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Using Comprehensive Scenarios to Identify Social–Ecological Threats to Salmon in the Kenai River Watershed, Alaska

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Abstract: Environmental changes caused by climate change in Alaska pose a serious threat to the food, energy and water systems that support the culturally diverse communities statewide. The fishing industry, watershed managers and other stakeholders struggle with understanding and predicting the rates, magnitude and location of changes occurring in their regions primarily because of the significant range of uncertainty inherent in these changes. With the guidance of stakeholders, we demonstrate a scenario analysis methodology to elucidate the interactions among various components and uncertainties within the food, energy and water systems of the Kenai River Watershed. Alternative scenario analysis provided stakeholders with a venue and process to consider plausible futures in which rates of change in critical uncertainties were modeled to elucidate potential responses. Critical uncertainties ranged from climatic impacts on freshwater systems, to new energy development proposals, to changes in sport and personal use fisheries. Working together, stakeholders developed narratives that reflected different combinations of future uncertainty to guide potential management actions now and in the future. Five scenarios were developed by stakeholders that capture the complex interactions in the Kenai River Watershed as a social–ecological system. This process provides a way for managers and stakeholders to plan for the future in a richer way than extrapolating trends for obvious drivers of change. We present this framework as a platform for integrating climate, landscape and cultural change data into actionable decisions, crafted by stakeholders, to improve future food, energy and water resource management at the watershed scale.

Keywords: alternative futures; salmon; scenarios; social–ecological systems; stakeholders; watershed management



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1. Introduction

Ecosystems in northern latitudes have already experienced significant climate change impacts [1,2], and this is expected to continue well into the future [3,4]. Changes to the cryosphere are especially prominent [5] and require an integrated hydroclimatological approach in order to understand simple metrics such as future streamflow in many northern rivers [6]. Uncertainty associated with future streamflow and water temperature has limited the ability of resource managers in Alaska to make effective management decisions regarding one of the most culturally and economically important food resources in the state—salmon. Water temperature directly affects Pacific salmon (*Oncorhynchus* spp.) by impacting prey abundance, availability and taxonomic composition [7,8]; changing growth rates [9]; altering life history events [10,11]; blocking migration corridors [12,13]; and increasing disease [14,15] and mortality rates [16]. All of these shifting dynamics challenge Alaska's salmon management, which relies upon managers' ability to predict the magnitude and scope of ecological changes to freshwater habitats [17].

Uncertainties, such as impacts from climate change, can heighten user conflict and potentially result in both biophysical and socioeconomic collapse [18]. Managing resources against the unknown variables of climate change and other exogenous factors is a daunting task, especially in places such as the Kenai River Watershed (KRW), where management jurisdictional space is highly complex. There will always be inherent uncertainty and unpredictability in the dynamics and behavior of complex ecological systems as a result of non-linear interactions among components and emergence, yet management decisions must still be made [19]. For these reasons complex systems approaches, such as social–ecological systems (SES) frameworks that elucidate the dynamics among social, ecological and physical processes, are now being advocated [20].

Anticipation of future changes by managers and other stakeholders in ecosystems often involves linear projections of isolated indicators into the future [21,22]. For example, an agency may project trends in summer air temperature change as a proxy for stream temperatures without considering interactions of glacial streams in the system [23]. Interactions among components in an ecosystem or watershed are critical to consider but are often ignored because the level of associated uncertainty and a lack of data about interrelationships makes them difficult to predict [24–26]. Scenario analysis can be used to help managers overcome the challenges of uncertainties in natural resource management by having them consider how they might respond to a set of future scenarios that vary the impact of key uncertainties on decisions and issues that they will face [27–29], utilizing both qualitative and quantitative methods and data [30,31].

A scenario is a coherent, internally consistent and plausible description of a potential future trajectory of a system [32]. Scenario analysis has been increasingly applied in the field of environmental research over the last 25 years [33–39] as a way to address complex and interrelated environmental problems. Scenario planning processes are often oriented toward influencing decisions [40,41]. The process of scenario analysis provides a systematic framework to evaluate plausible futures of a given social–ecological system. Scenario analysis is becoming a popular tool in place-based environmental research and has enriched environmental management and scientific research through building common understanding and providing a procedure and practice for planning for the future of social–ecological systems [42]. The use of scenario analysis can increase adaptive capacity [43,44], identify policy recommendations for sustainable development (e.g., [45–48]) and identify adaptation pathways [49,50].

