URBAN STREAM MANAGEMENT:

INTERDISCIPLINARY ASSESSMENT OF AN ALASKAN SALMON FISHERY

By

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URBAN STREAM MANAGEMENT:

INTERDISCIPLINARY ASSESSMENT OF THE SHIP CREEK FISHERY

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Abstract

The Lower Ship Creek Fishery in the city of Anchorage, Alaska is one of the state's most popular sport fisheries. After years of channelization and development, this social-ecological system (SES) continues to experience the effects of urbanization and is struggling to achieve robustness. I applied a robustness framework to the management of this fishery because of its semi-engineered nature. This framework uses interdisciplinary methods to study the interrelationships between the fishery's socio-economic and ecological components. Robustness is more appropriate than resilience as an analytical framework because of the relative insensitivity of the engineered components to ecological feedbacks. On Lower Ship Creek, the engineered hatchery fish continue to thrive despite declining stream conditions. The robustness of this fishery contributes to the resilience of the city by increasing local food and recreation options and supporting a diverse set of businesses. To study the robustness of this SES in the context of the resilience of Anchorage, I first combined historical photos and existing Ship Creek data with research conducted on other streams to create an environmental history of the creek. This history then was used to describe how eras of urban development have altered the creek's ecosystem processes and created new ecological constraints related to 1) loss of wetlands and riparian vegetation; 2) erosion, pollution, and channelization; 3) loss of fish species; and 4) flow alteration and habitat loss. Using Lovecraft's (2008) typology, I proposed four plausible management scenarios that highlight the trade-offs associated with management of this fishery: 1) Ship Creek Redesign, 2) Mitigation, Construction, and Maintenance, 3) KAPP Dam Removal, and 4) Business as Usual. The second of these scenarios is most consistent with the current ecological constraints, the characteristics preferred by most stakeholders, and current socio-economic trends. Since Scenario 2 will require a large monetary investment, I examined this SES's cost structure and compared it with previously published analyses of the economic benefits of the fishery. By quantifying the costs borne by each agency, I showed how externalities produce intra- and inter-agency tension. These data were used to construct a new cost-sharing framework that provides decision makers with an economic incentive to work more cooperatively in the future. I then explored the interrelationship of the SES's socio-economic and ecological subsystems, using Anderies et al.'s (2004) framework. I applied Ostrom's design principles (1990) to sport fisheries to explore the reasons why agencies have not cooperated to produce a more robust fishery. This SES fails to meet three of the design principles: it lacks 1) an equal proportion of benefits and costs, 2) collective-choice arrangements, and 3) user and biophysical monitoring. I then suggest how to improve the design and increase the robustness of this SES. This study proposes that the maintenance of semi-engineered systems is important both for local users and for the resilience of states and countries. In the context of global trends toward increasing urbanization, this study provides an interdisciplinary approach to increasing the robustness of urban streams and building resilience within states and countries.

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1.0 Chapter 1 The Changing Pacific Northwest

1.1 Introduction

The Earth is undergoing profound changes in environment and ecosystems as a result of rising human population and its consumption of resources (Steffen et al. 2004). This has caused widespread degradation of ecosystems and the services they provide to society (MEA 2005). Rivers and stream ecosystems, which receive the runoff from human-modified surfaces, are particularly sensitive indicators of the overall impacts of human actions on the planet.

Over 130,000 km of streams in the United States are impaired by urbanization (EPA 2000). The U.S. Census Bureau (2001) characterizes urbanized areas as places with at least 50,000 people and a periurban or suburban fringe with at least 230 people km^{-2}. Urban stream impairments include habitat alteration, invasive species, contaminants, overexploitation of food resources, and climate change (Allan and Flecker 1993, Pringle 2000, Malmqvist and Rundle 2002, Dudgeon et al. 2006, Strayer 2006, Allan and Castillo 2007).

Since streams reflect the condition of the broader landscape, their characteristics represent broader environmental changes produced by the political, social, and economic conditions associated with development (Naiman 1992). For example, increased population density results in land-use changes that often create impermeable surfaces and increase the rate of runoff into streams. The runoff contains pollutants, such as fertilizers and oil that can alter streams' productivity (Paul and Meyer 2001).

Increasing rates of species extinction and declining water quality associated with urbanization have led to a recent surge in stream restoration projects throughout the United States (Palmer et al. 2003, Malakoff 2004). Bernhardt et al. (2005) estimate an annual expenditure of one billion dollars on stream restoration projects. A number of incentives exist for conducting stream restoration projects, including flood control, historical preservation, improving fish and wildlife habitat, increasing property values, improving the quality of life, and creating recreational opportunities (Riley 1998).

Managers have begun to integrate ecology, engineering, and geomorphology into the design of urban streams (Gilvear 1999, Lake et al. 2007). Stream management could also benefit from a more extensive inclusion of the social sciences. Many biophysical symptoms are the result of the socio-economic frameworks that govern urban stream systems. For example, increased total allowable catch (TAC) limits within sport fisheries can increase erosion rates as more anglers access the stream. To ensure that future restoration projects address the unique characteristics and constraints of urban streams, management actions may benefit from addressing the interacting, cross-scale characteristics of social-ecological systems (SES).

1.2 The Pacific Northwest

Streams in the Pacific Northwest region, which includes Alaska, California, Oregon, Washington, and British Columbia, are particularly vulnerable to the effects of urbanization. Some of North America's largest rivers (Columbia, Fraser, Skeena, Stikine, and Yukon) are located in the Pacific Northwest, and thousands of smaller streams comprise the flow into the Pacific Ocean. The streams of the Pacific Northwest are naturally cool, clear, typically shaded, of high chemical quality, have relatively low acid neutralizing capacity, and are oligotrophic in nutrient status (Welch et al. 1998). These characteristics make the streams and their biota highly sensitive to changes associated with increased development, including nutrient enrichment, increases in temperature and suspended solids, and acidic precipitation.

Increasing urbanization has pushed wild salmon populations to the brink of extinction in the Pacific Northwest states of Oregon, California and Washington, where human population growth has exponentially increased since 1990 (NRC 1996). At current growth rates, the Pacific Northwest's population is expected to double in the next forty years, with most of the population growth in urban areas (Naiman and Bilby 1998).

Many streams in the Pacific Northwest have been transformed from self-sustaining, ecologically resilient systems into vulnerable, semi-engineered social-ecological systems (SES). When salmon populations began to collapse, communities spent millions of dollars in an attempt to restore fish runs using hatcheries and stream restoration techniques. Even with extensive funding, salmon are now absent in almost forty percent of the rivers in Oregon, California, and Washington (Lichatowich 1999). The salmon populations in forty-four percent of the remaining streams are at risk (NRC 1996).

The collapse of salmon populations has had serious consequences on some local communities in the Pacific Northwest. Salmon are an iconic species and an economically, culturally, and recreationally important resource. In 1992, Pacific salmonids (*Oncorhynchus spp.*) supported commercial and recreational fishing industries that produced over one billion dollars in personal income and more than 60,000 jobs in the Pacific Northwest (ORC 1992). The loss of salmon populations also means that the next generation of children will not learn how to fish in urban streams.

In light of increasing urbanization and its impacts on streams, how can lessons learned from the experiences of other Pacific Northwest states benefit Alaska's salmon populations? As Alaska's largest city, Anchorage provides an excellent opportunity to study human interactions with salmon. Anchorage is a rapidly growing city that formally supported wild runs of all five Alaskan salmon species but now has several large hatchery-supported fisheries.

This research brings together biology (Chapter 2), economics (Chapter 3), and social science (Chapter 4) to explore the historical and institutional factors that threaten the sustainability of this urban salmon fishery. I apply the principles of robustness theory to frame the definition of the fishery as an SES. The robustness framework has not previously been applied to streams and fisheries but provides an excellent framework for analyzing human-nature interactions in the context of highly-engineered environments that characterize cities. The goal of this study is to help managers conceptualize what restoration is possible within the constraints of urban SESs and better understand the trade-offs associated with the management of semi-engineered systems.

1.3 The Lower Ship Creek Fishery SES Case Study

Tarbox and Bendock (1996) have shown that the increasing urbanization of Alaska parallels the increasing urbanization of the Columbia Basin in the Pacific Northwest. Similar to the experiences of communities in the lower Pacific Northwest, numerous decision makers are individually struggling to manage Anchorage's freshwater fisheries as the effects of urban development increase. One example of an Alaskan stream that is beginning to show the effects of urbanization is Ship Creek, which is located in downtown Anchorage, Alaska. Despite the widely recognized value and desirability of this fishery, the agencies involved in managing various aspects of this fishery often work at cross-purposes and have been ineffective in taking actions to sustain this fishery in a socially desirable state.

The Lower Ship Creek Fishery is an illustrative SES case study for improving urban stream management because its clearly identified ecological and socio-economic components are typical of semi-engineered systems. The single-case study approach allows for a better understanding of the complex, multivariate conditions found within urban stream management (Yin 2009).

1.3.1 Methods Overview

By combining historical photographs with existing data and scientific literature on urban streams, I examined historical and current land use to assess current ecological and socio-economic constraints. Lower Ship Creek has an unusually complete record documenting the creek's history over the past century. I analyzed the photos and grouped them into four main eras of development: 1) 1900-1930s – colonization, 2) 1940-1960s – dam construction and water diversion, 3) 1970s – hatchery production, and 4) 1980 to present – urban development and recreation. I then chose photos that best documented the changes associated with each of these eras. For example, photos documenting the era of colonization show vegetation removal and the channelization of the creek.

While I was able to use some Ship Creek data, such as stream gauging, water quality monitoring, and toxic spill records, much of the data needed to precisely document the creek's history of ecological change do not exist. Since little data exist on Ship Creek, I conducted a thorough literature review of studies conducted on other urban streams to infer the likely changes in Lower Ship Creek's ecosystem processes. Using the historical photos and eras of development as a guide, I drew comparisons from other urban stream research to outline the probable impacts of urban development on ecosystem services. For example, the construction of a "Tent City" in Lower Ship Creek led to the clear cutting of the forest surrounding the creek. Research on other urban streams has shown that the removal of vegetation increases the probability of flooding, erodes banks, increases water temperatures, alters food webs, and reduces the capacity of the wetlands to filter contaminants emerging from the settlement (Lowrance et al. 1997, Hickey and Doran 2004).

The desired characteristics of the public infrastructure providers within this SES were determined through a combination of questionnaires, public comments, and formal mandates. I sent a questionnaire to each of the public infrastructure providers within the fishery to determine their specific short and long term goals for Lower Ship Creek (Appendix A). I received questionnaires from the U.S. Fish and Wildlife Service, Anchorage Waterways Council, and the Municipality of Anchorage. I was also able to obtain information requested in the questionnaire from the Alaska Railroad and Alaska Department of Fish and Game via phone calls and email exchanges. I combined the results of these questionnaires with the formal agency mandates and public comments made by the public infrastructure providers on projects within Lower Ship Creek (ADFG 2007).

The desired characteristics of the fishery's users were determined through a survey that I conducted in the summer of 2003 with the help of trained volunteers from the Anchorage Waterways Council (AWC). The main goal of the survey was to assess the users' interest in major Ship Creek issues, which include fish passage, water quality, public infrastructure, and safety (Appendix B). The Lower Ship Creek Fishery is known as a "combat fishery," which means that it has a very crowded and competitive nature. To address this challenge, the surveys were conducted as users arrived and departed from the fishery, and during low tides, when there were less fish.

Several factors should be noted about the survey results. Resident users had a much higher participation level in the survey than visitors. Out of the 113 participants in the 2003 survey, 92 were Alaskan residents, 12 were out-of-state visitors and 9 were of unknown residence. Surveyors did note that visitors generally knew less about the fishery and were therefore less likely to participate in the survey. The ratio of residents to visitors remains unknown, although it is likely that more residents participate in the fishery because most visitors who originated from tour buses watched salmon and users but did not directly participate in the fishery.

Another factor that complicated the survey results was the difficulty in getting all types of users to participate. Since the anglers are not organized into groups that represent their interests, I needed to find a way to group the main types of users. Based on the AWC volunteers' observations of the users that actively participated within the fishery, I divided the users into two categories based on types of fishing gear: 1) subsistence users and 2) recreational users. Recreational users tended to use more expensive and elaborate fishing gear than subsistence users. Volunteers conducting the surveys reported that subsistence users had little interest in participating in the survey. It is therefore likely that the survey results do not accurately represent the interests of subsistence users. One potential impact of decreased subsistence user participation is a decrease in the amount of people favoring increased fish passage. The removal of the KAPP Dam, which is used to block fish passage upstream during the fishery openings, could decrease catch rates and reduce subsistence users' ability to obtain salmon.

While these surveys were difficult to conduct due to the nature of the "combat" fishery and its unorganized groups of participants, I was able to infer general preferences of users within the fishery. For example, users are very interested in improving the water quality of Lower Ship Creek. These data combined with the AWC's volunteer observations were used to determine the desired characteristics of the users.

I use Lovecraft's (2008) typology to propose four plausible scenarios that may help managers increase the robustness of urban SESs by accounting for trade-offs within semi-engineered urban streams. Lovecraft's (2008) typology is well suited to developing scenarios for coupled SESs, such as the Lower Ship Creek Fishery, because its four dimensions capture the choices that need to be made between ecological and social systems. Since it is unlikely that the creek will either be completely encased in concrete or returned to its natural condition, the four scenarios developed from this typology represent the range of realistic management options for the future of the creek. These scenarios account for the creek's historical changes and altered ecosystem processes, the desired SES characteristics of user and public infrastructure providers, and the greater socio-economic context (i.e.,, potential stakeholder conflict and political climate) of each option.

The broader socio-economic context of the four scenarios includes conflict within public infrastructure providers and users. I show how the cost structure of the Lower Ship Creek Fishery SES creates inter-agency conflict and decreases robustness by first estimating the costs of the fishery and comparing these costs to published estimates of its economic benefits (King 2004). In the summer of 2008, I contacted each of the fishery's public infrastructure providers (Alaska Department of Environmental Conservation, Alaska Department of Fish and Game, Alaska Railroad Corporation, Anchorage Waterways Council, Conservation Fund, Environmental Protection Agency, Municipality of Anchorage, National Fish and Wildlife Foundation, National Marine Fisheries Service, State of Alaska, U.S. Fish and Wildlife Service, Williams Petroleum) and requested the annual project costs incurred within and directly adjacent to the fishery from 2000-2008. I received accounting data from most of the providers and compiled a total cost estimate with these data. I used the Bureau of Labor Statistics' Inflation Calculator to account for inflation (BLS 2008).

To gain additional insight, I separated the total costs into the following categories: 1) streambank restoration, 2) user education and outreach, 3) user and biophysical monitoring, and 4) infrastructure design, construction, and maintenance. These categories all reflect Baumol and Oates' (1998) two conditions for the existence of externalities. The utility of each of the agencies contributing to these categories is affected by ADFG's decision to create a popular sport fishery on Lower Ship Creek without acknowledging effects on the welfare of these agencies. For example, both user outreach and education and user monitoring are negative externalities because they are addressing trespassing and safety issues created by the Lower Ship Creek Fishery and attempting to protect the fishery's infrastructure from danger. The State of Alaska (ADFG), which is the decision-maker on Ship Creek, is not receiving an amount equal in value to the resulting costs to others.

These data are then used to discuss how this cost structure creates externalities that generate inter-agency tension. I describe a specific example of a project on Lower Ship Creek to illustrate how inter-agency tension can impede project design and completion. With the goal of reducing inter-agency tension, I suggest a new cost sharing framework by examining which agencies are primarily paying for the externalities within the four categories of 1) streambank restoration, 2) user education and outreach, 3) user and biophysical monitoring, and 4) infrastructure design, construction, and maintenance. In addition to the amount of money that each agency is contributing to these categories, I consider the agencies' formal mandates, land ownership, Ship Creek project history, and potential incentives. I then use these data to assign lead agencies to each category and suggest that formalizing the cost structure may increase the overall robustness of the SES by reducing uncertainty over project costs and responsibilities.

The fishery's cost structure is only one potential barrier to the robustness of this SES. It is also important to take a holistic look at the entire SES to determine other potential challenges. The SES, its relevant components, and the interactions between the social and ecological systems are defined and analyzed using Anderies et al.'s (2004) framework. The ecological and social components include the components that most directly influence the fishery. For example, the ecological components of water quality and water quantity can affect hatchery production, which controls the fishery. Lower Ship Creek's public infrastructure providers and recreational and subsistence users are the social components that most directly affect the fishery.

Once the ecological and social components are identified, the interactions within and between these systems are discussed using Anderies et al.'s (2004) concepts of strategic interaction. I assessed the fit of this SES to Ostrom's (1990) design principles by applying each of the principles to the Lower Ship Creek Fishery SES to determine which principles this SES failed to meet. I then analyzed the failed principles to make specific recommendations to increase the overall robustness of this SES.

1.3.2 Chapter Overview

The dissertation begins with a historical examination of how land-use changes have impacted the creek's ecosystem processes over time. Chapter 2 describes the changes to biophysical processes associated with the urbanization of Anchorage and then predicts the constraints produced by these changes by drawing from historical photographs, limited Ship Creek data, as well as the extensive body of scientific literature on the impacts of urbanization on streams. The constraints produced by Lower Ship Creek's history and Lovecraft's (2008) typology are used to develop four of the possible scenarios for Lower Ship Creek's future. The chapter then discusses the likelihood of each scenario and recommends the most realistic scenario within the context of existing ecological and socio-economic constraints.

The Lower Ship Creek Fishery is annually designed and managed by the Sport Fish Division of the Alaska Department of Fish and Game (ADFG). At present, the ADFG's Elmendorf and Fort Richardson Hatcheries stock the creek with chinook and coho salmon. Hatcheries alone cannot prevent the loss of wild salmon, but they do present an opportunity to connect people with nature, create opportunities for economic development, and relieve other wild fish stocks from fishing pressure.

The popularity of the ADFG's Lower Ship Creek Fishery has led to an increase in angler conflict and pollution rates over the last ten years. Municipal, state, and federal agencies are struggling to address these negative externalities, but the long-term success of stream restoration and public infrastructure projects is often inhibited by intra- and inter-agency conflict over project costs and responsibilities.

Chapter 3 investigates how externalities produced by the Lower Ship Creek Fishery may be producing intra- and inter-agency conflict that reduces robustness by inhibiting the successful completion of restoration projects. This is achieved by estimating the fishery's costs and benefits from 2000-2008 and identifying which costs are negative externalities. Then the chapter analyzes which of the public infrastructure providers paid for the fishery's negative externalities during this time period. The chapter concludes with the formalization of a new cost sharing framework that may help to achieve the recommended scenario (Chapter 2) by providing decision makers with an economic incentive to work more cooperatively in the future.

Public infrastructure providers are paying for the fishery's negative externalities by addressing problems created by the fishery, such as streambank erosion and declining water quality. As agencies individually attempt to construct public infrastructure to support high use rates, some of their attempts counteract previous projects or create new problems. Site-specific streambank stabilization projects are the most obvious example of this disconnect on Ship Creek. Over the last five years, four major stream restoration projects have been completed by three different agencies and businesses. At least two of these efforts attempted to mitigate earlier stream restoration projects completed by a different agency. This phenomenon suggests that Ship Creek may be in need of a more interdisciplinary restoration approach that accounts for the socio-economic drivers behind biophysical problems.

In order to help managers better address the causes of biophysical degradation, Chapter 4 identifies the Lower Ship Creek Fishery's relevant socio-economic and ecological systems, establishes the desired system characteristics based on the mission statements and mandates of the public infrastructure providers, and examines the interactions between these systems using the concepts of strategic interaction established by Anderies et al. (2004). Ostrom's (1990) design principles are then used to identify opportunities for achieving the recommended scenario (Chapter 2). The Chapter concludes with specific recommendations that may increase the overall robustness of the Lower Ship Creek Fishery SES.

1.4 Summary

As cities throughout the U.S. and across the world continue to grow, communities need a more realistic approach to urban stream management. Many urban streams are neither pristine ecosystems nor concrete channels. They are engineered nature within the constraints of a city. The restoration of some urban streams may not be possible within existing biophysical and socio-economic constraints. In these cases, the task may become one of designing ecosystems to maximize attainable ecosystem services (Gillilan et al. 2000). The characterization of urban streams' history and biophysical symptoms by combining existing data with scientific literature allows managers to develop future scenarios that recognize the constraints of engineered systems.

Some of these constraints, such as dams, are not likely to be removed; but other economic (Chapter 3), socio-political (Chapter 4) constraints may be alleviated if managers identify trade-offs (Chapters 2 and 4) to establish a common management goal (Chapter 2). The success of building and maintaining an urban connection to nature will depend upon managers' ability to understand what is possible within the constraints of urbanization and anticipate the ecological and socio-economic costs and benefits produced by urban streams.

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2.0 Chapter 2 Ecological Constraints and Opportunities to Enhance the Robustness of Urban Streams[1]

2.1 Abstract

Many urban streams are experiencing the impacts of urbanization and struggling to maintain the key ecosystem services of water quality, water quantity, and flood control while delivering other services, such as artificially produced fish runs. Lower Ship Creek in the city of Anchorage, Alaska contains one of the state's most popular sport fisheries. After years of channelization and development, this social-ecological system (SES) continues to experience the effects of urbanization. By combining historical photographs with existing data and scientific literature on urban streams, this chapter examines historical and current land use to assess current constraints and propose a new set of plausible scenarios that may help managers increase the robustness of this urban SES by accounting for trade-offs within semi-engineered urban streams. I describe the history of changes in ecosystem processes associated with development and discuss how these alterations produce the constraints of 1) loss of wetlands and riparian vegetation, 2) erosion, pollution, and channelization, 3) loss of fish species, and 4) flow alteration and habitat loss. I then use Lovecraft's [2008] typology to present four realistic management scenarios: 1) Ship Creek Redesign, 2) Mitigation, Construction, and Maintenance, 3) KAPP Dam Removal, and 4) Business as Usual. I propose that Scenario 2 may increase robustness because it best enhances the ecological services provided by this SES within the context of existing socio-economic and ecological constraints.

[1] Krupa, M. B., F. S. Chapin, and M. S. Wipfli. 2009. Ecological Constraints and Opportunities to Enhance the Robustness of Urban Streams. Prepared for submission in Water Resources Research.

2.2 Introduction

There has been a historical reluctance by many academic ecologists to accept humans as an integral part of ecosystems [Ruess 2005]. One of the value judgments that has shaped the concepts of ecological integrity and restoration is that naturally evolved genomes, communities, and landscapes are more valuable than artificial ones [Angermeier 2000].

Studies of urban ecosystems are growing with increased urbanization [McDonnell and Pickett 1990, USGS 1999, Grimm et al. 2000]. This paper utilizes the U.S. Census Bureau's definition of urban, which characterizes urbanized areas as places with at least 50,000 people and a periurban or suburban fringe with at least 230 people km^{-2} [U.S. Census Bureau 2001]. More than 75% of the U. S. population lives in urban areas, and it is predicted that more than 60% of the world's population will live in urban areas by the year 2030 [UN Population Division 1997, U.S. Census Bureau 2001]. Over 130,000 km of streams and rivers in the United States are impaired within urban areas [EPA 2000]. The impacts of expanding urbanization on ecosystem processes are well documented and include habitat alteration, invasive species, contaminants, overexploitation of food resources, and climate change [Allan and Flecker 1993, Pringle 2000, Malmqvist and Rundle 2002, Dudgeon et al. 2006, Strayer 2006, Allan and Castillo 2007].

Ecosystem processes are the physical, chemical, and biological actions or events that link organisms and their environment. In this study, ecosystem processes are grouped into the categories of ecological processes and physical processes. Primary productivity is an example of an ecological process. Sediment transport is an example of a physical process.

Ecological and physical processes interact to produce ecosystem services, which are the benefits that society receives from ecosystems [Chapin et al. in press]. Examples of ecosystem services include flood control, biodiversity, and a clean and sufficient water supply [Daily 1997]. Increased nutrient loads can enhance plant growth (i.e.,, create an algal bloom), which leads to a decrease in dissolved oxygen in the water. When dead plant material decomposes and falls to the bottom, other organisms can die.

The major components that comprise Lower Ship Creek's desired ecosystem services can be divided into the categories of essential and desirable. The essential components of this fishery include the minimum ecological components needed to maintain a fishery. This urban fishery will include 1) efficient hatcheries, 2) public infrastructure, and 3) sufficient water quality and quantity to sustain hatchery production. The desired components include the characteristics desired by stakeholders within the SES and will be discussed in more detail in Chapter 4. The major stakeholders within this SES include public infrastructure providers as well as recreational and subsistence users. Public infrastructure providers are the agencies, businesses, and organizations that directly or indirectly contribute to the operation and maintenance of the fishery. Recreational users sport fish on Ship Creek for recreation. Subsistence users rely upon the fishery to feed their families.

Grimm et al. [2000] made an important distinction between ecology *in* cities and ecology *of* cities. The former applies ecological techniques to study ecological systems within cities. In other words, the ecological systems are studied apart from human systems. This study utilizes the ecology-of-cities approach and examines the interaction of human and ecological systems as a single social-ecological system (SES). A SES consists of physical components, organisms, and the products of human activities [Chapin et al. in press].

In recent years, there has been growing interest in balancing ecological considerations with urban constraints, such as channelization and nonpoint-source pollution, to develop more realistic restoration goals [Morris and Moses 1999, Purcell et al. 2002]. A restoration effort that was conducted on Baxter Creek in Northern California is a good example of how urban streams produce restoration challenges [Purcell et al. 2002]. Since no reference site (i.e., undisturbed stream reach) existed on Baxter Creek, managers collected pre- and post- restoration data on the same stream reach to determine project success. While the Baxter Creek restoration project did improve the stream reach's biological and habitat quality and was considered a success, it is likely the reach was still somewhat impaired by the effects of urbanization.

Since the patterns of development, sequencing of construction, and net departure from natural hydrologic processes influence the nature and extent of impacts on receiving streams, it is important to examine and include this history of change in the setting of restoration goals [Wolman 1967, Roberts 1989, Booth 2005, Roesner and Bledsoe 2002]. Many streams, especially those in urban areas, are still adjusting to historical impacts that produce ongoing, lagged, geomorphic responses [Trimble 1977, 1995]. Geomorphic responses to land use are often highly context-specific, within and among physiographic regions [Poff et al. 2006]. The prior impacts on Ship Creek [Table 1] substantially affect the ecosystem processes that govern its delivery of ecosystem services today [Table 2].

Restoration practitioners and academics are interested in understanding the ecological limitations to restoring urban watersheds [Morris and Moses, 1999, Purcell et al. 2002, Alberti and Marzluff 2004, Gillilan et al. 2005, Palmer et al 2005]. Ecological limitations arise from historical as well as current land use [Wohl 2005]. A lack of understanding of the historical land uses and their effects on rivers make it impossible to determine the degree to which rivers have been altered from natural conditions and therefore the goals and types of restoration needed [Wohl 2004]. For example, rivers in the Front Range of the Colorado Rocky Mountains appear pristine; but historical land use activities have compromised the function of these rivers [Wohl 2001]. Some restoration projects conducted on these Rocky Mountain streams failed because they did not take into account the historical (e.g., mining) and geographical (e.g., mountainous) constraints [Wohl 2005].

Current land use also needs to be considered in the management of urban systems. Alberti and Marzluff [2004] studied the relationships between urban land use patterns and bird and aquatic macroinvertebrate diversity in the Puget Sound region and concluded that urban ecosystems are a function of the patterns of human activities and natural habitats that control and are controlled by both socio-economic and biophysical processes operating at various scales. In other words, the complexity of land use patterns cannot be captured by a single land-cover metric, such as impervious surface. This finding has implications for urban planning and design because an accurate characterization of interacting land use patterns is vital to enhancing watershed function.

