitat restoration projects could be more successful in the coming decades.

ECONOMIC ANALYSIS OF RECOVERY ACTION ALTERNATIVES

This section reviews literature that applies economic analysis to recovery action evaluation and prioritization using cost effectiveness analysis (CEA) and cost benefit analysis (CBA). Restoration is likely not efficient when prioritized to minimize project costs or maximize project benefits, but Barnas et al. (2015) find that the selected restoration actions tend to be those with the lowest costs. Instead, recovery actions can be prioritized using CEA when the cost of recovery actions are quantified as well as the expected biological response. CEA asks the question: “what recovery action yields the largest expected biological response possible with a given recovery budget?” or alternatively “what is the least cost strategy for achieving a given biological response target?” A number of studies in the literature conduct cost effectiveness analysis across habitat restoration alternatives (Fullerton et al., 2010; Halsing & Moore, 2008; Newbold & Siikamäki, 2009; Null & Lund, 2012; Ogston et al., 2014; Watanabe et al., 2006; Watanabe et al., 2005) Paulsen and Wernstedt (1995) conduct a CEA across habitat, harvest, and hatchery-related recovery actions. Ogston et al. (2014) show that generating smolts via cost-effective restoration is similar in cost to the cost of hatchery smolt production. Fullerton et al. (2010) incorporate restoration costs within a simulation framework to capture the economic and biological uncertainty associated with alternative recovery actions. Watanabe et al. (2006) find that targeting habitat features rather than biological recovery can lead to substantial inefficiencies.

The location of where restoration is undertaken affects an action’s effectiveness. Watersheds are spatially connected and water flows downstream. Moreover, the spatial distribution of fish across river basins is an important component of viability for ESUs (McElhany et al., 2000). It follows that the impact of habitat restoration varies significantly depending on where the habitat is restored (e.g. Fullerton et al., 2010; Newbold & Siikamäki, 2009; Null & Lund, 2012; Watanabe et al., 2006; Watanabe et al., 2005). Further, Barnas et al. (2015) found that enacted restoration projects in the Pacific Northwest tend to be mis-aligned with the biological needs of salmon at the sub-watershed scale. For managers, the implication is that the choice of restoration location and if possible, restoration effort, should be spatially targeted at the sub-watershed spatial scale.

Cost effectiveness analysis allows for prioritization of alternative recovery actions based on cost subject to a specified budget or biological target. However, socially efficient allocation of recovery resources requires knowledge of which policy alternatives yield the largest net present benefits to society. The benefits from a recovery action include the total economic value of both salmon recovery, and changes in ancillary ecosystem services. An economically efficient recovery plan maximizes the net present economic value of recovery actions subject to fulfilling population viability objectives. Implementing economically efficient recovery is complicated by valuation of the ecosystem service changes, and other non-market values, associated with recovery actions. Previous studies have measured the value of Pacific salmon recovery (Bell et al., 2003; Layton et al., 1999), and the ecosystem service changes associated with salmon recovery actions including stream habitat restoration (L. E. Anderson & Lee, 2013; Collins et al., 2005; Loomis et al., 2000). Other research has investigated the regional economic impact of restoration activities in terms of employment and expenditures (e.g. Nielsen-Pincus & Moseley, 2013).

Dam removal is a recovery action associated with a multitude of ecosystem service changes affecting a diverse set of stakeholders. Because of these characteristics, dam removal should be evaluated with CBA. Estimating the associated welfare changes entails evaluating a range of market and non-market ecosystem services. This requires a large effort, but is possible as evidenced by the Department of Interior (DOI) led CBA of the proposed removal of the Klamath River Dams (DOI, 2012). Thus, while they are difficult to estimate, recovery action evaluation should incorporate the total economic value of ecosystem service changes when it is feasible and appropriate.

A ROLE FOR ECONOMIC ANALYSIS IN SALMON RECOVERY

The preceding sections reviewed the threats facing protected Pacific salmon populations, alternative recovery actions, and methods for prioritizing recovery actions. The breadth of issues covered in this review illustrates the complexities involved with recovery of Pacific salmon populations. Sources of this complexity include:

1. The complex life histories of salmon and the wide range of habitats they occupy;
2. The diverse set of stakeholders and associated values for salmon resources and habitat;
3. The complex institutional landscape spanning state, federal, and tribal arenas;
4. The interactions among threats facing Pacific salmon populations and;
5. The uncertain impact climate change will have on salmon across their diverse habitats.

This section synthesizes the information reviewed in the preceding sections to identify areas where economics and other social sciences may contribute to informing efficient and effective policies for Pacific salmon recovery. We begin by describing an idealized procedure for identifying and prioritizing salmon recovery actions. Using the previously reviewed literature as context, we then aim to identify where economics and other social sciences can contribute to the process.