We utilized stakeholder-driven scenario analysis to explore the inherent uncertainty associated with managing salmon resources (food) given future climate (water), landscape (energy) and cultural changes that might occur as a way to integrate both the biophysical and socioeconomic trends in the KRW [20]. Synthesizing the best available science with local stakeholder-driven knowledge about the SES in the KRW, we developed five comprehensive scenarios that describe the interactions of the food–energy–water systems, and implications of plausible management decisions under a range of social and environmental drivers likely to impact salmon resources into the future. We describe our process as a framework for addressing environmental uncertainty, increasing coordination in watershed management and planning for potential future changes at the watershed scale.

2. Materials and Methods

2.1. Study Area

The KRW (population~45,000) is located in Southcentral Alaska (Figure 1), approximately 200km south of Anchorage (~300,000 residents), but within the largest population center in the state (~450,000 residents in Southcentral Alaska) [51]. The Kenai River has multiple glacial- and snow-fed tributaries that range from 3000 m in elevation to sea-level. The mouth of the river enters Cook Inlet at the town of Kenai, which derives most of its economy from natural resource extraction [52]. The KRW has been characterized as a SES partly dominated by physical and social feedbacks surrounding salmon fisheries [20]. Additionally, the watershed has experienced significant biophysical changes recently, in-

cluding substantial increases in impervious surfaces [23], increased stream temperatures [4], increased fire activity and significant loss of glacial ice [52]. While some policies have been developed to address the impervious surface encroachment into riparian areas, the lack of sufficient stream setbacks has not been addressed, and public support remains volatile [53].

