Integrating Climate Change Adaptation into the Management of Alaska's Kenai River Watershed

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I understand that my capstone project will become a permanent collection of Oregon State University libraries. My signature below authorizes release of my capstone project to a reader upon request.

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Abstract

The impacts of climate change are being observed worldwide. However, some regions and context specific situations make particular areas more vulnerable to the impacts than others. Alaska's Kenai River Watershed (KRW) is on the front lines of climate change and may be especially vulnerable to the impacts due to distinct circumstances shaped by differences in geography, environmental, socio-economic, and political factors. This report provides a thorough assessment of the most vulnerable social-ecological-economic systems within the KRW. The purpose of this comprehensive assessment is to ensure that climate change impacts are examined in relationship to context specific vulnerabilities and that local resource issues and community concerns within the KRW are not being overlooked. Several policy objectives, adaptive strategies, and research goals, that address a multitude of issues both old and new, are suggested as starting points. The hope is that by approaching climate change at a more localized level and taking into consideration site-specific circumstances, future policy debates may become better informed and the fundamental frameworks needed to develop effective adaptation response strategies will become more recognizable and manageable, not only within the KRW, but worldwide.

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1 Introduction

According to the U.S. National Academies of Science (2014), global surface temperatures have increased by about 0.8 °Celsius (C) (1.4 °Fahrenheit (F)) since 1900 and all future model projections indicate that Earth will continue to warm considerably over the next few decades to centuries. There is now worldwide consensus that the Earth's recent warming is in large part a direct result from increases in anthropogenic fossil fuel emissions. Many independent lines of evidence demonstrate that temperature increases over the past 50 years is primarily due to human activities, predominantly carbon dioxide (CO_2) emissions from the burning of fossil fuels for energy production, transportation, and industrial processes (Melillo et al. 2014). These current warming trends have already resulted in measurable increases in sea surface temperatures, ocean acidification, melting of sea ice and glaciers, rises in ocean levels, and changes in precipitation worldwide (IPCC 2014).

The state of Alaska is proving to be extremely sensitive to global climate changes. Over the past 50 years, the state has warmed at more than twice the rate of the rest of the United States (Haufler et al. 2010) and has experienced a variety of impacts ranging from permafrost melt to phenological shifts in plant and animal life. If global CO_2 emissions continue to increase during this century, temperatures throughout the state are expected to rise 2°F to 4°F by 2050 (Chapin et al. 2014) and could cause markedly different biological communities than what currently exists today. In fact, even if atmospheric CO_2 concentrations are stabilized at any given point in time, there is a commitment to future climate changes that will be greater than those we have already observed (Meehl et al. 2005). Therefore, the impacts from climate change will continue to increase regardless of mitigation efforts.

The impacts from global warming and climate change do not have the same implications for every location. These processes involve a set of complex interactions between many earth-system mechanisms that have indistinguishable boundaries and although there may be broad patterns worldwide, impacts are not uniform. Understanding the physical realities of climate change for a specific impact or geographic location is challenging. Furthermore, various socioecological structures and personal values will respond to the same biophysical impact differently; whether or not it results in a positive or negative change depends largely on value-based judgements. Therefore, the predisposition to be either negatively or positively affected, along with the need to build adaptive capacities, is highly variable and depends on unique local circumstances.

Alaska's Kenai River Watershed (KRW) is on the front lines of climate change and may be especially vulnerable to the impacts due to distinct circumstances shaped by differences in geography, environmental, socio-economic, and political factors. Several ecological transformations associated with climate change have already been well-documented within the watershed. Moreover, the watershed's vulnerabilities in relation to climate change may be exacerbated by its geographic isolation, high levels of dependency on salmon populations, and localized ecological disturbances from other compounding management issues. Increased public use, decreased habitat, and conflicting land use pressures continue to be persistent challenges for policy makers.

There are also many fundamental barriers to integrating climate change adaptation and developing response strategies in the context of uncertain climate regimes, remains one of the most difficult challenges faced by watershed management. As a result, management choices in relation to both existing public use issues and climate change adaptation have been based on self-regulation, i.e. allowing people and the environment to respond to changes as they unfold. However, this hands-off approach will likely not be effective at addressing existing watershed policy issues in the face of new climate regimes.

In an attempt to facilitate the integration of climate change adaptation and help ensure that specific local issues and community concerns within the KRW are being consciously addressed, this case study assesses the most vulnerable social-ecological-economic systems within the watershed. It examines the localized impacts from climate change in relation to the distinguishing characteristics, main compounding management issues, and the specific barriers to integrating climate change adaptation. This information is then used to outline current KRW management questions and potential policy objectives that will likely need more attention to begin addressing climate change. Lastly, several site specific management strategies are evaluated for their ability to address existing vulnerabilities as well as integrate climate change adaptation. These strategies include 1) expanding climate change research, 2) data networking and technology sharing, 3) addressing increased public use, 4) protecting local salmon populations, 5) diversifying land use industries and community participation and 6) developing institutional flexibility.

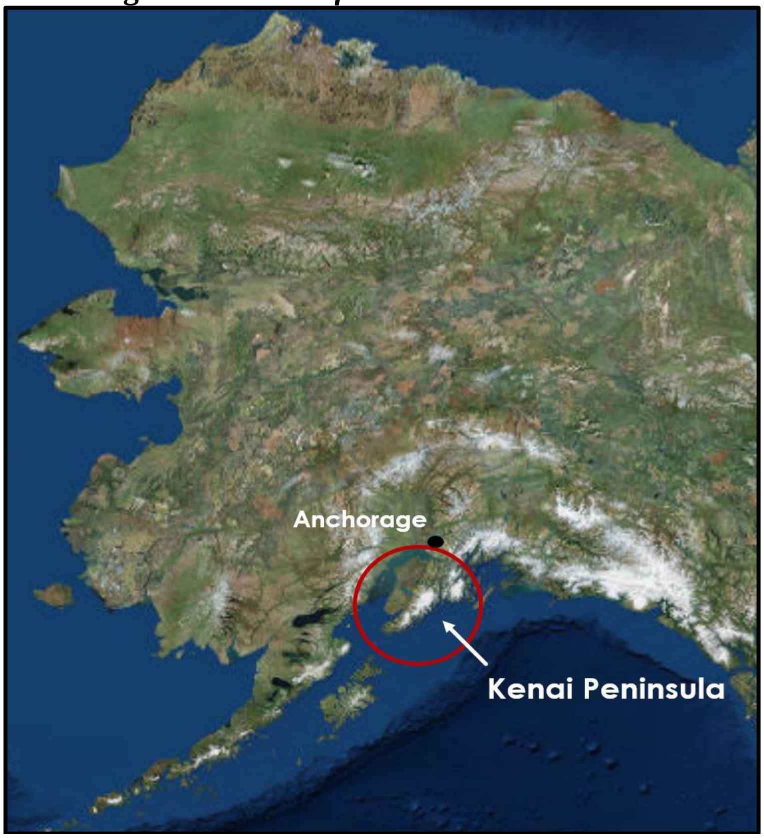
Several goals are involved in this localized analysis and proposal of site-specific strategies. First, that the integration of climate change adaptation will become more realistic and manageable rather than approaching the situation from a regional or international level. Secondly, that the different factors affecting the KRW's adaptive capacities will be better synthesized into a cohesive perspective. This will encourage agencies, policy makers, and community members to begin making deliberate choices between the many different response options and be more active in localized resource and climate change issues. And due to its set of distinctive qualities, that the KRW be used as a pilot zone for assessing the effectiveness of response strategies and climate change adaptation that could later be implemented in other areas worldwide.

2 Study Area: Alaska's Kenai River Watershed

2.1 <u>Location, Morphometry and Climate</u>

The KRW is located in south-central Alaska in the heart of Kenai Peninsula, which extends approximately 150 miles south-west from Anchorage, one of the most populated cities in the state. Image 1. *Location of Alaska's Kenai Peninsula* shows the geographic location of the peninsula within Alaska.

Image 1. ***Location of Alaska's Kenai Peninsula***



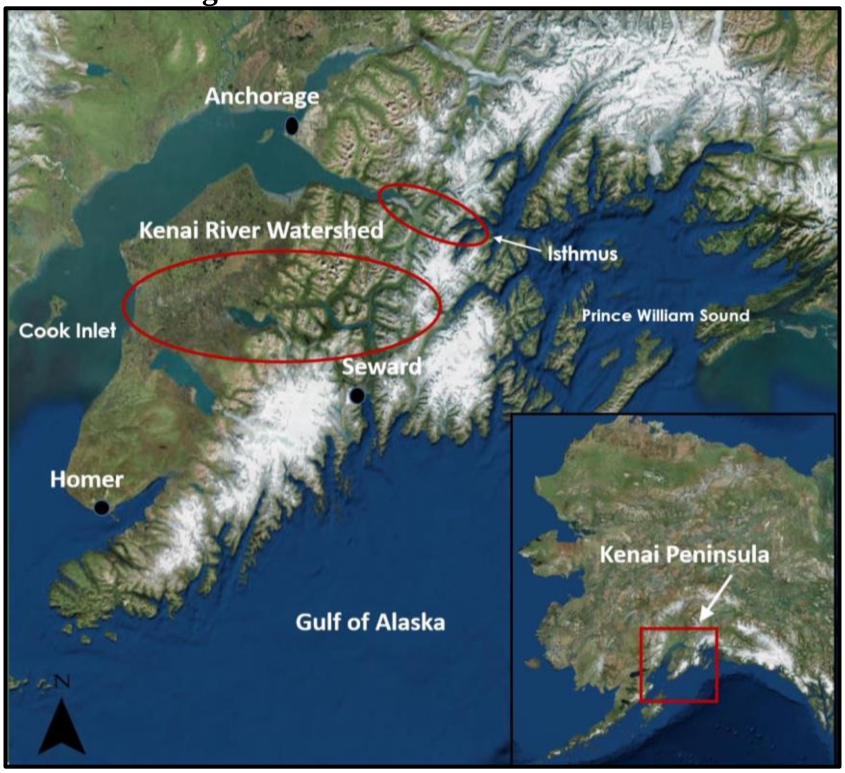
The Kenai Peninsula's climate is affected by both continental and maritime influences and is divided into two ecoregions. The western half is temperate continental and the eastern half is temperate coastal or maritime. Terrain on the eastern section of the watershed primarily consists of high alpine tundra, stunted boreal forest, and more rugged terrain, including large glaciers and ice fields. The western side primarily contains lowlands of coastal salt marshes, muskegs, bogs, spruce forests, and grasslands.