The core objective of the ESA is to recover endangered species. Thus, effective recovery strategies should be crafted upon an understanding of how human activities and the natural environment influence the viability of salmon populations moving forward. Models of these processes already exist for specific areas and contexts. Ideal models will accurately incorporate the myriad of factors influencing population viability and capture the interplay among these factors across time and space. Moreover, the spatial scope of models would be expanded to at a minimum, the extent of habitat utilized by a given ESU. The models should be spatially explicit at the sub-watershed (e.g. HUC6 or smaller) scale to sufficiently target the biological needs of a given watershed (Barnas et al., 2015). Ideally, these models will also account for species interactions in the multiple habitats salmon occupy.

A next step in identifying effective instruments of Pacific salmon recovery is constructing scenarios that define how factors affecting population viability evolve from their baseline state over time. These scenarios require specification of alternative futures for climate change and human development. These scenarios can then serve as inputs into the population models to construct status-quo population viability predictions under a given set of assumptions.

With baseline scenarios specified, analysts may then construct a set of specific recovery actions expected to influence salmon population viability. Next, sets of recovery actions can be identified that, according to the specified models, will achieve population (ESU) recovery objectives. Potential recovery plans can be winnowed down based on their recovery performance and institutional feasibility. Recovery performance would be judged based on their ability to influence viability (production, diversity, spatial structure) and the robustness of their performance across the alternative future scenarios. The models should also account for the interactions among the recovery actions in a given recovery plan and be readily adaptable to new information as it becomes available.

Economics, which concerns itself with the efficient allocation of scarce resources, brings tools to bear for comparison of alternative recovery plans. One tool, cost effectiveness analysis, requires information on the costs of alternative recovery actions. If scenarios are constructed as defined above, cost effectiveness analysis assigns costs to the alternatives so that the lowest cost plan for meeting biological goals can be selected. Alternatively, if restoration managers are tasked with allocating a specified budget, cost effectiveness analysis prioritizes alternatives that generate the largest biological response per restoration dollar spent. Cost effectiveness analysis is most useful in cases where the costs associated with a given recovery action are easily observed. This is generally the case, for example, when prioritizing alternative habitat restoration projects. There are a number of studies that use CEA to prioritize restoration actions (Fullerton et al., 2010; Halsing & Moore, 2008; Newbold & Siikamäki, 2009; Null & Lund, 2012; Ogston et al., 2014; Watanabe et al., 2006; Watanabe et al., 2005). However, these studies consider only a small fraction of the potential areas and actions considered for restoration. Given the significant resources that are spent on Pacific salmon habitat restoration, expanding the use of CEA could substantially improve the effectiveness and efficiency of these restoration efforts. Such an expansion of CEA for habitat restoration would involve scaling up existing biophysical models of salmon population viability across basins[5]. While this would require significant resources and effort, the methods and data are available, and the potential for efficiency gains are significant. Furthermore, such models would enable restoration managers to map restoration priorities across the landscape and craft appropriate land-acquisition strategies. Of note, these models should predict population recovery rather than habitat improvements, as the habitat needs of salmon populations are heterogeneous across the landscape (Watanabe et al., 2005).

Cost benefit analysis (CBA) offers a more comprehensive method for evaluating recovery actions compared to CEA. The advantage of CEA is its simplicity, as CEA only requires information on the costs and expected biological response alternative recovery actions. The downside of CEA is that it does not account for the benefits of the prioritization analysis. Thus, CEA equally ranks actions that incur the same costs and produce the same biological response, even if one of those actions is associated with significant ancillary benefits and the other is not. Habitat restoration, for example, generally influences a variety of ecosystem

[5] Currently these models have been developed for only a limited number of watersheds areas.

services in addition to protected species recovery. These services may include flood control, water filtration, recreation, aesthetic value, habitat provision for other species, etc. Evaluation of habitat restoration alternatives with CBA compares the net benefits of actions, including the changes in ecosystem service values.

The advantages of CBA are most pronounced when the costs and benefits of recovery actions are not observable in markets, and when the action affects several diverse groups. Dam removal, for example, is a recovery action alternative that affects a variety of stakeholder groups, and leads to ecosystem service changes whose values cannot be observed in markets.

Conducting CBA involves a variety of tasks including determination of an affected population, defining a discount rate, and estimating a stream of current and future costs and benefits. All of these tasks are important, but estimating the stream of non-market costs and benefits presents a particular challenge, and an opportunity for economists to contribute to more efficient protected species recovery plans. These values can be estimated with revealed preference or stated preference methods. Appropriate valuation of non-market goods and services requires significant expertise and financial resources. When estimation of these values is not feasible, rigorous application of benefit transfer[6] (BT) methods can also inform CBA for recovery actions. Beyond direct application of BT to CBA efforts, BT may also inform the decision of whether to undertake a full CBA (i.e. cases where estimating full benefits and costs of an action could lead to large efficiency gains) vs. when CEA is sufficient.