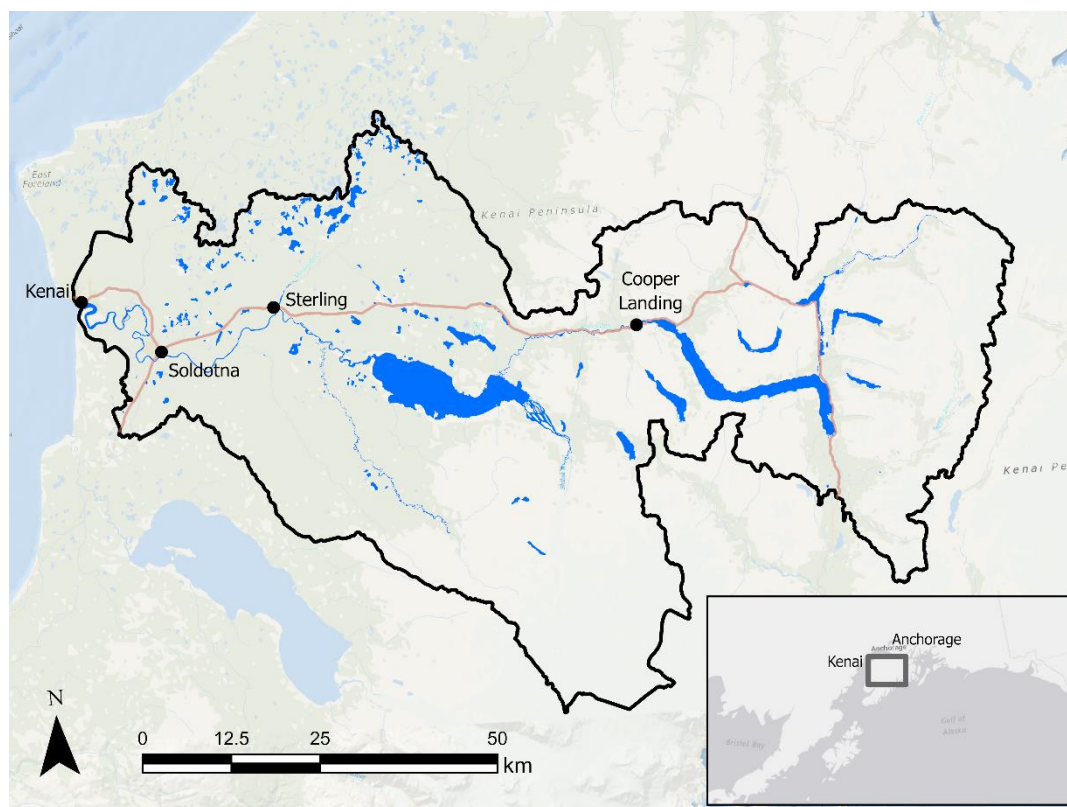


Figure 1. The Kenai River Watershed (KRW) in Southcentral Alaska.

Salmon management in Alaska, and specifically within the Kenai River Watershed (KRW), is multi-layered and complex. The North Pacific Fishery Management Council (NPFMC) manages fisheries in the 200-mile Exclusive Economic Zone (<https://www.npfmc.org/overview/> (accessed on 11 May 2021)) with regulatory responsibility vested in the National Marine Fisheries Service. The U.S. Fish and Wildlife Service (USFWS) manages freshwater and subsistence fisheries on federal lands, while the Alaska State Board of Fisheries (Board) and the Alaska Department of Fish and Game (ADFG) regulate state fisheries from inland waters to three miles offshore. The most contentious region overseen by the Board is Cook Inlet, which contains the Kenai River. The fishery has a complex network of stakeholders engaged in commercial, personal use, subsistence and sport fisheries [54]. (Personal use fishing is restricted to Alaska residents and is defined by Alaska regulations as “the taking, fishing for, or possession of finfish, shellfish, or other fishery resources, by Alaska residents for personal use and not for sale or barter, with gill or dip net, seine, fish wheel, long line, or other means defined by the Board of Fisheries” (AS 16.05.940 [27]).) Subsistence uses of wild resources are defined as ‘noncommercial, customary and traditional uses’ for a variety of purposes including: direct personal or family consumption as food, shelter, fuel, clothing, tools or transportation; for the making and selling of handicraft articles out of nonedible by-products of fish and wildlife resources taken for personal or family consumption; and for the customary trade, barter or sharing for personal or family consumption (AS 16.05.940 [32]). Sport fishing requires a license and authorizes both Alaska residents and non-residents the “taking of or attempting to take for personal use, and not for sale or barter, any fresh water, marine, or anadromous fish by hook and line held in the hand, or by hook and line with the line attached to a pole or rod

which is held in the hand or closely attended, or by other means defined by the Board of Fisheries” (AS 16.05.940 [31])). Approximately 40 species of resident and anadromous fish live within the KRW. The Kenai River is the most heavily fished river in Alaska [54].

The inherent conflict and cross-jurisdictional management structure of the Kenai River Fishery requires a diverse group of agencies to work very closely together. However, agencies’ authority and control over policy issues in the overall decision-making structure are fragmented and several of the managing agencies have Memoranda of Understanding to enforce fishing regulations across jurisdictions. Federal, state and local agencies also participate on governance boards, such as the Kenai River Special Management Authority (KRSMA). Although they frequently work together, each agency has its own mandate and follows a specific set of directives, which may limit or enhance the agency’s ability to respond to social–ecological change [55]. All of this makes the KRW a good candidate for developing integrated scenarios to address future stressors.

2.2. Scenario Approach

We utilized a modified Steinitz Geodesign approach [56] to develop our scenarios for the KRW. Geodesign, also referred to as alternative futures, seeks to answer whether the landscape (usually a study area) is functioning well, and how that might change that in the future [56]. Geodesign works across scales, temporal and geographical, to produce modeled or designed physical changes to a landscape as a way to visualize the way society values and changes its geography. This framework relies on an interconnected, representative matrix of experts, including regional stakeholders that Steinitz describes as “the people of the place,” geographic scientists, design professionals and information technologists. We placed particular focus on stakeholder participation and validation [57], using a similar methodology to Shearer et al. [58] by iterating through a set of exercises described below, to refine both stakeholder and researcher assumptions [57]. Results of this iterative process demonstrate plausible futures, described through scenario narratives, for a given landscape or site. Two workshops were held in the town of Kenai, Alaska in October of 2015 and May of 2016, and fifteen agencies and individuals attended both workshops. Each workshop began with a Science Seminar the night before that presented the research team’s current state of knowledge of the system. This provided an opportunity for immediate feedback from stakeholders and the community at large regarding research assumptions and ensured the research team was utilizing the best available data for the region and capture additional local knowledge.