By piecing together the historical and current land uses within a SES, managers can begin to address one of the greatest challenges in urban stream management, which is the lack of data. It is common for urban stream managers to have little or no chemical, physical, or biological data. When there are insufficient data to inform decision-making, historical photographs can be used to determine land use changes. Since both land use and physiography can be major determinants of biotic patterns in systems [Rabeni and Sowa 1996], these land use changes can be paired with existing data as well as urban stream literature to determine how these changes may limit the stream's ecological restoration potential.

Once the constraints to the ecological restoration of urban streams are generally understood, managers can put together a set of realistic management scenarios. Realistic scenarios reflect the unique characteristics and constraints of urban streams and combine socio-economic and ecological goals. Existing constraints can be used to assess potential trade-offs associated with each scenario. For example, Lower Ship Creek in Anchorage, Alaska is a semi-engineered SES that contains engineered components (e.g., an artificially produced sport fishery) and natural components (e.g., hydrologic cycle). Any efforts to improve the ecological condition of Lower Ship Creek must also consider potential impacts to the lucrative sport fishery. Resource managers may benefit from producing management scenarios that incorporate the ecological constraints produced by historical and current land use as well as the socio-economic values provided by urban streams.

2.3 Objectives

The objectives of this chapter are to 1) describe how urbanization has altered Lower Ship Creek's ecosystem processes by using existing historical photographs and data to draw comparisons from existing scientific literature on urban streams, 2) describe how alterations to ecosystem processes have created constraints and altered ecosystem services, and 3) develop and discuss four of the possible scenarios within these constraints for this SES's future. This information is intended to help resource managers make better decisions that reflect the stream's restoration potential and account for socio-economic and ecological trade-offs.

2.4 Theory and Methods

By combining historical photographs with existing data and scientific literature on urban streams, this paper examines historical and current land use to assess current ecological and socio-economic constraints and uses Lovecraft's [2008] typology to propose a new set of realistic scenarios that may help managers increase the robustness of urban SESs by accounting for trade-offs within semi-engineered urban streams.

I use the robustness framework because it encompasses the unique attributes of this SES, which has relatively weak feedbacks among its designed and self-organized components. Robustness is defined as "the maintenance of some desired system characteristics despite fluctuations in the behavior of its component parts or its environment" [Carlson and Doyle 2002]. Robustness emphasizes the cost-benefit trade-offs associated with engineered systems [Anderies et al. 2004]. This emphasis is especially relevant to an urban fishery SES, where the engineered components often require a trade-off through their replacement of ecological components (e.g., hatchery salmon replace wild, naturally spawning salmon). The inherent trade-offs within urban systems should be recognized within any management scenarios. Perceived environmental problems, social conflicts, and economic fluctuations all produce challenges; but with the proper infrastructure, no single shock will bring ruin to a robust system [Anderies et al. 2004].

When dealing with an engineered urban system that has few data but requires decision making, there are two ways to inform decision making: 1) managers can design, fund, and conduct major field work to produce baseline data that could be used to determine the success of restoration projects [see Baxter Creek example above], or 2) managers can document ecological changes associated with historical and current land uses by drawing from scientific literature to make comparisons with existing photographs and data. While the former method provides valuable insight into the current condition of the creek, it fails to document the historical land uses that produced these conditions. The latter method documents the historical land uses but fails to document existing conditions, which complicates determining the success of restoration projects.

If time and funding were unlimited, both methods should be implemented. Extensive field studies would be conducted to accurately assess the exact present condition of each urban stream within the context of its historical and current land uses.

These stream-specific data would then be used to direct restoration projects and determine any future changes resulting from the projects.

Unfortunately, the resources required to undertake such an effort rarely exist with urban streams. This paper adopts the latter method (#2), which combines historical photographs and existing data with the growing list of widely accepted effects of urbanization on streams [Paul and Meyer 2001]. Little funding is available to collect data that document the changes to Ship Creek's ecosystem processes, but many decisions need to be made quickly to ensure safety and/or prevent loss of infrastructure [see discussion of culvert removal project below]. The latter method (#2) provides a low cost and relatively quick way for managers to develop project designs that account for the biophysical impacts commonly associated with engineering techniques.

Since many of the changes related to urbanization, such as bridge construction and water withdrawal, are present on Lower Ship Creek, it is likely that the creek experienced the impacts documented in the urban stream literature. Historical photographs of Ship Creek and existing data were used to provide insights into the processes that created the present channel condition. These insights create a context for the causes, duration, spatial extent, and intensity of human-induced changes to the river over time [Petts 1989, Sear 1994, Kondolf and Larson 1995]. While this method is far from ideal, it does allow resource managers to identify some of the constraints likely produced by urbanization and generally predict the restoration potential of any given urban stream.

For example, projects on Lower Ship Creek often replace one problem with another. In 2003, three collapsed culverts at the mouth of Ship Creek created a powerful hydraulic flow that endangered anglers and needed to be removed. In addition to posing a threat to anglers, the hydraulic flow created a plunge pool and inhibited fish passage. In 2005, the culverts were removed and a new bridge was constructed without baseline biophysical data collection or an understanding of how the placement of a support in the middle of the stream would affect the stream's already altered hydrology [additional details in Chapter 4]. Erosion has increased around the instream bridge support on Ship Creek. As documented by Roberts' [1989] study of erosion around bridge supports, this is a common problem on other urban streams. The problem of increased erosion around the bridge has replaced the danger of collapsed culverts.

If the culvert removal and bridge construction project had used the former method (#1) to look at the existing biophysical conditions of Ship Creek within the context of historical and current land use, the project design would have likely avoided the new erosion problem and been able to document any changes to biophysical processes. Although #1 is the preferred method, the project design also could have benefited from the latter method (#2), which could have predicted possible negative impacts (i.e., trade-offs) of the project design based on urban streams literature review. This approach would have alerted managers to the potential for increased erosion, and a list of scenarios could have been developed to better understand the ecological and socio-economic trade-offs associated with the culvert removal project.

A scenario is an account of a plausible future. Scenarios are constructed to provide insight into drivers of change, reveal the implications of current trajectories, and illuminate options for action [Peterson et al. 2003]. Kahn and Weiner [1967] originally developed scenarios in response to the difficulty of predicting accurate weather forecasts. The concept of scenario planning was then expanded at Stanford Research Institute (SRI) International in May of 1996 and by Shell Oil [Wack 1985, Wack 1985a, Schwartz 1991, van der Heijden 1996]. Scenario planning consists of using a few contrasting scenarios to explore the uncertainty surrounding the future consequences of decisions that cannot be predicted.

The development of scenarios has proven to be a useful tool in the interdisciplinary management of social-ecological systems [White et al. 1997, Folke et al. 2002, Walker et al. 2002, Alberti and Marzluff 2004, Cork et al. 2006]. Postel and Richter [2003] used scenarios to protect river systems while meeting human needs. Other tools that are used to predict possible futures, such as modeling, are often not a feasible option on urban streams because they require a substantial amount of quantitative data that rarely exists and are expensive and time consuming to obtain. The scenarios approach is a viable interdisciplinary tool because it can draw from both quantitative exploration of future change [Alcamo et al. 2005] and expert judgment and imagination where current judgment does not allow for the development of robust quantitative models [MEA 2005]. Scenario exercises have helped decision makers to incorporate more realistic and detailed ecological dynamics and explore the trade-offs among ecosystem services [Raskin 2005, MEA 2005]. Although a complete accounting of risks, benefits, and costs is difficult to establish, scenarios have helped managers to discuss the logical consequences of each scenario [Carpenter et al. 2006].

It is important to consider the consequences of different scenarios because there are significant feedbacks from ecosystem change to livelihoods, health, economies, and societies that can change human systems and lead to more ecosystem changes [Carpenter et al. 2006]. For example, if the hatchery fish were removed from Lower Ship Creek, Alaska would lose a valuable socio-economic resource. Many residents rely upon Ship Creek's easily accessed hatchery runs as a food source and/or a convenient place to teach their children to fish. Local guiding businesses also rely upon the tourism industry produced by the popular fishery.

Lovecraft [2008] proposes a fourfold typology to describe potential options for coupled SESs: 1) a flourishing society and a flourishing ecosystem, 2) a flourishing society with a nearly unsustainable ecosystem, 3) a precariously sustainable society with a flourishing ecosystem, and 4) an unsustainable society with a barren ecosystem.

This chapter uses Lovecraft's [2008] typology to create four plausible scenarios for the Lower Ship Creek Fishery. As managers discuss the trade-offs produced by future scenarios, Lovecraft's [2008] typology provides additional insight into the trade-offs that need to be made and the reasoning behind them. Currently on Ship Creek, some public infrastructure providers have decided to improve the sport fishery at the expense of the greater ecosystem while others are working solely on restoring the ecosystem with little concern for the social system. This typology may help Ship Creek's managers to better achieve a balance between social and ecosystem sustainability.

The scenarios proposed in this chapter account for the formally and informally defined desired characteristics of the Lower Ship Creek Fishery's public infrastructure providers [Table 16, Chapter 4] and recreational and subsistence users [Table 3]. The public infrastructure providers that own land (e.g., the Alaska Railroad Corporation and the Municipality of Anchorage) are interested in maintaining their infrastructure and reducing trespassing within Lower Ship Creek [Table 6, Chapter 3]. Other public infrastructure providers that have regulatory authority (e.g., Alaska Department of Environmental Conservation and National Marine Fisheries Service) are respectively interested in protecting the creek's water quality and fish and wildlife resources [Table 6, Chapter 3].

According to the results of a survey conducted by the Anchorage Waterways Council in 2003 [Appendix B], users are primarily interested in improving the water quality of the creek [Table 3]. Users are also interested in improving fish passage, user access and safety, and adding "healthy" development to Lower Ship Creek [Table 3]. "Healthy" development is defined as non-industrialized development, such as bait shops, that supports the Lower Ship Creek Fishery.

By documenting constraints produced by historical changes and using these constraints to create a list of scenarios that describe how potential trade-offs may affect public infrastructure providers and users, managers can account for the semi-engineered characteristics of urban streams. Four of the possible scenarios for Lower Ship Creek are outlined in the Discussion. The likelihood of each of these scenarios is then assessed within the system's current ecological and socio-economic constraints.

2.5 The Lower Ship Creek Fishery SES

This chapter is focused on the Lower Ship Creek Fishery SES, which exists in the last 1.45 km of Lower Ship Creek, from the Knik Arm Power Plant (KAPP) Dam to the mouth [Figure 1]. Along the upper 30.6 km of the creek, Ship Creek is relatively undeveloped as it flows northwesterly through Chugach State Park. Within the lower 16.9 km, the creek first passes through the Ship Creek Dam and Intake Facility and enters Department of Defense (DOD) lands. The creek then flows through two military bases (Elmendorf Air Force Base and Fort Richardson Army Base) and the headquarters of the Alaska Railroad Corporation (ARRC). The creek has four dams, and approximately 4.8 to 6.4 km of the creek have been channelized [USACOE 1998].

Toward its mouth, the creek flows adjacent to the Port of Anchorage, passes through tidelands, and enters into the Knik Arm of Cook Inlet near Anchorage's only small-boat harbor. Intertidal mudflats and freshwater wetlands historically surrounded this reach. Lower Ship Creek's estuarine/riverine habitat type is especially valuable because it is rare within the Municipality of Anchorage (MOA) [MOA 2001].

Historically, all five species of Pacific salmon (*Oncorhynchus spp.*), Dolly Varden (*Salvelinus malma*), eulachon (*Thaleichthys pacificus*), and stickleback (*Gasterosteus aculeatus*) used Ship Creek for migration and spawning [ADFG 2007]. Human activity on Lower Ship Creek dates back to as early as 500 A.D., when the Dena'ina set up seasonal fishing camps on the banks of Ship Creek [Tower 1999].

Like many creeks, Ship Creek has changed over time. Due to its downtown setting, Ship Creek is now surrounded by nearly 300,000 permanent residents and contains a hatchery-supported sport fishery. Ship Creek averages 53,000 angler days per year (King 2004). The fishery provides the highest economic benefit to the state of any hatchery program and annually contributes an advertised figure of nearly $7.3 million to the local economy [King 2004, see Chapter 3 for a more complete economic assessment].

2.6 Eras of Urbanization

The urbanization of Lower Ship Creek can be grouped into four main eras: 1) 1900-1930s – colonization, 2) 1940-1960s – dam construction and water diversion, 3) 1970s – hatchery production, and 4) 1980 to the present – urban development and recreation. The most significant ecological impacts of each era are examined below. Although full restoration of this urban SES is inhibited by the lingering ecological constraints of these development eras, examining these constraints can lead to the creation of scenarios that may help managers shape the creek's future.

2.6.1 1900-1930s: Colonization

In 1912, the government passed legislation to build a railroad in Alaska. In search of employment, approximately 2,000 squatters cleared trees to construct a "Tent City" on the banks of Ship Creek [Figures 2, 3]. The year-round settlement of Lower Ship Creek differed from the seasonal settlements of the Dena'ina people because the creek was altered to accommodate permanent infrastructure.

The most significant ecological impacts associated with this era of colonization are channelization and the loss of vegetation. Urban expansion caused the filling of tidal flats and brackish wetlands adjacent to Ship Creek to make room for houses and rudimentary roads. New lands adjacent to the creek were also cleared of vegetation and sold at auctions to meet the needs of the growing population [Figures 4, 5, Table 2]. The construction of roads and houses also resulted in changes to the morphology of Lower Ship Creek. To facilitate navigation and new construction, the creek was dredged and channelized [Figures 6, 7], and a bridge was built across the creek for a railroad crossing [Figure 8].

Based on Wolman's [1967] research on urban streams in Maryland, it is likely that vegetation removal led to the destabilization of the hill slopes, which probably increased the water and sediment yield to the creek and led to increased flooding, overbank sediment deposition, and bank heights. Drawing from studies of other creeks impacted by development-related sedimentation, the increases in turbidity, scouring, and abrasion likely decreased primary and secondary production in the lower creek; and therefore less food would have been available to juvenile salmon [Wagener and LaPerriere 1985, Van Nieuwenhuyse and LaPerriere 1986, Allan 2004]. Increased sediment input would also bury stream gravels and make this portion of the creek less suitable as spawning habitat [Allan 2004].

In other studies, widespread clearing of vegetation decreases the input of litter and wood into the creek [Finkenbine et al. 2000, Allan 2004]. Ship Creek probably experienced a similar deficit. Decreased nitrogen fixation rates due to reduced inputs of large woody debris could reduce the productivity of the entire food chain, including desired fish species [Allan 2004].

The ecosystem services affected by vegetation removal include decreased water quality of the stream due to sedimentation, loss of flood control, and a reduction in the filtering of contaminants by wetlands [Table 2, Wagener and LaPerriere 1985, Van Nieuwenhuyse and LaPerriere 1986, Pollock and Meyer 2001].

In addition to the changes in ecosystem processes associated with a loss of vegetation discussed above [Table 2], research on other urban streams has shown that channelization also produces ecological changes. Wohl [2005] concludes that bridges and roadside slopes create constrictions that alter the morphology of creeks through scouring and ice/debris damming [Figure 9]. Studies of other creeks have documented that the dredging and channelization of creeks leads to a decreased width of the floodplain and riparian corridors, decreased large woody debris and baseflow inputs, increased peak discharges, and altered sediment types [Espey et al. 1965, Seaburn 1969, Dunne and Leopold 1978, Arnold et al. 1982]. A decreased width of the floodplain and riparian corridors slows the rate of carbon processing and nutrient cycling [Dunne and Leopold 1978]. Decreased base flows reduce the retention of organic matter resulting in decreased secondary production [Paul 1999]. Increased peak discharges can alter the creek's disturbance regime [Finkenbine et al. 2000, Pizzuto et al. 2000]. Altered sediment types decrease the retention of particulate organic matter and limits primary production [Finkenbine et al. 2000, Bilby 1981].

Affected ecosystem services potentially include loss of flood control due to decreased floodplain and riparian corridor width and increased peak discharges [Table 2, Espey et al. 1969, Seaburn 1969, Dunne and Leopold 1978, Finkenbine et al. 2000, Pizzuto et al. 2000]; decreased water quantity due to decreased baseflows, [Paul 1999]; decreased water quality due to altered sediment types and transport [Bilby 1981, Finkenbine et al. 2000]; and a decrease in the abundance and diversity of desired species (e.g., fish) [Bilby 1981, Finkenbine et al. 2000].

2.6.2 1940-1960s: Dam Construction and Water Diversion

In 1940, Elmendorf Air Force Base (EAFB) was established on Ship Creek. One year later, Fort Richardson Army Base (FRAB) was established adjacent to EAFB. Construction began on the Glenn Highway that same year (1941) and would cross over Ship Creek twice upon its completion [Figure 1]. In 1961, the Port of Anchorage was established along the north shore of the mouth of Ship Creek. New roads were built, and old ones were improved to accommodate the busy port. Traffic within the Ship Creek district drastically increased as trucks hauled the barged freight to and from the city.

The 1950s and 60s brought more change to Ship Creek as people migrated to Anchorage and water demands grew [Figure 10]. Four dams were built on Ship Creek between 1952 and 1965. The Knik Arm Power Plant Dam (KAPP) Dam was constructed in 1952 and used creek water to supply steam heat to the Alaska Railroad and downtown businesses. Fort Richardson built a dam in 1953 and added a hatchery in 1958. The city of Anchorage increased its water supply by constructing Ship Creek Dam and Intake in 1954, which continues to provide the city with water today. Elmendorf followed with the construction of its own dam and hatchery in 1965.

The most significant ecological impact associated with this era is flow alteration. Research on other streams has shown that dams can alter the magnitude, duration, and frequency of flows, as well as sediment transport, disturbance regimes, water chemistry, and water temperatures [Wolman 1967, Leopold 1968, Stanford and Ward 1979]. It is possible that Lower Ship Creek experienced all of these changes to some degree during this era. Dams can also sever vital upstream and downstream linkages, which can decrease the creek's ability to retain organic matter and nutrients [Stanford and Ward 1979]. This reduces invertebrate abundance and changes the life histories in decomposer food webs, reduces leaf decomposition rates, and reduces dispersal and migration of fish. Flows associated with dams can create unstable habitat conditions that can disrupt the life cycles of juvenile fish and limit spawning opportunities for adults [Freeman et al. 2001]. In tidal areas, dams (e.g., the KAPP Dam on Ship Creek) can prevent the mixing of fresh and salt water. Anadromous fish rely on these mixing zones as they make the transition from the ocean to creeks. If the zones disappear, anadromous fish can die from freshwater shock.

Increased water withdrawals related to the construction of these dams further compounded earlier impacts on the stream's ecosystem processes [see earlier discussion, Table 2]. It is widely agreed that Ship Creek's water has been over-allocated, but there is uncertainty about the exact amount since many water-right applications are still pending adjudication. Although its main water supply comes from Eklutna Lake, the MOA annually draws a percentage of its water supply from the upper Ship Lake Dam and Intake Facility [Moran and Galloway 2006]. In years of high use or low flows, the MOA increases its use of Ship Creek water, which exacerbates the naturally occurring ecological impacts of low flow in these years [Table 2]. Low instream flows present a challenge to the hatcheries, which would like to use creek water for their operations.

Potential impacts to ecosystem services related to this era were decreased water quality due to changes in water chemistry and temperatures resulting from altered flow and sediment transport regimes; decreased water quantity due to instream flow diversion; reduced dispersal and migration of fish due to both the loss of freshwater mixing zones and severed upstream and downstream linkages; and loss of flood control due to altered hydrological processes, such as floodplain connection [Table 2, Wolman 1967, Leopold 1968, Stanford and Ward 1979]. On Lower Ship Creek, ice can pile up behind the dams and lead to flooding problems during winter.

2.6.3 1970s: Hatchery Production

In 1970, the establishment of Chugach State Park officially protected the headwaters of the Ship Creek watershed. Despite this good news, the creek continued to show the cumulative effects of urbanization as more people settled in the Anchorage Bowl [Figure 11, Table 2]. Ship Creek's two hatcheries (EAFB and FRAB) created record runs of chinook and coho salmon and established a thriving sport fishery on Lower Ship Creek [Figure 12].

Currently, once the hatchery receives enough broodstock to produce the next year's salmon runs, catch rates are increased through the closure of the KAPP Dam, which blocks upstream fish passage and essentially creates a pond from which fish cannot escape. Unusually high catch rates due to the partial barrier of the KAPP Dam has potentially reduced input to upper stream reaches of marine-derived nutrients (MDN) from salmon carcasses, which would decrease the input of nutrients and organic matter into the stream headwaters. MDN are important because even small amounts of nutrients and carbon from anadromous fish may be critical in stimulating primary production and maintaining trophic productivity [Larkin and Slaney 1997, Wipfli et al. 1998, Gende et al. 2002, Wipfli et al. 2003].

The major ecological impacts of the hatchery era impacted the ecosystem services provided by the Lower Ship Creek SES by eliminating some fish species through the construction of dams that blocked fish passage (e.g., sockeye salmon can no longer reach their spawning grounds in Ship Lake because of dams) and producing large and reliable runs of highly desired fish species (e.g., chinook and coho salmon) [Table 2, Allendorf and Phelps 1980]. The large catch rates within the fishery decreased the energy subsidy of MDN to the vegetation in upper stream reaches, which could affect wildlife viewing [Larkin and Slaney 1997, Wipfli et al. 1998, Gende et al. 2002, Wipfli 2003].

2.6.4 1980 – Present: Urban Development and Recreation

From 1980 to the present, the population and development of Anchorage have continued to increase [Figure 10, 11]. In 2003, approximately 270,951 people lived in the MOA [U.S. Census Bureau 2008]. In less than 100 years, the population surrounding Ship Creek increased from approximately 2,000 to 270,951 people. Ship Creek, like many other urban creeks, is showing the cumulative effects of urbanization.

Some of these effects, such as flow alteration, channelization, and vegetation loss, have already been discussed; but studies have demonstrated other ongoing impacts produced by urban development. The most significant ecological impacts associated with this era are pollution and erosion. Unlike earlier estimates of what may have happened on Ship Creek, some of the impacts of contaminant loading and recreation during this era are documented. However, these documented impacts are not entirely isolated to this era. Much of the contamination is the result of decades of cumulative changes to physical and ecosystem processes that have reduced the creek's ability to filter pollutants [Table 2] combined with increasing levels of nonpoint-source pollution.

As Ship Creek approaches Cook Inlet, it now flows through several contaminated sites. High stormwater runoff resulting from an increase in impermeable surface area carries pollutants into the creek from the heavily industrialized district. Polychlorinated biphenyls (PCBs), dioxins, petroleum hydrocarbons, volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), pesticides, asphalt, white phosphorous, and heavy metals are all present in the creek [Table 1, EPA 2004].

Since 1990, the Alaska Department of Environmental Conservation (ADEC) has listed the last 3.2 km of Ship Creek from the Glenn Highway bridge to its mouth at Cook Inlet as a 303(d) Impaired Waterbody due to the presence of petroleum hydrocarbons, oil, grease, fecal coliform bacteria, and biological community alteration from urban runoff and industrial spills [EPA 2004]. By 1994, the Environmental Protection Agency (EPA) had designated three Superfund Sites within Lower Ship Creek [Table 1].

When existing literature is used to infer the impacts of the documented presence of these substances, it is likely that Ship Creek is constrained by pollutants [Table 2]. Since studies of streams have concluded that community diversity within and along a creek is reduced by the presence of any pollutant [Wright et al. 1995, Mackenthun and Stanford et al. 1996, McClain et al. 1998], the toxins in Lower Ship Creek are likely to have considerably altered its community composition. Rauch and Morrison [1999] showed that increased trace metal and toxin (e.g., pesticide) concentrations, such as those documented by the EPA [2004] within Lower Ship Creek, result in decreased species abundances and altered community structures.

The increased contamination rates discussed above can decrease ecosystem services through a decline in water quality and the loss of desired species (e.g., fish) that cannot tolerate high contamination levels [Table 2, Turner et al. 1998, Rauch and Morrison 1999].

The increasing popularity of the Lower Ship Creek Sport Fishery is also impacting the creek by increasing erosion. The fishery is now managed to protect other Southcentral Alaska fisheries by drawing large numbers of anglers to the two hatchery-produced salmon species. According to the Alaska Department of Fish and Game (ADFG), the stocking of fish is a vital part of the statewide sport fish program because 1) it diverts angling pressure away from other fragile stocks, and 2) it maintains angling opportunities [ADFG 2008]. Increased recreational fishing pressure from thousands of anglers has removed riparian vegetation, eroded the streambanks, and polluted the waters with debris [Figures 13, 14].

Streambank failure due to the lack of angler infrastructure is increasingly becoming a problem on Ship Creek [Boltwood and Rice 2005]. The loss of vegetation is resulting in decreased nutrient and organic matter inputs [see earlier discussion, Allan 2004]. With few public restrooms and garbage cans, pollution enters the creek on a daily basis and compounds the impacts of contaminants [see earlier discussion]. Anglers increase the creek's sediment load as they slide down the banks. An increased sediment load has been shown to decrease invertebrate species diversity [Resh and Grodhaus 1983, Wiederholm 1984].

The loss of vegetation from recreational use is reducing the ecosystem services of water quality and quantity by reducing the capability of the stream to filter out contaminants and increasing sediment transport, which can decrease the rate of groundwater discharge [Table 2, Resh and Grodhaus 1983, Wiederholm 1984, Allan 2004].

All of these changes are interacting to create serious impediments to the full ecological restoration of Ship Creek, but some opportunity does exist for restoration. By acknowledging the limits of these constraints and understanding that the creek is experiencing ongoing impacts (e.g., nonpoint source pollution), managers can begin to talk about the future of this and other urban creeks. Once all of these historical changes are understood in terms of the creek's ecosystem processes and services, managers can develop scenarios to facilitate urban stream management.

2.8 Discussion

Over the past century, Lower Ship Creek has been transformed from a seasonally inhabited, forested river connected to its alluvial floodplain with all five species of Pacific salmon to a channelized, dammed, polluted, and hatchery-stocked system surrounded by nearly 300,000 year-round residents [Figures 10, 15]. The SES has changed from a self-sustaining, biologically controlled system into a vulnerable, hatchery-controlled system with ecosystem processes modified by the structural, hydrological, chemical, and recreational impacts of an urban environment [Table 2].

The major constraints on ecosystem processes within this SES include 1) channelization and loss of vegetation; 2) flow alteration; 3) loss of fish species; and 4) erosion and pollution. These constraints limit the creek's ability to provide desired ecosystem services within this SES, such as a clean and dependable water supply, diverse species of fish and wildlife, and flood control [Table 2]. While these constraints impose limits on the creek's ecosystem processes, they also present opportunities. An increasing social recognition of the value of ecosystem services on the creek creates the potential for more successful urban stream management.

The desired ecosystem services that are likely most affected on Lower Ship Creek include: 1) water quality, 2) water quantity, and 3) flood control. Recreational and subsistence users and public infrastructure providers are affected when these ecosystem services are decreased [Chapter 4]. Users are interested in improving Ship Creek's water quality and concerned about pollution levels [Table 3]. The ADFG needs a sufficient supply of clean water to efficiently run its hatchery operations. The MOA relies upon Ship Creek as a secondary source for the city's water supply during times of high use and is therefore interested in maintaining Ship Creek's water quality and quantity. As the major landowner, the ARRC is interested in minimizing the risk of floods.