The paragraphs above outline an idealized process for developing effective and efficient recovery plans for Pacific salmon. In reality, significant obstacles exist to actually implementing such plans. Institutional challenges are among the most significant obstacles. For example,

[6] Benefit transfer involves applying values derived from some study site, to a different policy site

federal laws and tribal interests promote the operation of fish hatcheries, which may interfere with the status of protected wild salmon populations. Likewise, many of the large hydropower dams on the West Coast are publically owned, and represent large, entrenched bureaucracies. In the Columbia system, for example, power from federal dams is marketed widely using a federally-owned transmission system. Furthermore, a portion of revenues from the federal dams is used to fund salmon habitat restoration projects as mitigation for their negative impacts. In addition, federal and state agencies are tasked with both conserving protected salmon populations and promoting salmon harvest, two objectives that are often at odds.

Lackey (2017) claims that efforts to recover declining Pacific salmon have given rise to a "salmon recovery industry" that public bureaucracies and associated contractors now depend on. The authors advocate for increased focus on the public policy and economic aspects of salmon recovery. Looking back on decades of salmon recovery policy, the authors identify conflicting policy priorities, limitations of the ESA, market forces, competing resource users, and future population growth as public policy issues that must be addressed to bring about Pacific wild salmon recovery.

The number of federally listed salmon species has been growing for decades but resources for salmon recovery are scarce. If these conditions persist, a day may come when allocation decisions will involve tradeoffs between salmon ESUs. With regard to this possibility, scientists have discussed a form of recovery triage (e.g. Levin & Stunz, 2005), where resources are diverted from ESUs that are "too far gone" to those for which recovery is possible. If this situation arises, economic analysis could help to compare the expected biological response achievable across ESUs with the available resources. Moreover, stated preference studies could measure public preferences for species recovery outcomes to further illuminate management trade-offs and inform the allocation of resources across ESUs.

Conflicting protected species mandates can present a further obstacle to endangered salmon recovery. One visible example of this emerges from recent heavy predation of salmon by protected sea lions below Bonneville Dam on the Columbia River. Management of the sea lions is limited by the MMPA despite their threat to listed salmon. A second case of conflicting protected species mandates occurs when MMPA and ESA protected Southern Resident Killer whales prey upon the ESA listed Puget Sound salmon population. These and other cases of conflicting and overlapping mandates suggest the need for more holistic, ecosystem-based approaches to management of ESA listed Pacific salmon.

The literature on Pacific salmon biology, management and recovery collectively echoes a number of important themes that help define ideal Pacific salmon recovery policies. First, recovery policies should be robust to uncertainty, particularly the uncertainty related to climate change. Second, recovery policies should consider the complex set of interdependent threats facing salmon. Third, recovery policies should be readily adaptable to emerging science, environmental change and institutional change. Finally, and most relevant to the current report, is that recovery policies should account for the economic tradeoffs associated with salmon recovery policies. Economic analysis can contribute to this discussion through estimation of the total economic value, and associated distributional impacts, associated with alternative salmon recovery policies. Economics can further contribute through analysis of the institutions (e.g. regulations, property rights, informal agreements) and stakeholder dynamics associated with salmon recovery management.

III. EULACHON

Eulachon (*Thaleichthys pacificus*, Osmeridae), also known as “hooligan” or “candlefish” is a small (adults 200-254 mm) anadromous fish from the smelt family that occupies coastal areas in the Northeast Pacific Ocean. Eulachon populations range from northern California to the southeastern Bering Sea coast of Alaska (Willson et al. 2006, Moody and Pitcher 2010). The fish live their adult lives (2-5 years) at sea before returning to freshwater to spawn from late winter to spring (Gustafson et al. 2010). Eulachon spawning habitat is characterized by cool waters (4-10 degrees centigrade) in the lower reaches of large, snow melt-fed rivers (Gustafson et al. 2010). Likewise, Eulachon thrive in cool, nutrient rich marine waters. Eulachon have long been an important harvest species for local native peoples who use their oil (Eulachon are 15-20 percent fat). Commercial and recreational fisheries also exist for the species in its freshwater habitats (Gustafson et al. 2016).

The process of listing eulachon as a protected species began in 1999 when NMFS was petitioned to list the Columbia River population under the Endangered Species Act. This petition was rejected due to a lack of supporting information. In 2007, the Cowlitz tribe again petitioned to list eulachon, this time for all populations in OR, WA, and CA. After analyzing genetic and ecological eulochon data, NMFS’s biological review team (BRT) found that a distinct population segment (DPS) of eucholon exists from northern California to an area near the Fraser River in British Columbia. This “Southern DPS” can be further divided into four subpopulations: Fraser river, Mainland British Columbia, Columbia River and tributaries, and Klamath River populations. The BRT further found that the Southern DPS Eulachon faced a “moderate risk of extinction throughout its range”. The Southern DPS Eulachon was listed as Threatened in 2010 under the ESA.