Identification of stakeholders is often the most important part of any watershed-based management approach but can also be incredibly time-consuming. We applied an SES framework [20] that utilized Social Network Analysis (SNA) to identify relevant stakeholders in the KRW to ensure a representative selection of managers and agencies. Full details of our stakeholder selection process can be found in [59], but, briefly, the process began with targeted interviews and snowball sampling to identify key players in the watershed that were (a) active in salmon management and (b) regularly communicating across the system [59]. This process identified 45 individuals working for 20 agencies. Roughly 20 individuals and agencies were identified by the SNA as key stakeholders in the KRW, and these stakeholders were invited to each of the workshops [59].

Based on the list of confirmed attendees of the October 2015 workshop, the scenarios team divided participants into subgroups to maximize diversity of experience and viewpoints during small-group work. The full-day workshop guided participants through a series of exercises. To set bounds for the scenarios, the participants first described their best and worst possible futures for the KRW. Participants were asked to make their description of the futures discreet and mutually exclusive in order to isolate specific drivers, and then were ranked for preference by the larger group of stakeholders.

Within the subgroups, participants then identified the top five important issues and/or decisions facing Kenai River salmon and the top five uncertainties that they anticipated would impact the issues and/or decisions they had listed [58]. After each exercise, groups

reported their unique decisions/issues and then uncertainties. Actors were selected from the top five actors identified in the SNA, but participants were able to vote in one additional actor. Groups developed a profile describing typical actions, means of agency, motivation for action, scene of action and factor of increased agency or greater effectiveness for each of the six primary actors.

Group ranking was used to create consensus on the most important issues/decisions and uncertainties. Participants were tasked with choosing three that were the most important issues to them, prioritizing each issue/decision from 1 (not pressing) to 15 (very pressing). A similar procedure was used to prioritize uncertainties with scores of 1 (not critical) to 26 (very critical). Those with the highest scores identified the top six decisions/issues and uncertainties. The final activity of the October workshop linked the critical uncertainties with the six major actors when participants indicated whether the uncertainty did or did not occur and to what extent the uncertainty might impact each primary actor's ability to execute its plans (hinders ability on a scale of −1 to −5 or helps ability +1 to +5).

The year 2050 was chosen as the end point to balance the near and long-term changes facing the region. We named the effort "Salmon 2050" and established a website where stakeholders could review data and materials pre- and post-workshops (<http://www.alaska.edu/epscor/archive/phase-4/southcentral-test-case/salmon-2050/> (accessed on 11 May 2021)). Between the first and second workshops, the research team developed strawman (rough draft narratives without any social response described) scenarios (simplistic, draft narratives that do not include any social response), described below. The role of the strawman narratives was to (1) define some of the known unknowns (i.e., range of climate conditions expected), which were then validated by the stakeholders at the second workshop, and (2) ensure the suite of scenarios sufficiently covered all of the critical uncertainties.

The strawman narratives varied the amount of change in the critical uncertainties for each of the scenarios. For the first draft of the scenarios, only basic biophysical interaction was varied; social intervention was not included. Climate change projections were based on downscaled AR5 GCMs that perform best in Alaska. Data were obtained from Scenarios Network for Alaska and Arctic Planning (snap.uaf.edu) downscaled to the Kenai and summarized at the watershed scale. Lower bounds of climate change were represented by the RCP 4.5, upper was represented by RCP 8.0, and RCP 6.5 was chosen as the trend projection. The choice of RCPs 8.0 and 6.5 was driven by stakeholder feedback that RCPs with lower emission projections did not accurately reflect the amount of climate change that they had observed in the region. Population projections for the Kenai Peninsula Borough were taken from the U.S. Census and American Community Survey. The lower bounds represented maintenance of current population levels, while the upper bounds represented the highest forecast from the U.S. Census. Regional economic trends were obtained from the Kenai Peninsula Borough Economic Development Division. Upper and lower bounds were based on historical variability and stakeholder input. Fishing impact in the watershed was estimated using sport fishing and personal use data from the Alaska Department of Fish & Game with a linear rate to represent the upper bounds, while a decrease to 2001 levels was set as the lower bound, as defined by the stakeholders. Links to these sources can be found on the Salmon 2050 website cited above.