There is significantly less precipitation on the western side of the peninsula due to being in the rain shadow of the Kenai Mountains which extends 120 miles northeast from the southern end of the peninsula. For example, the town of Cooper Landing (which is situated just leeward of the mountains) receives approximately 47 inches less rainfall per year than the city of Seward (68.2 inches in total), which is located on the southeastern tip of the peninsula (WRCC 2015). This substantial difference in precipitation patterns play a large role in species distribution and land cover types throughout the KRW. However, in general, the entire peninsula has subarctic conditions, with temperatures reported as rarely exceeding 80°F (26°C) in the summer or falling below -30°F (-34°C) in the winter (Banks and Ruffner 2004).

The peninsula is also geographically separated from the rest of Alaska by a 10 mile wide isthmus. This strip of land acts as a major barrier for fish and wildlife and as a result, many genetically isolated populations are prevented from migrating. As the impacts from climate change continue to grow, this inability to migrate could potentially make these populations more at risk to future change.

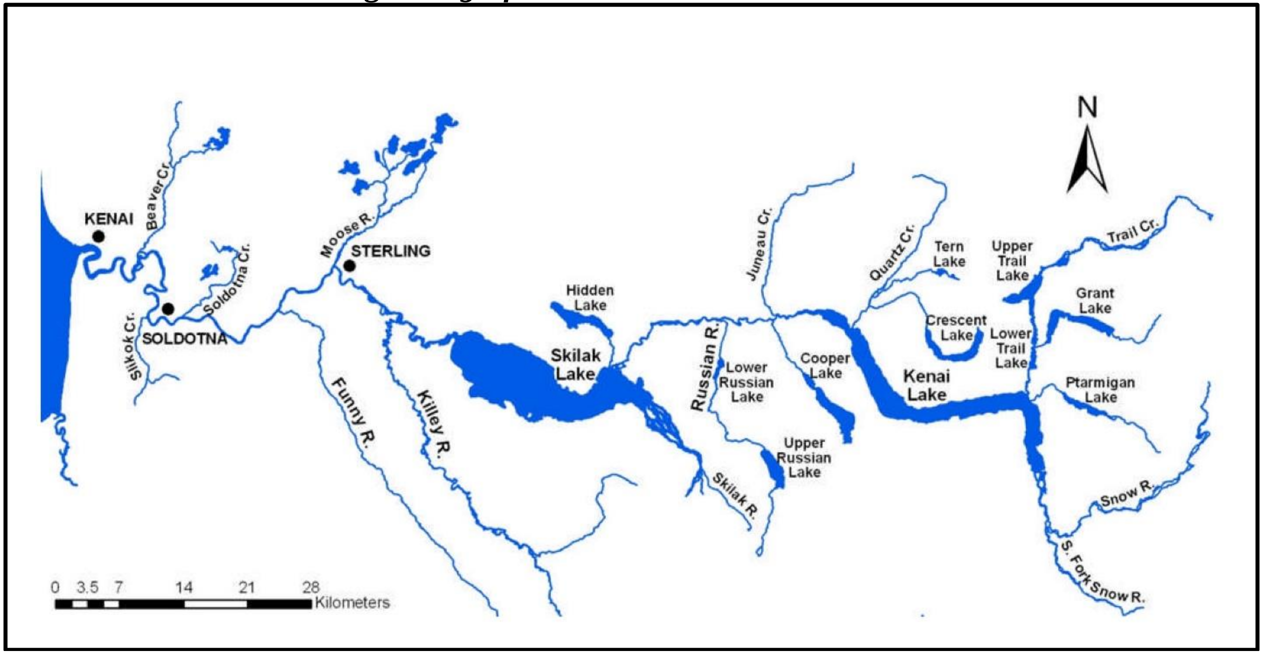
The KRW itself is divided by the Kenai Mountains and straddles the two different ecoregions. The western side of the watershed is part of the Cook Inlet Basin and is surrounded by extensive mountain ranges to the east, west, and north. The eastern side contains the southern portion of the Chugach Mountain Range which supports the largest portion of glaciers and ice fields outside of the Polar Regions (ADF&G 2006). The area of the basin totals 2,200 square miles, elevations range from sea level to over 6,000 feet, and water flows from east to west across nearly the entire width of the peninsula. Image 2. *Alaska's Kenai River Watershed* highlights more detail on the peninsula, including main cities, the location of the KRW, and isthmus migration barrier.

Image 3. ***Alaska's Kenai River Watershed***



The Kenai River itself spans 82 miles and is divided into upper, middle, and lower sections. It has 10 main tributaries and two natural lake systems, Kenai and Skilak Lake. Kenai Lake is located in the upper section of the watershed, while Skilak Lake is situated in the middle and acts as the divide between the upper and middle/lower sections of the watershed. Although the watershed has a diverse network of tributaries, including montane clear water streams and lower elevation wetland drainages, the Kenai River is primarily fed by high mountain glacier runoff. Over the past 60 years, stream flow averages for the Kenai River have been recorded at 1,900 cubic feet per second (cfs) in January and 13,500 cfs for the month of July (for detailed cfs data refer to USGS 2015). Average flow differences are primarily due to substantial seasonal fluctuations in air temperatures. Image 3. *Significant Tributaries and Lakes in the KRW*, details the main surface hydrology within the entire drainage.

Image 3. ***Significant Tributaries and Lakes in the KRW***



Source: Arendt et al. 2010

The upper eastern section of the watershed is largely undeveloped and has many important salmon spawning streams. Quartz Creek, near the small town of Cooper Landing, supports both chinook and sockeye salmon and is a popular trout fishery. The Russian River, located west of Quartz Creek, is one of the largest tributaries and is also one of the most popular sockeye fisheries in the state. It is often referred to as a one of a kind fishery. The only dam in the watershed is located in this upper section on Cooper Creek, located just east of the Russian River. Water is diverted from Cooper Lake, which is formed as a result of the dam, to a power plant on the shores of Kenai Lake.

The middle and lower stretches of the river have substantially more development compared to the upper section. The larger cities of Sterling, Soldotna, and Kenai are situated along the riverbanks in these lower sections and many developments that were built in sensitive riparian zones before habitat protection easements were established still remain today. Several major salmon spawning tributaries also flow in the middle and lower sections, including the Killey, which is near Skilak Lake, and Slikok Creek just west of Soldotna. Image 4. *KRW Canyon and Upper Sections* and Image 5. *KRW Lower and Middle Sections* provide more detail of the different watershed sections, main tributaries, and nearby cities and towns. (Notice Skilak Lake acts as the divide between the upper and middle/lower sections of the river.)