A review of the status of the Southern euchalon DPS was conducted in 2016. The review found that since listing, eulachon abundance had increased in all four Southern DPS subpopulations. However, the review concluded that the listing status of the eulachon should remain unchanged since abundance increases were related to temporarily favorable ocean conditions which had since dissipated. In the words of the status review report:

> "*Although eulachon abundance in monitored populations has generally improved, especially in the 2013–2015 return years, recent poor ocean conditions and the likelihood that these conditions will persist into the near future suggest that population declines may be widespread in the upcoming return years*." (Gustafson et al. 2016)

This finding underscores the difficulty with assessing recovery for the southern DPS eulachon. Observed population densities depend on stochastic environmental conditions, and can vary substantially from year-to-year.

Historical and recent observations of eulachon density further illustrate challenges involved in determining the status of Southern DPS eulachon. Historical accounts of Columbia basin eulachon runs describe an unpredictable fishery with significant variation in run size, spatial distribution, and timing (Gustafson et al 2010). Recent observations also reflect high variation the in density of Southern DPS eulachon in its freshwater and ocean habitats. In fresh water, for example, estimated total eulachon run biomass in the Columbia river between the years 2000-2010 ranged from a high of 3,105 mt in 2001 to a low of 35 mt in 2005 (Gustafson et al 2016). Evidence suggests that Eulachon density varies widely in the ocean as well. Particularly, the large variance in bycatch ratios (eulachon per mt of target fish) by commercial fishermen suggests significant inter-annual variation in densities of eulachon populations. Ward et al. (2015) examined eulachon bycatch in the west coast shrimp fishery and found “that increases in bycatch [are] not due to an increase in incidental targeting of eulachon by fishing vessels, but because of an increasing population size of eulachon”. In summary, determining the status of Southern DPS eulachon is challenging due to difficulties with separating the natural variation in population density from long-term population trends.

THREATS TO EULACHON AND THREAT UNCERTAINTY

In its 2010 status review, the BRT rated the threats facing each subpopulation of Southern DPS of eulachon from 1 (very low) to 5 (very high). On aggregate, the BRT rated climate change impacts on ocean conditions as the most severe threat facing Southern DPS eulachon. The BRT rated this threat as high-level or moderate-level across all four subpopulations. Other identified threats included: bycatch, dams/water diversions, predation, dredging, and climate change impacts on freshwater systems. The table below contains a summary of the threats facing southern DPS eulachon that received a moderate risk (3) or higher rating for at least one subpopulation.

Table 1. Eulachon Threats by Severity for Each Subpopulation[7]

Threat type	Threat description	Threat Severity			
		Klamath	Columbia	BC	Fraser
Climate change	Climate change impacts on ocean conditions	high	high	high	high
	Climate change impacts on freshwater habitat	moderate	moderate	moderate	moderate
Interactions with Human activities	Bycatch	moderate	high	high	moderate
	Dams / water diversions	moderate	moderate	very low	very low
	Dredging[8]	very low	moderate	very low	low
Interactions with other species	Predation	moderate	moderate	moderate	moderate
Habitat degradation	Water quality	moderate	moderate	low	moderate
	Shoreline construction	very low	moderate	low	moderate

Since its Threatened listing under the ESA in 2010, the abundance of Southern DPS eulachon has increased in each subpopulation. These increases are likely attributable to favorable ocean conditions during that period (Gustafson et al. 2016). However, recent conditions have been less favorable, including development of the "warm blob" during the winter of 2013-2014 and the subsequent strong El Nino that occurred from 2015-2016. Gustafson et al. (2016) concluded that these unfavorable ocean conditions, combined with an ongoing degradation of freshwater habitats, may reverse recent gains in eulachon abundance.

State of Available Science

Uncertainty is perhaps the greatest challenge in restoring eulachon populations. Particularly, fisheries scientists do not understand how environmental conditions directly or indirectly influence eulachon survival (Gustafson et al. 2016). Furthermore, observed abundance of

[7] As assessed by the 2010 BRT

[8] Can also degrade eulachon habitat

eulachon can vary widely, making it difficult to discern trends in population viability and the effectiveness of policy instruments aimed at population recovery. Reducing this uncertainty will require substantial research and monitoring effort. In its 5-year listing review (2016), NOAA recommended implementing monitoring that can adequately detect changes in eulachon habitat and eulachon survival. In terms of habitat assessment, this effort would include monitoring of large-scale oceanographic conditions in the California Current and analysis of how said conditions influence planktonic assemblages and in turn larval survival in nearshore environments. Some of this information is already being collected by NOAA scientists through the California Current Integrated Ecosystem Assessment. Furthermore, parallel monitoring and modeling efforts in freshwater environments are needed to understand how environmental conditions impact eulachon survival in riverine and estuarine habitats.