Agencies, nonprofit organizations, and businesses have made several attempts to maintain these ecosystem services by reducing streambank failures on Ship Creek [AWC 2003, ARRC 2006] and reducing the amount of pollution entering the creek from contaminated sites [EPA 2008]. No attempts have been made to improve flood control because it would require economically and socially prohibitive restoration efforts that would remove existing development to re-establish the stream's connection to its floodplain.

Despite the numerous restoration attempts, the creek continues to experience degradation. Until there is consensus on what Lower Ship Creek should look like, these projects will be conducted under different management goals and produce conflicting results [Chapter 4]. To alleviate this conflict, I propose that the resource users and public infrastructure providers work toward establishing a single management scenario.

Using Lovecraft's [2008] typology, four of the potential scenarios for the management of Lower Ship Creek [Table 4], and the costs and benefits associated with each scenario are discussed below [Table 5]. These scenarios are endpoints along a continuum of many potential options and were chosen because they represent a plausible portrayal of what could occur within Lower Ship Creek's current ecological and socio-economic conditions. For example, it is unlikely that the creek will be paved and turned into a culvert because the fishery is extremely popular and averages over 53,000 angler days annually [King 2004]. It is also unlikely that all four dams will be removed and the creek restored to its natural condition because of the persistent impacts of urbanization and location of vital infrastructure, such as a railroad, within the creek's historical floodplain.

Currently on Ship Creek, some public infrastructure providers have made the decision to improve the sport fishery at the expense of the greater ecosystem degradation while others are working solely on restoring the ecosystem with little concern for the social system. The scenarios produced by the Lovecraft's [2008] typology may help Ship

Creek's managers to better achieve a balance between social and ecosystem sustainability.

2.8.1 Scenario 1: Ship Creek Redesign

Scenario 1 involves the complete redesign of the lower 1.45 km of Ship Creek to enhance ecological integrity and maintain the social benefits of the current high-output fishery (maximize ecological and social benefits). A team of professionals, including hydrologists, physical engineers, biologists, and civil engineers, would redesign the creek to increase sediment transport and restore natural flow conditions. This involves the construction of engineered instream features, such as point bars.

The Knik Arm Power Plant (KAPP) Dam would be modified or rebuilt to allow for the transport of sediments while still blocking upstream fish passage to maintain the fishery's high catch rates. The ADFG is currently using the KAPP dam to control the passage of fish upstream. After sufficient brood stock has been obtained, the dam's gates are closed. The dam blocks salmon passage and allows anglers to achieve high catch rates. The removal of the KAPP Dam would likely reduce users' ability to successfully participate in the fishery. It is therefore important to maintain this function of the dam to continue to support the fishery as it currently exists.

The benefits of Scenario 1 include the continuation of hatchery operations and an enhanced fishing experience for users because the stream could be engineered to create more accessible fishing holes, and the KAPP Dam would still block upstream passage and maintain high catch rates. This scenario would also improve up and downstream linkages which would enhance biophysical processes, such as sediment transport. The redesign would also incorporate features, such as vegetation, that would improve the aesthetic of the creek for visitors and residents [Table 5].

Scenario 1 requires an extensive and expensive data collection process and the expertise of a wide range of professionals. Since no creeks in Alaska have been redesigned this extensively, many of these experts would need to be flown in from other states, which would increase the project cost. The project timeline is also likely to be significant and could span the political cycle of several Anchorage mayors, which could threaten the project's completion [Table 5].

This scenario could increase intra- and inter-agency tension because of the large costs associated with redesigning the creek. Another potential source of conflict between the public infrastructure providers could occur over the project design. The large number of public infrastructure providers could significantly delay the project if a cost sharing framework and collective-choice arrangements are not developed [see Chapters 3, 4].

Scenario 1 is currently unlikely to occur because of the large amount of money and long time frame required. Due to the short construction season in Alaska, this project would require implementation in many phases and take a very long time to complete. This project could begin if a politician interested in Ship Creek took office and was able to leverage a large sum of money and direct it toward Lower Ship Creek. However, due to short political cycles, this project and its funding would need to be housed within another capable agency to ensure completion if the politician were to leave office.

2.8.2 Scenario 2: Mitigation, Construction & Maintenance

In Scenario 2, the goal is to maximize social benefits without further reductions in ecological integrity. In this scenario, management actions are taken to reduce contaminants and maintain water quantity and hatchery operations. The installation of new stormwater treatment techniques, fish cleaning stations, the cleanup of contaminated sites, increased monitoring, and additional garbage cans and restrooms would all reduce pollution. The adjudication and enforcement of water rights on Ship Creek would enable managers to better prevent instream flow shortages. The construction of new angler infrastructure, such as staircases and walkways, would reduce erosion on the creek. Coordinated and bioengineered streambank stabilization projects would mitigate some of the effects of an active transportation corridor. Newer and more efficient hatcheries would increase the hatchery's productivity and decrease the use of resources.

The benefits of Scenario 2 include a reduced health risk to resource users, more aesthetically pleasing environment for visitors and residents, and the continuation of hatchery operations [Table 5].

The costs include the expenses and maintenance of contaminant mitigation, construction of public infrastructure and streambank stabilization, the adjudication of water rights due to unknown and lagged use, and the construction of a new hatchery [Table 5].

Some of the main challenges to this scenario are the out-dated and inefficient facilities, which are out of compliance with numerous state regulations and currently contribute to decreased hatchery production [Table 5]. Outdoor raceways expose the hatchery fish to disease and predation, which increase the risk of mortality [Milton 2004]. Initially, warm-water effluent from the power plants on the military bases was directed to the Elmendorf and Fort Richardson Hatcheries, where it was combined with the cold creek water and used to increase fish production. The addition of warm water produced ocean-ready smolts in one year instead of the two years it takes in the wild [ADFG 2001]. The recent closure of both base power plants (Fort Richardson closed in March 2004 and Elmendorf Air Force Base closed in October 2005) reduced overall fish numbers [ADFG 2001].

Pollution events resulting in poor water quality increase the probability of disease-related impacts on fish populations [Arkoosh et al. 1998]. In 2007, *Myxobolus cerebralis* (Mc), the causitive agent of whirling disease, was discovered in some rainbow trout (*Oncorhynchus mykiss*) from the Elmendorf State Fish Hatchery [Arsan 2006]. *M. cerebralis* is one of the most pathogenic myxozoans known for fish [Hedrick et al. 1998]. The presence of Mc has forced the hatchery to use ground water and not release its anadromous fish populations in open systems outside of Ship Creek [ADFG 2007a].

This option could lead to increased intra- and inter-agency tension over project cost and design that could delay project completions if a cost sharing framework and collective-choice arrangements are not in place [see Chapters 3, 4].

Although Scenario 2 is costly, it is the likely and recommended choice because of strong political interest in maintaining Ship Creek's fishery through the stabilization of streambanks, user education and outreach, and construction of public infrastructure [Chapter 4]. There is also strong interest in and support for constructing a new hatchery to increase operational efficiency. This scenario could be facilitated by the formation of cost-sharing and management agreements that establish responsibility for the maintenance of the components that sustain the fishery [Chapter 3, 4]. This scenario could also serve as a starting point to implement scenario 1, which would further increase ecological integrity but would be even more costly.

2.8.3 Scenario 3: KAPP Dam Removal

Scenario 3 maximizes ecological integrity but reduces social benefits from the current fishery. It would completely remove the KAPP Dam, including the instream supports and concrete foundation, to allow for upstream fish passage. The hatchery-supported fishery would still exist within its current boundaries and regulations.

The benefits of Scenario 3 are largely ecological. Restored flow and sediment transport regimes would increase instream flow and fish dispersal and migration. Restored up- and downstream linkages would mitigate habitat loss and improve flood control. Restored natural water chemistry and temperatures would improve invertebrate community structures and water supply for the MOA and the hatcheries. The removal of the KAPP Dam would also eliminate the problem of freshwater shock, which has caused fish kills in the past. As fish migrate from salt to fresh water, they require a mixing zone as they adapt to the decreased salinity levels. When the KAPP Dam is opened to allow brood stock upstream, some of the fish die from the shock as they move from brackish to fresh water. Some indirect economic benefits also exist and include option, existence, and bequest values, which represent the values of goods or services for which there are no well-defined markets. Examples of the fishery's potential indirect use values are the capacity of the stream to assimilate waste or the value that a person receives from simply knowing that the fishery exists [Table 8, Chapter 3].

The costs, which are largely socio-economic, may include a decrease in fishing opportunity on Ship Creek because fish would be able to migrate upstream with the removal of dams. The resulting decreased catch rates would negatively impact subsistence users, who rely upon the fishery to feed their families. The reduction in fishing opportunity could decrease the revenues of local businesses, which currently profit from the large number of anglers on Ship Creek. A decrease in the fishery's catch rates may also decrease purchasing of sport fishing licenses and impact the ADFG's revenues. Another potential cost would be the increased need for user monitoring. Currently, the dam acts as the fishery's legal barrier. If the KAPP Dam were removed, users would be able to walk upstream and fish for salmon. There could also be a significant cost associated with the purchase of the KAPP Dam from its current owners. One potential ecological cost could be associated with the mobilization of sediments behind the dam. The sediments are believed to be nontoxic; but if the sediments were contaminated, this could pose a threat to both users and fish and wildlife downstream [Table 5].

This scenario could produce tension between the recreational and subsistence users and the public infrastructure providers because of the reduced catch rates. The removal of the KAPP Dam would also result in increased monitoring costs by the Alaska Railroad, which could potentially block the public infrastructure providers' projects by refusing to grant permission to access the creek via their land.

It is unlikely that Scenario 3 would occur because 1) the owners of the KAPP Dam still obtain a water right associated with the dam and are not interested in its removal, and 2) it is socially unacceptable to alter the popular fishery by allowing fish to move upstream.

2.8.4 Scenario 4: Business as Usual

This scenario minimizes both ecological integrity and social benefit. In this scenario, no efforts are taken to mitigate the degradation of Lower Ship Creek. The creek continues to experience contaminant loading, with particularly high fecal coliform and petroleum levels. A warming climate, urbanization within the watershed, and increased water withdrawals during low-flow periods could lead to increased water temperatures. Warmer stream flow could increase the likelihood of disease outbreaks within the hatcheries and stream. This could lead to a reduction or shutdown of hatchery operations and reduction or elimination of the fishery due to a contaminated or limited water supply.

Some benefits would accrue from the elimination of fish. There would be a decrease in trespassing violations on ARRC land because pedestrian traffic would greatly decrease with the elimination of the fishery. Bear-human interactions would also decrease on an upstream golf course because the bear's food source (salmon) would disappear [Table 5].

The costs of this project are mainly associated with a decrease in water quality and quantity and the loss of fish. Contaminated water would pose a potential health risk to resource users, increase the cost of supplying water to the MOA, and lead to a decline in fish and wildlife habitat. A decrease in water quantity would reduce the MOA's available water supply. This could lead to water shortages for the MOA in peak use times. Declines in both the quality and/or quantity of water would close hatchery operations and create a poor aesthetic for visitors and tourists. This could lead to the potential loss of the advertised $7.3 million annually brought into the state by the Lower Ship Creek Fishery [King 2004, Table 5].

This scenario would likely increase tension throughout the SES and produce conflict because it would negatively affect all of the subsistence and recreational users and public infrastructure providers. For example, the Alaska Railroad would suffer from increased erosion rates and possibly lose some of their railway infrastructure. The limited fishery would likely result in extreme competition between subsistence users for the declining fish population and decrease the aesthetic value of the fishery to recreational users.

Currently, this scenario is socially unacceptable because of high political interest in the maintenance of Ship Creek's fishery and the restoration of Ship Creek. However, it could occur if 1) a regime change (e.g., a new mayor) results in less interest in the fishery, and/or 2) public infrastructure providers are unable to establish cost sharing and management agreement frameworks.

Managers may benefit from using these scenarios to facilitate a discussion about existing and potential ecosystem services produced by the Lower Ship Creek Fishery. In other words: 1) what ecosystem services are desired? 2) which of these services still exist and what can be done to protect them? and 3) which of the lost services can be restored?

The maintenance and/or restoration of the identified key ecosystem services will then work to increase the robustness of the SES.

2.9 Conclusion

The ongoing effects of historical constraints and future stresses on the ecosystem processes of semi-engineered, urban streams demonstrate a need for more realistic restoration and management plans. The four major eras of Ship Creek's urbanization and the creation of a popular hatchery fishery have created constraints that limit the creek's restoration potential and reduce desired ecosystem services. The use of scenarios incorporates existing constraints and future stressors and creates a list of possible futures that may help managers to better understand the costs and benefits of trade-offs within urban SESs.

The four management scenarios proposed in this paper acknowledge 1) constraints on ecosystem processes over time, 2) current socio-economic constraints that may limit ecological restoration potential, and 3) the need for identification and management of desired ecosystem services. These scenarios recognize that by monitoring trends in stress indicators and their ecological impacts, managers can gage change from some historic reference point and take appropriate actions to reduce the stress [Chapin et al. in press].

Scenarios also allow managers to better understand the economic and social structures required to achieve the desired scenario. To determine the nature and extent of the required resources to support the recommended Scenario #2, the cost structure [Chapter 3] and political infrastructure [Chapter 4] of this SES must be examined. The cost of increasing robustness within the Lower Ship Creek Fishery SES is high because it relies on ongoing management efforts to sustain its intensive use [Chapter 3]. Political and social challenges include developing and maintaining partnerships between entities with conflicting mandates to develop large scale angler infrastructure [Chapter 4].

As more streams experience the cumulative and lagged effects of urbanization, the classic concepts of stream restoration become increasingly difficult to achieve. When restoration is not an option and sustainability is not a reality, resource managers can increase the system's robustness by analyzing the SES's constraints and desired ecosystem services to produce scenarios that contextualize ecological and socio-economic trade-offs.

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2.11 Figures

Figure 1: Lower 1.45 km of Ship Creek, Anchorage, Alaska, 2007.

Figure 2: Clearing Land to Construct a Tent City on Ship Creek, Early Summer, 1915.

Figure 3: Tent City on Ship Creek, 1915.

Figure 4: Government Hill Land Auction, Ship Creek, 1915.

Figure 5: Road Construction on Ship Creek, 1915.

Figure 6: Alaska Engineering Commission Dredges Ship Creek, October 7, 1917.

Figure 7: Alaska Railroad on Ship Creek, June 21, 1921.

Figure 8: Railroad Bridge Construction, Ship Creek, 1915.

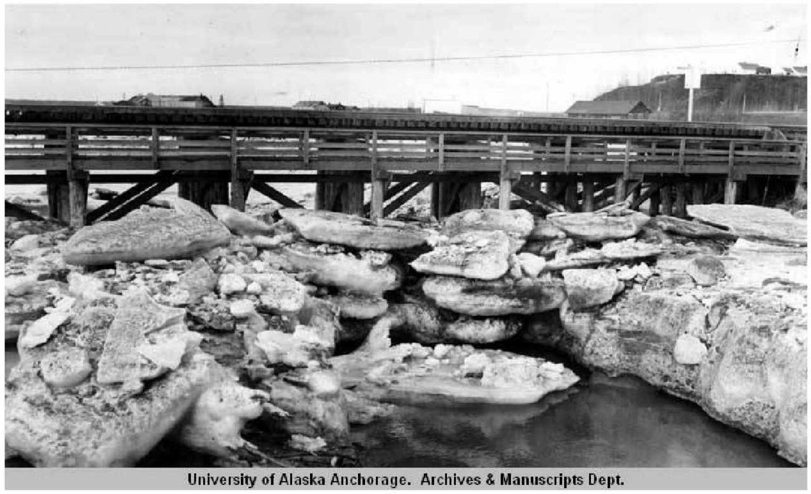

Figure 9: Ice Dam at Railroad Crossing, Ship Creek,1942.

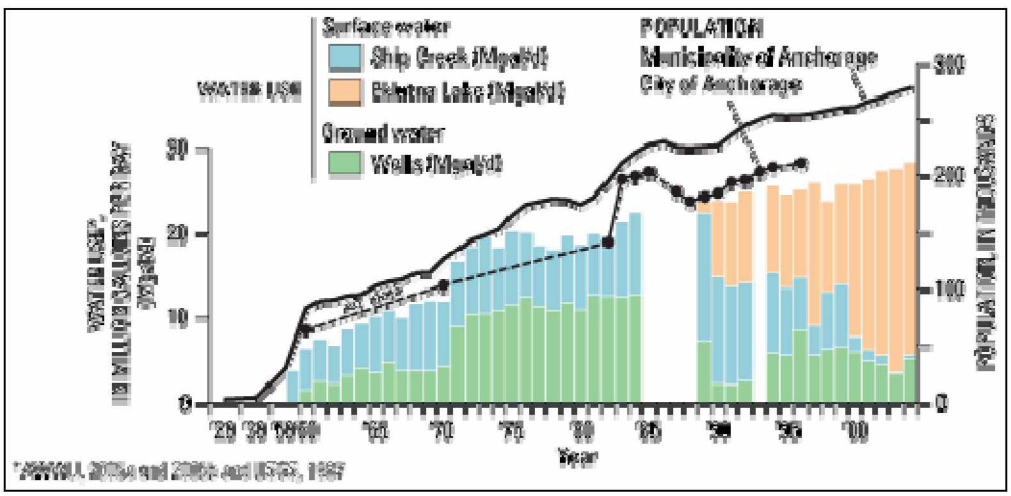

Figure 10: Population & Water Use, Anchorage, Alaska.

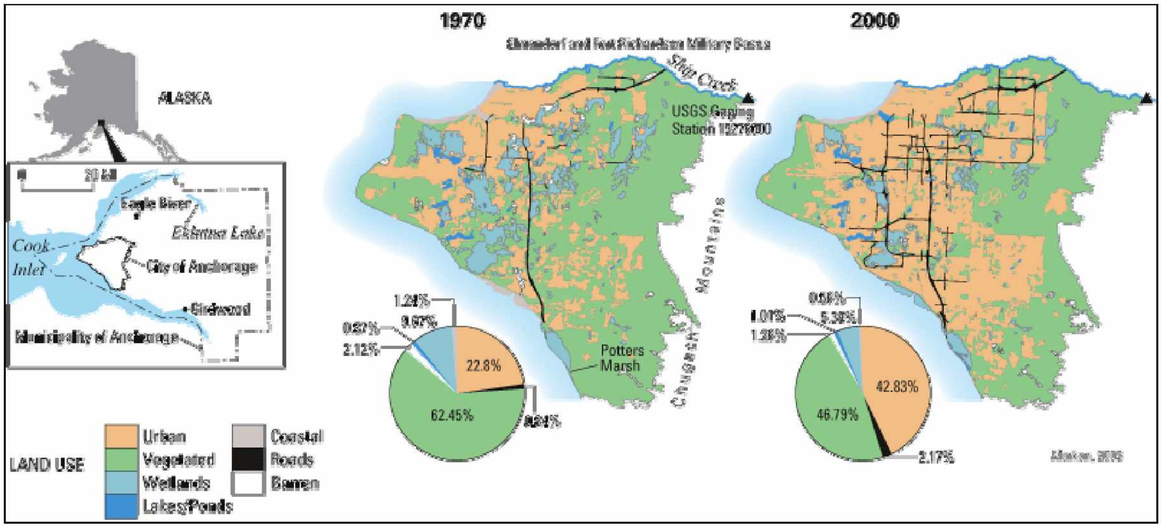

Figure 11: 1970-2000 Land Use, Anchorage, Alaska.

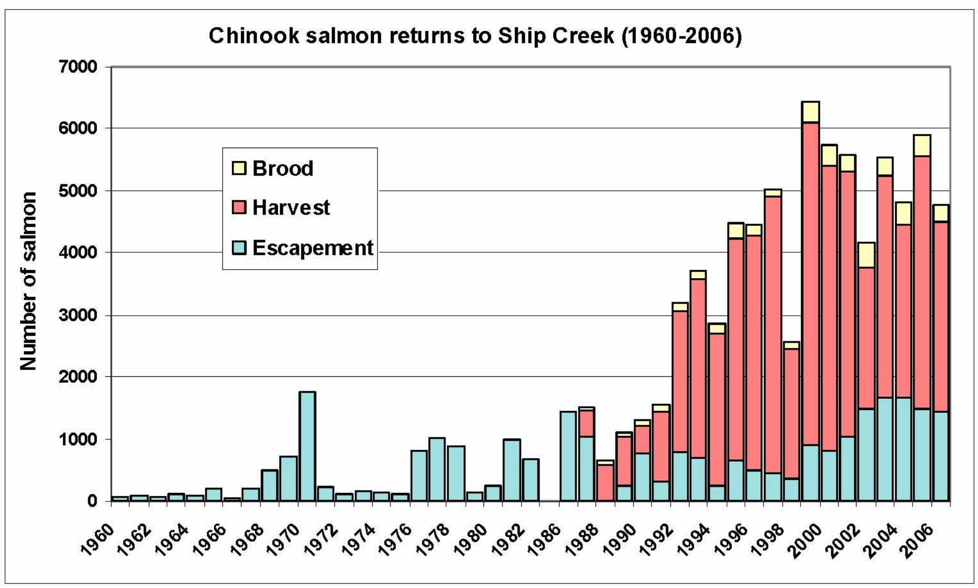

Figure 12: 1960-2006 Ship Creek Chinook Salmon Returns, ADFG (2007b).

Figure 13: Ship Creek Anglers, USGS.

Figure 14: Bank Erosion, Ship Creek, 2003.

Figure 15: Aerial Photo of Lower Ship Creek, August 5, 1950.

2.12 Tables

Table 1: Lower Ship Creek Historical Timeline of Urbanization.

Year	Event	Urban Land Use Category
1914	Alaska Railroad Act Passed	Water Diversion
1915	Tent City formed (2,000 residents)	Contaminants, Water Diversion
1917	Alaska Railroad Water System	Water Diversion
1920	Channelization of Ship Creek	Channelization
	Tidal flats/wetlands are filled in	Tidal Flats/Wetland Fill
	Alaska Railroad Sets up HQ	Urban Development
1921	Alaska Engineering Water System	Water Diversion
1935	City Water System	Water Diversion
1940	Elmendorf Air Force Base	Urban Development, Contaminants
1941	Fort Richardson Army Base	Urban Development, Contaminants
	Glenn Highway	Bridges & Culverts, Contaminants
1952	Ship Creek Dam & Intake	Dam, Water Diversion
	Moose Run Golf Course	Contaminants, Urban Development
	KAPP Dam	Dam, Water Diversion
1953	Fort Richardson Dam	Dam, Water Diversion
1958	Fort Richardson Hatchery	River Recreation
1961	Port of Anchorage	Urban Development
1965	Elmendorf Hatchery & Dam	River Recreation, Dam, Water Diversion
1986	Standard Steel Salvage Yard: Superfund Site*	Contaminants
1990	Elmendorf Air Force Base: Superfund Site**	Contaminants
1994	Fort Richardson Army Base: Superfund Site***	Contaminants
	* polychlorinated biphenyls (PCB)s & dioxins **petroleum hydrocarbons and other fuel contaminants, volatile organic compounds (VOCs), polyaromatic hydrocarbons (PAHs), PCBs, pesticides, asphalt and associated chemicals, and heavy metals including lead ***white phosphorous, VOCs, heavy metals, and PCBs	

Table 2: Sources of Constraints on Lower Ship Creek and the Affected Physical and Ecological Processes and Services.

Era	**Constraint**	**Physical Processes**	**Ecological Processes**	**Ecological Services**	**References**
1900-1930s: Colonization	Loss of Vegetation	Decreased Width of Floodplain & Riparian Corridors	Decreased Primary Production Rates (Due to Decreased Plant Export Material & Nutrient Distribution)	Decreased Water Quality, Flood Control & Water Quantity (Groundwater Recharge)	Wagener and LaPerriere 1985, Van Nieuwenhuyse and LaPerriere 1986
		Loss of Large Woody Debris Input	Altered Food Web Dynamics (Due to Altered Nitrogen Fixation Rates)	Decrease in Desired Species Abundance & Diversity	Allan 2004
		Decreased Permeable Surface	Decreased Nutrient & Water Retention & Flux	Decreased Groundwater Recharge Rates & Energy Inputs, Nutrient Loading of Downstream Water Bodies	Wagener and LaPerriere 1985, Van Nieuwenhuyse and LaPerriere 1986, Pollock and Meyer 2001
	Channel-ization	Decreased Floodplain & Riparian Corridor Width	Altered Carbon Processing & Nutrient Cycling Rates	Loss of Flood Control	Dunne and Leopold 1978
		Decreased Base Flows	Decreased Secondary Production	Decreased Water Quantity	Paul 1999
		Decreased Large Woody Debris	Altered Nitrogen Fixation Rates	Decrease in Desired Fish Species	Bilby 1981, Finkenbine et al. 2000

Table 2 Cont'd.

Era	Constraint	Physical Processes	Ecological Processes	Ecological Services	References
1900-1930s: Colonization Continued	Channel-ization Cont'd.	Increased Peak Discharges	Altered Disturbance Regime, Change in Assemblage Composition	Loss of Flood Control	Espey et al. 1965, Seaburn 1969, Finkenbine et al. 2000, Pizzuto et al. 2000
		Altered Sediment Types	Decreased Retention of Particulate Organic Matter & Limited Primary Production	Water Quality	Bilby 1981, Finkenbine et al. 2000
1940-1960s: Dam Construction & Water Diversion	Flow Alteration	Altered Flow & Sediment Transport Regimes	Decreased Organic Matter & Nutrient Retention	Loss of Instream Flow, Reduced Dispersal & Migration of Fish, Decreased Invertebrate Abundance & Diversity	Wolman 1967, Leopold 1968
		Severed Upstream & Downstream Linkages	Altered Riparian Community Composition Stream Food Webs	Loss of Flood Control & Freshwater Mixing Zones	Stanford and Ward 1979
		Altered Water Chemistry & Temperatures	Altered Leaf Decomposition Rates & Invertebrate Life Histories	Decreased Water Quality	Stanford and Ward 1979

Table 2 Cont'd.