Image 4. ***KRW Canyon and Upper Sections***

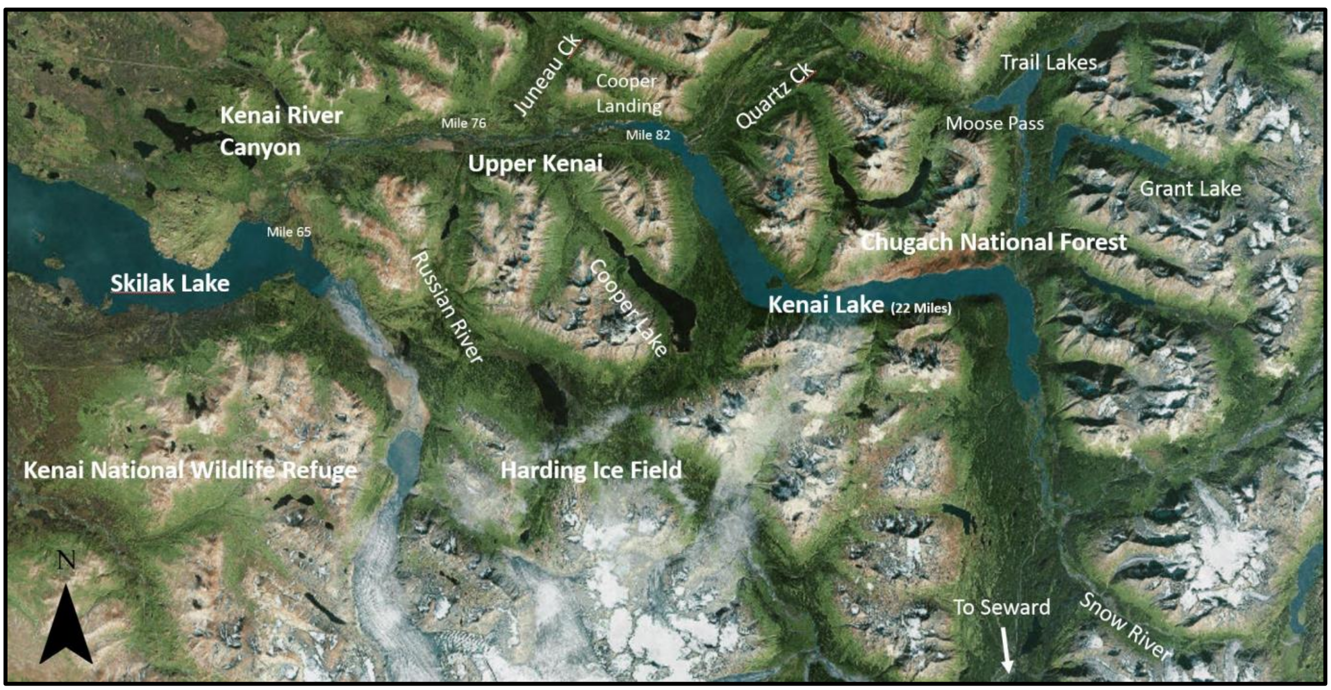
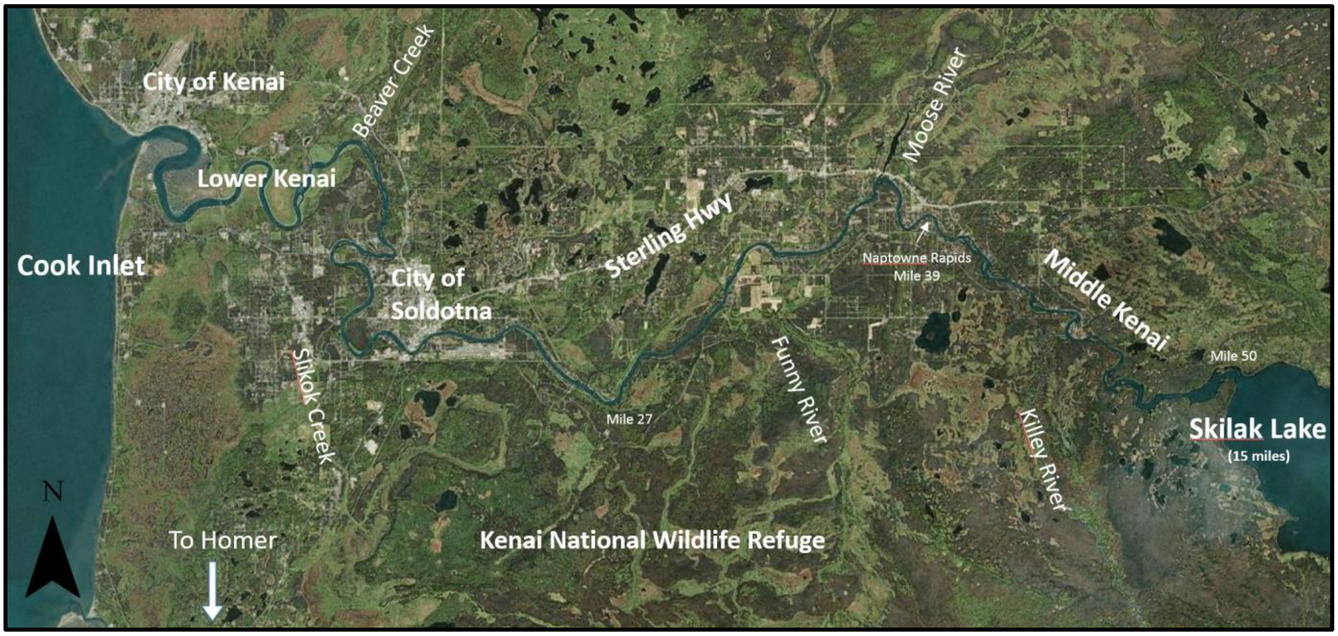


Image 5. ***KRW Lower and Middle Sections***



2.2 Fish and Wildlife Populations

The KRW supports abundant fish and wildlife populations, including several endangered and iconic species, such as wild Pacific salmon, brown bears *Ursus arctos,* and American bald eagles *Haliaeetus leucocephalus*. Many of these species play a critical role in key trophic interactions that are responsible for supporting current ecosystem structure throughout the entire region. It is also home to a wide range of important management species including one sensitive species, the Trumpeter Swan *Cygnus buccinators*, three indicator species: brown bear, moose *Alces*, and mountain goat *Oreamnos americanus,* and eight species of special interest: grey wolf *Canis lupus,* wolverine *Gulo*, lynx *canadensis*, river otter *Lontra canadensis,* American bald eagle, Northern Goshawk *Accipiter gentilis,* Marbled Murrelet *Brachyramphus marmoratus* and Townsend Warbler *Dendroica townsendi* (USDA 2004). Populations of caribou *Rangifer* *tarandus,* Dall sheep *Ovis dalli* and black bears *Ursus americanus* can also be found within the watershed.

The watershed also supports thirty-seven species of fish, including four species of wild salmon: chinook salmon *Oncorhynchus tshawytscha*, sockeye salmon *Oncorhynchus nerka,* coho salmon *Oncorhynchus kisutch,* and pink salmon *Oncorhynchus gorbuscha*. Both sockeye and chinook salmon have an early and late run, with the latter being the larger of the two. Both aquatic and terrestrial ecosystems rely heavily on the marine derived nutrients brought back by the annual return of these anadromous fish runs. All resident fish populations are also wild and include: rainbow trout *Oncorhynchus mykiss*, Dolly Varden *Salvelinus malma*, whitefish *Coregoninae,* Arctic Grayling *Thymallus arcticus,* sculpin *Cottoidea,* stickleback *Gasterosteidae,* and lake trout *Salvelinus namaycush*. The Kenai River itself is known to support trophy sized rainbow trout and officially takes the blue ribbon for having some of the largest chinook salmon in the world. In fact, in 1985, Les Anderson of Soldotna landed the world record chinook salmon from the Kenai River. The mammoth fish weighed 97 pounds, was nearly 5 feet long, and had a 37.5-inch girth. Image 6. *World Record Chinook* below shows Les holding his prized catch.

Image 6. ***World Record Chinook***

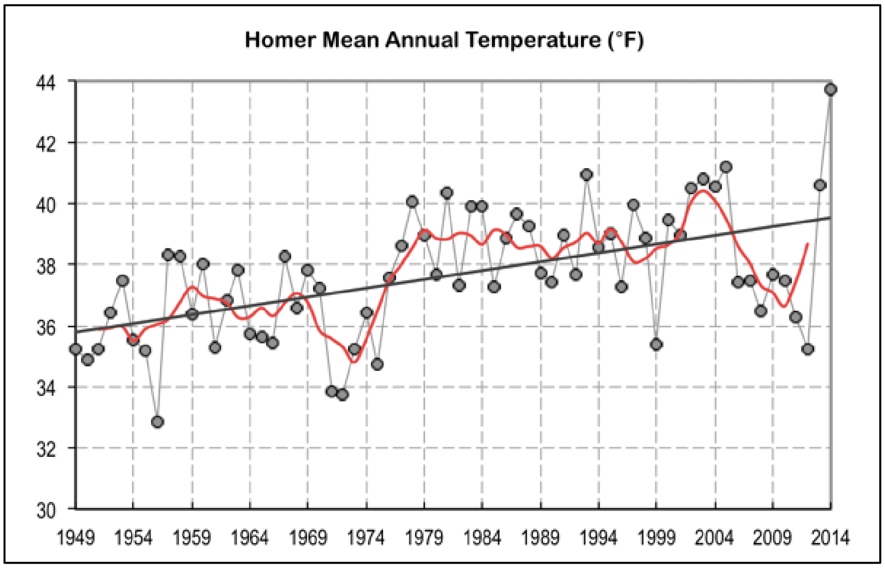
These fish and wildlife populations have endured previous periods of climate change and are well adapted to living in harsh environments. However, it is difficult to know whether or not they will be able to withstand new climate stressors as they have in the past and the question remains what responsibility humans should have in helping these species confront or adapt to new climate regimes.