The Influence of Stakeholder Incentives and Government Regulations on Threat Persistence

Climate change impacts were the most severe threat identified by the BRT in 2010. The drivers and impacts of climate change are highly diffuse, meaning that many parties are both responsible for, and impacted by climate change at a global scale. Thus it is nearly impossible to make responsible parties internalize the external costs of climate change on eulachon populations. Because of this, it is highly unlikely that eulachon-specific policy instruments will be able to protect eulachon from climate-related impacts. Threats from interactions with human activities and habitat degradation are more easily addressed on a local scale. However, these threats are generally associated with economic activity (e.g. commercial fishing, river dredging, dams) and stakeholders may be reluctant to curb their production to improve conditions for eulachon. Understanding the incentive facing stakeholders and demonstrating the link between economic activities and eulachon population impacts is critical to crafting effective policies.

POLICY INSTRUMENTS USED FOR SPECIES RECOVERY AND THEIR RELATIVE EFFECTIVENESS

Current Instruments and Their Effectiveness

Since it was listed in 2010, the only regulation enacted for eulachon protection is the prohibition of take in California's inland waters (NOAA 2016). However, a limited number of existing regulations restrict stakeholders' operating in eulachon habitats. After its listing, areas of critical habitat were designated for eulachon in the lower reaches of a number of large rivers within its range. Further, the ESA stipulates that actions with a federal nexus must consult with NOAA when said action may affect eulachon populations or adversely modify designated critical habitat. In British Columbia, recreational fishing with nets is prohibited and there is a dredging moratorium within eulachon habitat. While not mandated by regulation, one of the most promising recent advances has been the development of LED excluder lights that help prevent eulachon bycatch in the ocean shrimp fishery.

Effectiveness of Current Instruments

Very few policy instruments directed at eulachon recovery have been deployed. The effectiveness of instruments that are in place is also largely unknown. This uncertainty stems from poor understanding of how biophysical conditions in eulachon habitat will evolve, and further from poor understanding of the mechanism linking biophysical conditions to eulachon survival and recovery. One recovery effort that has demonstrated success in reducing eulachon mortality is the development and widespread adoption of LED gear lights by shrimp fishers to reduce eulachon bycatch. In 2014, after observing high eulachon bycatch rates in the ocean shrimp fishery, Oregon Department of Fish and Wildlife developed LED gear lights as a technical bycatch reduction mechanism. Subsequent experiments suggested that these lights were highly effective. Particularly, 42 paired trials showed that gear equipped with the LED lights had 91% less eulachon bycatch compared to hauls using gear without the LED lights (NOAA 2016).

Potentially Promising Instruments

Determining which policy instruments will be effective in facilitating eulachon recovery requires a better understanding of the threats facing eulachon, and the mechanisms by which threats impact eulachon populations. Thus, the first step towards this goal is to gather existing data and developed models that explain biophysical processes within the eulachon's ocean and freshwater habitats. Next, researchers should determine what additional data, modeling, and monitoring is necessary to adequately understand those processes. Next, researchers should enact targeted population monitoring studies to better understand the eulachon lifecycle and the mechanisms by which biophysical conditions impact eulachon survival in each of its life stages. One challenge in implementing this strategy is that the drivers and impacts of climate change, which the BRT assessed as the largest threat facing eulachon, are not well understood. As climate science evolves, so will understanding of promising eulachon management instruments. On a positive note, this review concludes that opportunities exist for enacting recovery instruments that could improve the viability of other protected species (e.g. salmon and steelhead) as well as eulachon under the emerging ecosystem-based management framework. Protecting multiple species within the same policy instrument may tip the scales when evaluating the costs and benefits of that instrument (e.g. estuary restoration, dam removal).

IV. PUGET SOUND ROCK FISH

Yelloweye and Bocaccio rockfish live in Pacific Ocean waters from California to Alaska. Upon being petitioned, NOAA determined that the Puget Sound/Georgia Strait (hereafter referred to as Puget Sound) populations of Yelloweye and Bacaccio rockfish represent a Distinct Population Segment (DPS). Notably, the Puget Sound DPS extends north into the Canadian portion of the Salish Sea. In 2010 the Puget Sound DPS of yelloweye and bocaccio rockfish were designated threatened and endangered respectively. Canary Rockfish were also included in the original listing included but were delisted in 2017 after research (citation) found the Puget Sound population of canary do not meet the criteria for a DPS since they are not genetically distinct from the larger coastal population. Total rockfish abundance has declined by 70 percent over the past 40 years, while Bocaccio and Yelloweye stocks have declined by even further (NOAA 2015).