In the second workshop, stakeholders critiqued the scenarios, created fuller narratives to describe possible futures of the KRW and named and mapped the implications of each of the possible futures. Attendees were again assigned to groups to maximize diversity, where stakeholders discussed the past implications of each scenario to the economy, population, climate change, ocean conditions, sport fishing and personal use fishery, with the central issue being salmon abundance in the KRW. This followed with a discussion of the future implications using the same criteria. Stakeholders also addressed clarifications, compliments, concerns and changes for each scenario, ensuring that the scenarios were truly co-developed by the stakeholders. Although most of the editing was done during the

two workshops, multiple follow-up web conferences and phone calls ensured that (a) all stakeholders had an opportunity to submit comments and revisions, and (b) each iteration of the scenarios was validated by stakeholders (i.e., minor modifications to language were always validated by the scenarios).

Following this process, each group was assigned one scenario to discuss. Large maps of the KRW and markers of 10 to 15 different colors were placed at each table to be used to color code each agency's area of management decision and where impacts arising from the scenario might occur. Facilitators noted distinct events and triggers that might occur for each scenario identified by the stakeholders. When the time expired to complete the discussion of one of the scenarios, each group moved around the room to the other groups' tables and reviewed notes and maps created by each of the other groups. Maps and notes were added to, deleted, modified and, in cases where many notable events and dynamics were listed, they were sorted as high impact, medium impact or low impact by each group. Groups returned to the scenario with which they had begun the process and were asked to create a song, a story, a play or a poem to help name the future.

At the conclusion of the second workshop, stakeholders moved into agency groups and discussed how they would use the scenarios in their management processes, and what resources it would take to utilize them. Results from this discussion were recorded and used to develop a long-term stewardship plan for the scenarios.

3. Results

3.1. Stakeholder Workshops

The first workshop, held in October of 2015, included 15 stakeholders from the Kenai Peninsula Borough, Alaska Department of Fish and Game, U.S. Fish and Wildlife Service, the Kenaitze Nation (the indigenous group and rights holders on whose ancestral homeland the workshops were held), Alaska Department of Natural Resources, City of Kenai, City of Soldotna, Alaska Department of Environmental Conservation, Kenai River Fish Habitat Partnership, Cook Inletkeeper, Kenai Watershed Forum, U.S. National Park Service and the U.S. Forest Service. The second workshop, held in May of 2016, included the same 15 stakeholders as the first workshop, but also included an Alaska Board of Fish representative, based on feedback from the first workshop.

3.2. Scenario Narratives

Results from the first workshop yielded three top issues or decisions that stakeholders identified will have to be addressed by the year 2050. Those included:

1. Should we consider an uncertain climate future?
2. Should we make habitat conservation a priority?
3. Should we create a watershed plan that will pool resources, funding, and planning processes?

Additionally, stakeholders identified and ranked the critical uncertainties likely to face the region and influence salmon. The top (in order of ranked importance) six critical uncertainties identified were:

4. Will climate-induced stream temperature and hydrological regime changes harm Kenai salmon?
5. Will new economic pressures (land and energy development) affect protection of salmon resources?
6. Will fish availability decrease due to changing marine conditions?
7. Will population and land use changes in Southcentral Alaska increase demand for salmon?
8. Will participation in the personal use fishery continue to increase?
9. Will local population increases result in an increase in sport fishing?

The critical uncertainties were summarized in creating the scenarios as climate change, economic development, marine conditions, local demand, personal use and sport fishing (see Table 1 below).