Era	Constraint	Physical Processes	Ecological Processes	Ecological Services	References
1970s: Hatchery Production	Loss of Fish Species	Severed Upstream and Downstream Linkages (Due to Hatchery Dams)	Loss of Some Fish Species	Increased Number of Desirable Fish Species (Coho and Chinook Salmon)	Allendorf and Phelps 1980
			Decreased Input of Nutrients & Organic Matter (Marine-Derived Nutrients)	Decreased Energy Subsidy to the Vegetation Near the Channel & Wildlife	Larkin and Slaney 1997, Wipfli et al. 1998, Gende et al. 2002, Wipfli 2003
1980-Present: Urban Development & Recreation	Pollution	Altered Water Chemistry & Temperatures	Altered Leaf Decomposition Rates & Invertebrate Life Histories	Decrease in Desired Species Abundance & Diversity	Stanford et al. 1996, Wright et al. 1995
		Severely Increased N & P	Increased Productivity & Macroinvertebrates, Algal Blooms	Decreased Water Quality	Turner et al. 1998
		Increased Trace Metal & Toxins (Pesticides)	Decreased Species Abundances, Altered Community Structures	Decreased Water Quality	Rauch and Morrison 1999
	Erosion	Increased Sediment Load	Sedimentation of Interstitial Spaces	Decrease in Invertebrate Fish Species & Loss of Fish Species	Resh and Grodhaus 1983, Wiederholm 1984

Table 3: Anchorage Waterways Council 2003 User Survey

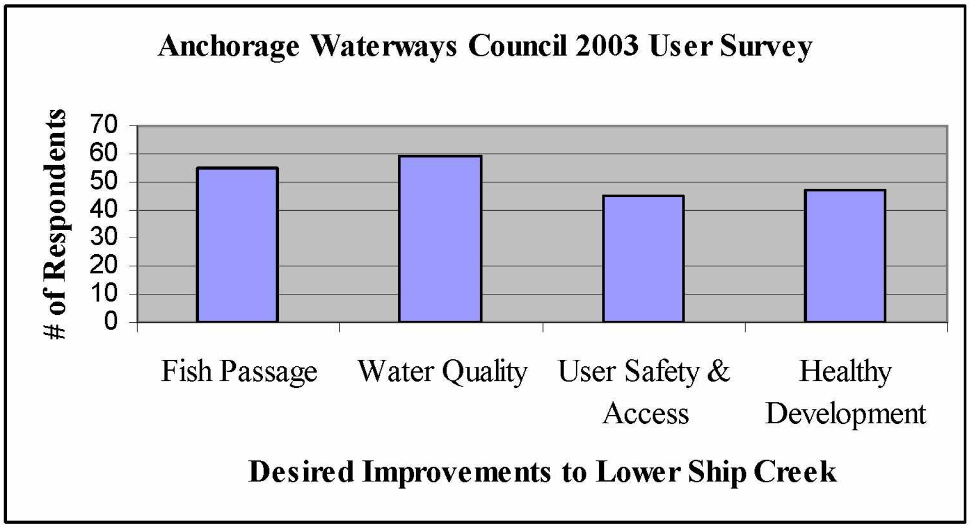

Table 4: Robustness Typology for Lower Ship Creek Fishery Coupled SES

	Max Ecosystem	**Min Ecosystem**
Max Society	(1) "Ship Creek Redesign" – sport fishery and restored biophysical processes	(2) "Mitigation, Construction, and Maintenance" – sport fisheries and limited biophysical processes
Min Society	(3) "KAPP Dam Removal" – a limited sport fishery and restored biophysical processes	(4) "Business as Usual" – no sport fishery and decreased water quantity and quality

Table 5: The Benefits & Costs of Future Scenarios for Lower Ship Creek.

Scenario 1: Ship Creek Redesign

Benefits	Costs
Restored biophysical processes	Requires extensive data collection
Maintenance of the fishery/continuation of hatchery operations	Lengthy project completion timeframe
Improved aesthetic value	Expensive to design & construct
Reduced health risk to users	

Scenario 2: Mitigation, Construction & Maintenance

Benefits	Costs
Reduced health risk to users	Mitigation of contaminants is expensive
Improved aesthetic value	Construction of public infrastructure and streambank stabilization is costly and difficult to maintain
Continuation of hatchery operations	The adjudication of water rights is expensive and complicated due to unknown and lagged use
	The construction of a hatchery is expensive

Scenario 3: KAPP Dam Removal

Benefits	Costs
Restored flow and sediment transport regimes which would increase instream flow and wild fish dispersal and migration	Closure of hatchery would result in loss of revenue from fishing
Restored up and downstream linkages, which would mitigate habitat loss and improve flood control	Mobilization of potentially toxic sediments behind the KAPP Dam
Restored natural water chemistry and temperatures which would improve invertebrate community structures and water supply for the MOA and hatcheries	Loss of sport and subsistence fishing benefits in downtown. Loss of visitors interested in the fishery, which would decrease revenue to local businesses
Increased aesthetic value with the mitigation of contaminants	Increased user monitoring with the removal of the KAPP Dam barrier

Table 5 Cont'd.

Scenario 4: Business as Usual

Benefits	Costs
ARRC would have decreased trespassing problems because pedestrian traffic would greatly decrease with the elimination of the fishery	Contaminants pose a potential health risk to resource users
EAFB would have fewer bears on its upstream golf course with the elimination of fish runs	Decreased quality or quantity of water would close hatchery operations & lead to loss of revenue from fishing
	Decline in fish and wildlife habitat and invertebrate communities
	Poor aesthetic for visitors and tourists

3.0 Chapter 3 The Externality Problem: How an unequal distribution of benefits and costs can prevent successful stream management[2]

3.1 Abstract

This paper examines who profits and who pays for an artificially produced, common-pool fishery on Ship Creek in Anchorage, Alaska, and how this cost structure acts as a barrier to robustness. The economic benefits of the fishery have been calculated and published by the Alaska Department of Fish and Game, but the costs paid to mitigate the fishery's biophysical and social externalities are undocumented. I first describe the structure of the Lower Ship Creek Fishery. Then, by quantifying the benefits and costs of the Lower Ship Creek Fishery from 2000-2008, I describe how externalities produce intra- and inter-agency tension within this social-ecological system. These data are used to construct a new cost-sharing framework that provides decision makers with an economic incentive to increase the robustness of the fishery by working more cooperatively in the future.

3.2 Introduction

Over the past century, Lower Ship Creek has been transformed. What was once a seasonally inhabited, forested river connected to its alluvial floodplain with all five species of Pacific salmon (*Oncorhynchus spp.*) is now a channelized, dammed, polluted, and hatchery-stocked system surrounded by nearly 300,000 year-round residents (Chapter 2). As managers struggle to address these biophysical changes, intra- and inter-agency

[2] Krupa, M. B. and B. Valcic. 2009. The Externality Problem: How an unequal distribution of benefits and costs can prevent successful stream management. Prepared for submission in the Journal of Environmental Management.

tension is preventing cooperation and delaying restoration projects. This tension is partly produced by an unequal distribution of benefits and costs within this social-ecological system (SES). Sport fisheries are popular in Alaska as well as in the greater Pacific Northwest so a closer examination of the economic structure of these SESs may provide new insight into addressing common management challenges.

Increasing urbanization in the lower Pacific Northwest states of Washington, Oregon, and California has pushed wild salmon populations to the brink of extinction. Millions of dollars have been spent to prevent the loss of salmon through streambank stabilization and habitat restoration, and fish are still disappearing. While the reasons for the failure of the Pacific Northwest's restoration projects are complicated, one of the main drivers was that most of the money was used to address the stream's biophysical symptoms, not the socio-economic causes of inter-agency conflict. Although the biophysical symptoms need to be understood to identify socio-economic shortfalls (Chapter 2), these symptoms can only be mitigated or removed through a modification of the institutional structures (Chapter 4) and cost arrangements (this Chapter) that govern them.

The concept of robustness is poised to play a pivotal role in decision-making processes because it can help managers contextualize the socio-economic causes that lead to biophysical symptoms. This knowledge will enable managers to characterize and manage the components of urban systems, which possess great socio-economic value and provide vital ecological services. Robustness is defined as "the maintenance of some desired system characteristics despite fluctuations in the behavior of its component parts or its environment" (Carlson and Doyle 2002).

Robustness emphasizes the cost-benefit trade-offs associated with systems designed to cope with uncertainty (Anderies et al. 2004, 2006). This emphasis is especially relevant to an urban fishery SES, where the engineered components often generate a trade-off through the replacement of wild fish by hatchery fish. Perceived environmental problems, social conflicts, and economic fluctuations all produce challenges; but with the proper infrastructure, no single shock is likely to bring ruin to a robust system.

Robust systems are generally characterized as semi-engineered systems, with both self-organized and designed components (Anderies et al. 2003). Since urban hatchery fisheries are partly designed systems that contain both engineered (i.e., hatchery fish) and biological (i.e., nutrient cycling) components, robustness provides a strong analytical framework for this particular case study. Robustness focuses on the ability of a SES to maintain its social and/or ecological domain of attraction within a specified time frame (Anderies et al. 2003). A system may be robust during one time period and not in another.

Management decisions rely upon feedbacks between both slow (e.g., evolution, long-lived institutions) and fast variables (e.g., pollution event, organizational collapse) (Carpenter and Gunderson 2001). Managers are able to make predictions based on slow variables, but the self-organizing properties of ecological and social systems cause increased uncertainty over time (Levin 2000).

The ability of public infrastructure providers to respond to coinciding occurrences of socio-economic and ecological changes impacts SES robustness (Anderies et al. 2004, 2006). This paper proposes that the current cost structure of the Lower Ship Creek Fishery is decreasing the robustness of the fishery because it produces an unequal distribution of costs and benefits, which breeds social distrust and a lack of cooperation among the public infrastructure providers.

The proportional equivalence of benefits and costs is one of the key properties of well designed institutions because it shapes intra- and inter-agency relationships (Chapter 4, Ostrom 1990). Inequity creates incentives to undermine the established management system by those who perceive it as unfair (Hanna 1996, Pálsson and Helgason 1996). Therefore, understanding the economic dimension of institutions is fundamental to the sustainable management of fisheries (Hanna 1998).

A SES is an ecological system linked to and affected by one or more social systems. A SES is defined as the subset of social systems in which some of the interdependent relationships among humans are mediated through interacting biophysical and non-human biological units (Anderies et al. 2004). I define hatchery fish as fish produced from brood stock by artificial spawning in a hatchery environment. Conversely, wild fish are produced by natural spawning in natural fish habitat by parents that were also spawned and reared in natural fish habitat.

3.3 The Lower Ship Creek Fishery SES Description

The Lower Ship Creek Fishery SES (Figure 16) is examined because it is a highly utilized common-pool resource in an urbanized environment. This SES provides a good opportunity to measure robustness because of the clearly identifiable intersystem interactions between the biological and social systems. When anglers (resource users) fish Ship Creek, they interact not only with each other and the fish, but also with public infrastructure providers. Public infrastructure providers are the agencies, businesses, and organizations that directly or indirectly contribute to the operation and maintenance of the fishery. These include the Alaska Department of Environmental Conservation (ADEC), Alaska Department of Fish and Game (ADFG), Alaska Railroad Corporation (ARRC), Anchorage Waterways Council (AWC), Conservation Fund, Environmental Protection Agency (EPA), Municipality of Anchorage (MOA), National Fish and Wildlife Foundation (NFWF), National Marine Fisheries Service (NMFS), State of Alaska (SOA), U. S. Fish and Wildlife Service (USFWS), and Williams Petroleum. Two different groups of resource users exist on Lower Ship Creek: subsistence users and recreational users. Subsistence users rely upon the easily accessed fishery to stock their freezers with fish. Recreational users fish for sport and do not rely upon the fishery as a food source.

The fishery is a popular, artificially-produced, urban fishery within a heavily industrialized zone. Its social and ecological histories tell the story of Anchorage's transition from the site of a seasonal fishing camp to a major Alaskan city. Lower Ship Creek has changed considerably over the years, but the creek has always played a vital role in human settlement (Chapter 2).

The construction of the Fort Richardson hatchery in 1958 and the Elmendorf Hatchery in 1965 established a popular downtown sport fishery by producing fish runs that far exceeded historical numbers (Figure 12 in Chapter 2). Record numbers of anglers continue to fish for hatchery chinook *(Oncorhynchus tshawytscha)* and coho (*Oncorhynchus kisutch)* salmon. The fishery provides the highest economic benefit to the state of any hatchery program and is advertised to contribute $7.3 million to the local economy (King 2004).

The high use of the fishery led to increased rates of erosion and pollution. Water quality decreased from the sewage and waste produced by urbanization (Tower 1999). Safety issues, such as trespassing and access, also became a concern because of the fishery's presence within an active rail yard. Lower Ship Creek now sits in the middle of Alaska's ground transportation network and industrial zone. Historically, all five species of Pacific salmon, Dolly Varden (*Salvelinus malma*), eulachon (*Thaleichthys pacificus*), and stickleback (*Gasterosteus aculeatus*) used Ship Creek for migration and spawning.

Along the upper 30.6 km of the creek, Ship Creek is relatively undeveloped as it flows northwesterly through Chugach State Park. Within the lower 16.9 km, the creek first passes through the Ship Creek Dam and Intake Facility and enters Department of Defense (DOD) lands. The creek then flows through two military bases (Elmendorf Air Force Base and Fort Richardson Army Base) and the headquarters of the Alaska Railroad Corporation (ARRC). The land adjacent to Lower Ship Creek is owned by the Alaska Railroad and leased to over 200 different businesses. Toward its mouth, the creek flows adjacent to the Port of Anchorage, passes through tidelands, and enters into the Knik Arm of Cook Inlet near Anchorage's only small-boat harbor. Lower Ship Creek is approximately 1.45 km long and stretches from the Knik Arm Power Plant (KAPP) Dam to the mouth of the creek (Figure 16).

Over the years, several entities have made efforts to restore or revitalize the area to create more user amenities and reduce erosion and pollution. The greatest effort was put forth by a citizen's coalition named the Ship Creek Enhancement Citizens Advisory Task Force (SCECATF). The SCECATF effort was created in response to the fact that "more recent hatchery runs of salmon have created an urban fishery unrivaled in other cities, and this convergence of highly popular sport fishing in an area that has otherwise been most important as a primary economic force in Anchorage, an area that does not offer many other recreational amenities – including the most basic, such as safe access to the creek" (SCECATF 1998). The SCECATF produced a concept design for Lower Ship Creek, including user access and amenities that would greatly improve the safety and aesthetic of the fishery while reducing pollution and erosion. Due to a change in political leadership that did not favor revitalizing the creek and the subsequent lack of funding, the concept design never became a reality.

Other entities, such as the ARRC, the Municipality of Anchorage (MOA), the Anchorage Waterways Council (AWC), U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Alaska Department of Environmental Conservation (ADEC), and the Environmental Protection Agency (EPA), conducted projects that supported the Lower Ship Creek Fishery from 2000-2008. These projects were largely uncoordinated and often conflicting in their intended goals and objectives.

In an attempt to induce more cooperation, the Mayor's Watershed Task Force was established in 2005 to create a monthly forum for the sharing of agency information, new projects, and expertise on watershed issues in Anchorage (MOA 2008). The new task force has increased communication between agencies, but it has not erased the fundamental barriers to increased cooperation.

Until the entities agree on what should be done (Chapter 2), who should do what (Chapter 4), and how it should be paid for (this Chapter), it is unlikely that any rehabilitation efforts will produce results. If both users and managers have long-term goals for using the resources, they will have an incentive to behave in ways that are compatible with maintaining ecosystem heath and protecting its productivity (Hanna 1999). This paper suggests that providing decision makers with an economic incentive to work more cooperatively in the future by internalizing the fishery's externalities can increase the robustness of a SES.

A more accurate explanation of the cost structure is needed on Ship Creek because a disproportionate equivalence between benefits and costs is producing inter-and intra-agency conflict that is hindering the management efforts of public infrastructure providers (Chapter 4). The disproportionate equivalence between benefits and costs refers to the lack of rules on Ship Creek that specify the amount of resource products that a user is allocated in relation to local conditions and to rules requiring labor, materials and/or money inputs (Anderies et al. 2004). For example, fishing efforts on Ship Creek operate independently of mounting biophysical costs.

In order to increase the robustness of the fishery, it is important for the infrastructure providers to understand and anticipate both the benefits and costs produced by management decisions. Game theory shows that altruistic behavior occurs when individuals realize the costs and benefits of their actions through more strongly/tightened feedback loops (Levin 2006). On Ship Creek, very few public infrastructure providers fully realize the costs and benefits of their management efforts and are therefore insulated from the resulting externalities. Increased awareness of the benefits and costs is therefore likely to increase the potential for cooperation in the management of the Lower Ship Creek Fishery. Levin (2006) states that cooperation can only occur when managers move "beyond optimization theory to a theory of games in dynamic and changing environments, and the incorporation of that theory into a broader context that considers the emergence of patterns at higher levels of organization."

Managers can account for these costs by identifying the key desired components within the SES (Chapters 3 and 4), outlining the steps that public infrastructure providers need to take to maintain these components (Chapter 4), and establishing a cost sharing agreement that designates which agency or agencies will take the lead role(s) in future public infrastructure construction and maintenance.

3.4 Theoretical Background

An economic good is a commodity or service for which there is market or nonmarket demand and for which a monetary value can be determined. The economic good under examination in this paper is the Lower Ship Creek Fishery, which exists within the last 1.45 km of Ship Creek near the mouth at Cook Inlet in Anchorage, Alaska. The fishery contains two hatchery-supported runs of chinook and coho salmon, which return to the creek beginning in late May and mid-August, respectively.

Since all human activity depends on resources, there will always be a scarcity of goods. When resources are scarce, trade-offs among economic, social, and ecological goods will need to be made (Hanna and Munasinghe 1995). On Ship Creek, the Alaska Department of Fish and Game (ADFG) made the decision to heavily stock the creek with two salmon species to take pressure off other wild fish stocks and provide a downtown fishing opportunity for anglers (ADFG 2008). The trade-offs made by this decision include the loss of species diversity across the five species of wild Pacific salmon for the increased abundance of just two species of hatchery salmon. Opportunity costs of this decision, i.e., the benefits that could have been received by making an alternate choice, include the presence of all five species of wild Pacific salmon in an urban area that could have occurred with an alternative management strategy.

Economic theory generally assumes that people make choices with the intent of maximizing their individual utility (well-being) within the constraint of their individual incomes. While it may be possible to maximize utility on an individual level, this becomes more difficult at larger scales. For example, when multiple agencies work within the same system, the actions of one agency may limit the utility that another can achieve.

When ADFG began stocking the creek with chinook and coho salmon, they created a popular sport fishery that produced new problems, such as erosion and pollution, which other agencies have had to address. These problems, or externalities, negatively impact other entities within the Ship Creek District. An externality is a type of market failure that occurs when a market economy has not achieved an efficient allocation of resources due to one or more conditions (Bator 1958, Baumol and Oates 1988, Steinemann et al. 2005). Externalities occur when the actions of a producer or consumer cause additional costs or benefits for others without providing or receiving compensation from those others (Steinemann et al. 2005). A positive externality of the Lower Ship Creek Fishery is the additional income earned by local restaurants and guide services. The cost of streambank erosion is a negative externality produced by users.

Externalities and the associated inefficiencies and resource misallocations are present when two conditions exist: 1) some individual's utility or production relationships include real (i.e., non-monetary) values chosen by others without particular attention to the individual's welfare, and 2) the decision-maker, whose activity affects others' utility levels or enters their production functions, does not receive an amount equal in value to the resulting benefits or costs to others (Baumol and Oates 1988). Utility refers to the satisfaction or pleasure derived from consumption (Steinemann et al. 2005). For example, an externality need not occur if an individual relies upon a farmer for corn because the farmer does not determine how much corn the individual purchases, and the individual's consumption does not directly enter into the farmer's utility functions. An externality also does not exist if someone does something to deliberately affect someone else's welfare.

Institutional economists have analyzed the externalities produced by commercial fisheries and found empirical evidence that fewer economic problems (e.g., externalities) exist when local entities devise locally appropriate rules (Schlager and Ostrom 1992). Because commercial fisheries often exist within multiple international jurisdictions, internalizing the externalities is difficult to achieve (Dasgupta and Mäler 1992, Young 1992, Barrett 1993).

While much attention has been paid to the institutional economics of commercial fishing, the externalities produced by sport fisheries have received little examination. Since many sport fisheries exist within one national jurisdiction, it is likely that their externalities could be more easily addressed.

This paper focuses on the negative externalities produced by sport fisheries because these are the economic conditions that produce intra- and inter-agency conflict within the fishery. Once these negative externalities are identified, the next challenge is to reduce conflict by resolving these problems. In general, the efficient solution to an externality problem is to set marginal costs equal to marginal benefits (Steinemann et al. 2005). Marginal costs and benefits are the difference between total costs and benefits for one more or one less unit of output. An efficient solution to the fishery's externalities would set the marginal cost of streambank erosion to the producer (i.e., ADFG) equal to the marginal benefit that the fishery provides to society by reducing the erosion. There are several common incentive systems for setting marginal costs equal to marginal benefits, including the creation of regulations in terms of fees, imposition taxes and subsidies, and the reallocation of property rights.

It is highly unlikely that efficiency can be achieved within this system; but when combined with other criteria (e.g., equity, ecosystem health), the concept serves as an ideal state towards which the public infrastructure providers could work. In other words, if a management solution is found that reduces the expenditure of time and money while simultaneously improving fishing benefits and reducing ecosystem damage, then this management structure would be a success.

In addition to efficiency, other criteria that should be considered in the selection of a solution to the externality problem include 1) equal distribution of costs and benefits among the affected groups; 2) ease of administration; 3) ability to maintain flexibility (e.g., transferability) within administration; 4) anticipation of uncertainty about implementation and impacts; and 5) whether the criteria provide incentives to reduce the negative externality (or increase the positive externality) (Steinemann et al. 2005).

The Coase theorem proposes that externality problems can be resolved through negotiation among affected groups (Coase 1960). This theorem requires: 1) well-defined property rights; 2) a small number of affected parties; 3) the parties' complete knowledge of benefits and costs; and 4) negligible transaction costs (e.g., bargaining or litigation).

The concept of property rights suggests private access or ownership, but fisheries problems also require the involvement of multiple parties and involve different sets of formal rights (Pinkerton 1999). When devising solutions to externality problems, it can be useful to consider management rights in addition to the purely extractive resource rights. Management rights emphasize the multi-generational benefits that arise from the responsibilities of resource users.

Schlager and Ostrom (1992) break down property rights into two categories: 1) use rights and 2) control rights. Use rights include the ability to enter into the resource domain (access) and remove something (withdrawal). Control rights include the ability to modify or transform the resource (management), determine who else may use the resource (exclusion), and transfer rights to others via inheritance, sale, or gift (alienation). The bundles of entitlements plus the rules under which they are used make up a property rights regime, which embodies peoples' expectations about their claims to resources (Bromley 1989).

Some property-rights are well defined in the Lower Ship Creek Fishery (Table 6). Use rights are obtained by purchasing a fishing license from the Alaska Department of Fish and Game (ADFG). The license gives users the right to enter the fishery and remove fish. The ADFG has water rights that allow them to remove a set quantity of water from Ship Creek. The MOA also owns water rights on Ship Creek. There are trade-offs between the use of water by residents of the municipality and by the ADFG. These trade-offs influence the cost of the fishery.

As the landowners, the State of Alaska (SOA), the Alaska Railroad Corporation (ARRC), and the Municipality of Anchorage (MOA) possess control rights (Table 6). The ARRC owns the property adjacent to the fishery and the streambed. The MOA owns a 9.14-meter setback directly between the stream and the ARRC property. Most of the infrastructure used to access the creek, such as staircases, is located within this municipal setback. As the agencies responsible for the management of the resource, the ADEC, ADFG, EPA, NMFS, National Oceanic and Atmospheric Association (NOAA), State of Alaska (Alaska State Troopers and State Historic Preservation Office), U. S. Army Corps of Engineers (USACOE), and the USFWS also posses control rights (Table 6).

Other property rights are less clearly defined. The ownership of several structures built prior to statehood and located within the fishery is disputed. An example of one of these structures is a road crossing that contained three culverts (see Discussion). A framework for addressing these issues is proposed below.

It is also important to note that any objectives for the long-term use of the fishery resource (Chapter 1) must be specified within the property rights regime so that expectations of resource users and society at large remain consistent (Young 1982, Gadgil 1987, Bromley 1989, Daly and Cobb 1989, Ostrom 1992, Young 1992, Gadgil et al. 1993, Jodha 1993, McCay 1993).

Negotiation among the fishery's relatively small number of affected groups is likely to be successful with the creation of well-defined property rights based on a more complete knowledge of the externalities. This negotiation process could be overseen by the Mayor's Watershed Task Force, which was established by the Municipality of Anchorage (MOA) in 2005 to create a monthly forum for the sharing of agency information, new projects, and expertise. The Task Force could eliminate or at least substantially reduce transaction costs by providing an outlet for bargaining and/or disputes.

When clear property rights exist between two parties, the resolution of externalities is fairly straightforward; but in the case of a fishery, which is a public good, the resolution becomes more complicated. Multiple parties with unclear responsibilities for costs make it more difficult to identify and establish property rights. By designing a well-defined, context-specific, and enforceable property rights regime that recognizes the shorter time frame of human economic and social systems within the longer time frame of ecological systems (Hanna and Munasinghe 1995), the fishery's externality problem and intra- and inter-agency tension can be reduced. The analysis of socio-economic data within fisheries management could internalize some of the external costs that currently undermine the robustness of the fishery.

3.5 Objectives & Methods

This paper argues that the cost structure of SESs act as a barrier to robustness because of a disproportionate equivalence of benefits and costs. By examining an artificially produced, common-pool fishery on Ship Creek in Anchorage, Alaska, I will show how cost structure acts as a barrier to robustness. I will first estimate the benefits and costs of the Lower Ship Creek Fishery from 2000-2008. These data will then be used to discuss how this cost structure creates externalities that generate inter- and intra-agency tension. Finally, I conclude that the formalization of a new cost sharing framework could increase the robustness of a SES by providing decision makers with an economic incentive to work more cooperatively in the future.

3.6 Benefits & Costs

The benefits to Anchorage's local economy used in this paper are derived from a study conducted by King (2004). The Anchorage Urban Chinook Salmon Program, which stocks the Lower Ship Creek Fishery, has the highest number of user days and the highest statewide economic effect per year (Figures 17 and 18, King 2004). The fishery provides angler days (days spent fishing that can be attributed to the hatchery) worth nearly $7.3 million per year to the State's economy (Figure 17, 18, King 2004).

The $7.3 million was calculated by estimating a total expenditure for the number of angler days attributed to the hatchery. King (2004) estimates costs as a total daily expenditure per person (residents and non-residents) times the number of days. This number is then multiplied by a "multiplier" to estimate how much additional value gets accumulated within the State of Alaska. For example, more tourists increase local business sales, and then the business owners use this additional income to eat at local restaurants, which have increased profits that are also disbursed throughout the state. It is important to note that this estimate represents the gross rather than the net value of the fishery. To provide a more accurate representation of the value of the fishery's value, its costs also need to be accounted for (see next section).

Based on the 2004 benefits estimate and accounting for inflation, the total benefits produced by the fishery from 2000-2008 are $65,765,386.98 (Table 7). The economic effect of this hatchery program is high because of the high number of anadromous days and the large number of non-resident anglers (Figure 19). An anadromous day is defined as a day spent fishing for anadromous fish species, such as salmon. Non-resident anglers spend more money than residents because they require lodging, meals, and guide services. Anadromous angler days produce higher value because they require more expensive fishing gear.

This benefit assessment is not complete because it fails to account for all direct use values and does not include indirect use (or non-use) values. Values of goods such as the fishery should capture both its direct and indirect use values (Krutilla 1967). The data in King's (2004) study only reflect direct use and do so incompletely. Table 8 identifies some potential direct and indirect use values of the fishery. Direct use values represent values users receive by utilizing the fishery and can be expressed in existing markets (Freeman 2003). Potential direct use values not accounted for by King (2004) include the dollar value of salmon (as measured, for example, by its price in a store) captured by subsistence users and the fines collected for violations. Indirect use values, such as option, existence, and bequest values, represent the values of goods or services for which there are no well-defined markets (Freeman 2003). Examples of the fishery's potential indirect use values are the ability of the stream to assimilate waste or the value that a person receives from simply knowing that the fishery exists.

In the summer of 2008, I contacted each of the fishery's public infrastructure providers (ADEC, ADFG, ARRC, AWC, Conservation Fund, EPA, MOA, NFWF, NMFS, SOA, USFWS, Williams Petroleum) and requested the annual project costs incurred within and directly adjacent to the fishery from 2000-2008. I received accounting data from most of the providers and compiled a total cost estimate with these data. I used the Bureau of Labor Statistics' Inflation Calculator to account for inflation (BLS 2008). The total cost estimate for the fishery is $46,369,164.77 (Table 9).