THREATS AND THREAT ASSESSMENT

NOAA's recovery plan (NOAA 2015) included an assessment of the threats facing rockfish in Puget Sound. The ESA directs scientists to assess five threat "factors" and determine whether species being considered for listing are threatened or endangered by impacts fitting within any of the five factors. The threat assessment considered the severity, certainty, and geographic range of the threat, as well as the potential for threat reduction. The five factors include: (1) the present or threatened destruction, modification, or curtailment of its habitat or range; (2) overutilization for commercial, recreational, scientific, or educational purposes; (3) disease or predation; (4) inadequacy of existing regulatory mechanisms; and (5) other natural or human-made factors affecting continued existence of the populations. NOAA scientists determined that threats from four of the five categories pose moderate to high risks to Puget Sound rockfish. For the fifth category, disease and predation, there were not enough data to determine threat severity. Table 2. presents a summary of NOAA's threat assessment findings by management unit. Notably, the relative severity of threats varies across space, a pattern that reflects heterogeneity and economic activity and urbanization across management units. Habitat-based threats pose the highest risk in the southern management units (Hood Canal, Main Basin, South Sound) through hypoxia and nearshore habitat disruption. Within factor (5), derelict fishing gear poses a moderate or high risk in northern (San Juan and Canada) and western (Hood Canal) three management units, but very low risk in the other southeastern management areas (Main Basin, South Sound). Conversely, contamination poses moderate or high threat in Hood Canal and the South Sound, but poses a low or very low risk in the other management units.

Commercial fishing for Puget Sound rockfish is prohibited, and recreational harvest is only a fraction of historical levels. Still, bycatch poses mortality risk to Puget Sound rockfish, primarily in the San Juan management unit.

The interrelated threats of climate change and ocean acidification pose a significant risk to future persistence of listed rockfish in Puget Sound. Likewise, all management units are face high risk from oil spill contamination.

In accordance with NMFS guidelines, bocaccio and yelloweye were assigned recovery priority numbers (1=high; 12=low) based on threat magnitudes, recovery potential, and conflicts with economic activity. Bocaccio were designated a priority number of three and yelloweye a seven based on the higher magnitude of threats faced by bocaccio.

Table 2. Summary of Threats Assessment for Management Units and Puget Sound/Georgia Basin (NOAA 2015)

	Listing Factor	Canada	San Juan	Main Basin	South Sound	Hood Canal
Derelict Fishing Gear	E	1	1	2	4	4
Commercial Catch/Bycatch	B, D	3	1	3	3	3
Recreational Catch/Bycatch	B, D	3	1	2	3	4
Nearshore Habitat Disruption	A	4	3	1	1	2
Deepwater Habitat Disruption	A	3	3	3	3	3
Non-native Species Habitat Disruption	E	P	P	P	P	P
Hypoxia/Nutrient Addition	E	4	4	3	2	1
Chemical Contamination/Bioaccumulants	A	3	3	1	1	2
		Entire Puget Sound/Georgia Basin				
Marine Mammal Predation	C	4				
Fish Predation/Hatchery Practices	C, E	4				
Competition	C	P				
Diseases	C	P				
Oil Spills	E	1				
Genetic Changes	E	P				
Anthropogenic Noise	E	P				
Ocean Acidification	E	1				
Climate Change		1				

A = Present or threatened destruction, modification, or curtailment of its habitat or range
B = Over-utilization for commercial, recreational, scientific, or educational purpose
C = Disease or predation
D = Inadequacy of existing regulatory mechanism
E = Other natural or manmade factors affecting its continued existence
1 = High risk
2 = Moderate risk

3 = Low risk
4 = Very Low risk
P = Potential threat. Not enough information to determine if it is a threat at the current time, but could plausibly become a threat in the future.

INSTRUMENTS OF RECOVERY AND THEIR EVALUATION

NOAA evaluates promise based on threat severity, uncertainty, and likelihood of recovery. The recovery plan is in progress and will outline recovery action priorities. Several recovery actions have been undertaken since the rockfish ESA listing. Government, academic, and conservation group researchers are also collaborating with local stakeholders to improve understanding of Puget Sound rockfish and the factors threatening their viability.

NOAA's 2015 draft recovery plan recommended and prioritized an additional 45 recovery actions for listed rockfish from five distinct categories. The categories included actions that improve understanding of rockfish abundance, biology, and habitat associations, actions that align fisheries management with recovery goals, actions that research and protect rockfish habitats, actions that educate fishermen on identifying rockfish and preventing rockfish bycatch mortality, and actions that secure additional resources for rockfish recovery. In 2010 the Washington State Fish and Wildlife Commission passed regulations prohibiting targeting of rockfish by recreational anglers. Managers also closed recreational angling for bottom fish in waters deeper than 120 feet to reduce rockfish bycatch (NOAA 2015).

On the commercial fishing side, Washington Department of Fish and Wildlife also closed several non-tribal fisheries in the summer of 2010[9]. As a condition for receiving an incidental take permit, WDFW initiated a monitoring and management program to reduce interactions with protected rockfish in two remaining Puget Sound fisheries. In particular, the state initiated an

[9] These included: the set net, set line, bottom trawl, inactive pelagic trawl, and inactive bottom fish pot fisheries.

observer program the shrimp trawl fishery and increased monitoring of bycatch in the recreational bottom fish fishery.

The Department of Fisheries and Oceans (DFO) in Canada also took action to protect listed rockfish from fishing threats. The efforts included improving stock assessments and monitoring and designating Rockfish Conservation Areas where fishing is limited. Using these tools, DFO's policy is to ensure that rockfish are subjected to fisheries mortality that is less than half that of natural mortality.