3 Climate Change and Alaska's Kenai River Watershed

3.1 Warming Trends

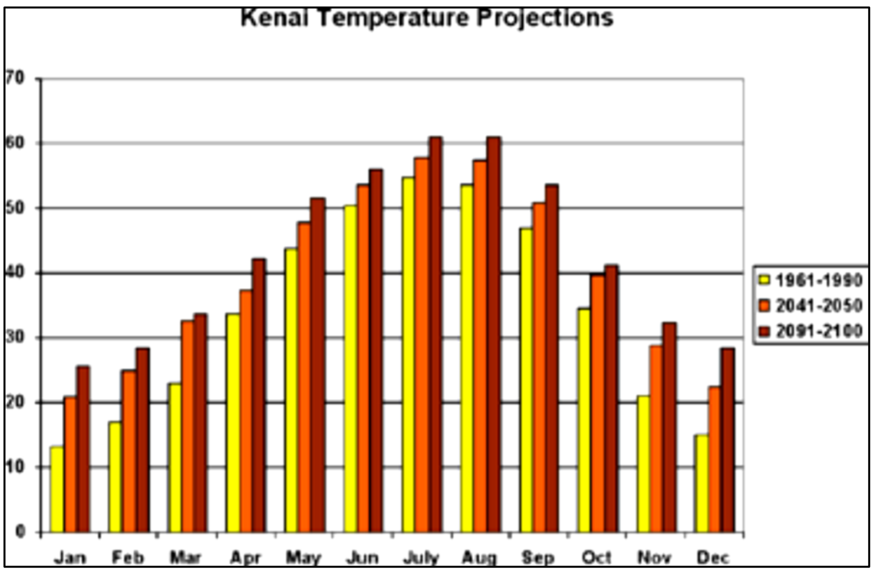
Since climate observations began on the Kenai Peninsula in the 1940s, a steady rise in mean annual temperatures has been recorded with sharper increases observed after the start of the 21st century. Figure 1. *Rising Temperatures in Homer Alaska*, shows that over the last 60 years a clear warming trend has occurred on the Kenai Peninsula with rapid increases reaching nearly 10°F after 2010. It is also reported by the U. S. Climate Data (2016) that in 2014, Cooper Landing experienced an unseasonably warm January by reaching an average high temperature of 40°F, nearly 17°F above the normal average high of 23°F. During 2015, the hottest recorded year in Alaska to date, the city of Kenai near the mouth of the Kenai River, reached a +2.6°F departure from normal annual temperatures (Kenai Weather Live 2016). The University of Alaska's Scenarios Network for Alaska and Arctic Planning climate scenarios predict continually rising temperatures for the city of Kenai over the next century with the highest temperature departures being during winter months. Figure 2. *Temperature Projections for the City of Kenai*, shows month by month temperature projections up to the year 2100.

Figure 1. ***Rising Temperatures in Homer Alaska***



Source: http://akclimate.org/ClimTrends/Location

Figure 2. ***Temperature Projections for the City of Kenai***



Source: SNAP 2009

3.2 Ecological Transformations

Several ecological transformations throughout the KRW associated with climate change have already been well-documented. Tree lines are rising 10 meters per decade (Dial et al 2007) and the most recent spruce bark beetle *Dendroctonus rufipennis* outbreaks have been associated with warmer than average summer temperatures (Berg et al. 2006). The State of Alaska recently moved the official fire season from May 1 to April 1 due to fire regimes departing from historical norms (Berg and Anderson 2006). There has been an acceleration of woody shrub encroachment into 8,000 year old sphagnum peatlands and shrinking of herbaceous areas throughout wetlands on the western Kenai Peninsula lowlands since 1970s, which has resulted in a 6-11% loss in wetland habitat from historical conditions (Berg et al. 2009). Overall, lowland areas on the peninsula are getting both woodier in vegetation and drier (Klein et al. 2005). Future projections conducted by the U.S. Fish and Wildlife Service (USFWS) show the potential for a 37% change of land cover types by 2100 with western boreal spruce forests converting to grasslands and afforestation of hemlock and Sitka spruce in eastern alpine and coastal areas (Morton 2016). Glaciers and ice fields are melting and freshwater temperatures are on the rise. From 1950 to the1990s, the Harding Ice Field, which is located south of the KRW and is nearly the size of Rhode Island, reduced in elevation by 21 meters (Adageirsdottir et al. 1998). From 2008 to 2012, several important spawning tributaries of the Kenai River exceeded the preferred upper temperature ranges of 53°F to 57°F for salmonid productivity and began approaching the upper lethal limits of 73°F (Mauger 2013). It is likely there are many more ecological transitions occurring throughout the KRW in response to climate change that have not been formally recognized. Also, the overall impacts that changing climate patterns will have on species' distribution and abundancies, ecological functioning, and socioecological relationships in the future is difficult to quantify with absolute certainty.

3.3 Impacts to Local Fisheries

Declining Chinook Populations

Over the past 10 years, the Kenai River has experienced declines in returning early and late runs of chinook salmon. In 2005, Alaska Department of Fish and Game (ADF&G) cumulative net apportioned sonar estimates were 125,872 returning chinook and in 2013 the estimate dropped to 17,758. This is a substantial decline of 108,114 fish. Similarly, in 2003, 638 cumulative returning chinook salmon were recorded in the Russian River and in 2013, 111 cumulative returning chinook salmon were recorded (ADF&G 2015 Fish Count Data Search). The same declining trend is occurring in nearby river basins throughout the Peninsula (for more detailed fish counts and population parameters for both the Russian and Kenai Rivers refer to ADF&G Recreational Fishing Series and Fish Counts provided in reference section.) Additionally, both runs of chinook salmon have also experienced drastic reduction in the size of fish returning. The cause for these declining numbers and reduced size of returning adults is speculative. However, several ecological transformations, differences in physiological capabilities, and compounding management issues may be playing a role.

Changing Freshwater Systems and Adaptive Capacities

High water events coupled with cooler water temperatures have played a major role in supporting the KRW's abundant fisheries. In fact, most physical, chemical, and biological properties of water are temperature dependent (Smith 1981) and natural flood pulse events are a principal driving force responsible for the existence, productivity, and interactions of the major biotic in river-floodplain systems (Junk et al. 1989). The right combination of flood-pulse events and stream temperatures may be no more important to any other fish species than salmon. Each species has developed physiological adaptations to specific spawning times and temperatures in order for incubation and emergence to occur at the most favorable time of the year (Kyle and Brabets 2001).

A shift in stream water supplies as air temperatures continue to warm and snowfall turns into rain, not only has the potential to cause stream temperatures to increase but could also change hydrological flow patterns. For instance, transitions from snowfall to rain will result in less snow and ice pack potentially causing higher flows during winter months, lower water levels during spring runoff, and the timing of melt-off to occur earlier than historical patterns. Warming freshwater temperatures and shifts in stream water supplies could affect the physiological and reproductive requirements of fish populations. Reduced flows in the spring can limit access to some streams by adults during spawning migrations. Temperatures that exceed the upper thermal limits can cause low juvenile survivorship, pre-spawning mortality, poor egg and fry incubation, and the timing of fry emergence or smoltification to occur earlier and possibly no longer be paired with optimal survival conditions. However, during winter months, warmer temperatures and increased flows could improve over-wintering habitat and possibly increase juvenile survivorship. Overall, the influence that higher fresh water temperatures and changes in flow patterns will have on individual fish species within the KRW is difficult to predict. Also, genetic variations in Pacific salmon can constrain the physiological adaptabilities and affect the upper limits of thermal tolerances of certain populations (Muñoz et al. 2015). Quantifying the impacts to specific stocks from other compounding socioecological factors also remains challenging.

Shifting Ocean Conditions and Salmon Productivity

Another concern for the KRW is the potential impacts to productivity rates and migration patterns of local salmon populations from changes in off-shore ocean conditions, sea surface temperatures, and oscillation patterns. In particular, the Pacific Decadal Oscillation (PDO), an ocean pattern mainly characterized by reoccurring patterns of ocean variability, atmospheric circulation, and inter-decadal variability of SSTs primarily from mid-latitude to the northern areas of the Pacific Ocean, can have profound impacts on marine productivity effecting salmon returns in Alaska (Hare et al. 1999, Mantua and Hare 2002, Mantua et al. 1997). The recent cool phase of the PDO (which may be playing a large role in halting the effects of global warming) could explain the inverse production relationship between Alaskan and southern BC/lower 48 salmon stocks. Sharp declines in chinook salmon throughout Alaska may be largely due to cooler offshore conditions while favorable warm conditions in the Pacific Northwest may have helped salmon runs make a slight comeback in recent years. However, temperatures in Alaskan waters have recently been unusually warm to the point that warm water marine species have migrated farther north than ever recorded before, potentially indicating significant shifts towards warming PDO trends or changes in the spatial parameters of large-scale ocean cycling (Alaska Dispatch

News 2014). Unexplained warmer conditions in Alaskan marine waters compounded with other less noticeable impacts of climate change, could have devastating consequences on marine productivity, especially anadromous fish stock abundances, and potentially expand the habitat range of competitive exotic species. As their migration patterns move farther north, there will likely be a competitive disadvantage for native species and salmon stocks from the KRW.

Currently, one of the biggest questions in the KRW is why chinook salmon returns continue to decline even though off-shore ocean conditions are warming and usually correlate to more favorable conditions for salmon production. Also, one puzzling phenomenon is that runs of chinook salmon have had a steady decline over the past ten years, yet runs of sockeye, pink, and coho salmon have continued to be strong. The reason for this difference has raised concerns that it may potentially be an indicator of a much more complex issue. One explanation could be changes in available food sources and foraging habits or genetic differences in species tolerance associated with warmer ocean conditions. In a recent study, juvenile chinook salmon were found to consume 30% more food in warm water regimes versus cold in order to keep up with increased metabolic rates. Yet, despite higher consumption, the salmon studied in warm water conditions were smaller and skinnier (Daly and Brodeur 2015).

Understanding how climate change will affect the relationship between the ocean environment and salmon survival is important for predicting future stock strengths and identifying what species may be better adapted to new conditions. Furthermore, if warming PDO and southern oscillation (El Nino) trends couple together, ocean temperatures could rise significantly and magnify the impacts of climate change. Unfortunately, prediction models do not yet exist that are aimed towards understanding the degree of influence warming PDO and southern oscillation trends, if combined together with rising surface temperatures, could have on local climates, anadromous fish stocks, and marine food chains.

Acidification and Salmon Productivity

Changes in ocean temperatures and ocean oscillation patterns are not the only concern affecting salmon productivity and distribution throughout the KRW. Likely also playing a role is changes in ocean chemistry and increased acidification as a result of rising atmospheric CO_2 concentrations. Acidification is impacting species at all levels of the food chain, including factors such as reproductive health, organism growth, species composition and distribution (Sasse et al. 2015). The current and projected increases in Alaska's ocean temperatures and changes in ocean chemistry are expected to alter the distribution and productivity of Alaska's marine fisheries (Chapin et al. 2014). However, it is still largely unknown at what rate acidification will occur, how acidity levels will effect different species, and if specific thresholds exist in which irreversible damage will occur.