Table 1. Relative treatment of each stakeholder-defined uncertainty included in each strawman scenario. In order to isolate management response to specific directional changes in the uncertainties, some critical uncertainties were not varied in every scenario (those in bold). Thus, each scenario focused on one primary uncertainty, but still considered relevant and plausible changes in the other uncertainties to ensure that they were internally logical.

Scenario	Climate Change	Economic Development	Marine Conditions	Local Demand	Personal Use	Sport Fishing
Scenario 1 (Retirement Paradise)	Moderate increases in stream temp	Increase in retirement housing and industry	Negligible change	Moderate increase	Decrease	Large increase
Scenario 2 (Industrial Boom)	Large increase in stream temperature, less water available	Increase in industrial development	Negligible change	Slight increase	Negligible change	Large decrease
Scenario 3 (More People More Fish)	Negligible change	Increase in residential housing	Negligible change	Large increase	Up a little, leveled off	Large increase
Scenario 4 (Ocean Crash)	Negligible change	Increase in industrial development	Colder ocean temps, less productive fishery	Slight decrease	Shut down	Large increase, new species focus
Scenario 5 (Fish for the Masses)	Large increase in stream temperature	Negligible change	More variable, hard to predict	Negligible changes	Significant increase	Negligible change

The SNA results [59] and a voting process identified the six key actors in the KRW as the Kenai Watershed Forum; Alaska Department of Natural Resources, Division of Parks; Kenai Peninsula Borough; Alaska Department of Fish & Game; U.S. Fish & Wildlife Service; and Alaska Board of Fish. Figure 2 is a radar chart developed using Microsoft Excel® to represent stakeholder-perceived adaptive capacity for the actors developed during the final exercise of the first workshop. The diagram shows the average scores that stakeholders individually gave each actor in their ability to respond to the critical uncertainties.

Using the information generated during the first workshop, strawman scenarios were developed in which levels of change in the critical uncertainties were varied to begin to explore the different ends of the uncertainty spectrum. Each scenario was developed by the research team to describe a plausible future, meaning that changes in uncertainties that would be expected to correlate with each other did so. Scenario one extended the current trends in the KRW which involved moderate increases in stream temperature but were not significant enough to impact fish returns, an increase in economic development related to more people retiring to the area and an accompanying increase in housing and retirement industries and services, no change in marine conditions, a moderate increase in local demand for fish (based on the population increase), a decrease in personal use fishing and a large increase in sport fishing by local residents. In scenario two, we assumed a large increase in climate-related environmental change impacting the number of fish returning to the system, an increase in industrial economic development (new liquefied natural gas port) to compensate for the economic loss caused by the downturn in the fishery, no change in marine conditions, a slight increase in local fishing demand, no change in the personal use fishery numbers and a large decrease in sport fishing because lower fish numbers would result in less motivation for non-residents to fish. Scenario three represented a future

involving a large influx of people moving to the area. Changes reflected no climate change or change in marine conditions, an increase in local population and residential housing resulting in a large increase in local demand for fish, a slight increase in the personal use fishery and a large increase in sport fishing.