The Northwest Straights Commission received a federal grant to remove over 4,500 fishing derelict fishing nets and 140 pots from waters less than 100 feet (NOAA 2015). These efforts reduced the threat posed by derelict gear and improved habitat quality for rockfish. Removal of the remaining nets from deeper waters is ongoing.

To that end, NOAA funded a pilot program in the San Juan management area to detect and map deep water (i.e. >100 ft) derelict gear using sonar technology. NMFS is also working with partners to quantify mortality associated with derelict gear through genetic sampling of removed gear.

In 2012, Washington State passed a bill requiring non-tribal fishers to report lost nets within 24 hours of loss so that they can be retrieved. The legislature appropriated 3.5 million dollars to fund the program in 2013, leading to the removal 5,660 nets and 3,800 shellfish pots, and 813 acres of improved habitat (NOAA 2015). Additionally, a variety of government, conservation, and academic partners are collaborating to map and characterize the benthic habitat of Puget Sound in terms of its suitability for listed rockfish. This effort will inform, among other things, future abundance surveys, critical habitat designation reviews, and fisheries management.

Future habitat actions recommended by the draft recovery plan include restoring nearshore and deep water habitats, cleaning up contaminated sediments, and expanding habitat monitoring efforts. The recovery plan also recommends following Canada in designating priority habitats as protected areas for listed rockfish (e.g. marine protected areas or rockfish conservation areas) Uncertainty about the biology of Puget Sound rockfish and the threats they face is an obstacle to creating effective recovery plans. After their listing, NMFS initiated research to improve scientific understanding of Puget Sound rockfish. A number of these efforts leveraged the knowledge and perspectives of fishermen to inform policy. Notably, in 2013-2014 NMFS partnered with WDFW and recreational fishing guides in Puget Sound to locate and genetically sample listed rockfish. The samples revealed that Puget Sound canary rockfish are not a genetically distinct a DPS and led to delisting of canary rockfish in 2017. Ongoing studies of Puget Sound rockfish are targeted at understanding rockfish abundance, spatial structure/habitat usage, connectivity, diversity, and mortality (NOAA 2015).

Ongoing data collection and recovery projects include mapping and removal of derelict fishing gear, remote video surveys, trawl surveys and habitat mapping. In addition, research is being conducted to study historic abundance, larval dispersal, habitat function, habitat usage, and post-bycatch survival (NOAA 2015).

In 2015 NOAA released a draft recovery plan that recommended actions to reduce threats to listed rockfish and advance scientific understanding of listed rockfish populations. The draft recovery plan specifies rockfish recovery actions, including cost estimates and priority scores, which should be undertaken to recover the populations.

The actions target five objectives. The first objective is to further our understanding of rockfish science and the associated actions are largely scientific surveys, genetic testing and other biological research. The second objective is to align management with the recovery goals and the key actions are the establishment and monitoring of protected areas for listed rockfish. The third objective is to restore, protect, and research rockfish habitat. The associated actions include derelict gear prevention and removal, and research on rockfish habitat. The research investigates the potential impacts of climate change, ocean acidification, hatcheries, noise, contaminants, and predation on rockfish recovery outcomes. The fourth objective is to engage and educate fishermen and the public about rockfish recovery and reducing bycatch mortality. The budget for the recovery actions is 23.4 million. Further, the recovery plan recommends research to evaluate the potential impacts of Ocean Acidification and climate change on rockfish population viability and recovery.

SYNTHESIS AND OPPORTUNITIES FOR APPLYING ECONOMIC ANALYSIS

In many ways the listing and recovering planning process for Puget Sound Rockfish reflects effective implementation of ESA principles and objectives. After the rockfish listing, researchers initiated research to reduce the uncertainty associated with the determination that Puget Sound rockfish are a distinct population segment.

The research engaged local fishermen and leveraged their unique local knowledge to collect data on rockfish genetics. The results of this research revealed that canary rockfish do not represent a distinct population segment, a finding that led to delisting of canary rockfish.

The process that led to canary delisting illustrates two effective components of PR research. First, the researchers engaged local stakeholders to improve understanding of PR science (Andrews 2013; Beadreau and Levin 2011) and used historical population observations to inform delisting criteria (Williams et al 2010). Second, the delisting illustrates adaptive management, where management priorities and strategies are modified as understanding of recovery science develops. Additionally, the cost estimates of recommended recovery actions in the Puget Sound rockfish draft recovery plan are potentially useful for conducting future analyses. Economic analysis could further improve the Puget Sound rockfish draft recovery plan through a quantitative prioritization of recovery actions. The draft plan acknowledges that all of the actions in the recovery plan are not possible under current funding (NOAA 2015) levels yet rates 38 of 45 recommended recovery actions as the highest possible priority. Application of CEA or other analysis frameworks to the plan may further differentiate prioritization across actions. Still, the analysis conducted for Puget Sound rockfish listing and recovery stands out among considered species in terms of approach, implementation, and adaptability.