What is known is that ocean acidification effects the production of phytoplankton, shellfish, and other shell-producing organisms, mainly due to reductions in calcium carbonate production (Shaw et al. 2015). Therefore, rising acidification levels will certainly have a ripple effect throughout trophic levels that salmon species depend on. For instance, acidification may affect zooplankton productivity, thus affecting sockeye salmon populations which rely heavily on zooplankton as a food source.

Acidification may also affect salmon populations beyond the marine environment. Pink salmon have been shown to have sensitivity to higher concentrations of CO_2 in freshwater life stages. A recent study has shown growth reductions and significant alterations in olfactory responses, anti-predator behavior, and anxiety under higher concentrations of CO_2 in both freshwater and early sea water entry phases (Ou et al. 2015).

Identifying direct impacts to salmon productivity from climate change induced acidification, in both marine and freshwater environments, including offshore trophic influences in relation to ocean cycling, may help to explain differences in stock abundances between various species within the KRW. More specifically, this type of review may identify species that will do well under future climate change scenarios and help clarify future policy options.

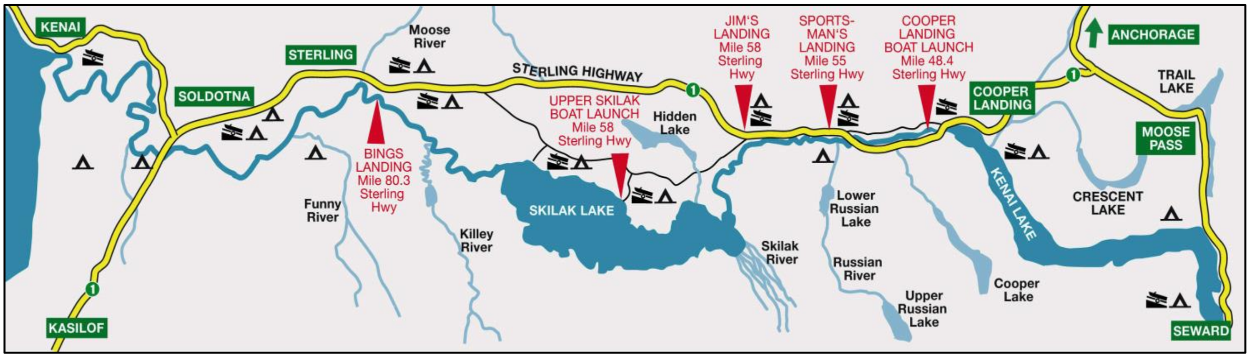
4 Compounding Management Issues in Alaska’s Kenai River Watershed

4.1 Increasing Public Use

The KRW has become a highly popular tourist destination for both international visitors and Alaskan residents compared to other areas throughout the region. The watershed experiences high volumes of public users seeking sport-fishing opportunities and other desired recreational activities like camping, hiking, boating, and wildlife viewing especially during the summer months. In an ADF&G recreational fishing publication, it is reported that an average of 275,000 angler days of participation have been reported in recent years on the Kenai River and that the tourism industry is only expected to increase.

The Kenai-Russian River confluence area is one of the most popular areas in the watershed. As many as 100,000 to 150,000 visitors come to fish and recreate at the Russian-Kenai confluence area alone between the months of May and September (USDA 2012). Oftentimes, salmon anglers experience “combat fishing” or shoulder to shoulder conditions fighting for bank space to fish. Map 1. *Main Kenai River Development* highlights the main public access points and recreational areas throughout the watershed.

Map 1. *Main Kenai River Development*



Source: http://www.boatmansalaska.com/#!kenai-river/ca4p

The effects from heavy public use are prevalent throughout most of the KRW. Decades of heavy public pressure have caused soil compaction, bank erosion, and destruction to riparian vegetation. According to the USDA (2009) many of the human use impacts have affected critical fish and wildlife habitat, channel morphology, and stream ecology and these damages have become severe enough that they will not be able to repair themselves. With little to no carrying capacity limits in place, resource use has become a classic “tragedy of the commons” situation and there is very little incentive to limit personal use even though collective use is currently degrading resources (Hardin 1968). In fact, many locals refer to the watershed as being “loved to death.”

Current stewardship opportunities, educational programs, and public signage fail to elicit personal responsibility. The diverse set of user groups that utilize resources and the web of agency involvement make public education and outreach programs challenging to administer.

New action plans and educational strategies often get stuck in jurisdictional battles which has caused existing educational signage to be outdated and/or insufficient to evolving social pressures. Image 7. *Russian River Failed Fencing Attempt 2014* highlights the challenges of protecting riverbank vegetation from the impacts of heavy foot traffic. Image 8. *Kenai River Sockeye Dip Netting Crowds 2009* shows the massive crowds that the subsistence dip net fishery brings to the mouth of the Kenai River near the City of Kenai.

Image 7. *Russian River Failed Fencing Attempt 2014*

Image 8. ***Kenai River Sockeye Dip Netting Crowds 2009***

Credit: http://photo.accuweather.com/photogallery/details/photo/84345/Kenai+Dip+net

Although the majority of the watershed remains dam and diversion free, several water quality concerns linked to increasing public use do exist including high levels of bacteria, turbidity, and hydrocarbon pollution. One major issue is the impact from human waste. Many areas throughout the KRW lack in appropriate bathroom facilities to accommodate large volumes of public use pressures. One area of immediate concern for increased bacteria levels due to human waste has been the mouth of the Kenai River especially during the busy dip-net season. In fact, accumulations of the bacteria enterococci and fecal coliform have been recorded at levels high enough to exceed state and federal safety standards and cause public health concerns. Also, decades of turbidity from boat motors operating in-river have caused substantial shore-line erosion and degraded overall water quality. A major growing concern surrounding climate change is that a variety of new water quality disturbances will exacerbate the impacts from heavy public use.

4.2 Dependency on Salmon Populations

Most KRW communities still today have long-standing cultural legacies in relation to the natural world and are highly dependent on the watershed's natural resources, especially salmon populations, for subsistence and personal use opportunities, as well as overall economic stability. For instance, in 2012, estimated harvests from the personal use dip net fishery on the Kenai River totaled 535,235 salmon, with 98% of that total being sockeye (Fall et al. 2014) and in 2013 the small Port of Kenai, located near the outlet of the Kenai River, had an estimated commercial harvest of 36 million pounds equaling a value of 40 million dollars (NMFS 2015). Salmon are also very important for cultural and social bonding. In fact, wild salmon populations are considered a source of pride and purpose by many stakeholders and in most cases, is not substitutable by any other resource.

Over the last several years, due to the very low in-river returns, ADF&G has been forced to close sport-fishing for chinook salmon within the KRW. Local businesses, particularly in the lower section of the watershed where the chinook fishery is most popular, were hit hard during these closures. Also, businesses throughout the entire watershed which rely on the influx of tourism surrounding the chinook fishery experienced economic downturns from these restrictions. As a result, many companies had nowhere to turn other than increasing pressure on other species, such as sockeye, coho, and rainbow trout. However, the natural timing of substitute species availability does not always align with economic needs, so in some cases companies had no alternatives. If chinook returns continue to be low in the coming years, and the fishery is forced to remain highly restricted or closed, even more pressure may be deflected onto other resources. The management of other fisheries and economic industries may lack adequate monitoring and authoritative power making the added pressure too much to regulate. However, the severity of impacts from increasing pressures on other species or resources throughout the watershed may take many years, if ever, to materialize and develop into recognizable patterns.

4.3 Social Clashing and Conflicting Priorities

The fact that salmon populations support both economic industries and longstanding cultural traditions sets the stage for conflicting priorities. For instance, balancing fishing allocation rights of local salmon stocks may in fact be the most contentious debate within the watershed. A recent example of this is the Federal Subsistence Board ruling to allow subsistence gillnetting for sockeye salmon in the Kenai River after receiving proposals from the Ninilchik Tribal Council. The decision was made despite concerns from ADF&G fish biologists that these nets would indiscriminately target sensitive populations of rainbow trout, Dolly Varden, and chinook salmon and has resulted in tensions between state, tribal, and federal interests. News of the non-selective fishing gear being allowed, despite continued drops in chinook salmon populations and lack of consistent population assessments for other stocks, has resulted in frustration and confusion among local conservation groups. The ruling has also fueled local skepticism as to how effective top-down agendas are at protecting and managing local stocks.

There has been substantial protest among local stakeholders and area biologists. These strong reactions have exacerbated cultural clashing and community divides.

Social clashing is also common among groups working in different fishing industries, such as recreational guiding versus commercial fishing. Oftentimes people are at odds with each other regarding what they consider proper allocation and methods of fishery management. Many sectors have significant ethical considerations around conservation, including spiritual relationships and rich cultural past-times in connection to fishing. Whereas, other groups are more focused on utilizing the watershed's resources more for economic gain.

Overall, high levels of public use, resource dependencies, and mix of stakeholder preferences puts an additional strain on resource management and limits the capabilities for integrating of climate change adaptation. Along with these challenges, there are many fundamental barriers to integrating climate change adaptation into resource management.