To gain additional insight, I separated the total costs into the following categories: 1) streambank restoration, 2) user education and outreach, 3) user and biophysical monitoring, and 4) infrastructure design, construction, and maintenance (Table 10). These categories all reflect Baumol's and Oates' (1988) two conditions for the existence of externalities. The utility of each of the agencies contributing to these categories is being affected by ADFG's decision to create a popular sport fishery on Lower Ship Creek without acknowledging the effects on the welfare these agencies. For example, both user outreach and education and user monitoring are negative externalities because they address trespassing and safety issues created by the Lower Ship Creek Fishery and attempt to protect the fishery's infrastructure from high use. The State of Alaska (ADFG), which is the decision-maker on Ship Creek, is not receiving an amount equal in value to the resulting costs to others. The annual net benefit of the fishery to the State of Alaska is $2,155,000. When the total cost of externalities in Table 9 is divided over nine years, the average estimated annual cost of externalities is $5,152,129.42. The fishery would need to increase its annual benefits by $2,997,129.42 to compensate for the negative externalities it is producing.

Table 10 shows that the least amount of money was spent on User Education and Outreach. This category included projects, such as interpretive displays, that were conducted by the AWC, NFWF, and USFWS to protect infrastructure, improve user safety, and reduce trespassing on Alaska Railroad land. Additionally, the ARRC, AWC, NFWF, State of Alaska (SOA), and USFWS all funded streambank restoration projects to address erosion problems and protect infrastructure. User monitoring was conducted by the Alaska State Troopers to improve safety and reduce trespassing. This amount includes the full time salaries of two State Troopers. The ARRC also conducted monitoring, but an estimate was unavailable due to security measures. The Alaska Department of Conservation (ADEC) and the Environmental Protection Agency (EPA) conducted biophysical monitoring, but their cost estimates were also unavailable at the time of this study. The most money was spent on Infrastructure Construction and Maintenance (Table 10). The ADFG, ARRC, Conservation Fund, MOA, NMFS, USFWS, and Williams Petroleum all contributed $45,026,351.17 (97% of the total documented costs) to build and maintain infrastructure, such as walkways and restrooms, to support the fishery.

This accounting of costs associated with the fishery is not comprehensive. Opportunity costs are not included due to the lack of data. Potential opportunity costs in this fishery include alternative uses of Lower Fish Creek, such as maintaining wild fish runs or constructing a whitewater kayaking course. Other potential costs associated with extractive uses of the fishery include costs associated with 1) user conflicts, 2) congestion within the fishery, 3) increased safety risks, 4) greater transportation costs associated with the fishery, such as the construction and maintenance of roads that lead down to Ship Creek, and 5) an increase in the ARRC's monitoring and enforcement costs (Table 8). Finally, potential costs may also be associated with non-extractive uses of the fishery, such as the loss of species diversity and damage to the stream ecosystem (Table 8).

To obtain the net value of the fishery, based on the available data from 2000-2008, its total cost of $46,369,164.77 is subtracted from its total gross benefit of $65,765,386.98, producing a net benefit of $19,396,222.21, or $2,155,135.80 per year, which is considerably less than the commonly advertised annual $7.3 million (King 2004).

Differences in geographic scale of costs and benefits create additional complications. The benefits estimate state-wide benefits, such as those received by restaurants and hotels frequented by recreational users, using an economic multiplier that includes benefits to businesses outside of the Anchorage area, while the costs are limited to the area within and directly adjacent to the fishery. This difference of scale reflects both availability of benefits data and locally incurred costs produced by the fishery within a small area.

3.7 Discussion

Even though the costs and benefits produced by this study are incomplete and occur at different scales, an initial look at the cost structure of this fishery provides a starting point for constructing a new cost framework. Within the constraints of my analysis, it appears that the benefits of the Lower Ship Creek Fishery substantially outweigh the costs, suggesting that society would benefit from a more robust accounting framework for sustaining the fishery. The new cost framework could reduce future disputes by acknowledging who is paying what costs and identifying which of these costs are externalities. Identifying the externalities is important because these costs are imposed on other groups that do not benefit from the fishery.

The data show a disproportionate equivalence between the benefits and costs associated with the fishery. According to Ostrom (1990), one of the key design principles of long-enduring institutions for governing resources is the existence of rules that allocate resources to create a proportionate equivalence between benefits and costs (Chapter 4). In some SESs, such as irrigation systems, the overall attempt is to maintain individual actors' proportional equivalence between benefits and costs (Sarker and Itoh 2001). Due to the fact that most of the public infrastructure providers do not directly benefit from this SES, the goal is to devise mechanisms (e.g., a cost-sharing framework) to diffuse costs among the public infrastructure providers.

While the fishery's success continues to draw more users, it is producing externalities that are paid for by entities, such as the ARRC, that do not benefit from its existence. If there were a proportional equivalence of benefits and costs within the fishery, then the amount of fish that a user could take would be related to the condition of the creek and the costs (labor, materials, money) required to manage the fishery. On Ship Creek, accelerated rates of erosion have not led to a decrease of user participation or to the establishment of institutional rules to provide for the creek's maintenance and therefore the long-term benefit of users.

While the benefits do exceed the costs in this estimation, a careful analysis of their structure shows a much different picture of the fishery's value. A large portion of the costs associated with the fishery's benefits are externalities. Consequently, agencies and organizations other than resource users are bearing the brunt of the fishery's success. This cost structure creates inter- and intra-agency tension that prevents cooperation and leads to an inefficient use of resources.

The only public infrastructure provider that annually contributed money to the fishery from 2000-2008 is the State of Alaska (SOA) (Table 11). The ADFG, which is a department within the SOA, paid the costs of annually operating and maintaining the Elmendorf Hatchery and Sport Fish Access Program, which consists of Port-a-Potty maintenance and trash removal (Table 11). The SOA also contributed money to annually pay two State Trooper salaries (Table 11). The SOA's Coastal Impact Assistance Program (CIAP) contributed funding to re-vegetate 100 linear feet of streambank and install a walkway for user access in 2003 (Table 11). These costs are not externalities because they were all paid by entities within the State of Alaska, which receives 75% of its hatchery funding from the Federal Aid to Sport Fish Restoration, Dingell-Johnson/Wallop-Breaux program and the other 25% comes from sport fishing license fees and king salmon stamp sales (ADFG 2008b).

Other public infrastructure providers paid the costs of the fishery from 2000-2008 but did not receive compensation. These are the agencies that are absorbing the externalities produced by this fishery. The ARRC, AWC, Conservation Fund, MOA, NFWF, NMFS, USFWS, and Williams Petroleum all contributed money to but did not directly profit from the fishery (Table 12). The largest amount of money was spent by the three agencies that removed a safety threat to users at the mouth of the fishery. The MOA, NMFS, and USFWS together funded the removal of three collapsing culverts and construction of a bridge at the mouth of Ship Creek.

Analyzing the externalities within a SES may allow managers to better understand why some intra- and inter-agency conflicts arise. Since there is no arrangement (i.e., management rights) in place for who deals with these externalities, the problems escalate until there is an immediate safety concern or impending crisis. At that point, action needs to be swift; but inter- and intra-agency conflicts routinely hold up the projects while the problem worsens. An example of the conflict that can emerge from externalities occurred when public infrastructure providers were faced with three collapsing culverts at the mouth of Lower Ship Creek. The culverts, which were located beneath a road crossing that provided the only access to Anchorage's small boat harbor, were causing a considerable safety problem within the fishery (Figure 20). In 2002, three public infrastructure providers (MOA, USFWS, and NMFS) came together and agreed that the culverts should be removed by the summer of 2003 (USFWS 2008).

The project stalled twice due to debates over ownership and project costs. With financial assistance from the USFWS and NMFS, the project went to construction (Figure 21). This was an important turning point within the fishery because it established property rights to the road and eliminated future disputes over ownership. In the spring of 2005, the two pipelines were relocated, all three culverts were removed, and a bridge replaced the road crossing (Figure 22).

While the ADFG did attend several of the culvert removal meetings, the effort was largely driven by and paid for by public infrastructure providers who did not benefit from the fishery but had access to the technical and financial resources to solve the problem. The culvert removal, like many other projects within the fishery, was a crisis-driven project. Although there was an immediate need to remove the culverts because of safety concerns, it took several years and additional funding to complete the project because of cost-based conflicts.

The socio-economic challenges of watershed conservation may provide insight into the unequal distribution of benefits and costs within this SES. One of the biggest challenges to watershed management is that its costs and benefits are distributed unevenly, yet cooperation is required to make it work (Kerr 2007). The spatial variation and multiple, conflicting uses of natural resources within the system create uneven impacts. The conflict between withdrawing water from Ship Creek for municipal use and providing instream flow for fish habitat is a good example.

If the benefits are large and quickly realized, then devising mechanisms to diffuse costs may be possible because those who lose in the short term may be willing to wait for the gains (Kerr 2007). For example, efforts to curtail trespassing and streambank erosion create short-term costs that provide longer term benefits to the Alaska Railroad Corporation (ARRC). When the benefits are incremental and gradual, there is a less visible connection between investments made and benefits realized, and organizational challenges become more apparent (Kerr 2002). An example of this is the Alaska Department of Conservation's (ADEC) ongoing efforts to improve the water quality of Ship Creek.

3.8 Conclusion

Although the conflict over the culvert removal spurred a serious discussion over property rights associated with the fishery's road crossing, there is still more work to be done to prevent future project delays. The culvert removal project is only one example of the myriad of problems produced by the fishery's externalities. Other agencies are struggling to address the problems of streambank erosion and trespassing violations. Once the externalities have been identified and analyzed, public infrastructure providers can begin a discussion of how to develop cost-sharing agreements.

This chapter recommends a combination of two approaches to address the externality problem. The first is for the producer (ADFG) to internalize the greater production costs by raising user fees. Increased fees could then be used to compensate the agencies for addressing problems (i.e., externalities), such as the need for streambank restoration, created by the fishery.

There are several reasons why it would be socially beneficial for the ADFG to raise user fees even though it would increase the price to consumers (e.g., recreational and subsistence users). Since many of the fishery's costs are not internalized, other members of society who do not participate in the fishery are forced to bear the costs. Another reason has to do with efficiency. When all of the potential benefits and costs of the fishery are measured, lower use fees may be producing an inefficient level of fish production (i.e., marginal costs of the fishery may be exceeding its marginal benefits). Finally, if the user fees reflected social costs, such as erosion, the higher fees might provide an incentive for both producers and consumers to recognize the full costs of the fishery and reduce the magnitude of negative externality (Steinemann et al. 2005). The internalization of these costs would also free up funding from state and federal agencies, which may become more amenable to providing the ADFG with funding for the construction of a new hatchery. A potential challenge to this approach is that the ADFG recently increased statewide license fees to pay for the construction of a new hatchery. Additional increases may affect both recreational and subsistence users' ability to participate in the fishery.

The second approach is to establish a cost sharing framework by identifying the public infrastructure providers that have incentives to pay the fishery's external costs (see discussion below). The economic law of comparative advantage states that division of labor according to relative ability improves outcomes. Economic theories of public finance explore arrangements for providing and paying for goods and services that any of the agencies could in theory provide (Musgrave 1959, Oates 1991, Ferejohn and

Weingast 1997). These theories state that the absolutely most effective provider should be given full management authority because the costs of inter-agency coordination will almost always exceed the modest potential gains from skill specialization. Pinkerton and Weinstein (1995) similarly argue that management problems are best solved when rights accrue to the parties best situated to be accountable to sustainable management practices and to resolve inter-sectoral conflicts.

By examining the 2000-2008 cost estimates and agency mandates and mission statements, it is possible to identify who is the most capable of paying the external costs in the general categories of 1) streambank restoration, 2) user education and outreach, 3) user and biophysical monitoring, and 4) infrastructure design, construction, and maintenance (Table 10).

3.8.1 Streambank Restoration

The AWC and ARRC are the two agencies most capable of conducting streambank restoration projects. They complement each other with technical expertise in both the structural (ARRC) and ecological (AWC) requirements of successful streambank restoration. The AWC is a 501c(3) nonprofit organization with the technical skills required to conduct streambank restoration projects and can receive funding from a wide variety of other nonprofit organizations (NFWF), and state (CIAP) and federal (USFWS, NMFS) agencies. The AWC's mission is "to protect, restore, and enhance the waterways, wetlands, and associated uplands of Anchorage" (AWC 2007). The organization has devoted a considerable amount of resources to reducing erosion though streambank restoration. With the cooperation of local businesses and federal grants, the AWC spent

$75,000 to restore streambanks on Ship Creek in 2003. The ARRC is interested in streambank restoration because, as the major land owner, they are concerned with stabilizing the land adjacent to their tracks and are willing to direct funds to support these efforts. In its 1999 Annual Report, the ARRC recognized the need for streambank improvements and spent $136,835.39 on streambank restoration projects from 2000-2008 (Table 10, ARRC 1999).

In the future, the AWC and ARRC may mutually benefit from combining technical and financial resources to coordinate streambank restoration projects on the creek. It should also be noted that the MOA, which is the other land owner in the fishery, could potentially play a large role in streambank restoration in the future. Since the MOA benefits from the positive externality of tourism, it has an incentive to contribute to the cost of maintaining the fishery. The MOA has designated a considerable amount of funds to be spent on future streambank restoration projects on Lower Ship Creek, although this designation could disappear with a regime change.

3.8.2 User Education and Outreach

The least amount of money was contributed to user education and outreach from 2000-2008. With financial support from the NFWF and USFWS, the AWC has been and should be the lead organization in user education and outreach. As a nonprofit organization with an active membership, the AWC can mobilize volunteers and provide cost-efficient education and outreach programs. The fishery would greatly benefit if the public infrastructure providers financially supported the AWC's efforts to educate users about maintaining the integrity of the fishery. The public infrastructure providers would benefit from the reduced pollution and erosion rates due to educated users.

User education and outreach is a powerful and often underutilized tool that is critical to successful land management practices (e.g., Wuest et al. 1999, Anciso et al. 2001, Mitchell et al. 2001, Marra et al. 2003) and could therefore help to reduce the fishery's negative externalities. For example, an education campaign to encourage users to access the creek via established infrastructure (e.g., walkways and trails) could help reduce erosion.

3.8.3 User and Biophysical Monitoring

From the data in Table 10, it is clear that the two agencies that monitor user behavior within the fishery are the SOA (Alaska State Troopers) and the ARRC. While the costs incurred by the SOA are known (Table 10), the ARRC's costs are unknown. Based on public comments received by other agencies and statements made in its planning documents, it can be inferred that the ARRC is paying a considerable amount of money to address trespassing issues associated with the fishery. In its 2006 Ship Creek Master Plan, the ARRC identified trespassing and safety issues associated with the fishery and pedestrian traffic, and the effect that these issues may have on their leaseholders as one of its major concerns (ARRC 2006).

The ADEC and EPA are spending money on biophysical monitoring, but the amount is unknown. These two organizations could take the lead role in water quality and sediment contaminant monitoring because their mandates both include the protection of human health and the environment (EPA 2007, ADEC 2008). The EPA is already working with the Alaska Railroad Corporation (ARRC) to monitor Ship Creek's water quality for petroleum (EPA 2004).

3.8.4 Infrastructure Design, Construction, and Maintenance

The greatest costs within the fishery are infrastructure design, construction, and maintenance (Table 10). From 2000-2008, these costs were primarily paid by the ARRC, MOA, NMFS, and USFWS (Table 10). Of these entities, the ARRC and MOA are in the best position to design, construct, and maintain infrastructure because they own the land within the fishery and have a solid history of conducting projects. Infrastructure projects on Ship Creek are also routinely identified in their annual planning efforts (ARRC 2006, MOA 2008). With technical and financial support from the NMFS and USFWS, the ARRC and MOA can ensure that future infrastructure projects support the fishery's social and ecological needs.

3.8.5 Incentives for Cost-Sharing Agreements

The agencies have incentives to participate in the definition of a formal cost sharing arrangement. Agencies are paying higher projects costs because cost disputes delay project completion. Previous problems, such as the removal of collapsing culverts, within the fishery have escalated to crisis proportions and greatly inflated project costs. Due to disputes over the culvert removal costs, the total project cost, which was largely paid by the NMFS and USFWS, increased. The assignment of responsibility would also reduce the additional safety threats posed to recreational and subsistence users when projects are delayed because of cost disputes. Increased safety problems pose potential legal and public relations problems to the ARRC and MOA. By creating a cost sharing mechanism that recognizes the strengths of public infrastructure providers and addresses both known and unknown problems, the providers can work more efficiently and therefore conserve valuable resources.

3.8.6 Implementation

With approximately a dozen public infrastructure providers actively working within the fishery, it is important that these providers have an outlet to formalize these cost arrangements. The recently established Mayor's Watershed Task Force is well positioned to bring the infrastructure providers together to discuss the issue of robustness in its entirety and specifically address implementing the cost sharing structure. Currently, the Task Force is a multi-agency advisory team that provides information and advice on the prioritization of restoration projects in Anchorage. In this capacity, it would be difficult for the team to implement steps toward increased robustness.

The Task Force is currently seeking to upgrade its status to a municipal board. If the Task Force formalized its existence as a board, it could assume an increased role in watershed management and create more opportunities for multi-agency involvement in decision-making processes. As a municipal board, the team could provide oversight and a venue to resolve any disputes that may arise. The existence of this board would reduce the transaction costs of coordination and implementation efforts. The board could also apply this framework to increasing the robustness of other creeks within the Municipality.

There are many other creeks across the U.S. and the world experiencing similar discrepancies between who pays for and who benefits from artificially produced fisheries and other popular recreational activities. The barriers created by these tensions are real but not insurmountable. Acknowledging and planning for the externalities produced by sport fisheries will allow public infrastructure providers to approach these problems in a more timely and cost effective manner that will increase the robustness of this and other social-ecological systems.

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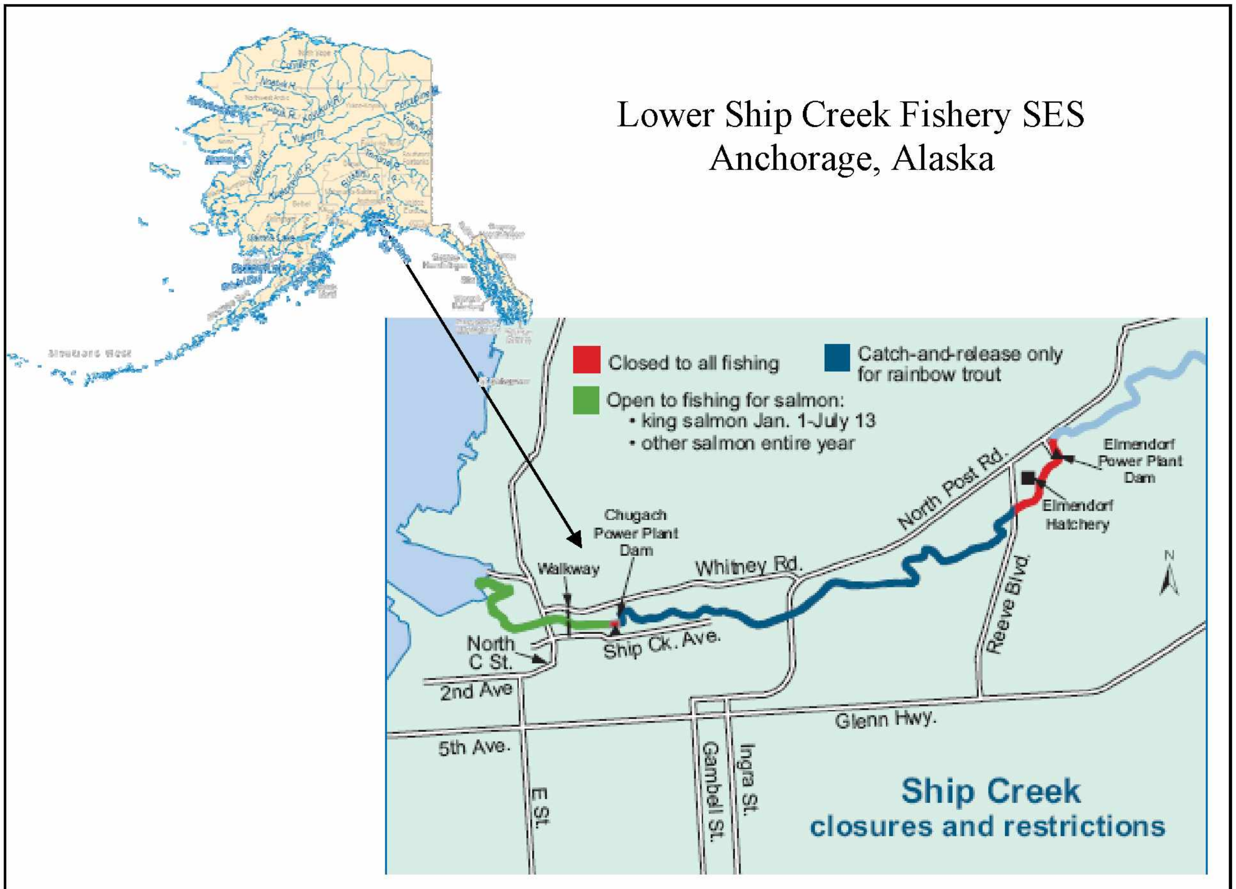
3.10 Figures



Map From ADFG 2007 Sport Fishing Regulations

Figure 16: Map of Lower Ship Creek Fishery, Anchorage, Alaska.

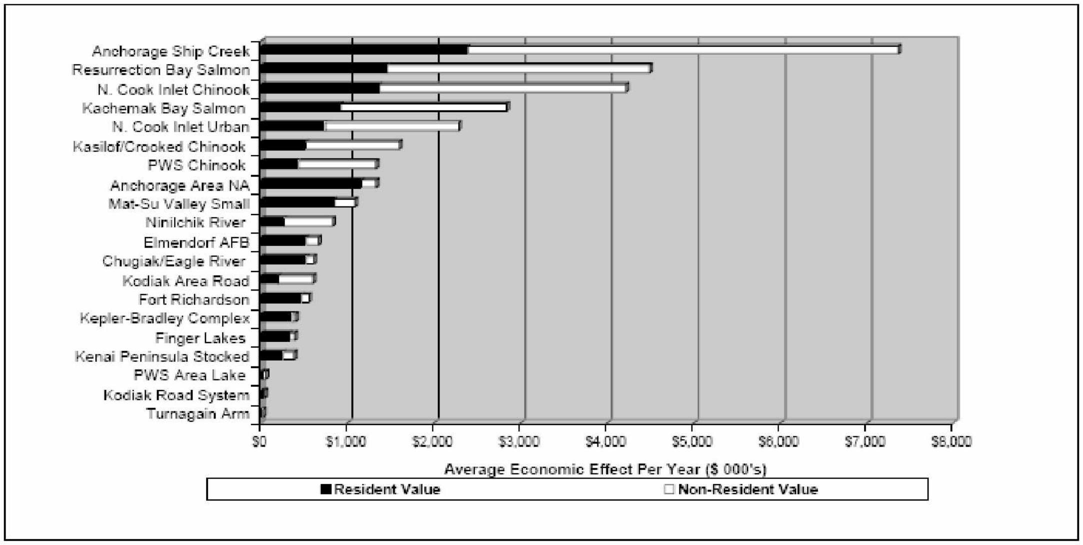


Figure 17: Average Yearly Economic Effect for South Central Alaska's Hatchery Programs, Source: King (2004).

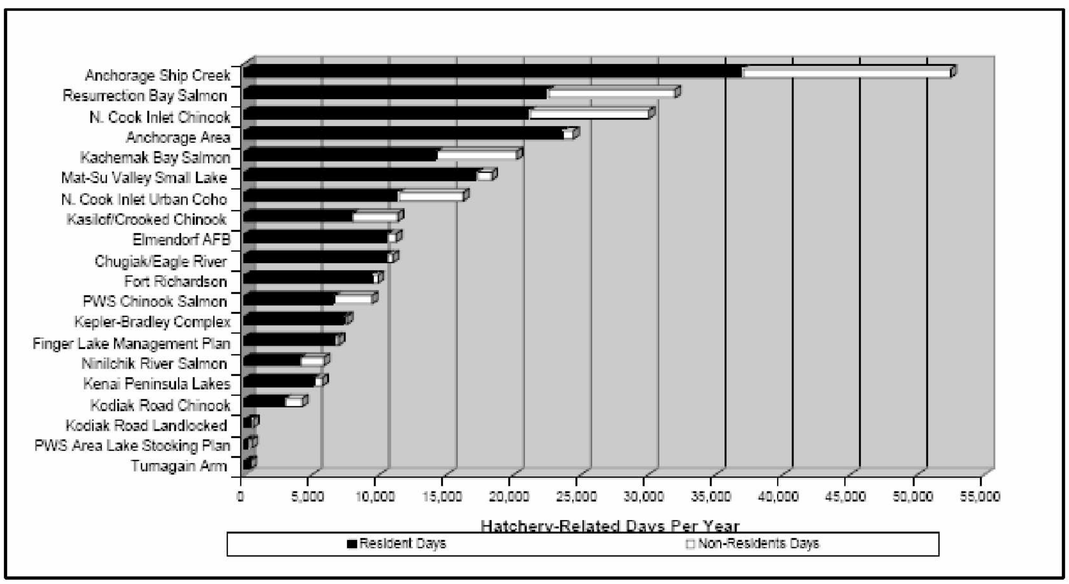


Figure 18: Average Angler Days per Year for Region II Programs, Source: King 2004.

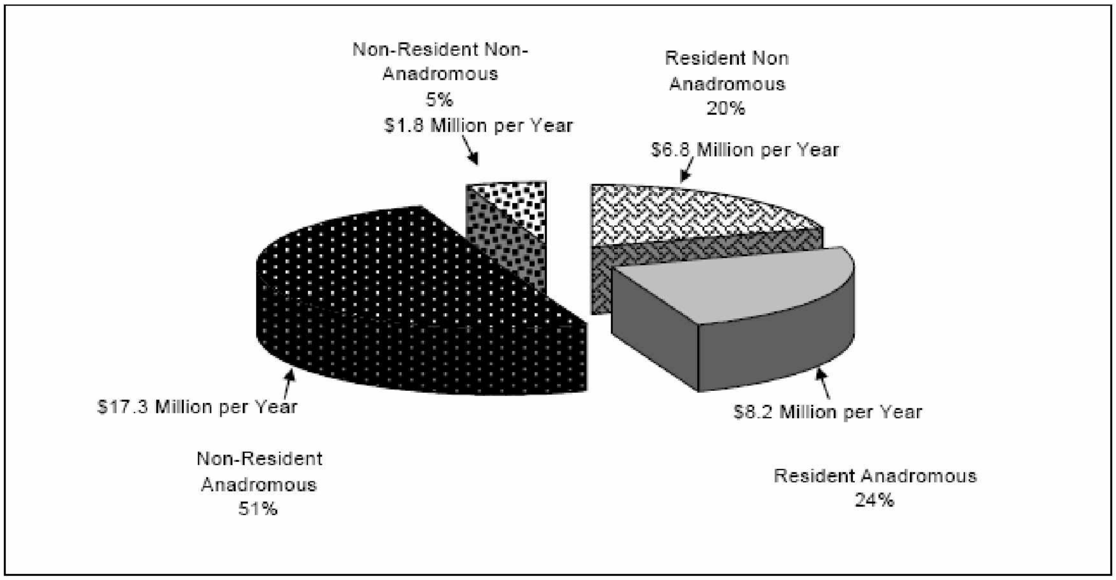


Figure 19: Distribution of Economic Effect across Angling Category, Source: King 2004.