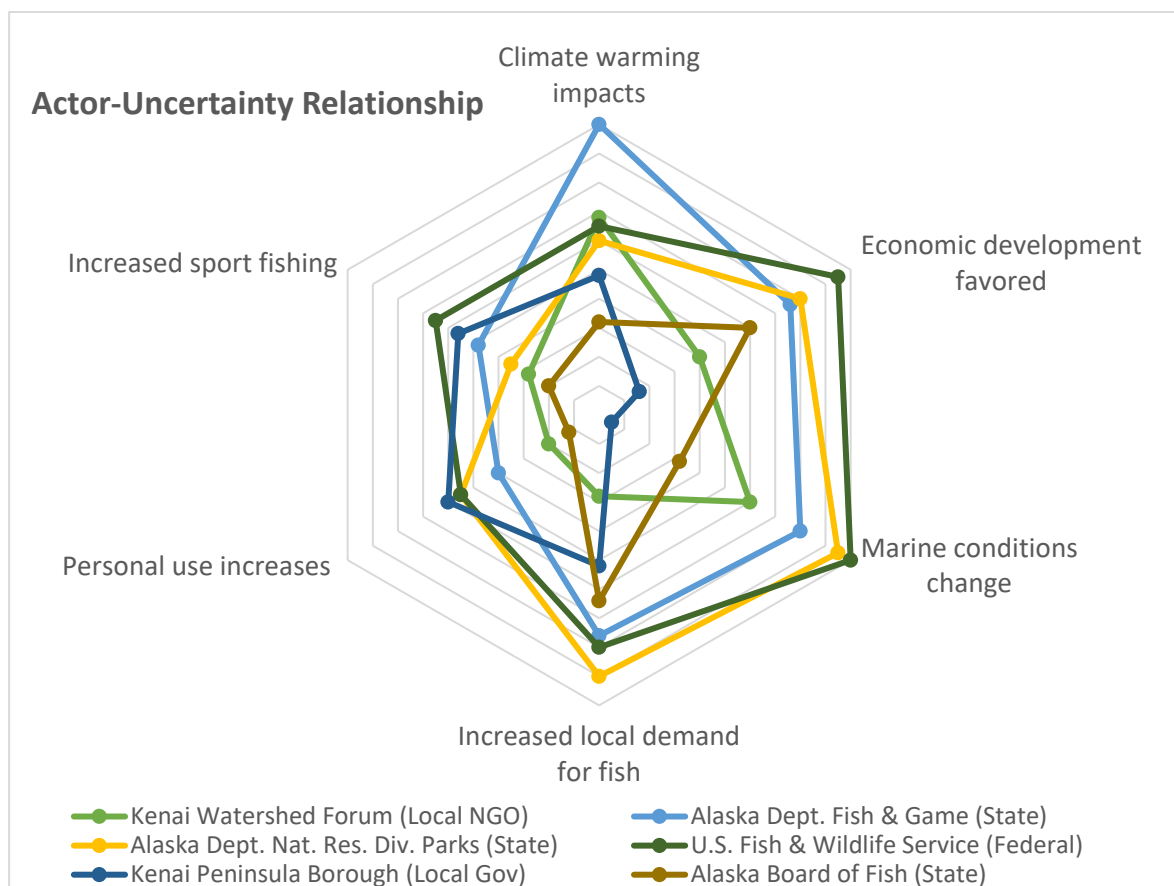


Figure 2. Actor–uncertainty relationships as defined by the stakeholders of the Kenai River Watershed, Alaska. Dots and lines on the outside of the hexagon indicate that the actor would be negatively impacted if that critical uncertainty (driver of change) was to occur as projected (i.e., climate warming will impact the Alaska Department of Fish & Game more than it will impact the Alaska Board of Fish). Dots and lines in the middle of the diagram either suggest that the impact is less negative or, in the case of the Kenai Peninsula Borough, perceived to have a positive impact. The Alaska Dept. of Fish & Game is responsible for directly managing salmon in state waters and the Alaska Board of Fish is responsible for conservation and allocation of the various salmon fisheries. The Kenai Watershed Forum is a local environmental non-governmental agency (NGO). Other actors in this diagram are primarily responsible for land management within the KRW.

Scenario four posited a future of increased industrial development in the KRW, with negligible climate change, colder ocean temperatures resulting in a less productive fishery, a slight decrease in local demand for fish, termination of the personal use fishery and a large increase in demand for sport fishing from non-residents with a focus on different species. Scenario five predicted a future with high stream temperatures, and marine conditions that were more variable and difficult to predict. Economic development in this scenario was not changed, nor was local demand for fishing and sport fishing. We assumed a significant increase in personal use fishing based on input from the stakeholders. Table 1 shows how uncertainty was explicitly considered across the five strawman scenarios.

Each scenario was treated as an opportunity to explore some aspect of an uncertainty, whether it was based on data or based on perceptions defined by the stakeholders (Figure 3).

