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Confronting challenges to integrating Pacific salmon into ecosystem-based management policies

Michael J. Malick*, Murray B. Rutherford, Sean P. Cox

School of Resource and Environmental Management, Simon Fraser University, 8888 University Drive, Burnaby, British Columbia, Canada V5A 1S6

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ABSTRACT

Ecosystem-based management is an increasingly prominent paradigm for the management of living marine resources with a focus on maintaining ecosystem level properties and processes. Although highly migratory marine and anadromous fish species often disproportionately contribute to the structure and function of ecosystems, incorporating these species into ecosystem-based management policies remains difficult because they spend a considerable portion of time outside the boundaries that define a particular management area. In this paper, two case studies are used to examine how the challenges of ecosystem openness, imperfect information, and ecosystem complexity can impede efforts to integrate highly migratory Pacific salmon into ecosystem-based management policies. This analysis highlights three main factors that hinder more effective integration: (1) uncertainties about impacts of human activities and ecological processes that occur in geographically distant jurisdictional areas or at spatial scales larger than the ecosystem-based management area, (2) spatial asymmetries in the distribution of costs and benefits associated with management decisions (i.e., positive or negative externalities), and (3) static management policies that prevent updating management decisions in a timely manner when ecosystem conditions change or new information becomes available. Given these factors, two potential strategies to address migratory challenges are suggested. First, the creation of an international ecosystem synthesis group is recommended to facilitate the collection, analysis, and dissemination of ecological, social, and policy information across national and other jurisdictional boundaries. Second, the expanded use of dynamic in-season management policies is recommended, which allow for rapid updating of management decisions based on evolving information about ecosystem conditions.

1. Introduction

Over the past few decades, ecosystem-based management (EBM) has emerged as a leading paradigm for the management of living marine resources in many parts of the world, with a focus on maintaining ecosystem level properties and processes (e.g., nutrient cycles and trophic interactions) in the presence of anthropogenic and natural disturbances [1–5]. A key principle underlying EBM is that distinct boundaries demarcate the management area, with the boundaries ideally being chosen based on the ecological properties of the system rather than existing socio-political boundaries [1,6]. However, in addition to the difficulties of managing across existing jurisdictional boundaries, most marine ecosystems cannot be easily discretized into manageable units because ecosystem boundaries remain open, i.e., organisms, energy, or matter can move across specified ecosystem boundaries [7].

Ecosystem openness presents a first challenge to integrating highly migratory species into EBM policies because these species frequently move across ecosystem and jurisdictional boundaries. Indeed, highly migratory marine and anadromous fish species provide critical connectivity between geographically distant ecosystems and these species often play a disproportionately large role in the structure and function of ecosystems by translocating organic material, nutrients, and energy [8,9]. However, factors external to the management area may strongly affect the status and contributions of species that spend a considerable portion of their life cycle outside the human defined boundaries of an ecosystem. In particular, this movement across management and jurisdictional boundaries may lead to mismatches between the scale of management and the biology of a migratory fish stock [10,11]. To overcome these potential mismatches, some EBM initiatives are using very large spatial boundaries (e.g., large marine ecosystems) in an attempt to capture full ecosystems; however, even these larger EBM initiatives are often not successful at including the full life cycle of many highly migratory species, such as Pacific salmon (*Oncorhynchus* spp.) [12–14]. Jurisdictional issues make it unrealistic to expect that management will be able to scale up to the necessary level to capture the

* Corresponding author.
E-mail address: mmalick@sfu.ca (M.J. Malick).

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full spatial range of highly migratory species [15,16]. Therefore, in this study, the focus is on the challenges associated with accounting for and incorporating highly migratory species into existing local and regional scale EBM initiatives.

A second major source of challenges to integrating highly migratory marine species into EBM is the quality of the available information. In order to practice EBM, scientists must identify and estimate cumulative impacts from a diverse suite of physical, biological, and human influences on marine ecosystems across multiple spatio-temporal scales [16,17]. However, the ability to study and manage these cumulative impacts is limited because scientists and managers often have imperfect information (e.g., non-existent data or data with potentially large observation error) about the status of particular ecosystem components or the drivers of ecosystem dynamics [18–20]. For instance, information is usually lacking to separate particular cause and effect relationships because research tends to focus on only the most economically dominant components and drivers of ecosystems [21,22].

A third source of challenges is that even when good information is available, ecosystem complexity (i.e., numerous ecological processes interacting in multiple, and often non-linear ways) can limit the ability to recognize the drivers of patterns and processes in natural systems because underlying cause-effect relationships may be spontaneous and non-stationary over space and time [23–25]. In other words, new cause-effect relationships may emerge while others disappear by the time enough information has accumulated to understand any particular one [22].