Old Bridge over Ship Creek. Source: USFWS

Figure 20: Collapsing culverts at mouth of Lower Ship Creek, 2002.

New bridge under construction, culverts have been removed, creek channel restored. Source: MOA Project Management & Engineering.

Figure 21: Construction of Bridge over Ship Creek, 2005.

New bridge finished summer 2005. Source: MOA Project Management & Engineering.

Figure 22: New Bridge over Ship Creek, 2005.

3.11 Tables

Table 6: The Lower Ship Creek Fishery Property Rights Scheme.

Agency	Control Property Rights
Alaska Department of Environmental Conservation	Coastal Zone Management Act
Alaska Department of Fish and Game (SOA)	Alaska Statutes: Title 16, Title 41, Water Rights
Alaska State Troopers (SOA)	Alaska Statute: Title 11
Alaska Railroad Corporation	Landowner: Adjacent Land
Environmental Protection Agency	National Environmental Protection Act, Clean Water Act (Sect. 401, 404)
Municipality of Anchorage	Landowner: 30-foot setback, Water Rights
National Marine Fisheries Service	Endangered Species Act, Magnuson-Stevens Fishery Conservation and Management Act, Marine Mammal Protection Act
National Oceanic and Atmospheric Association	Coastal Zone Management Act
State of Alaska (SOA)	Landowner: Streambed
State Historic Preservation Office	National Historic Preservation Act (Sect. 106)
U.S. Fish & Wildlife Service	Endangered Species Act
U. S. Army Corps of Engineers	Clean Water Act (Sect. 404), Rivers & Harbors Act (Sect. 10)

Table 7: The Estimated Economic Benefit of the Lower Ship Creek Fishery from 2000-2008, Updated from King (2004).

Lower Ship Creek Fishery Calculated Benefits 2000-2008	
2000	$6,563,472.74
2001	$6,750,238.22
2002	$6,856,961.36
2003	$7,013,234.52
2004	$7,200,000.00
2005	$7,443,938.59
2006	$7,684,065.64
2007	$7,902,924.30
2008	$8,350,551.61
TOTAL	**$65,765,386.98**

Table 8: Potential Benefits and Costs of the Lower Ship Creek Fishery.

Categories	**Potential Benefits**	**Potential Costs**
Extractive Users (e.g., recreational and subsistence users)	Direct Use: -salmon as a food source -increased income due to fees paid for violations -stocking of other systems Indirect Use: -ability of the stream to assimilate waste	-user conflicts -congestion within fishery -increase in safety risks -greater transportation costs -increase in monitoring and enforcement costs (ARRC)
Non-extractive Users (e.g., tourists and existence value)	Indirect Use: -increased water quality -existence value	-loss of species diversity -damage to stream ecosystem (e.g., erosion)

Table 9: A Cost Estimate of the Lower Ship Creek Fishery from 2000-2008.

Lower Ship Creek Fishery Costs 2000-2008	
2000	$2,707,935.11
2001	$2,925,455.27
2002	$6,659,548.06
2003	$2,485,628.88
2004	$2,637,401.13
2005	$12,834,391.26
2006	$9,747,222.51
2007	$2,775,428.32
2008	$3,596,154.23
TOTAL	**$46,369,164.77**

Table 10: The Costs Paid by the Public Infrastructure Providers within the Lower Ship Creek Fishery from 2000-2008.

Costs 2000-2008	**User Education & Outreach**	**Stream-bank Restoration**	**User & Biophysical Monitoring**	**Infrastructure Design, Construction & Maintenance**
ADEC			(unknown)	
ADFG (SOA)				$19,817,241.82
AK State Troopers (SOA)			$825,801.17	
ARRC		$136,835.39	(unknown)	$2,573,528.68
AWC	$20,361.78	$105,839.86		
Conservation Fund				$6,950.19
EPA			(unknown)	
MOA				$18,958,107.71
NFWF	$121,631.46	$35,676.36		
NMFS				$2,199,742.84
CIAP (SOA)		$44,595.45		
USFWS	$37,206.98	$14,865.15		$1,301,658.75
Williams Petroleum				$169,121.18
TOTAL	**$179,200.22**	**$337,812.21**	**$825,801.17**	**$45,026,351.17**

Table 11: The Costs Paid by the State of Alaska within the Lower Ship Creek Fishery from 2000-2008.

	Lower Ship Creek Projects 2000-2008			
Year	**Project Description**	**ADFG**	**SOA**	**CIAP**
2000	Sport Fish Access Program (port-a potties maintenance & trash removal)	**$11,789.89**		
	Hatchery O&M Costs	**$1,964,981.79**		
	Two Urban State Trooper Salaries* (SOA 2008)		**$82,416.05**	
2001	Sport Fish Access Program (port-a potties maintenance & trash removal)	**$12,125.38**		
	Hatchery O&M Costs	**$2,020,895.90**		
	Two Urban State Trooper Salaries* (SOA 2008)		**$84,761.22**	
2002	Sport Fish Access Program (porta potties maintenance & trash removal)	**$12,317.08**		
	Hatchery O&M Costs	**$2,052,846.83**		
	Two Urban State Trooper Salaries* (SOA 2008)		**$86,101.32**	
2003	Sport Fish Access Program (port-a potties maintenance & trash removal)	**$12,597.79**		
	Hatchery O&M Costs	**$2,099,632.11**		
	Two Urban State Trooper Salaries* (SOA 2008)		**$88,063.61**	
	Revegetate 120 linear feet along Ship Creek; install elevated walkway for angler access			**$44,595.45**
2004	Sport Fish Access Program (port-a potties maintenance & trash removal)	**$12,933.28**		
	Hatchery O&M Costs	**$2,155,546.22**		
	Two Urban State Trooper Salaries* (SOA 2008)		**$90,408.78**	
2005	Sport Fish Access Program (port-a potties maintenance & trash removal)	**$13,371.46**		
	Hatchery O&M Costs	**$2,228,576.91**		

Table 11 Cont'd.

2005	Two Urban State Trooper Salaries* (SOA 2008)		**$93,471.86**	
2006	Sport Fish Access Program (port-a potties maintenance & trash removal)	**$13,802.80**		
	Hatchery O&M Costs	**$2,300,466.48**		
	Two Urban State Trooper Salaries* (SOA 2008)		**$96,487.09**	
2007	Sport Fish Access Program (port-a potties maintenance & trash removal)	**$14,195.93**		
	Hatchery O&M Costs	**$2,365,988.70**		
	Two Urban State Trooper Salaries* (SOA 2008)		**$99,235.24**	
2008	Sport Fish Access Program (port-a potties maintenance & trash removal)	**$15,000.00**		
	Hatchery O&M Costs	**$2,500,000.00**		
	Two Urban State Trooper Salaries* (SOA 2008)		**$104,856.00**	
	TOTALS	**$19,807,068.55**	**$825,801.17**	**$44,595.45**

*The Urban State Trooper Salaries are based on 2008 figures and account for inflation.

Table 12: Negative Externalities Produced by the Lower Ship Creek Fishery, 2000-2008.

Costs 2000-2008	User Education & Outreach	Streambank Restoration	Monitoring	Infrastructure Construction & Maintenance
ARRC		$136,835.39	(unknown)	$2,573,528.68
AWC	$20,361.78	$105,839.86		
Conservation Fund				$6,950.19
MOA				$18,958,107.71
NFWF	$121,631.46	$35,676.36		
NMFS				$2,199,742.84
USFWS	$37,206.98	$14,865.15		$1,301,658.75
Williams Petroleum				$169,121.18
TOTAL	**$179,200.22**	**$293,216.76**	**$0.00**	**$25,209,109.35**

*These are the costs paid by public infrastructure providers that meet Baumol's and Oates' (1988) two conditions for the existence of externalities: 1) the agency's utility is being affected by real values that are chosen by the State of Alaska without attention to the agency's welfare, and 2) the State of Alaska is not receiving an amount equal in value to the resulting costs to others.

*Table 8 contains all costs paid by public infrastructure providers.

4.0 Chapter 4 The Urban Fishery: An Application of System Robustness[3]

4.1 Abstract

This chapter applies the conceptual framework of robustness, as proposed by Anderies et al. (2004), to a case study of a common pool resource – the Lower Ship Creek Fishery in Anchorage, Alaska. I apply the robustness framework rather than resilience theory to address the management of this fishery because engineered systems, such as a hatchery fishery, operate independently of some ecological variables within the system. There is a need to distinguish the socio-economic and ecological components of the system and use interdisciplinary methods to study their interrelationships because of the unintended effects of engineered components that are relatively insensitive to ecological feedbacks. For example, engineered hatchery fish continue to thrive despite declining stream conditions. This is accomplished by exploring the interrelationship of socio-economic and ecological systems and then using Ostrom's design principles (1990) to define, assess, and suggest opportunities for increasing the robustness of an urban fishery.

4.2 Introduction

Every summer residents and visitors gather for a unique experience on a creek in downtown Anchorage, Alaska. Surrounded by industrial yards, the state's railroad, interlocking road systems, and the city's port, pulses of salmon carried by Cook Inlet's

[3] Krupa, M. B., A. Lovecraft, and F. S. Chapin, III. 2009. The Urban Fishery: An Application of System Robustness. Prepared for submission in Ecology and Society.

world record tides enter Ship Creek. The anglers enter the creek by descending down specially designed staircases built to withstand tides and ice flow. Standing shoulder to shoulder on the banks of Ship Creek, anglers fish for salmon. Under-cover patrols move up and down the creek to ensure safety and regulatory compliance. Anchorage's children line up on a kid-sized fishing platform to cast their first line into salmon-filled waters. Benches, garbage cans, fish cleaning stations, and restrooms are conveniently located and regularly maintained.

To visitors from cities like Seattle and Baltimore who take buses to see the salmon fishery, Ship Creek appears to have defied the odds. Here, in The Last Frontier, the salmon have seemingly prevailed over the effects of urbanization (Chapter 2). Or have they? What many visitors and residents don't realize is that the two salmon species are the product of a carefully engineered hatchery fishery, fueled by a complex network of inter-and intra-institutional arrangements and cost structures.

The above description is what a robust Lower Ship Creek Fishery might look like if it was supported by the appropriate social and economic frameworks. Today's fishery has all the people and fish with few of the amenities needed to sustain them. Declining water quality and quantity, erosion, and barriers to fish passage have substantially altered the creek. Lower Ship Creek is a semi-engineered system sitting at the crossroads between wilderness and concrete. In light of this position, the question that managers face is how to create a robust urban fishery when some of the components are engineered and others are natural. To achieve this, managers need to be able to identify the characteristics that decrease the robustness of this social-ecological system (SES) and then understand the ecological and socio-economic context that produce these characteristics.

A SES is an ecological system linked to and affected by one or more social systems. A SES is defined as the subset of social systems in which some of the interdependent relationships among humans are mediated through interacting biophysical and non-human biological units (Anderies et al. 2004).

Although this urban fishery SES is singular, its challenges are not unique. Increasing urbanization in the lower Pacific Northwest states of Washington, Oregon, Idaho, and California have pushed wild salmon populations to the brink of extinction (Netboy 1980, Nehlsen et al. 1991, Cone and Ridlington 1996, Huntington et al. 1996, National Research Council 1996, Gresh et al. 2000). Widespread public support has leveraged millions of restoration dollars to prevent the loss of salmon populations and still they are disappearing (Lee 1993, McGinnis 1994, 1995). While the reasons for the failure of salmon restoration in the lower Pacific Northwest are complicated, one of the main drivers may have been the allocation of funds to address the biophysical symptoms, rather than the socio-economic causes of these symptoms.

What methodological approach can best help managers delineate the socio-economic causes of biophysical degradation within an urban SES, and can this approach be used to better achieve the goals identified by users and public infrastructure providers that comprise robustness? This chapter proposes that the robustness framework and Ostrom's (1990) institutional design principles can help sport fishery managers contextualize the biophysical problems associated with the management of sport fisheries by evaluating the institutional robustness of this urban SES.

The complex interactions between the components of SESs have been studied in commercial fisheries (McHugh 1975, Finlayson and McCay 1998, Acheson 2003), but urban sport fisheries have received little attention. I define hatchery fish as fish produced from brood stock by artificial spawning in a hatchery environment. Conversely, wild fish are produced by natural spawning in natural fish habitat by parents that were spawned and reared in natural fish habitat.

The Lower Ship Creek Fishery SES is examined because it contains clearly identifiable interactions between the biological and social systems. The social interactions then can be studied to determine how and why biophysical symptoms are produced. When anglers (resource users) fish Lower Ship Creek, they interact not only with each other and the fish, but also with public infrastructure providers, who interact with each other as well. Public infrastructure providers are the agencies, businesses, and organizations that directly or indirectly contribute to the operation and maintenance of the fishery.

4.3 Theoretical Background

This chapter examines the SES's response to the engineered component (the hatchery fishery) through the robustness framework. I chose to apply a robustness framework rather than resilience theory because robustness encompasses the unique attributes of this SES, which has relatively weak feedbacks among its designed and self-organized components. Although robustness is more appropriate analytical framework than resilience for this SES, this study acknowledges that the robustness of semi-engineered systems contributes to the overall resilience of communities. For example, the robustness of the Lower Ship Creek sport fishery contributes to the resilience of Anchorage, Alaska by increasing local food and recreation options and supporting a diverse set of businesses.

Numerous studies have explored traditional and modern management in social-ecological systems (Berkes and Folke 1998, Gunderson and Holling 2002, Gunderson and Pritchard 2002, Berkes et al. 2003, Dasgupta and Mäler 2004, Folke 2004, Walker et al. 2006). Most of these studies have focused on identifying the ecological and social sources of resilience that would enable the system to persist in its current state or management techniques that might increase the system's resilience. While the goals of this study are similar, the semi-engineered characteristics of an urban fishery SES are different.

Holling (1996) distinguished between two types of resilience: engineering resilience and ecological resilience. Engineering resilience assumes that ecological systems exist close to a stable steady-state and measures the ability of a system to return to this steady state following a perturbation (Pimm 1984). An example of engineering resilience is a bridge, which one would prefer to be close to its stable steady-state. When wind causes oscillations of the bridge and leads to its destruction, an undesirable steady-state is reached.

The concept of ecological resilience addresses the amount of change or disruption that a system can sustain before changing to an alternative state characterized by a different set of critical processes, structures, and interactions (Walker et al. 2004). Although this "tipping point" approach is conceptually consistent with robustness and appropriate to many natural-resource issues, it may not provide answers for managers of semi-engineered systems, where structures and interactions among components are more tightly constrained by human design.

Robustness first emerged in the field of engineering. The Robust Design Methods, or the Taguchi Methods, make companies more competitive through more efficient development processes. Taguchi et al. (2000) define robustness as the state where the technology, product, or process is minimally sensitive to factors causing variability (either in the manufacturing or user's environment) and aging at the lowest unit manufacturing cost. The Taguchi Methods greatly improves engineering productivity by consciously considering the noise factors (environmental variation during the product's usage, manufacturing variation, and component deterioration) and the cost of failure in the field (Phadke 1989). Companies, such as Ford, Minolta, NASA, and Xerox, have all successfully used these methods (Taguchi et al. 2000).

Similar to what occurs manually in engineering, biological systems naturally develop responses to survive variable conditions. Developmental biology uses the concept of developmental robustness to describe the ability of an organism to continue to grow despite encounters with disturbances (Keller 2002, Felix and Wagner 2008). Robustness is also used in the field of community ecology (MacArthur and Wilson 1967, Tilman et al. 1996).

The field of social science uses the concept of robustness in the study of the institutional governance of common pool resources. Shepsle (1989) stated that social systems were considered robust if they were long-lived and governed by operational rules that had been devised and modified over time according to a set of collective choice rules. Due to the diverse range of operational and collective choice rules found in different social systems, it became apparent that more general design principles were needed to characterize common-pool resource institutions.

When Ostrom (1990) derived a set of design principles from studies of small-scale, long-enduring institutions for governing common-pool natural resources, she did not initially connect them with the concept of robustness. These principles were based on years of field work and case studies of simple-and-self-contained to complex-and-linked systems and have been well tested over the last two decades (de Moor et al. 2002, Kaijser 2002, Dietz et al. 2003). Ostrom eventually paired the concept of robustness with the design principles (1990) by stating that a social-ecological system is likely to be robust if it meets many (but perhaps not all) of these principles (Ostrom 1999, 2002, 2005, Ostrom et al. 2003).

Since SESs contain both engineered and biological components, they also experience variability and develop responses to disturbance. As applied to social-ecological systems, robustness is defined as "the maintenance of some desired system characteristics despite fluctuations in the behavior of its component parts or its environment" (Carlson and Doyle, 2002). Levin and Sugihara (2007) clarify the difference between the use of robustness in engineering and ecology by stating, "Social-ecological systems are systems in which whatever robustness exists has to emerge from the collective properties of the individual units that make up the system. No one planner or manager completely controls the system."

A SES that is subjected to a particular type and degree of variability may become highly optimized to tolerate that variability and become more sensitive to new disturbances (this characteristic of adaptive systems is referred to as highly optimized tolerance or HOT) (Carlson and Doyle 2002). Therefore, robustness emphasizes the cost-benefit trade-offs associated with systems designed to cope with uncertainty (Anderies et al. 2004, Janssen and Anderies 2007). This emphasis is especially relevant to an urban fishery SES, where the engineered components often generate a tradeoff through the replacement of wild fish by hatchery fish. Perceived environmental problems, social conflicts, and economic fluctuations all produce challenges; but with the proper infrastructure, no single shock is likely to bring ruin to a robust system.

The National Research Council (1999, 2002), the Millennium Ecosystem Assessment (2003), and The "Consortium for Sustainable Development" (of the International Council for Science, the Initiative on Science and Technology for Sustainability, and the Third World Academy of Science) (Walker et al. 2004) have all focused increasing attention on the concepts of robustness, vulnerability, and risk. More recently, Janssen et al. (2007) examined the robustness of SESs to spatial and temporal variability to determine why some long-lived SESs persist in the face of change and others do not. Anderies et al. (2007) applied the robustness framework to sustainability science to extract broader themes for the management of resources under uncertainty.

Levin and Lubchenco (2008) have applied robustness to the management of marine ecosystems.

Both ecological resilience and robustness denote the ability of a system to maintain its macroscopic functional features (e.g., species diversity) rather than the unattainable possibility of constancy (Webb and Levin 2005). The functional robustness or resilience of an ecosystem can be maintained despite some species extinction under conditions where other functionally similar species maintain the same ecosystem properties.

Although ecological resilience and robustness are frequently used interchangeably (Adger et al. 2005, Levin and Lubchenco 2008), there are important differences. Ecologically resilient systems, for example, are generally characterized as evolved systems that demonstrate high diversity, ecological variability, modularity, slow variables stabilized by tight feedbacks, social capital, innovation, overlap in governance, and sustained ecosystem services (Walker and Salt 2006). The characteristics of ecologically resilient systems are often poorly developed in human-designed and operated systems.

Unlike the ecological resilience perspective, which often considers human activities as perturbations of an ecological system, robustness considers SES where humans develop institutional feedback loops to respond to perturbations (Janssen and Anderies 2007). Robust systems are generally characterized as partly-designed systems, with both self-organized and designed components (Anderies et al. 2003). Crafted institutional arrangements aim to stimulate and support a particular performance of a SES, like engineers design systems to meet certain design criteria (Janssen and Anderies

2007). Since urban hatchery fisheries are partly-designed systems that contain both engineered (i.e., hatchery fish) and biological (i.e., nutrient cycling) components, robustness is a fitting framework for this particular case study.

The timeframe of analysis differs between resilience and robustness as well. Robustness focuses on the ability of a SES to maintain its social and/or ecological domain of attraction within a specified time frame (Anderies et al. 2003). A system may be robust during one time period and not in another. This is not the case with resilience, which seeks to attain resilience without lapses over a long time period.

SES robustness depends largely upon the ability of its public infrastructure providers to respond to coinciding occurrences of economic, social, and ecological changes (Anderies et al. 2004). When one resource collapses, managers have the ability to achieve desired outcome through the substitution of another valued good (see section VIII). Management decisions rely upon feedbacks between both slow (e.g., evolution, long-lived institutions) and fast variables (e.g., pollution event, organizational collapse) (Carpenter and Gunderson 2001). Managers are able to make predictions based on slow variables, but the self-organizing properties of ecological and social systems cause increased uncertainty over time (Levin 2000). It is therefore important to examine both self-organized and engineered components when determining robustness.

The hatcheries, which provide public infrastructure, are an engineered component within the SES that lacks many of the characteristics thought to characterize a resilient system. The hatcheries eliminate the diversity and number of species through several mechanisms. They produce larger numbers of targeted sport fish species than the lower creek could naturally support (ADFG 2007). They remove ecological variability by artificially controlling population levels and restricting genetic diversity (Figure 12 in Chapter 2). Hatchery fish are immune to natural sources of population variability because they are raised in a controlled environment until they are large and strong enough to be released and therefore not as susceptible to the effects of instream scouring, temperature changes, predation, or pollution. Hatchery fish also are therefore unlikely to experience stress related to the high number of pollution events (Table 13) within Lower Ship Creek.

Despite the cumulative impacts of urbanization, the hatcheries do not respond to these feedbacks and continue to produce large numbers of salmon because they are produced in a controlled environment (Figure 12 in Chapter 2). Wild fish populations, which spend their growth phase in the stream, generally decline in response to urbanization (Klein 1979, Steedman 1988, Limburg and Schmidt 1990, Schueler and Galli 1992, Wang et al. 1997, Yoder et al. 1999).

The hatcheries are managed by a single agency (ADFG 2007) rather than under overlapping governance among agencies. The ADFG does not seek innovation in managing fish stocks (ADFG 2003). Most importantly, the hatcheries do not address all of the ecosystem services affected by its production. Since there is little feedback from the social and ecological impacts of the fishery back to Alaska Department of Fish and Game (ADFG) decisions that drive the fishery, resilience theory fails to adequately address the complexity of this and other engineered systems.

Although biologists know approximately how many fish will annually return to a Ship Creek, the effect of this component on the greater SES is not known. Management challenges increase when engineered components interact with natural components because the artificial optimization of one system can produce negative effects on other components of the system. One agency may reap the benefits from a well engineered system, while others pay the costs (Chapter 3).

Robustness and Ostrom's (1990) design principles may allow managers to better understand the character of and interactions between the components of this semi-engineered, urban SES to reduce impacts that decrease the robustness of this SES.

4.4 Objectives & Methods

In order to help managers better address the causes of biophysical degradation, I (1) identify and describe the relevant socio-economic and ecological systems; (2) outline the desired system characteristics, as formally defined by resource users and public infrastructure providers; (3) discuss the interactions within and between these systems, using the concepts of strategic interaction established by Anderies et al. (2004); and (4) use Ostrom's design principles to identify opportunities for increased SES robustness (Anderies et al 2004).

The SES, its relevant components, and the interactions between the social and ecological systems were defined and analyzed using Anderies et al.'s (2004) framework. The ecological and social components include the components that most directly influence the fishery. For example, the ecological components of water quality and water quantity can affect hatchery production, which controls the fishery. Lower Ship Creek's public infrastructure providers and recreational and subsistence users are the social components that most directly affect the fishery.

The next step is to identify the desires of the public infrastructure providers and users in order to determine whether common goals can be established for the SES and identify potential sources of conflict. The desired social-ecological components of this SES are formally defined by the mandates and missions of public infrastructure providers, including municipal, state and federal agencies, nonprofit organizations, and local businesses and from the results of a standardized questionnaire that was sent to each public infrastructure provider (Appendix A). The desired social-ecological components of subsistence and recreational anglers are inferred from user surveys conducted by the Anchorage Waterways Council as well as the general interests and activities of the two groups (Table 3, Chapter 2, Appendix B).

Once the ecological and social components are identified, the interactions within and between these systems will be discussed using Anderies et al.'s (2004) concepts of strategic interaction. I assessed the fit of this SES to Ostrom's (1990) design principles by applying each of the principles to the Lower Ship Creek Fishery SES to determine which principles this SES failed to meet. I then analyzed the failed principles to identify opportunities to increase the overall robustness of this SES.

4.5 Components of the Lower Ship Creek Fishery SES

This SES is located within the Municipality of Anchorage (MOA) in downtown Anchorage, Alaska. The SES encompasses the last 1.45 km of Ship Creek and extends from the Knik Arm Power Plant Dam (KAPP) to the mouth of the creek at Cook Inlet (Note: KAPP Dam is labeled as Chugach Power Plant (Figure 16 in Chapter 3)).

4.5.1 The Ecological System

I define the Lower Ship Creek Fishery SES in terms of its ecological system (this section) and its social system (next section, Figure 23, Table 14, 15). The fishery under examination includes hatchery-produced chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (*Oncorhynchus kisutch*). The ecological components that most directly influence the fishery are the quantity and quality of water available for use by the hatcheries.

Lower Ship Creek experiences a tidal range of 11.3 meters, which is the second highest range in North America (NMFS 2002). The strength and height of these tides pose engineering challenges for the construction and maintenance of public infrastructure and streambank stabilization projects.

Historically, Ship Creek supported wild runs of all five Pacific salmon species (chinook, coho, pink (*Oncorhynchus gorbuscha*), chum (*Oncorhynchus keta*), and sockeye (*Oncorhynchus nerka*), as well as Dolly Varden (*Salvelinus malma*), rainbow trout (*Salmo gairdneri*), and stickleback (*Gasterosteus aculeatus*) (ADFG 2007). The run sizes of the original five salmon populations are unknown, but it is known that current, hatchery-supported runs greatly exceed historical numbers (ADFG 2007).

Two state-run hatcheries located on military bases now annually stock Ship Creek's popular fishery (see Chapter 2). The Fort Richardson Hatchery was built in 1958 and expanded in 1984. The Elmendorf Hatchery was built in 1965 and expanded in 1976. Ship Creek was first stocked with chinook salmon smolts in 1966 and coho smolts in 1968 (ADFG 2007). A limited chinook salmon fishery first opened in 1970 (ADFG 2007).

At present, the hatcheries continue to stock large runs of chinook and coho salmon in this SES. Declining wild runs of chum and pink salmon and Dolly Varden still spawn in the creek, but their numbers are undocumented. Sport fishing for salmon is permitted within the last 1.45 km of the creek, from the KAPP Dam to the mouth (ADFG 2007).

The hatcheries had an agreement with Elmendorf Air Force Base (EAFB) and Fort Richardson Army Base (FRAB) that allowed the hatcheries to take excess heated water from the base power plants and combine it with surface water from Ship Creek. This agreement enabled the hatcheries to maintain a year-round rearing program. With the addition of heated water, the hatchery was able to produce ocean-ready smolts in one year, instead of two years (ADFG 2008). The recent closure of both military plants has resulted in considerable declines in the state's salmon stocking programs (ADFG 2008).

The hatcheries, which now utilize Ship Creek surface water for their operations, are also concerned with the creek's water quantity and quality. Water quantity (instream flow) is a concern because it is a scarce resource that may be over-allocated. Instream flow is defined as the quantity of water that flows past a given point in a stream channel during one second. The lack of hydrologic data in Alaska is perhaps the most limiting factor in determining instream flow reservations, but other factors include costly and lengthy studies and administrative processes, and expensive application fees (Harle and Estes 1993). Under the current adjudication system, permitted water use may exceed supply during peak use times because many water rights applications are still pending (Estes 1998).