5 Key Barriers to Integrating Climate Change Adaptation

5.1 Universal Challenges of Climate Change Policy

One issue with designing climate change policy is that the sheer enormity of the situation makes scientific research and information synthesis challenging. It requires knowledge from a variety of disciplines and the support from statistics, physics, and computational analysis. Performing hypothesis testing to identify cause and effect correlations is difficult because most climate models are limited in their capabilities for scaled-down and localized analysis. Furthermore, efforts to monitor smaller-scaled changes, develop consistent baselines, and share information is often limited due to the high levels of funding, logistical support, and collaboration needs. As a result, climate monitoring programs are typically insufficient and overall disjointed.

Although there are many challenges with conducting and integrating scientific research, barriers from socio-political controversies far outweigh scientific uncertainties. Whether or not impacts should be addressed and if so how, is not a matter of scientific fact. There are many interpretations of what climate change actually is, what is causing it, and what the implications are. There is substantial debate over what degree humans should be responsible, if adaptation or mitigation is the best response, and how policy tradeoffs should be balanced. The process of weighing out the costs and benefits of different options results in contentious sociopolitical and economic disputes. Different preferences are driven by conflicting personal values and priorities. Even many scientists themselves, who should be objective and unbiased, have become tangled in the political run-around and have used science to advocate personal choices. Policy-inculcated science is common in literature and has caused the credibility of climate research to be questioned by much of the general public. This perpetuates personal opinions and politicians to lead policy decisions without integrating scientific fact.

The uneven distribution of social costs and benefits, both resulting from climate change itself and different policy options, is another main issue underlying sociopolitical debates. Making policy decisions that require substantial compromise from segments of society are not politically feasible in many cases or even practical with current economic conditions and infrastructure designs. In the end, developing politically viable policy at any level is socially challenging, functionally difficult, and typically results in political standstills.

5.2 Challenges Unique to Alaska's Kenai River Watershed

Many of the underlying forces that make integrating climate change at larger scales challenging are principally the same as those found within the KRW. According to responses from 13 employees working for different managing agencies on the Kenai Peninsula, there are a wide range of barriers to integrating climate change into local management. These barriers range from differences in priorities, existing policy challenges, lack of scientific data and interagency communication as well as complex adaptation options (Beach 2015). There are many different perceptions about what climate change is, what it should mean to the KRW, and to what degree humans should be responsible for directing biological trajectories. Bringing these different perceptions together to respond coherently across the landscape also remains challenging.

One major roadblock is the lack of inter and intra-agency collaboration. Individual agency management plans oftentimes do not incorporate neighboring lands and tributaries into comprehensive models. This results in haphazard un-synthesized scientific research and individual forest plans that are out of date, lack synergy, and landscape level policy applications. Part of this comes from the fact that funding for local research is insufficient. This makes the logistics of comprehensive studies difficult to plan and integrative pathways nearly impossible to support. Also, rigid top-down objectives, jurisdictional targets, and the undermining by political and administrative bureaucracies likely also has a large influence over the lack of interagency collaboration. Oftentimes, overarching legislature or larger industries, such as subsistence laws or commercial fishing interests, dominate political agendas and create political barriers. These larger powers often result in a one size fits all style of management that is typically out of touch with the local realities of climate change impacts and have no frameworks for developing adaptive response options. One size fits all strategies limit the capabilities of local agencies to respond to changing conditions and perpetuates policy stagnation.

Barriers specific to the fishery include a long-standing trend of segregated management regimes which fail to recognize the importance of local ecological knowledge and its ability to compliment conventional science. Further complicating the situation is the conflicting interests and public values surrounding allocation rights. These mutually exclusive preferences commonly lead to community members and agency employees to consider setting new policy goals as being too complex or controversial which ultimately exacerbates political gridlock. However, most realistic policy options are not necessarily complex; rather the issue is more that they are politically contentious or socially unacceptable. In fact, many policy options are quite simple and straight forward, they just require compromise. Furthermore, as a result of being marginalized and excluded from making decisions about what directly affects them, many citizens have come to distrust the political agendas behind land use management and question the capabilities of local agencies to protect their natural resources in the face of climate change. According to Flora et al. (2004), this divided social scenario creates an environment resistant to change, which only prolongs standstills in watershed management and climate change policy.

As a result of these existing challenges and barriers, there are few efforts to integrate climate change adaptation into current watershed management and many of the existing ecological issues are self-regulating or are managed by default, rather than making deliberate policy decisions. However, it is important to remember that just because climate change adaptation is not being actively addressed and existing management issues are left to be selfregulated, policy decisions are still being made. Basically, choosing to do nothing is still a policy decision.

Allowing self-regulating systems and taking a policy by default approach will likely not be effective for integrating climate change adaptation. Furthermore, this hands off method of management can lead to many questions and concerns in regards to climate change to remain unanswered and existing policy issues to be overlooked. A combination of the following future management directions, that aim to address issues both new and old, will likely need more attention to effectively integrate climate change adaptation within the KRW as well as address existing watershed policy issues.

6 Future Management Directions for Alaska's Kenai River Watershed

6.1 Confronting Difficult Adaptation Questions

Although broad climate impacts patterns exist, a concern is how can localized cause and effect relationships can be better recognized and understood. It is difficult to know what species will adapt and if they will be able to withstand new climate stressors as they have in the past. There is the idea that people should have more responsibility in helping affected populations adapt to current climate change now that it is thought humans are the likely cause of recent warming. There are many shoulds in how to manage the watershed from should it be left alone, should it be managed to restore historical conditions, or should entirely new systems be supported. There are concerns around how climate change information should be communicated, framed or structured and that currently managing agencies may not be prepared to make decisions which require people to compromise. Knowing whether conservation of historical ecological conditions is a viable goal in a rapidly changing climate is especially important. We are very used to managing for historical species composition, however as the impacts of climate change continue to grow, this may not be a realistic goal.

6.2 <u>Identifying Broad Policy Objectives</u>

#1 Gathering Information on Current and Projected Ecosystem Conditions

Researching ecosystem conditions could help identify cause and effect relationships at the local level and whether there is a need climate change adaptation policy. Identifying current and projected conditions is especially important for the management of salmon populations. Because there is such high levels of economic and cultural dependency on these species, knowing current and future population abundancies will likely be very important for designing future industry regulations and social adaptation strategies.

#2 *Identifying Top Issues and Adaptability Needs*

Narrowing down management issues may help consolidate priorities and identify common goals between stakeholders. This may also help to ensure watershed issues and concerns that are the most important to local communities are not being overlooked.

#3 *Examine Current Policies and Management Goals*

Revisiting and scrutinizing current management goals could help answer important questions such as, are policies and management actions achieving goals and are goals appropriate for current and future ecological conditions.

#4 Building the Capacity for Climate Change Adaptation

Neither top-down nor bottom-up efforts will be effective at adapting to climate change until the capacity to do so has been established. While this objective appears to be fairly straightforward, capacity building at any level is nothing short of complex. Working frameworks will likely need to be established to guide management, policy makers, and communities through the process.

6.3 Improve Local Climate Change Research

One of the most important reasons for developing consist baseline information and expanding exploratory field research is to help quantifying localized changes and identify cause-effect patterns that can be attributed to the changing climate. In turn, this information can help identify what changes can and cannot be controlled through management and policy. However, understanding landscape level processes and integrating scientific information into a cohesive perspective requires monitoring efforts beyond jurisdictional boundaries.

Over the last decade, several local agencies and organizations have started programs to develop long-term scientific baselines and improve decision-making in relation to climate change on the Kenai Peninsula. One of the largest undertakings within the KRW is monitoring freshwater temperatures. The stream temperature monitoring network program that was initiated in 2008 by the Cook InletKeeper, a non-governmental organization (NGO) based out of Homer, Alaska, is a program that monitors air and stream temperatures throughout 48 non-glacial salmon streams within the Cook Inlet basin. Data is then used to spatially map patterns and analyze air temperature influences on water temperature fluctuations. In addition to these efforts, the Kenai

Watershed Forum (KWF) has been collecting water quality samples from 22 different sites, including the Russian and Kenai Rivers, since 2000 to track concentrations of metals, nutrients, hydrocarbons, bacteria, and water temperatures. In 2009, they partnered with Cook InletKeeper and began participating in the stream temperature monitoring network program with a priority focus on the KRW. Many other agencies, such as the state of Alaska, USFWS, U.S. Geological Survey (USGS), and the U.S. Forest Service (USFS), along with other community-based groups have also become partners in this network program. These types of system-wide monitoring efforts that look at entire networks are critical for evaluating the larger influences of climate change. If expanded, collaborative projects of this caliber could help identify what ecological changes are occurring and if changes can be attributed to current watershed management, normal cyclical patterns, or are a direct result of climate change. This information can be valuable for identifying species or systems that could benefit from adaptation policy and that are capable of being better prepared to absorb the effects from climate change.

While improving exploratory efforts is important for understanding changes that have already occurred, developing projection models for future change is also important especially for predicting species composition. Using air temperatures to predict water temperature and simulate future warming trends in freshwater may be especially useful. For instance, by utilizing anticipated air temperature increases, Kyle and Brabets (2001) reported a predicted magnitude of 3℃ (37°F) or more in water-temperature change for 15 locations in the Cook Inlet basin, which is considered significant for the incidence of disease in fish populations. Replicating projected warming scenarios coupled with salmonid thermal tolerance studies may help identify specific populations that will be more sensitive to future warming and certain times of year when mortality risks may be higher. In turn, this synthesized information may be valuable for designing both current and future fishery management goals.