These three challenges—ecosystem openness, imperfect information, and ecosystem complexity—are clearly evident in coupled marine-terrestrial ecosystems along the west coast of North America, where policy-makers are struggling to integrate highly migratory Pacific salmon into EBM policies. In this paper, two case studies are used to examine how the challenges of openness, imperfect information, and ecosystem complexity can impede efforts to integrate highly migratory Pacific salmon into EBM policies. The first case study, interception harvest of chinook salmon, highlights how human impacts in areas geographically distant to an EBM area can impact the ecosystem services provided by salmon within the EBM area. The second case study, at-sea competition between hatchery and wild salmon, highlights how processes occurring at larger spatial-scales than an EBM area can influence the provisioning of ecosystem services within that area. Potential strategies are then explored that could be implemented to overcome these challenges. Although the focus is on two case studies involving Pacific salmon, the challenges and strategies discussed appear to be widely applicable to other highly migratory marine or anadromous fish species that move among jurisdictions and ecosystems.

2. Salmon and ecosystem-based management

A primary goal of EBM is to explicitly address cumulative impacts of human activities on ecosystem structure and function in order to maintain a continued supply of ecosystem services [6,26,27]. Assessing and managing for cumulative impacts generally requires defining a spatial extent in which to quantify the impacts. However, for highly migratory species this may lead to spatial mismatches between the scale of the management area and the scale at which natural or human activities impact the migratory species. This section reviews ecosystem services provided by Pacific salmon, identifies current ecosystem-based management initiatives along the west coast of North America, and discusses spatial mismatches within an EBM context.

2.1. Salmon and ecosystem services

Pacific salmon typically require a continuum of ecosystems spanning hundreds or thousands of kilometers to complete their anadromous life cycle [28]. The combined extent of these ecosystems ranges from diverse headwaters of large river systems to the pelagic ocean environment of the North Pacific Ocean, Gulf of Alaska, and Bering Sea. Within these varied ecosystems, Pacific salmon provide numerous ecosystem services, including contributing to critical ecosystem functions (e.g., nutrient cycles in freshwater ecosystems), providing economic and food provisioning services to commercial, subsistence, and recreational fishing sectors, and contributing to social and cultural dimensions of coastal North Pacific communities [29].

Declines in Pacific salmon abundance over the past few decades highlight their importance in numerous regions along the west coast of North America. For example, the Yukon and Kuskokwim River regions in western Alaska were declared economic disaster areas following declining returns of adult chinook salmon (*O. tshawytscha*) and chum salmon (*O. keta*) throughout the 1990s and 2000s [30]. Conflicts continue in these regions as government managers and stakeholders struggle to allocate the diminished adult salmon returns among fishery sectors [31,32]. Similarly, in southern British Columbia (BC), declining adult abundances of Fraser River sockeye salmon (*O. nerka*) throughout the 2000s resulted in limited opportunities for commercial, subsistence, and recreational harvest and prompted a federal judicial inquiry (the Cohen Commission) involving government officials, scientists, and other stakeholders to determine the causes of the declines [33]. Along the west coast of the United States, many salmon populations have been extirpated and several others are listed as threatened or endangered under the United States Endangered Species Act, severely reducing harvest opportunities and other ecosystem services provided by Pacific salmon in this region [34–36].

Declining adult salmon abundances have widespread effects on ecosystem structure and function that can detrimentally affect other valued components of ecosystems, including economically important species. For example, migration of adult salmon into freshwater provides a large influx of marine derived nutrients to aquatic and terrestrial ecosystems [37–39]. This large subsidy of nutrients (e.g., nitrogen and phosphorous) and organic matter (e.g., organic carbon) gets incorporated into multiple levels of the food chain, providing critical connectivity between marine and terrestrial ecosystems [37,38]. Migrating and spawning salmon, as well as post-spawning carcasses, are also a key food resource for numerous predators and scavengers in marine, freshwater, and terrestrial systems including birds, bears, whales, seals, and sea lions [40–43]. In some cases, such as orca whales (*Orcinus orca*) in the Salish Sea, adult chinook salmon are the primary diet item for most of the year [40]. Ultimately, declining adult salmon returns in regions like the Salish Sea and western Alaska have reduced the number of salmon available to support ecosystem processes in terrestrial and marine environments and have further complicated allocating salmon returns among fishery sectors.

2.2. EBM initiatives

Maintaining ecosystem level properties such as nutrient cycles and trophic linkages requires a holistic, ecosystem-based approach to management of living marine resources because of the complex and non-linear connections among ecosystem components [1]. Indeed, several state and federal agencies responsible for managing marine resources along the west coast of North America have either started to implement EBM policies or are in the process of developing EBM policies [44,45]. For example, in 2007 the state of Washington (WA) created the Puget Sound Partnership, a public-private partnership made up of government agencies, scientists, and private groups, with the goal of implementing an ecosystem-based management approach to resource use in Puget Sound, WA [45,46]. Similarly, in BC, the Marine Plan Partnership for the North Pacific Coast (MaPP)—a co-led partnership between the provincial government and First Nations—was created in 2011 to facilitate EBM efforts along the BC North Coast. At the federal level, the United States National Marine Fisheries Service recently released a policy directive that establishes “a framework of guiding principles to enhance and accelerate the implementation of EBFM