According to fecal coliform monitoring data collected by the Municipality of Anchorage (MOA) from 1989-1994, the water quality criteria for drinking water and contact recreation were exceeded at various times (EPA 2004). Since 1990, the Alaska Department of Environmental Conservation (ADEC) has listed Ship Creek from the Glenn Highway bridge to its mouth at Cook Inlet as a 303(d) Impaired Waterbody due to the presence of petroleum hydrocarbons, oil, grease, fecal coliform bacteria and biological community alteration from urban runoff and industrial spills (EPA 2004, Table 13).

In 2007, the presence of disease (*Myxobolus cerebralis)* in Ship Creek (Arsan 2006) forced ADFG's Elmendorf Hatchery to limit the introduction of hatchery fish to land-locked systems. To prevent further losses in production related to changes in water quantity or quality, the state is in the process of securing funding for the construction of one modern hatchery facility that will implement well-water reuse systems (ADFG 2008).

Other exogenous controls, such as oceanic and climatic cycles and predation, also influence the survival rate of both wild and hatchery salmon populations (Carpenter et al. 1992). Major climatic and oceanic shifts have significantly altered salmon survival in the Pacific Northwest (Anderson 2000). Predators, such as marine mammals and birds, are often identified as additional factors contributing to salmon decline (Smith et al. 1998). While the effects of these variables are difficult to quantify, they should be considered because they could play an important role in the long-term robustness of the system.

4.5.2 The Social System

The social components that most directly influence the fishery are the public infrastructure providers and resource users. The public infrastructure providers directly or indirectly support the operation and maintenance of the fishery by providing services such as fish production or trash removal services. Resource users consume the production of the fish and contribute to the public infrastructure providers via annual fees.

The public infrastructure providers and the resource users interact within a complex network of private land ownerships and federal and state jurisdictions. Resource users that purchase a fishing license and follow regulations are allowed to participate in the fishery. Ownership of the land surrounding Lower Ship Creek is somewhat complicated (Table 6, Chapter 3). The State of Alaska owns and has jurisdiction over the stream bed of Ship Creek. The Municipality of Anchorage (MOA) owns and has jurisdiction over a 30-foot setback on either side of the creek and is responsible for the maintenance of the infrastructure, such as trails, benches, and lighting, that exists within this setback. The MOA also owns the newly constructed bridge near the mouth of the creek. The Alaska Railroad Corporation (ARRC) owns the land adjacent to the last 1.4 km of Lower Ship Creek. Although much of the ARRC land is long-term leased to local businesses, the ARRC has ultimate jurisdiction over these lands. The ARRC also owns a railroad bridge that crosses over the creek within the fishery.

The State of Alaska's Sport Fish Division of the Alaska Department of Fish and Game (ADFG) has management authority under Title 16 and Title 41 in the State of Alaska's statues, and makes all decisions regarding the sport fishery on Ship Creek, and is responsible for maintaining garbage cans and port-a-potties during the fishery openings. The Habitat Division of the ADFG has jurisdiction over the quantity of water in Lower Ship Creek because it has obtained a water right that established a minimum instream flow. Another state agency, the Alaska Department of Environmental Conservation (ADEC), has jurisdiction over Ship Creek's water quality and can impose sanctions if water quality standards are not met under the Coastal Zone Management Act. The Environmental Protection Agency (EPA) also has jurisdiction over water quality and can impose sanctions under the National Environmental Protection Act (NEPA). The EPA and U.S. Army Corps of Engineers (USACOE) can impose sanctions under Sections 401 and 404 of the Clean Water Act. The USACOE can also impose sanctions under Section 10 of the Rivers and Harbors Act. The Alaska State Troopers have legal jurisdiction and the ability to impose sanctions under Title 11 in the Alaska Statutes. The National Marine Fisheries Service (NMFS) has regulatory authority under the Magnuson-Stevens Fishery Conservation and Management Act and the Marine Mammal Protection Act. The U.S. Fish and Wildlife Service (USFWS) has the ability to provide comments on any development actions within Lower Ship Creek but is not a regulatory authority. Both NMFS and USFWS have regulatory authority under the Endangered Species Act. The U.S. Geological Survey (USGS) collects hydrologic data on Ship Creek, but does not have regulatory authority and rarely comments on development actions.

Several of these agencies are working to improve the aesthetic appeal and environmental quality of Lower Ship Creek (see 4.6.1 for more detail). The SES is valued by residents because of the creek's unique history and accessibility. The creek once supplied Alaska's Native residents, the Dena'ina, with abundant salmon runs and is

Anchorage's original town site. Most recently, Mayor Mark Begich identified the Ship Creek Revitalization Project as one of the top priorities of his administration (MOA 2007). Many current residents learned how to fish on Ship Creek and are now teaching their children how to catch a salmon in downtown Anchorage. Local businesses recognize the economic potential of the SES and are interested in drawing more people to Ship Creek.

The Lower Ship Creek Fishery SES provides the highest economic benefit to the state of any hatchery program, contributing an advertised $7.3 million to the economy (King 2004). An annual average (1996-2005) of 47,000 angler days of effort produce an average catch of 8,900 chinook salmon and 16,500 coho salmon (ADFG 2007). This SES also benefits Grace Alaska's Downtown Soup Kitchen, which organizes two salmon derbies each summer (ADFG 2007). Ship Creek's hatcheries represent two of the three's state-run hatcheries and supply fish for local creeks throughout Alaska, including Upper Cook Inlet, Resurrection Bay and Prince William Sound (ADFG 2003a, Loopstra and Hansen 2005).

Although this easily accessed fishery provides large socio-economic benefits, it also imposes the external costs commonly associated with common pool resources (Hardin 1968, Ostrom 1990, Ostrom and Field 1999, Dietz et al. 2003, Schlüter and Post-Wostl 2007). As the ADFG has increased the release of hatchery fish over the years (Figure 12, Chapter 2), no provisions have been made for the fishery's infrastructure. The lack of public infrastructure, such as bathrooms, fish cleaning stations, and garbage cans, and an increase in trespassing, illegal fishing, angler conflicts, and erosion create annual problems within the fishery (ARRC 1999, AWC 2007). The Municipality of Anchorage (MOA), Alaska Railroad Corporation (ARRC), local law enforcement entities, NOAA/NMFS, Anchorage Waterways Council (AWC), ADFG, and other resource agencies have all spent money to mitigate pollution by updating and constructing infrastructure (Chapter 3, NMFS 2002, NOAA 2005, ARRC 2006, AWC 2007, MOA 2007).

4.5.3 Interaction of Ecological and Social Subsystems

The interaction of the ecological and socio-economic components of the SES determines the system's robustness. As demand for one ecological component increases, the socio-economic components can react by limiting or compensating for that increase. For example, during the 1970s and early 80s when ground water extracted from aquifers near Ship Creek was the principal source of the MOA water supply, area-wide declines in ground-water levels resulted in near-record low streamflows in Ship Creek (USGS 2006). Because of variable flows and water quality of Ship Creek, its use as a water supply was minimized to maintain flows for aquatic and riparian habitat and to mitigate fecal coliform contamination (ADEC 2004). The MOA now receives most of its water supply from Eklutna Lake.

The pressures that have been exerted on Ship Creek's ecosystem processes (Chapter 2) have created a management need for the maintenance of this fishery's socio-economic components. As more users come to Ship Creek in search of salmon, public infrastructure providers will be pressured to maintain and/or expand services to deal with trespassing and safety issues. Since agencies work within existing and sometime opposing mandates and users have different needs, it is beneficial to carefully examine the formally defined interests of both users and public infrastructure providers.

4.6 Desired Ecological and Socio-economic Components

The major components of this SES can be divided into the categories of essential and desirable. The essential components include the minimum ecological components needed to maintain a robust fishery. A robust urban fishery will include 1) efficient hatcheries, 2) public infrastructure, and 3) sufficient water quality and quantity to sustain hatchery production (Chapter 2). The desired components include the characteristics desired by stakeholders within the SES and will be discussed below (Table 16). If either the social (public infrastructure) or ecological (water quality and quantity) components collapse, then this SES would lose its robustness (see "Assessing Robustness" section below).

4.6.1 Public Infrastructure Providers

Removing Ship Creek from the 303(d) List of Impaired Waterways is a high priority for both the ADEC and the Environmental Protection Agency (EPA), which both possess regulatory authority within Lower Ship Creek (EPA 2006). The mission of both organizations includes the protection of human health and the environment (EPA 2007, ADEC 2008). In May 2004, the EPA approved the ADEC's Total Maximum Daily Load (TMDL) plan to impose controls on Ship Creek that will improve water quality by reducing fecal coliform bacteria (EPA 2004). A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources (EPA 2008). The EPA is working with the Alaska Railroad Corporation (ARRC) to monitor Ship Creek's water quality for petroleum (EPA 2006). This will enable the ADEC to determine the best recovery actions for Ship Creek, which may involve the development of a TMDL or similar recovery plan for petroleum (EPA 2006).

The mission of the U.S. Fish and Wildlife Service (USFWS) is "to work with others to conserve, protect and enhance fish, wildlife, and plants and their habitats for the continuing benefit of the American people" (USFWS 2008). The USFWS has the ability to provide comments on actions taken within Lower Ship Creek, but does not have any regulatory authority. The primary short-term goal for USFWS on Ship Creek is to remove barriers to anadromous and resident fish passage, through partial or complete dam removal or fish-way improvement, so that the creek is largely barrier-free by 2012 (Roy 2007). The USFWS' long-term goal for Ship Creek is to create a barrier-free, urban system that achieves a socially-accepted balance of augmented and natural fish runs providing ample angling opportunity, relatively natural stream function, and substantially improved riparian function (Roy 2007).

In accordance with its mission of "creating development opportunities for the highest public benefit, using innovation, partnerships, sound planning, and incentives," the MOA is interested in sustaining the Ship Creek's unique urban fishery, natural values, and economic activities (MOA 2007, 2008). The MOA would also like to see a new hatchery and visitor center built on EAFB (MOA 2007). As a land owner, the MOA has to grant permission for projects within the 30-foot setback on either side of the creek (see earlier discussion, Chapter 3).

The primary mission of the ADFG is "to protect, maintain, and improve the fish, game, and aquatic plant resources of the state and manage their use and development in the best interest of the economy and the well-being of the people of the state, consistent with the sustained yield principle" (ADFG 2003). The ADFG lists Ship Creek as anadromous in its "Catalog of Waters Important for the Spawning, Rearing or Migration of Anadromous Fishes" (ADFG 2008a). This is an important designation because Ship Creek is technically afforded protection from any activities that would harm the habitat of anadromous fish under AS 41.14.870 (ADFG 2007).

The goals of the ADFG's Ship Creek hatcheries include: 1) generating at least 50,000 angler days of opportunity directed at stocked chinook and coho salmon, 2) meeting the brood stock goals of 500 chinook salmon and 1,000 coho salmon, 3) maximizing the harvest of surplus hatchery salmon, 4) improving existing hatchery operations, and 5) accommodating future plans for a new fish hatchery and/or visitor facility adjacent to the creek (ADFG 2007). The ADFG is also interested in restoring fish passage to upper Ship Creek and reducing or minimizing operation and maintenance requirements caused by debris, sedimentation and icing on Ship Creek (ADFG 2007).

The mission of the ARRC is to be profitable while delivering safe, high quality service to their freight, passenger, and real estate customers and to foster the development of Alaska's economy by integrating railroad and rail-belt community development plans (ARRC 2007). As the landowner of most of the property and entire streambed within the SES, the ARRC is concerned about trespassing and safety issues associated with the fishery and pedestrian traffic, and the effect that these issues may have on their leaseholders (ARRC 2006). The ARRC is currently working with the EPA to search for and identify possible contaminants and devise strategies for either eliminating or mitigating risks according to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) regulatory guidelines (ARRC 2007a, EPA 2002).

The National Marine Fisheries Service (NMFS) provides for the stewardship of living marine resources through science-based conservation and management and the promotion of healthy ecosystems (NMFS 2007). The agency defines Knik Arm, including the Ship Creek estuary, as Essential Fish Habitat (EFH) under the Magnuson-Stevens Fishery Conservation and Management Act for natural runs of migrating and/or rearing chinook salmon, coho salmon, pink salmon, and chum salmon (Mechum 2006). In the past five years, the NMFS has contributed a considerable amount of money through federal grants for fish passage and habitat restoration projects to benefit natural runs of salmon adjacent to and on Ship Creek (NMFS 2002, NOAA 2005, MOA 2007).

The mission of the nonprofit organization Anchorage Waterways Council (AWC) is "to protect, restore, and enhance the waterways, wetlands, and associated uplands of Anchorage" (AWC 2007a). The AWC would like to see the lower three dams on Ship Creek removed, improved water quality, the restoration of wild runs in addition to the hatchery runs, and the construction of angler infrastructure (AWC 2007).

There are fundamental differences between the missions of the ARRC and the other public infrastructure providers, such as the AWC and state and federal agencies. Any efforts to improve angler opportunities, fish and wildlife habitat, or water quality fall outside of the ARRC's primary mission to provide safe transportation and improve Alaska's economy.

While each of the public infrastructure entities works under different mission statements, most of their goals are related (see Table 6, in Chapter 3). The federal natural resource agencies (USFWS, NMFS) and the nonprofit organization (AWC) are all concerned with the restoration of fish and wildlife habitat, including fish passage, and stream and riparian functions. The EPA and ARRC are concerned with improving water quality. In addition to these goals, the federal agencies and nonprofit organization are also interested in maintaining angler access and opportunity. The AWC, MOA, and ARRC are all concerned with preventing erosion. Since most of the goals of the public infrastructure providers are compatible, a broadly desirable outcome is possible without having to address the major tradeoffs often associated with common pool resources.

4.6.2 Resource Users

All resource users fish Lower Ship Creek, but there is varying interest in fish and wildlife restoration, fish passage, and water quality among resource users. According to a user survey conducted by the Anchorage Waterways Council (AWC) in 2003 (Appendix B), users are primarily interested in improving the water quality of the creek. Other concerns documented by the AWC survey in order of importance to users are: fish passage, user safety and access, and "healthy" development (Table 3, Chapter 2). "Healthy" development is defined as non-industrialized development, such as bait shops, that supports the Lower Ship Creek Fishery. While the survey did show that both residents and visitors participate in the fishery, the exact ratio of these user types is unknown. Based on the observations of volunteers conducting the surveys, the fishery's users were either fishing for recreation or subsistence. The determination of whether a user was recreational or subsistence was made based on the type of fishing gear used. Recreational users tended to use more expensive and elaborate fishing gear than subsistence users. Resource users can therefore be separated into the categories of 1) subsistence, and 2) recreational.

Subsistence users rely upon Ship Creek's salmon as a food source and spend a considerable amount of time fishing the creek. They are concerned about any impact that could decrease their ability to catch fish. They want high returns of fish populations and catch limits, and low licensing fees. An increase in licensing fees could prevent their participation in the fishery and/or lead to an increase in illegal fishing efforts since many of the subsistence users have low incomes. They do not support dam removal because the dam currently impedes fish movement and traps fish within the Lower Ship Creek fishing area. Its removal would therefore decrease their ability to catch fish.

Recreational users tend to spend less time on the creek and do not rely upon Ship Creek salmon as a food source. They want an aesthetically pleasing and safe environment for their sport fishing experience. They generally support the restoration of fish passage through dam removal because it would make catching fish more difficult and enhance their fishing experience. Increased licensing fees do not curtail their involvement in the fishery.

Subsistence and recreational users do have common interests as well. All users benefit from using public infrastructure to safely access the creek to fish. Several accidents over the years have affected both recreational and subsistence users' abilities to safely participate in the fishery. In 2005, three failing culverts at the mouth of Ship Creek were removed to improve recreational and subsistence user safety. Most users are also interested in the construction of a new hatchery because it would increase the fishery's robustness. Currently, there is widespread concern that the outdated hatchery facility will be unable to sustain current fish release levels due to inefficient production methods and the lack of an uncontaminated water supply (ADFG 2008).

4.7 Assessing Robustness

A SES can broadly be considered as robust if it "prevents the ecological systems upon which it relies from moving into a new domain of attraction that cannot support a human population, or induces a transition that causes long-term human suffering" (Anderies et al. 2004). Since the examination of cost-benefit trade-offs is inherent to the robustness framework (Anderies et al. 2004, 2006), it is beneficial to conceptualize the strengths and weaknesses of societies and ecosystems.

Using Ostroms' (1990) design principles derived from studies of long-enduring institutions for governing resources, the robustness of this SES can be assessed based on the ability of the public infrastructure providers to create a flexible yet inclusive management structure that allows the SES to adapt to changes in angler numbers, stream conditions, and development pressures (Table 15).

4.7.1 Clearly Defined Boundaries

The Ship Creek fishery has clearly defined boundaries (Table 15). The ADFG defines the salmon fishery 1.45 km from 15 meters below the KAPP Dam to the mouth of the creek at Cook Inlet. Anyone who has purchased a sport fishing license from ADFG and abides by the fishing regulations has a right to fish the creek.

4.7.2 Proportional Equivalence between Benefits and Costs

There is a disproportionate relationship between the benefits and costs of this SES. The costs of maintaining this fishery are currently not accounted for while the benefits are routinely advertised as producing $7.3 million annually to the State of Alaska (King 2004). The SES benefits include revenues associated with the purchase of sport fishing permits (ADFG), tourism (local businesses, MOA), annual salmon derby entrance fees (nonprofit organization), and outfitting (local businesses). The SES costs include all facilities, services, and programs supporting the fishery as well as the costs paid to mitigate the problems created by the Fishery (externalities). These costs are primarily borne by the MOA, ARRC, State of Alaska, ADFG, EAFB, FRAB, local businesses and nonprofit organizations (ADFG 2007, AWC 2007, MOA 2007, ARRC 2006, Chapter 3). The ADFG has not responded to these mounting costs by limiting the Total Allowable Catch (TAC), which reduces user traffic. In fact, the number of angler user days has increased each year (Figure 23).

4.7.3 Collective-choice Arrangements

There is no effective collective-choice arrangement on Ship Creek between the resource users and the ADFG. All rules regarding the fishery's TAC and openings are determined by the Sport Fish Division of the ADFG with survey input from Ship Creek anglers. However, there is no forum for dialogue with anglers or any mechanism for input from other public infrastructure providers. Since the other public infrastructure providers are directly affected by changes to the SES, their inclusion in the decision-making processes would likely increase this SES' robustness.

The ADFG is a state agency governed by the Alaska Board of Fisheries with several departments that provide different services and goals. Differing agendas can produce intra-agency tension between different departments, but opportunities for cooperation also do exist. One of the goals identified by the entire ADFG as a state agency is to optimize public participation in fish and wildlife pursuits (ADFG 2008b). The mission of the Habitat Division of ADFG is to preserve the state's fish and wildlife resources by protecting the areas they need to complete their life cycles (ADFG 2008c). This includes maintaining fish passage and instream flow. The ADFG therefore has incentive to work with public infrastructure providers to reduce erosion and protect fish and wildlife habitat within the fishery.

One potential challenge to including the public infrastructure providers in decision-making processes is their shifting roles within different scenarios. For example, the MOA's involvement in projects on Ship Creek has drastically increased with the election of Mayor Mark Begich. Another challenge is that the ADFG personnel who decide TAC are often politically appointed by the governor and therefore subjected to public scrutiny and influence.

4.7.4 Monitoring

The lack of user and biophysical monitoring restricts the system's robustness. Although the ADFG, Alaska State Troopers, and ARRC all monitor user licensing and behavior on Ship Creek, enforcement remains a problem in this easily accessed fishery.

The salmon fishery below the KAPP Dam is closed nightly from 11pm to 6am from May 25 to July 13, but the Alaska State Troopers routinely catch people snagging fish during this period (Alaska State Troopers 2007). The ARRC also closely monitors user behavior to ensure their safety and prevent trespassing on its railroad tracks and bridges.

The USGS currently monitors the quantity of water in Ship Creek at two gauge stations. The AWC, EPA, and ADEC monitor the water quality of Ship Creek; but other biophysical characteristics, such as fish habitat and morphology, go unmonitored. Due to a lack of biophysical monitoring, the ecological (and resulting social and economic) costs and benefits of restoration projects are largely unknown and therefore a source of conflict among public infrastructure providers.

4.7.5 Graduated Sanctions

Graduated sanctions do exist within the Lower Ship Creek Fishery. The bail schedule for sport fish violations takes into account the severity of the violation. A single violation only receives one penalty, with different penalties for increasing numbers of violations. However, if the violator harvests too many fish, they are fined a species-dependent set amount for each fish they have taken over the legal bag limit. For example, last winter an individual was caught with more than 100 fish over his limit on another Anchorage creek. His fine amounted to more than $7,000 (Bosch 2008).

4.7.6 Conflict-Resolution Mechanisms

Ship Creek anglers and officials have access to low cost, local arenas to resolve conflict. The most obvious conflicts occur between anglers during peak fishing times when space is limited and the fish are running. Safety concerns are usually quickly addressed by the Troopers or the ARRC police because of the creek's easy access. Plain-clothed troopers and the ARRC police patrol the creek on a daily basis. Citizens may contact the ADFG or the Alaska State Troopers with their concerns.

4.7.7 Minimal Recognition of Rights to Organize

The rights to organize are present within this system. If users wanted to create their own institution, they could do so and claim rights to participate in management decisions. However, the necessary institutional framework and social networks are currently lacking, and the diverse and scattered populations of users and their negative opinion of the agencies that govern their actions make organization highly unlikely. It is unclear whether the users could form a group that adequately represents all interests and work cooperatively with governing organizations.

By evaluating the strengths and weaknesses of the relationships between the public infrastructure providers and resource users, the SES fails to meet three of Ostrom's (1990) seven design principles. The SES does not have 1) a proportional equivalence between benefits and costs, 2) collective-choice agreements, and 3) sufficient user and biophysical monitoring (Table 15).

4.7.8 Interactions

The lack of a proportional equivalence between benefits and costs, collective-choice agreements, and sufficient user and biophysical monitoring interact to decrease SES robustness. The need for proportional equivalence between benefits and costs and collective-choice agreements addresses the problems of free riding and subtractability of use through the creation of rules (Anderies et al. 2004) but fails to address the problem of enforcing these rules. User and biophysical monitoring plays a vital role in enforcing these rules and increasing SES robustness. If addressed in unison, these three opportunities could increase SES robustness and sustain the resource.

4.8 Conclusion

The challenges of regulating an urban, engineered combat fishery are real but not insurmountable. Urban managers may be able to utilize the design principles (Ostrom 1990) within the robustness framework to distinguish the socio-economic and ecological components of engineered systems and use this knowledge to more effectively maintain engineered systems. Future research into the similarities between interacting public infrastructure providers and resource users in other urban engineered SESs as well as the SES's ability to meet the design criteria would provide further insight into the components of robustness.

Urban systems possess great social, economic, and ecological value and can be maintained despite uncertain conditions, but this will require a paradigm shift within the public infrastructure providers. Currently, the six strongest providers sit at opposite ends of the engineered to wild spectrum (Figure 24). The other two providers, the ADEC and EPA, are mainly concerned with water quality and therefore less concerned with the creek's engineering or wildness (Figure 24).

Lower Ship Creek is neither engineered nor wild. It is a unique combination of biophysical components reacting with an engineered resource in an urban setting. The current challenges within this SES are the result of the public infrastructure providers' failure to address both of these components in their management efforts.

Currently, the USFWS, NMFS, and AWC are all trying to “restore” the creek to a more natural condition by improving the creek’s overall fish and wildlife habitat and fish passage but are largely ignoring the need for the system’s engineered and social components. Costly fish and wildlife habitat restoration is extremely difficult if not impossible to maintain within a highly trafficked area such as Lower Ship Creek. The MOA, ARRC, and ADFG are trying to engineer the creek on a reach by reach basis to meet public needs and expectations but are generally failing to consider the biophysical components of the creek in their project designs. This has cost agencies a considerable amount of money and resulted in failed projects.

The good news is that no legal barriers prevent the public infrastructure providers from working together. In fact, many agency mandates and funding sources require the formation of partnerships (AWC, MOA, USFWS, and NMFS). All of the providers have partnered on a variety of reach-scale projects on Ship Creek. The challenge is to get these groups to work together within a more robust institutional framework to maintain Lower Ship Creek’s biophysical and engineered components and create a robust fishery (Table 17).

4.8.1 Creating a Proportional Equivalence of Benefits and Costs

Studies of irrigation systems have shown that appropriation and provisions are two major sources of collective-action problems (Tang 1992, Lee 1994). Appropriation problems are time-independent and the result of how a limited resource is allocated (Ostrom 1990). Provision problems are time-dependent and the result of how the responsibility for building, repairing, or maintaining resource systems is assigned, as well as the appropriators' well being (Ostrom 1990). This urban fishery SES experiences problems of ineffective appropriation with provisions.

The high production of hatchery fish and the associated increases in use are causing appropriation problems within this SES. The first step in creating a proportional equivalence of benefits and costs is for the ADFG to address the appropriation problem by decreasing the Total Allowable Catch (TAC) until adequate public infrastructure is in place to prevent further degradation to existing infrastructure and stream conditions or give actors in the system the choice of either reducing TAC or increasing infrastructure (Table 17). Physical (i.e., public) infrastructure is an important component of a robust SES because it determines the degree to which a commons can be exploited, the amount of waste produced by the use of the resource, and the effectiveness of resource and user monitoring (Dietz et al. 2003). For example, the use of relatively inexpensive barbed wire on grazing lands has decreased the cost of enforcing property rights (Krell 2002). On Lower Ship Creek, the addition of walkways and staircases would decrease the need for and cost of conducting streambank restoration projects.

Provision problems within this SES exist because of inequities and confusion in the assignment of resource system responsibilities. For example, the ADFG currently benefits from the fishery but pays very few of its infrastructure costs (Chapter 3). A more equitable cost sharing framework, such as the one established by a group of irrigators in Japan (Sarker and Itoh 2001), would enable the agencies to share project costs.

Therefore, the next step is for public infrastructure providers to work with the ADFG to identify improvements and maintenance costs needed to support the fishery at future TAC levels. These costs include both improvements (i.e., bathrooms and walkways) and ongoing maintenance (i.e., garbage removal and infrastructure repair) efforts. The public infrastructure providers can then establish a formal cost-sharing agreement for improvements and maintenance costs needed to support the fishery (Chapter 3). Past projects, such as the removal of three failing culverts at the mouth of the creek, have been delayed due to disputes over who pays what costs. A formal cost-sharing agreement would reduce future cost disputes and animosity among providers.

4.8.2 Developing Collective-choice Agreements

Effective governance requires the collection and communication of factual information about socio-economic and ecological conditions so that managers can make appropriate decisions. Dialogue between the public infrastructure providers and users allows for the correct use of information, building of social capital, and the ability to change and deal with inevitable conflicts (Dietz et al. 2003). Sarker and Itoh (2001) state that sound coordination between social and physical capital has significantly contributed to the success of Japanese irrigation management.

Currently, there is a gap between the public infrastructure providers and users. This gap could lead to the construction of infrastructure that does not match the needs of the users. The creation of a linkage between public infrastructure providers and users has proven to be an important component of robust SESs (Levine 1977, Moore 1989, Lam 1996). When the bureaucrats from the Indonesian government introduced new rules and infrastructure into a rice production system and ignored the indigenous rules of the users, water shortages and pest outbreaks ensued (Lansing 1991). Although the individual characteristics of long-lasting, common-pool resource SESs differ greatly, they all have resource users linked to public infrastructure providers (Coward 1979, Siy 1982, Laitos 1986, Martin and Yoder 1983, Maass and Anderson 1986, Blomquist 1992).