6.4 Data Networking and Technology Sharing

The bulk of ecological problems take place at the scale of whole networks and cannot be deduced from their basic elements (Bascompte 2009). This highlights that research and biophysical monitoring at individual levels or man-made boundaries may be missing key ecological components important for landscape level watershed management and integrating climate change adaptation. Synthesizing research methods between agencies can help keep baseline data consistent even over different jurisdictional boundaries and possibly identify larger scaled cause and effect relationships. The Cook Inletkeeper's stream temperature monitoring networking program is a great example of how different organizations can join together and collaborative research efforts.

Coordinating at a regional level is also useful for establishing more sophisticated survey methods at the local level. The University of Alaska's Scenarios Network for Alaska and Arctic Planning program, is one of the most well-know and utilized within the KRW. It develops plausible climatic scenarios throughout the Arctic and Alaska in response to climate change. These scenarios are important for supporting climate envelope modeling on the Kenai Peninsula to understand potential shifts in local biomes, including fish and wildlife distribution patterns, in response to climatic changes.

Another example of technology sharing is the recent work between Cook Inletkeeper and Watershed Science, Inc., an Oregon based company that specializes in airborne remote sensing and water quality analysis. Together, they conducted thermal infrared remote sensing to map spatial temperature patterns throughout the Anchor River basin on the Kenai Peninsula (WSI 2010).

Information exchange online can also be helpful for building platforms so others can benefit from different levels of expertise. The newly developed Kenaichange.org website, which organizes and promotes web resources, local workshop information, and climate change news, and the work of Alaska Fisheries Information Network to consolidate and dispense commercial fisheries data, are steps in the right direction. By sharing research technologies and scientific information at a broader level, more specificity, elements, and environmental components can be integrated into KRW specific analysis and perhaps be used to better guide policy and management at the local level. Also, local scientists can become better prepared to evaluate ecosystem functioning from a more comprehensive perspective and include critical components that are nearly impossible to evaluate by only looking within jurisdictional boundaries. Bridging the gap between different datasets, modeling techniques, and planning perspectives, may also help convey the societal significance of climate change science.

*6.5 **Address Increasing Public Use***

Designing mutually agreed upon carry capacity limits or user group restrictions have proved to be a constant challenge for the KRW. Even though public users are concerned with environmental impacts, there is little probability that increased public use long-term will become self-regulating. Whittaker and Shelby (2010), who recently conducted a public use survey throughout the KRW, suggest that eventually a “line in the sand” will be need to be drawn and that collectively limiting all user groups equally may be effective. This collective approach could help create an environment where not one user group is unfairly targeted and all groups are required to participate. Also, conducting studies that measure the pulse of public use trends and opinions, along with biophysical impacts and tolerances, could be useful for establishing limited entry targets for restricted use that are both socially acceptable as well as ecologically friendly.

Alterations to critical fish habitat, as a result of heavy public use, have also proved to be a persistent challenge for managing agencies. A piecemeal approach to restoration has been taken within the entire watershed, which has caused many areas and issues to be overlooked. In the future, cross-boundary interagency coordination will be required to adequately address public use hotspots that overlap jurisdictional boundaries.

One area that requires immediate attention and coordination to stop riparian damage from becoming permanent is the popular Kenai-Russian River confluence area. Currently, there is little to no habitat protection on the western banks of the Russian River and confluence area, which are primarily managed by USFWS. Public use pressure at the USFS developed campground and angler boardwalk system, located on the northern banks, regularly overflows severely impacting these unprotected areas. Bears are also common in this area and human-bear conflicts are a persistent problem. Public restroom facilities are sparse and it is common to find human waste along riverbanks. A possible option for addressing both these issues is building small visitor centers at the two main entrances that lead into the Russian River and confluence area. These new facilities could provide educational opportunities for foot traffic policies and angler responsibilities, human-bear safety, and habitat restoration efforts. It could also be a point of contact for promoting stewardship opportunities and relaying emergency fishing orders, cultural heritage information, and proper waste disposal.

Quartz Creek is another tributary that could benefit from more habitat protection and restoration efforts, as well as improved public outreach facilities. This tributary is oftentimes overlooked by management because of its year-round closure for salmon fishing; it is a sensitive spawning area for chinook, sockeye, and coho salmon. Despite this, the creek receives substantial angling pressure for both rainbow trout and Dolly Varden and in some areas, riparian habitat has become severely impacted. Also, educational signage is minimal. During popular summer months, it likely is not sufficient for the amount of people that recreate and fish on the creek. Addressing habitat issues and increasing public signage on this tributary could improve resource protection and in turn have a positive influence on KRW salmon productivity.

Educational signage throughout the entire KRW may need to be expanded and upgraded to accommodate the growing number of visitors with diverse backgrounds and those speaking different languages. Proper fish identification is especially important so that people with various levels of fish knowledge can distinguish between different species that look very similar. This may help ensure that illegal catches are not retained and sensitive populations are not mishandled. Addressing multi-cultural backgrounds may also help a wide range of visitors become aware of proper waste disposal, public use regulations, and habitat restoration goals.

Explaining proper catch and release etiquette is also very important. For instance, rainbow trout and Dolly Varden are the most highly sought after resident species for sport-fishing and are conservatively managed for catch and release. About 43,000 rainbow trout are caught every year in the Kenai River and about ninety-five percent of these fish are released (ADF&G 2015 Recreational Fishing Series). Despite the popularity of catch and release sport-fishing, very little public education is provided on proper techniques for the safe handling of fish. Unfortunately, improper handling is common and can increase fish mortality rates.

Increasing public signage at sacred archeological sites may also provide a special educational opportunity. The Sqilantnu Archeological District, located at the confluence of the Russian and Kenai Rivers, contains 15 pre-historic sites and has been an important gathering place for native people of Alaska for thousands of years with some archeological sites believed to be over 10,000 years old. This area is currently not marked by any public signage and is oftentimes heavily trampled by foot traffic during summer months. Developing interpretive signage to highlight these sites can teach visitors about the areas rich cultural heritage and the need to preserve these special ceremonial sites and ancient burial grounds to pass along native legacies. Adding interpretive and educational signage in these sacred areas may also provide protection from heavy foot traffic and exploitation, while at the same time offer natural history interpretation.

6.6 Protecting Local Chinook Salmon Populations

Knowing how and when salmon populations will be affected by climate change is important for designing adaptation policy within the KRW, especially because so many systems within the watershed rely on their existence. However, the majority of current fishery research within the watershed does not integrate the context of climate change. This could be a factor in our poor understanding of the recent decline in chinook salmon returns. Yet, even though the impacts of climate change to local salmon populations are still largely unknown or speculative, there are several realistic management options that may possibly help to restore and protect them.

One of the biggest influences on local stocks that may be managed differently is the incidental chinook salmon bycatch numbers allowed in offshore fishing industries. From 1990 to 2001, an average of 20,799 chinook salmon were incidentally caught annually in the Gulf of Alaska trawl fisheries (ADF&G 2002). Yet in 2010, chinook salmon bycatch numbers in the Gulf of Alaska were reported much higher at 51,736 fish (NOAA 2010). However, comprehensive measurements of marine harvest and estimation procedures for prohibited chinook populations may not always be accurate. In fact, there may be many more fish being caught than what is reported.

Higher numbers of incidental bycatches in offshore fishing industries could reduce the number of fish that return to spawn in the KRW. Although, no bycatch sampling studies have been conducted in the Gulf of Alaska trawl fishery, one of the largest industries, to look at the river origin of salmon bycatch. Also, research that addresses the impacts annual bycatch numbers have on salmon runs in the Kenai River has not been conducted. The lack of comprehensive population studies that include the effects of marine harvest makes it difficult to quantify the impact offshore bycatches from these larger industries have on local stocks. Until more research on the impacts from offshore bycatch is conducted, one response option that could be effective in protecting KRW chinook salmon stocks is to reduce the number of allowable bycatch numbers in off-shore fishing industries that are located near the mouth of the Kenai River, such as the set-net fishery in the Cook Inlet.

Other possible management options for chinook salmon populations within the KRW is to federally protect the species under the Endangered Species Act (ESA) or supplement with hatchery stocks. However, both of these options are highly controversial due to the impacts they will likely have on local economies from stricter fishing restrictions and wild fish populations, which most local communities want to protect. Also, identifying when a declining fish population has crossed critical thresholds, one in which the efforts needed for rehabilitation may no longer possible or worth the costs, is not always easy to do. The dramatic low returns of chinook salmon may be the clearest signal yet that tipping points are being challenged and addressing factors that initiated the decline, such as over-fishing or habitat loss, may not be enough to bring populations back, especially with the compounding influences from climate change. In this case, restoring the population may not be possible, even with ESA protection. Supplementing the population with hatchery stocks may be the only feasible option to ensure future productivity and sustainable yields.

6.7 Diversifying Economic Industries

Throughout the KRW, few alternative economic sources exist beyond sport and commercial fishing industries. This single-focused market relies heavily on environmental conditions and fish stock abundancies to be consistent and predictable. So, as ecological transformations continue to increase from climate change, and fish stock abundancies fluctuate, socio-economic vulnerabilities may be exacerbated. However, creating flexible industries and targeting fish species which are predicted to do well in future climate scenarios could help reduce these vulnerabilities.