V. PRELIMINARY SYNTHESIS OF THE SPECIES ASSESSMENTS

NOAA's West Coast region supports numerous protected resources facing diverse threats that are being addressed with a variety of policy instruments. Moreover, the scientific understanding of species threats and limiting factors, and the prospects for recovery vary significantly across listed species on the West Coast.

This section presents an outline of themes related to the role of economic analysis in PR management that are emerging from the preliminary gap analysis. Research gaps in the social science PR literature are identified, as well as opportunities to apply economic analysis to inform PR management.

The current role of economic analysis in PR Management

Characteristics of PR science and management on the West Coast

- ESA takes species-by-species approach to recovery planning and management.
- Adaptive management is utilized to incorporate new science and information into listing, management, and recovery planning.

The contribution of economic analysis PR management is currently limited

- There is a role for economic analysis in the evaluation of environmental regulations (Arrow et al. 1996).
- CHD econ analysis constitutes the majority of studies (NOAA 2015).
- The dearth of economic analysis in the PR management process to is related to uncertainty surrounding the appropriate application of such analysis.
    - In particular, guidance is lacking on when to conduct analysis, which analysis to undertake, and relevant best practices related to that type of analysis.

Challenges to effective PR protection and recovery management

Resources for PR recovery and management are increasingly scarce

- Increasing listings but flat resources
- Could force tradeoffs among species, ESUs

Scientific uncertainty is an obstacle to PR recovery planning and management.

- Uncertainty in: baseline status, threat risks, impact of recovery actions, climate change, modeling, environmental conditions.
- Adaptive management is key for dealing with uncertainty
- Uncertainty in PR analysis should be quantified (including uncertainty in costs and biological recovery)
- Uncertainty can influence prioritization
  - Stochastic, population viability analysis can accommodate uncertainty. For example, by incorporating the probability of rare and catastrophic events.

Management Institutions pose obstacles to PR management and recovery.

- Overlapping and conflicting management objectives (ESA, MMPA, MSA[harvest objective])
  - Highlight salmon/SRKW/sea lion situation
  - MSA promotes harvest of protected salmon
- Entrenched interests related to management choices
  - Mitchell act hatcheries feed commercial harvest and pose threats to wild runs
  - Hydroelectric dams subsidize power and fund habitat restoration industry

PR research gaps and opportunities for applying economic analysis

Provide guidance on the use of economic analysis in PR management

- Guidance on when to conduct analysis
- Guidance on which evaluation tools to use
- Guidance on best practices for conducting analysis, including a defined set of standard assumptions (e.g. discount rate, time horizon, affected populations)
  - What is specific to PR – uncertainty, distributional impacts, irreversibility

Evaluate alternative recovery and management plans

i. CEA for habitat restoration prioritization
   a. Many alternatives? Overall objective species recovery/resilience? Difficult to value recovery.
   b. CEA may have unrealized potential for informing recovery action prioritization

ii. Non-market valuation required for CBA
   a. Key criteria for CBA is large non-market benefits
   b. Species recovery – multiple value types can be (+/-)
   c. When there are multiple objectives (e.g. ecosystem services or EBM) or when objective cannot be monetized.

d. When achieved benefits trade off with costs to another party.

iii. Distributional Considerations

a. Important too! (Arrow et al. 1996)
b. Can be significant (e.g. dam removal)

Address challenges associated with scientific uncertainty

- How does climate change, OA and other change influence preferred alternatives?
- Do alternatives differ in their resiliency to environmental shocks?
    - Scientific uncertainty
- Cost effective analysis can also inform data collection and research effort allocation. Ask: " What is the least cost means of reducing uncertainty under some threshold"
- Assessing the value or scientific information – the cost of choosing wrong minus the cost of reducing uncertainty such that the correct alternative is selected.

Inform allocation of scarce PR management resources

- The current ESA system is under pressure as the growth listings continues to outpace the growth in recovery resources.
- Could force additional tradeoffs between species objectives.
- Conservation "triage"?
- EBM – sage grouse experience

Analyze the institutional barriers to effective PR management and recovery

i. Overlapping ESA and MMPA protections and listed species interactions

- Examples and related insights:
    - Magnusson-Stevens Act and ESA have conflicting mandates of ongoing harvest and endangered salmon recovery (Lackey et al 2017)
    - Interactions among individually managed listed species can create management conflicts. (e.g. Sea lions and salmon, Killer whales and salmon, Sea Otters and Abalone)
- Implications:
    - Conflicting mandates can create cases where advancing one mandate comes at the expense of another mandate.
    - Trading protection of one listed species for protection of another
    - EBM may be more effective than managing individual species

ii. Entrenched interests

- Can arise through management (e.g. reliance on hatcheries, habitat restoration industry)
- Can constrain recovery alternatives and can lead to inefficient allocation of recovery resources.

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