The ADFG is in a good position to bridge the existing gap between public infrastructure providers and users. The inclusion of public infrastructure providers into the annual hatchery planning process would enable the development of collective-choice agreements that would define specific roles in the implementation of relevant improvements and maintenance efforts (Table 17). The existing Mayor's Watershed Task Force would then monitor these agreements and settle disputes through mitigation.

4.8.3 Increasing User and Biophysical Monitoring

Increasing user and biophysical monitoring would protect the investment of improvements and maintenance costs on Lower Ship Creek. An increase of patrols would increase user safety through the strict enforcement of existing ADFG fishing and ARRC trespassing regulations. The AWC and USGS currently monitor water quality and quantity, respectively. Both of these organizations have experienced funding shortages that cut monitoring efforts in the past. To prevent future monitoring gaps, the EPA and DEC could develop a long-term funding plan to support the AWC's water monitoring efforts and the USGS's water gauging at their two existing sites (Table 17). Another way to support user and physical monitoring efforts is for public infrastructure providers to fund and include a monitoring component in the design of every improvement and maintenance effort.

Due to the presence of night time violations and non-point source pollution within this SES, managers should be aware that monitoring and enforcement efforts may become economically inefficient (Berkes and Folke 1998, Heal 1998, Colby 1995). Combining user education and outreach (Chapter 3) with monitoring and enforcement may prove to be a more effective solution.

4.8.4 Coordination & Implementation

The Mayor's Watershed Task Force may be in a good position to bring the public infrastructure providers together to discuss the issue of robustness in its entirety and specifically address the implementation of each of the above steps (Table 17). Currently, the Task Force is a multi-agency advisory team that provides information and advice on the prioritization of restoration projects in Anchorage. In this capacity, it would be difficult for the team to implement steps toward increased robustness. The good news is that the Task Force is seeking to upgrade its status to a municipal board. If the Task Force formalized its existence as a board within the municipal structure, it could assume an increased role in watershed management and create more opportunities for multi-agency involvement in decision-making processes.

As a municipal board, the team could establish a broad vision for Ship Creek as well as other creeks within the Municipality and use this vision to work toward increased robustness. The specific steps within the general goals of creating a proportional equivalence of benefits and costs, developing collective-choice agreements, and increasing user and biophysical monitoring could become milestones on the way to a more robust Ship Creek (Figure 23).

The popular Lower Ship Creek Fishery can demonstrate the robust management of an engineered fishery. A robust fishery has the ability to take pressure off other wild stocks while creating a sense of ownership within the greater community. Anchorage managers have a great opportunity to save time and money by robustly managing this engineered urban fishery for the thousands of people that wander down to the banks of Lower Ship Creek each summer. It is hoped that other managers will learn from the opportunities derived from this case study to increase the robustness of other creeks throughout Alaska and the world.

4.9 References

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4.10 Figures

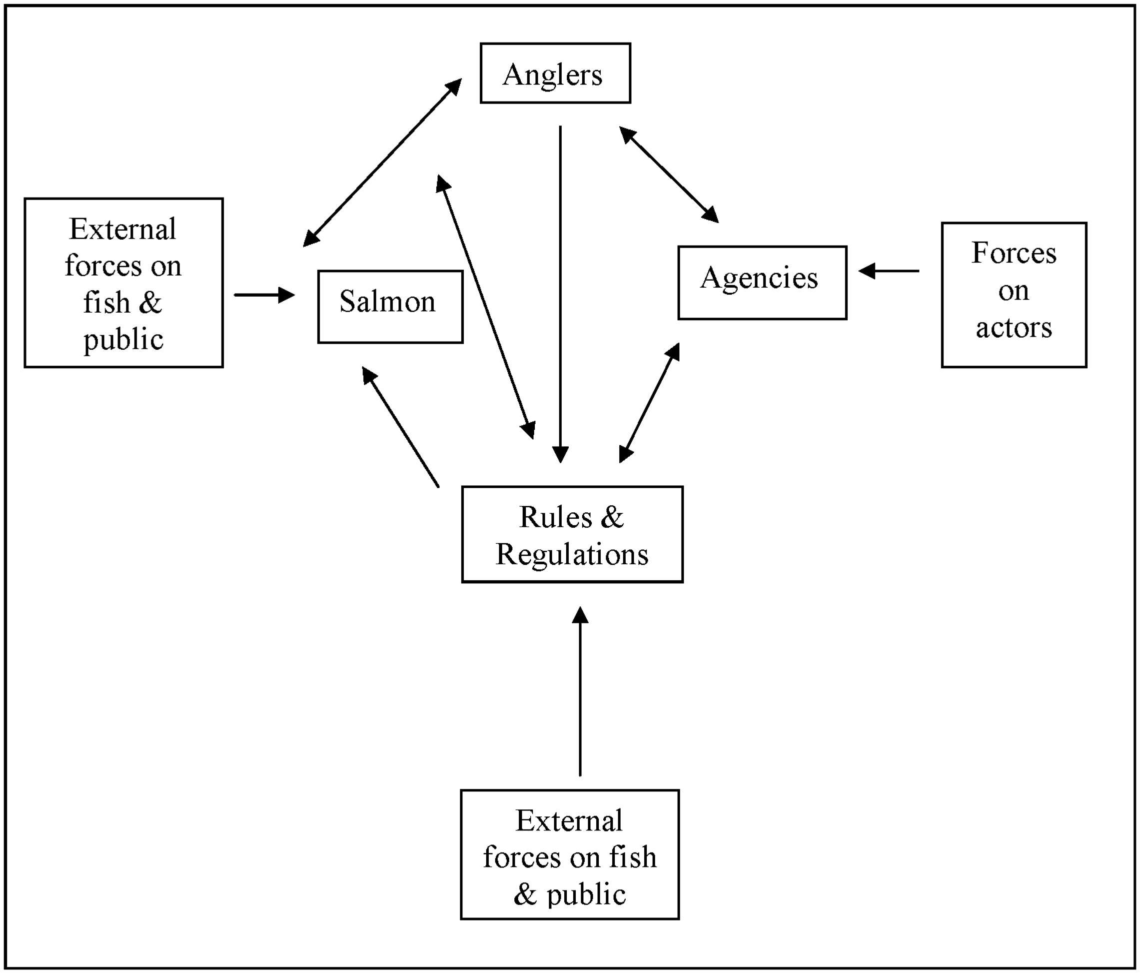

Figure 23: A conceptual model of the Ship Creek Fishery SES. Adapted from Anderies et al. 2004. Linkages are defined in Table 14.

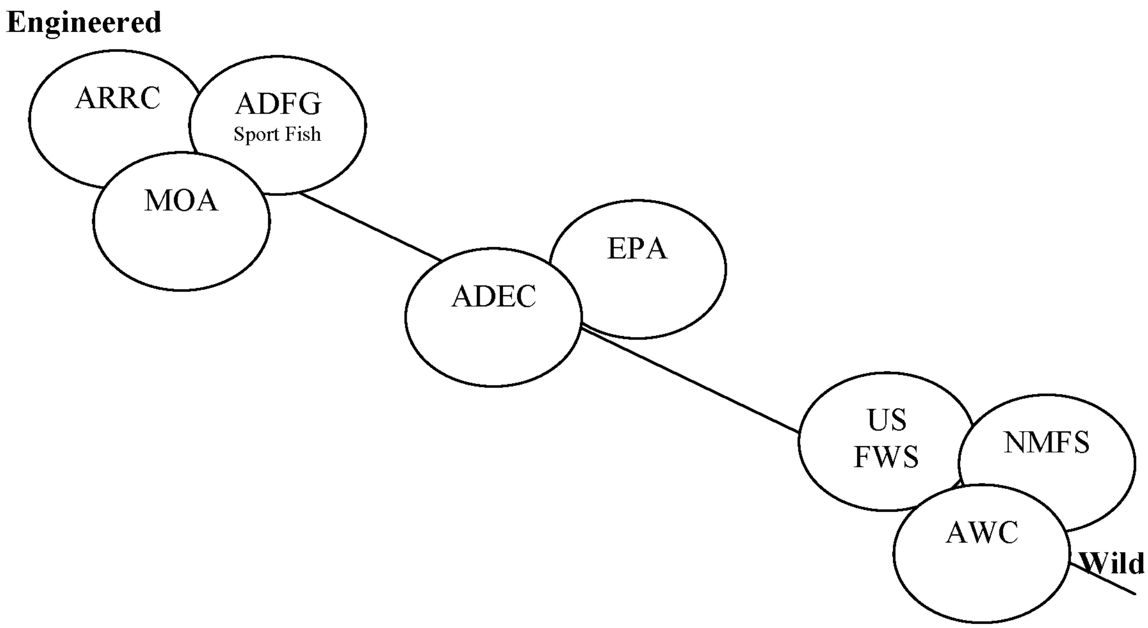

Figure 24: The Paradigm Divide within Public Infrastructure Providers on Lower Ship Creek, Anchorage, Alaska. Abbreviations for the infrastructure providers are given in the text.

4.11 Tables

Table 13: Significant Releases of Petroleum and Other Organic Compounds Into Ship Creek Watershed and Surrounding Cook Inlet (10/95-7/02). Source: EPA 2002.

Date	Spill Name	Spill Number
10/11/95	Ship Creek Anchorage School District	95239928401
02/29/96	Alaska Railroad	96309906002
07/17/97	Elmendorf Hardstand	97239918901
09/04/97	Elmendorf 10" Flight Line	97239924701
10/27/97	Elmendorf AERO Club	97239930001
11/06/99	Alaska Railroad Spills	99309931001
02/01/00	Alaska Railroad Anchorage Yard Roundhouse	00239903202
03/08/00	Tesoro Ethanol Anchorage	00239906701
04/13/00	Tesoro Pipeline Terminal–Anchorage	00239910491
05/14/01	Cook Inlet Mystery Sheen	01230013601
07/31/01	Cook Inlet Mystery Sheen	01239921201

Table 14: Lower Ship Creek Fishery SES Linkages. Adapted from Anderies (2004).

Linkages	Potential Problems
Between fish & anglers	"Endless" availability of fish / free riding
Between users, businesses, the military & agencies	Conflicting political agendas; free riding, inadequate inter/intra-agency information and communication, refusal to pay associated maintenance costs
Between public infrastructure & agencies	Unequal investments into the fishery; partitioning of responsibilities in ways that ignore interactions
Between public infrastructure & fish	Ineffective implementation of regulations; poor engineering and inappropriate construction
Between public infrastructure & fish dynamics	Unintended consequences
Between anglers & public infrastructure	Free riding
External forces on fish and public infrastructure	Destroyed fishery (via disease); collapsed public infrastructure (due to funding shortages)
Between forces on social actors	Increased demand, conflict

Table 15: Design Principles Derived from Studies of Long-enduring Institutions for Governing Resources. Adapted to the Lower Ship Creek Fishery from Ostrom (1990).

Principles that characterize Ship Creek	Principles that do not characterize Ship Creek
Clearly Defined Boundaries The physical boundaries of the resource system (Lower Ship Creek Fishery) and the anglers with rights to harvest salmon are clearly defined.	Proportional Equivalence between Benefits and Costs Rules do *not* allocate costs and benefits proportionately among infrastructure providers.
Graduated Sanctions Users who violate fishing regulations receive graduated sanctions (depending on the seriousness and context of the offense) from officials accountable to publicly elected officials.	Collective-Choice Arrangements Anglers that harvest salmon are *not* included in the group who can modify harvest and protection rules.
Conflict-Resolution Mechanisms Anglers and enforcement officials have rapid access to low-cost, local arenas to resolve conflict among users or between users and officials.	Monitoring Monitors do *not* adequately audit bio-physical conditions and user behavior, so infrastructure providers have no strong basis to manage adaptively for robustness.
Minimal Recognition of Rights to Organize Anglers' rights to organize are not challenged by external governmental authorities and users have long-term tenure rights to utilize the Fishery.	

Table 16: Public Infrastructure Providers' Desired Social and Ecological Components of the Lower Ship Creek Fishery.

Desired Social and Ecological Components	**Infrastructure Providers**
Improved Water Quality/Contaminant Removal	EPA, AWC, ARRC
Restored Fish Passage & Habitat	USFWS, ADFG, NMFS, AWC
Increased Stream/Riparian Function	USFWS, AWC
Angling Opportunity	USFWS, MOA, ADFG, AWC
Decreased Erosion	ARRC, AWC
Decreased Trespassing & Safety Issues	ARRC
New Hatchery Construction & Visitor Center	ADFG, MOA
Maximized Harvest & Minimized Maintenance Costs	ADFG
Increased Economic Activities in District	MOA

Table 17: Opportunities to Increase the Robustness of the Lower Ship Creek Fishery Using Three of Ostrom's (1990) Design Principles that this SES Failed to Meet.

Creating a Proportional Equivalence of Benefits and Costs	**Developing Collective-choice Agreements**	**Increasing User and Biophysical Monitoring**
Step One ADFG decreases TAC until adequate public infrastructure is in place to prevent further degradation to existing infrastructure	Step One ADFG creates a formal process for including Public Infrastructure Provider input in their annual hatchery operation plans	Step One ARRC and State Troopers increase patrols of Lower Ship Creek and strictly enforce existing ADFG fishing and ARRC trespassing regulations
Step Two Public infrastructure providers identify improvements and maintenance costs needed to support the fishery at future TAC levels	Step Two Public infrastructure providers work together to define specific roles in the implementation of improvements and maintenance efforts	Step Two EPA and DEC develop a long-term funding plan to support AWC's water monitoring efforts & USGS's water quantity monitoring at two existing sites
Step Three Public infrastructure providers establish a cost-sharing agreement for improvements and maintenance costs needed to support the fishery at future TAC levels	Step Three The MOA's Watershed Task Force monitors these agreements and settles disputes through arbitration	Step Three Public infrastructure providers include a monitoring component into the design of every improvement and maintenance effort

5.0 Chapter 5 Conclusion

5.1 Introduction

Urban streams possess great social, economic, and ecological value and can be managed to meet communities' needs despite uncertain conditions. The management scenarios for urban streams are much different than the restoration of wild streams and include a combination of engineering, ecology, and aesthetics. While this study does not advocate the widespread replacement of wild fish with hatchery runs, it does acknowledge that hatcheries may play an important role in the management of some urban streams. Since it is unlikely that most urban streams will ever be restored to their pre-urbanization states, it is important for cities to find new ways to successfully manage urban fisheries and streams within the socio-economic and ecological constraints of urbanization.

Classic restoration methods are often ill-equipped to deal with the complex nature of the urban environment. The goals of river restoration projects often conflict with the realities of nonpoint source pollution, road crossings, and channelization. Mapping the complex social and economic frameworks that govern stream management provides insight into new ways to balance social needs while maintaining fundamental ecological processes. If the management agencies can agree on what should be done (Chapter 2), who should do what (Chapter 4), and how it should be paid for (Chapter 3), it is likely that future urban restoration efforts will produce long-term results that benefit entire communities.

This research has produced a new interdisciplinary approach to managing urban streams and fisheries as social-ecological systems. This approach combines theoretical approaches, frameworks, and tools to help managers better anticipate the challenges associated with urban, semi-engineered systems.

The theoretical contribution includes conceptualizing the robustness framework as a building block of resilience. By increasing the robustness of individual semi-engineered SESs, managers can enhance the overall resilience of a city or state. This is the first study to apply Anderies et al.'s (2004) robustness framework to a sport fishery within an urban stream. The robustness framework is well suited for urban fisheries because they are SESs that contain both natural and engineered components.

This research has produced an environmental history of Lower Ship Creek and management scenarios, which hopefully will inform future decision-making processes. The environmental history provides a context for understanding the constraints on the creek's restoration potential. While the use of scenarios is a common approach to conceptualizing SESs, the scenarios in this study are produced from Lovecraft's (2008) typology, which gives managers a systematic approach for developing realistic options along a gradient of ecological and social dimensions.

The economic benefit produced by the Lower Ship Creek Fishery is well documented by the ADFG, but the fishery's costs were previously unknown. The externalities associated with the commercial fishing industry are also well documented, but no studies have documented the existence of externalities within sport fisheries. The data collected in this study on the costs associated with the fishery has shown that sport fisheries can produce a large number of externalities that can create tension between the agencies and inhibit the SES's robustness. Establishing a cost sharing structure should therefore be a vital component of any efforts to manage urban streams and fisheries.

Although Ostrom's (1990) design principles have been applied to many different types of SESs, this study is the first time that the principles have been applied to an urban sport fishery. Ostrom's (1990) design principles proved to be very helpful in diagnosing the Lower Ship Creek Fishery SES's main challenges to robustness. The management of other sport fisheries and urban streams may benefit from using this approach to include socio-economic considerations in future planning efforts.

5.2 Historical Constraints & Future Scenarios

As more and more streams experience the cumulative effects of urbanization, restoration efforts are increasingly acknowledging the inherent ecological constraints of urban stream management (Morris and Moses 1999, Paul and Meyer 2001, Purcell et al. 2002). Lower Ship Creek is a good example of how identifying the constraints produced by urbanization can help guide management efforts. Judging from a growing body of urban stream literature, it is likely that the historical legacies of Lower Ship Creek have affected the ecological processes that govern ecosystem services (Chapter 2). This SES has changed from a biologically controlled system into a hatchery-controlled system with biological processes modified by the structural, hydrological, chemical, and recreational impacts of an urban environment.

The constraints on biological processes within this SES include 1) loss of wetlands and riparian vegetation, 2) erosion, pollution, and channelization, 3) loss of fish species, and 4) flow alteration and habitat loss. These constraints have altered the stream's species composition, hydrograph, and geomorphology. Although full restoration of this urban SES is inhibited by the lingering constraints of historical changes, examining these constraints can lead to the setting of realistic goals to increase this SES' robustness.

Identifying the historical changes and current constraints of urban streams is a vital first step in planning restoration efforts because it allows managers to devise more realistic scenarios that account for the social, ecological, and economic trade-offs of highly engineered systems. Given the difficulty of working within the constraints of urban streams, managers may benefit from putting together a list of scenarios to guide their planning efforts. These scenarios can serve as a starting point for communities to discuss the possible futures for popular recreation sites.

The scenarios identified for the Lower Ship Creek Fishery are based on the key components that define the SES's robustness. These components are identified by public infrastructure providers and recreational and subsistence users and include 1) efficient hatcheries, 2) visitor and angler infrastructure, and 3) sufficient water quality and quantity to sustain hatchery production.

The four scenarios considered for this SES are: "Ship Creek Redesign," "KAPP Dam Removal," "Mitigation, Construction, and Maintenance," and "Business as Usual." Currently, the most viable scenario is "Mitigation, Construction, and Maintenance," which would increase user safety and ensure continued hatchery operations by mitigating contaminants, providing infrastructure, and creating a more equitable distribution of the costs and benefits produced by the fishery.

The scenarios approach allows communities to better understand the trade-offs involved within each scenario and provides a forum for discussing possible futures (Chapter 2). Scenarios create a level playing field that allows managers to conceptualize the trade-offs that exist between different possible futures. Once a scenario is chosen, managers can chart a course to reach the desired outcome by creating a supportive cost structure.

5.3 The Externality Problem

The trade-offs associated with urban stream management can produce externalities (Chapter 3). When one agency pays the costs but does not benefit while another agency benefits but pays less or no costs, intra- and inter-agency tension can emerge. The conflict produced by the inequity of benefits and costs can decrease the robustness of a SES because it reduces the potential for cooperation within the system.

The current cost structure of the Lower Ship Creek Fishery is decreasing the robustness of the fishery because it produces an unequal distribution of costs and benefits, which breeds social distrust and a lack of cooperation among the public infrastructure providers. Providing decision makers with an economic incentive to work more cooperatively in the future by internalizing the fishery's externalities can increase the robustness of this and other SESs.

Two simultaneous approaches are recommended to address this SES's externality problem: 1) the producer (Alaska Department of Fish and Game (ADFG)) could internalize the greater production costs by raising user fees, and 2) the public infrastructure providers could establish a cost sharing framework by identifying which agencies have incentives to pay the fishery's external costs. These two approaches could then be implemented through a municipal board, which would formalize agreements and provide a venue to settle disputes.

5.4 Design Principles & Robustness

Once the externality problem has been addressed, it is then possible to focus on reducing or eliminating other barriers to robustness. Managers can best manage the system as a whole by delineating the causes of biophysical degradation within an urban SES by closely examining the socio-economic framework that underlies the SES's biophysical symptoms. One methodological approach that can inform holistic management practices is the application of Ostrom's (1990) institutional design principles within the robustness framework (Anderies et al. 2004).

When Ostrom's (1990) design principles are applied to the case study of the Lower Ship Creek Fishery, this SES fails to meet three of the seven design principles. This SES does not have 1) a proportional equivalence between benefits and costs, 2) collective-choice agreements, and 3) sufficient user and biophysical monitoring. Reducing the externalities that produce intra- and inter-agency tension is important because successful user and biophysical monitoring efforts and the formation of collective-choice agreements relies upon cooperation between the public infrastructure providers.

The lack of a proportional equivalence between benefits and costs, collective-choice agreements, and sufficient user and biophysical monitoring interact to decrease this SES' robustness. The need for proportional equivalence between benefits and costs and collective-choice agreements addresses the problems of free riding and subtractability of use through the creation of rules (Anderies et al. 2004) but fails to address the problem of enforcement. The addition of increased user and biophysical monitoring enforces these rules. If addressed in unison, these three opportunities could increase SES robustness and sustain the sport fishery.

A proportional equivalence of benefits and costs could be created within this SES if 1) the ADFG decreased the Total Allowable Catch (TAC) on Lower Ship Creek until adequate public infrastructure is in place to prevent further degradation to existing infrastructure, 2) public infrastructure providers identified improvements and maintenance costs needed to support the fishery at future TAC levels, and 3) public infrastructure providers established a cost-sharing agreement for improvements and maintenance costs needed to support the fishery at future TAC levels.

Collective-choice agreements could be developed if 1) the ADFG created a formal process for including input from public infrastructure providers in their annual hatchery operation plans, 2) public infrastructure providers worked together to define specific roles in the implementation of improvements and maintenance efforts, and 3) the Municipality of Anchorage's (MOA) Watershed Task Force monitored these agreements and mitigated disputes.

User and biophysical monitoring could be increased if 1) the Alaska Railroad Corporation (ARRC) and Alaska State Troopers increased patrols of Lower Ship Creek and strictly enforced existing ADFG fishing and ARRC trespassing regulations, 2) the Environmental Protection Agency (EPA) and the Alaska Department of Environmental Conservation (ADEC) developed a long-term funding plan to support the Anchorage Waterways Council's (AWC) water monitoring efforts and the U.S. Geological Survey's (USGS) water quantity monitoring at two existing sites, and 3) public infrastructure providers included a monitoring component in the design of every improvement and maintenance effort.

5.5 Conclusion

By acknowledging the historical constraints and creating a list of future Scenarios for SESs, managers can better understand the potential benefits and costs of each Scenario. Many engineered systems, such as sport fisheries, are producing externalities that are causing tension within SESs. A closer examination of the SES cost structure may provide valuable insight into the success of restoration projects and eliminate other robustness barriers, such as the lack of collective-choice agreements and monitoring, through increased cooperation.

The Lower Ship Creek Fishery has the potential to become a well managed, robust SES that takes pressure off other wild fish stocks while continuing to provide social, economic, and ecological benefits to the community. As urbanization increases to spread throughout the world, areas like Lower Ship Creek are likely to become even more important sources for outdoor recreation. Urban fisheries and streams play a vital role in creating livable cities and providing easy access to the outdoors. Scientists, managers, and community members should continue to investigate ways to sustain urban links to the natural world, even when these links are partly engineered.

5.6 References

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Appendix A

Ship Creek Questionnaire

Your voluntary participation in this study will be assumed upon return of the completed questionnaire. All information collected in this study will be used in a PhD dissertation, which is an interdisciplinary assessment of the social, economic and ecological dimensions of Ship Creek. A draft of the findings will be submitted to all participants for review to ensure accuracy. For more information, please contact me.

Name:____

Position Title:____

Agency:____

Length of time in current position:____

Contact Information:____

Note: The Ship Creek District (SCD) is defined as the last .9 River Miles & associated uplands of Ship Creek.

What is your role in the SCD?____

Is the SCD important to the City of Anchorage? If yes, in what way?__________________

Why do you think past efforts to revitalize the SCD have failed?_____________________

Appendix A Cont'd.

Does your agency have *short* term goals & objectives for the SCD? If yes, what are they and is there a timeline for their achievement?____________________________________

____

____

____

Does your agency have *long* term goals & objectives for the SCD? If yes, what are they and is there a timeline for their achievement?____________________________________

____

____

____

What is working well in the SCD? Why?____

____

____

____

What could be improved in the SCD? Why?_____________________________________

____

____

____

Are you currently using Adaptive Management? If yes, how does your agency define and implement Adaptive Management? ____

____

____

____

____

Appendix B

Anchorage Waterways Council's Ship Creek 2003 User Survey

We greatly appreciate your time and input.

1. Please rank the importance of the following issues on Ship Creek:
(Circle your choice 1=most important, 4=least important)

Improving Fish Passage
1 2 3 4

Improving Water Quality
1 2 3 4

Improving User Safety and Access to the Creek
1 2 3 4

Promoting Healthy Development of the Ship Creek District
1 2 3 4

2. Do you think fish passage in Ship Creek should be improved?

___YES ___NO ___NOT SURE

If yes, how?____

____

____

3. Do you think Ship Creek is polluted? ___YES ___NO

If yes, what are the sources of the pollution? ______________________________

____

____

____

Appendix B Cont'd.

4. Are there any sites along the creek where you feel that access should be improved or where you feel it is unsafe?

___ YES ___NO ___NOT SURE

If yes, where? ____

____

____

5. What types of development would you like to see in the Ship Creek District? (check all that apply)

___ Industry ___Fishing Access
___Parking ___Stores
___Restaurants ___Parks/Open Space

6. Do you have any other concerns about Ship Creek? ________________________________

____

____

____

Would you like to be contacted about future AWC activities?

___YES ___NO

Would you be interested in volunteering with AWC?

___YES ___NO

Name: ____
Address: ____
Email: ____

Appendix B Cont'd.

4. Are there any sites along the creek where you feel that access should be improved or where you feel it is unsafe?

___ YES ___NO ___NOT SURE

If yes, where? ____

5. What types of development would you like to see in the Ship Creek District? (check all that apply)

___ Industry ___Fishing Access
___Parking ___Stores
___Restaurants ___Parks/Open Space

6. Do you have any other concerns about Ship Creek? _____________________________

Would you like to be contacted about future AWC activities?
___YES ___NO

Would you be interested in volunteering with AWC?
___YES ___NO

Name: ____
Address: ____
Email: ____

Appendix C

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Institutional Review Board

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March 7, 2007

To: Mark Wipfli, Ph.D
Principal Investigator

From: Bridget Stockdale, Research Integrity Administrator
Office of Research Integrity

Re: IRB Protocol Application

Thank you for submitting the IRB protocol application identified below. I have administratively reviewed this protocol and determined that while it utilizes survey tools, it is not intended to gather information about living individuals and therefore does not meet the criteria for human subjects research requiring IRB review.

Title: *Ship Creek Stakeholder Survey (with Meagan Boltwood)*

Received: March 6, 2007

If the scope of this work changes, please contact the Office of Research Integrity to determine if further review is required prior to the beginning of any research activity.