Not all species of fish within the KRW will respond the same to climate change. In fact, climate-related impacts are thought to have contributed to increases in pink and chum salmon and decreases in coho and chinook salmon observed in the North Pacific Ocean during the past 80 years (Irvine and Fukuwaka 2011). The reason for these differences are likely in part due to the fact that chum and pink salmon have similar life history patterns that vary significantly from chinook, coho, and sockeye, which all have distinctly different life cycles. For instance, pink salmon migrate to the ocean soon after hatching in freshwater. In contrast, coho spend several years in freshwater before migrating to marine environments. Chum and pink tend to spend the same amount of time in the marine environment before they return to freshwater for spawning and chinook salmon typically spend the longest time at sea. Differences in life history, such as these, mean that coho may be more susceptible to variables in freshwater environments than pink salmon and chinook salmon. And because chinook salmon spend the longest time in the ocean, they could be more vulnerable to changes in the marine environment versus pink and chum salmon. Overall, the environmental variables that different species will be exposed at certain ages will likely vary significantly overtime.

With this, it is possible that fishing industries could continue to be a main source of economic revenue if there is flexibility in what species they target. If chum and pink populations do exceptionally well in response to climate change, they could be a legitimate alternative to other more susceptible species. However, estimating fish species abundance trends in relation to future climate change within the KRW is nearly impossible. Therefore, developing alternative industries altogether may help avoid economic downturns in the future. Additionally, if returns of chinook salmon continue to be low in the coming years and other stocks also begin to dwindle, fishing communities will have to transform not only their ways of making a living, but also their methods for social bonding and defining cultural identities.

A viable alternative is moving towards eco-tourism based industries. This may be one of the easiest transitions and most beneficial for improving economic stability as well as conserving cultural traditions and the natural systems that attract visitors to the area in the first place. According to the International Ecotourism Society, ecotourism is defined as, responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education. There are many benefits of ecotourism that go beyond resource conservation and protection. The industry has the capacity to raise awareness of local watershed issues, offer interpretation and educational opportunities, and improve social adaptability.

Eco-tourism is already doing fairly well within the KRW, especially in the upper less developed sections. Alaska Wildland Adventures, located in Cooper Landing, is one company known for its outstanding eco-tourism programs, including natural history interpretation safaris, guided back-country hiking, and remote rafting trips. However, modifications to infrastructure design, public use zoning, educational resources, and management goals will likely be required to support a wider range of eco-tourism industries, such as wildlife viewing and scenic appreciation, throughout other parts of the watershed.

6.8 Diversify Community Participation and Policymaking Groups

While it is important that resource management collaborate, adapt, and transform to address current issues of climate change, diversifying community participation and local representation in policy making groups is equally important to address local vulnerabilities. Larson and Ribot’s (2004) theory of democratic decentralization emphasizes the need for local groups to address resource management issues where centralized efforts may be falling short. This is important for the KRW because top-down management will likely not be able to solve watershed issues alone. Some of the most effective ways to diversify community participation and decentralize management is through community forestry practices, social networking, and increased local representation.

Community forestry practices include stakeholder interests and public participation in resource management agendas via pathways such as stewardship and volunteer opportunities, public awareness events, locally-based interest groups, and open public forums. These modes of community forestry promote conflict resolution between different interest group agendas, open communication, and the sharing of knowledge between broad spectrums of stakeholders (Baker & Kusel 2003). They help to reduce political marginalization, support social equity, and empower people to participate in sharing their local knowledge and land use visions.

Community forestry practices throughout the KRW are growing. StreamWatch, a nationally recognized volunteer program, has provided public education messages, light habitat restoration upkeep, and refuse collection throughout the Kenai and Russian River confluence area for over 30 years. More recently, their efforts have been expanded to include stretches of the middle and lower Kenai River. Altogether, this program has had profound positive impacts to streamside habitat, public awareness, and community involvement.

A new local Trout Unlimited chapter has also recently been established so locals can formally discuss fishery specific issues, problem solve management strategies, and share valuable ecological knowledge with one another. The chapter has empowered many community members to now have a voice in policy-making processes. These types of community based platforms can create incentive for people of all backgrounds to be more active in their local resources and perhaps rise above their own self-interests and work towards common goals.

Furthermore, community-based models that include public input can be effective at managing common-pooled resources, as in the case of the KRW fisheries, towards more sustainable levels. In Elinor Ostrom's (1990) book Reflections on the Commons, she provides empirical evidence from a common-property fishery in Alanya, Turkey that was successfully self-governed and sustained by access rules that were devised, modified, and enforced by the public participants themselves. This example supports the idea that by increasing community participation in shared resources issues specific to the KRW, such as declining salmon returns and climate change, adaptive capacities can be improved beyond what agencies alone can provide.

Encouraging public participation and integration of local knowledge in management, not only can help bridge the gap between scientific communities, stakeholders, and policy makers, it can also promote social networking between different user groups. Increased communication and information sharing at a local level may help identify similar interests between stakeholders and common goals may surface leading to collective endeavors. Local representation in state-wide policy making groups, such as Alaska's Board of Fisheries, the Federal Subsistence Board, and North Pacific Fishery Council, may also help ensure knowledge from those who experience the resources firsthand is being utilized in decision making processes and that issues within the KRW are being formally recognized. In addition, as local citizens gain more participation and power in political agendas, they may become more supportive of policies thus in turn making institutions more socially sustainable into the future.

6.9 Institutional Adaptability and Overcoming Policy Stagnation

Institutional flexibility may also play a large role in creating the momentum needed to overcome contentious policy decisions needed to address the growing impacts of climate change. Clarifying the roles that agencies, local watershed groups, and the public have in resource policy decisions is important for developing inter-organizational and stakeholder trust (Chaffin et al. 2015), which may be an important first step. Improving rapport with one another and building stronger interagency partnerships can also promote the sharing of technical watershed information. Strong interagency coordination and public trust may help ensure that the most up to date scientific information is being utilized in policy analysis and that the impacts of climate change are being formally recognized.

Part of the process of institutional adaptability may also require that agencies decentralize planning, overcome past policy failures and fragmented jurisdictional boundaries, and continue to diversify the policy-making process. However, one concern with diverse policy-making groups is a tendency towards political standstills from opposing views and preferences. One option to resolve this issues, is to use a lead agency, such as the Kenai River Special Management Advisory Board, as an institutional mechanism for coordinating agency interests and implementing new policy initiatives (Whittaker and Shelby 2010).

Public citizens themselves must also be willing to change. Within the KRW, there are many longstanding social norms and standards that direct peoples' interaction with the natural world. Metaphorically, these social arrangements influence people's behavior the same way top-down political agendas affect local management. Narrow policy agendas and inflexible social systems, not only amplify political controversies and stagnation; they also tend to lack the capability to address changing conditions. Many social groups within the KRW may be very resistant to change, especially those who depend on long-standing relationships with resource use. They tend to follow social patterns and policy just because they are the norm or because they have clear cut parameters. These rigid arrangements may not have the capacity to deal with the impacts of climate change adequately. Adjusting these institutional patterns to address new issues within the watershed will likely boil down to requiring a combination of compromise between different users groups and building fundamentally new systems altogether.

And lastly, it is possible that management goals to retain historical species composition may no longer be feasible in the future with new climate regimes. For example, the watershed's ability to support chinook salmon populations may no longer be possible. Instead, having flexibility in management goals and adjusting species composition targets so as to be better suited for new climate patterns may be the more realistic and effective strategy.

7 Conclusion

Climate change is a challenge affecting every place on earth and biological systems at all levels. However, the impacts of climate change are not uniform and do not have the same implications for every location. Alaska's KRW has a set of distinctive qualities that may make it especially vulnerable to the impacts of climate change. It is also referred to as a watershed with wicked resource problems, those that are difficult or seemingly impossible to resolve, and has a long history of management challenges. As a result, cohesive management and collaborative research continues to be a challenge for managing agencies and contentious policy decisions are oftentimes neglected. Climate change adaptation goals continue to fall short and many resource issues continue to be overlooked. Furthermore, the growing impacts of climate change may make these contentious management issues even more difficult to resolve. While at the same time, many existing management challenges could exacerbate the watershed's vulnerabilities to climate change.

Building adaptive capacities in response to climate change and existing issues within the KRW is not simply about identify problems, strategizing options, and setting specific targets. These are certainly important first steps in which this assessment in part aims to improve. Achieving adaptation goes far beyond developing strategy and goals. It is a dynamic process that requires institutional adjustment and on the ground action. It demands flexibility to changing conditions, strong community alliances, and deliberate policy decisions. It will require meaningful and intentional collaboration between a variety of scientific disciplines and social systems, as well as strong political and public will that together can address a multitude of issues both old and new.

Moreover, as ecosystems continue to change within the KRW, adapting climate change, while simultaneously addressing existing watershed issues, may be reaching a pivotal point. It is a common theory among natural scientists that biotic conservation is most successful where actions are aimed at protecting ecosystems rather than restoring or reclaiming them after damage is done (Mitsch and Gosslink 2007). Likewise, when systems are transitioning to a new state, there is a window of opportunity, often limited to a very short period of time, in which to guide or navigate the change in trajectory (Olsson et al. 2006). Therefore, in order to effectively prepare and adapt to the inevitable impact of climate change, the KRW's socioecological system community must take advantage of this window of opportunity to guide its own future and perhaps conserve its' one of a kind environment.

By utilizing the information provided in this assessment, the goal is that future management endeavors can begin deliberately weighing out different research agendas and policy options. Managers and residents will be inspired to take the preemptive measures necessary to ensure resource protection and adaptability as the inevitable impacts from climate change continue to grow. From this, hopefully, opportunities will emerge to build a greater understanding of the fundamental frameworks and cross-scale interactions needed to better prepare us for the impacts of climate change not only within the KRW, but worldwide.

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