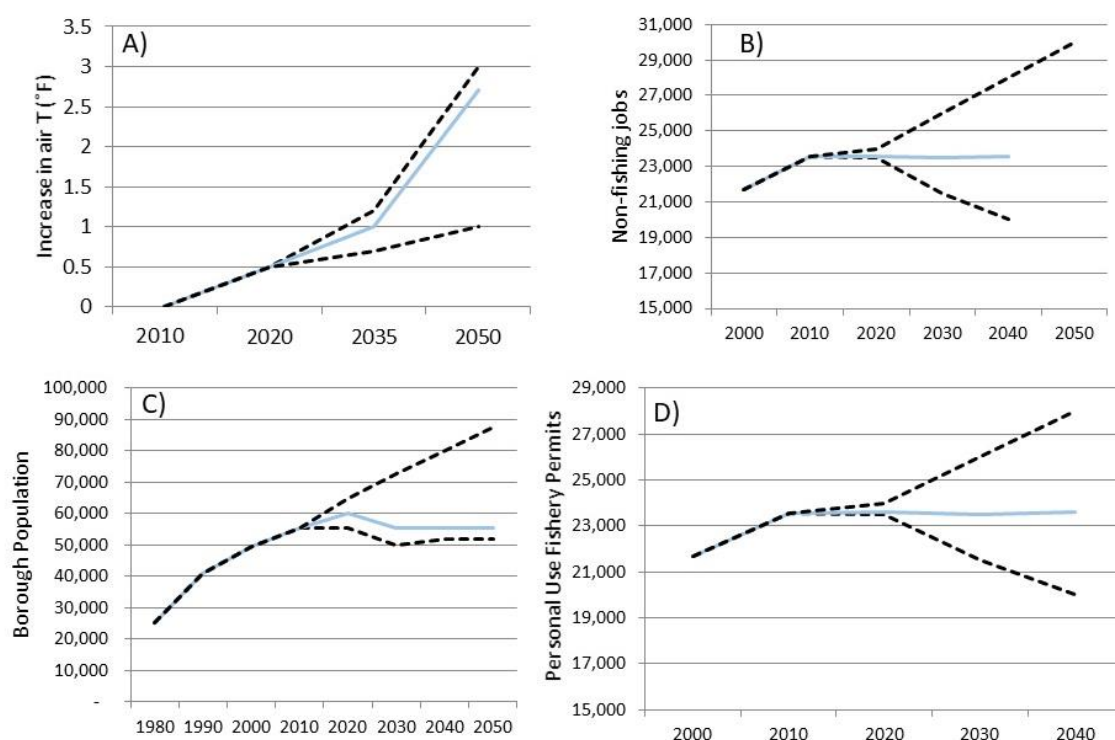


Figure 3. Example from Scenario 5 (shown in the blue lines, later named Fish for the Masses) of how uncertainty in projections were explored in each scenario. (A) Climate projections based on downscaled Global Circulation Models that perform best in Alaska (snap.uaf.edu); Representative Concentration Pathway (RCP) 6.5 was chosen for this particular scenario to be internally logical with the other uncertainties. (B) Number of jobs related to natural resource development, from the Kenai Peninsula Borough Economic Development Division. (C) Population projections for the Kenai Peninsula Borough taken from the U.S. Census and American Community Survey. (D) The personal use fishery is only open to Alaska residents and requires a permit taken from ADFG data.

The second workshop resulted in improved strawman scenarios, where stakeholders helped to define how uncertainties might interact, scenarios were named according to overall themes, and implications of each of the scenarios were defined both topically and spatially. Spatial implications were drawn on large format maps to show where impacts were most likely to be found for each scenario, and those impacts were assigned to the managing agencies using different colors. Figure 4 provides an example of this exercise.

After the second workshop, scenario narratives were revised to include the stakeholder comments, and some of the potential management actions were included in order to provide a realistic depiction of each scenario. Narratives included place names, management agencies and a depiction of how the future might unfold given the range in uncertainty. Full scenario narratives can be found on the Salmon 2050 website (<http://www.alaska.edu/epscor/archive/phase-4/southcentral-test-case/salmon-2050/workshop-summaries/>) (accessed on 11 May 2021)).

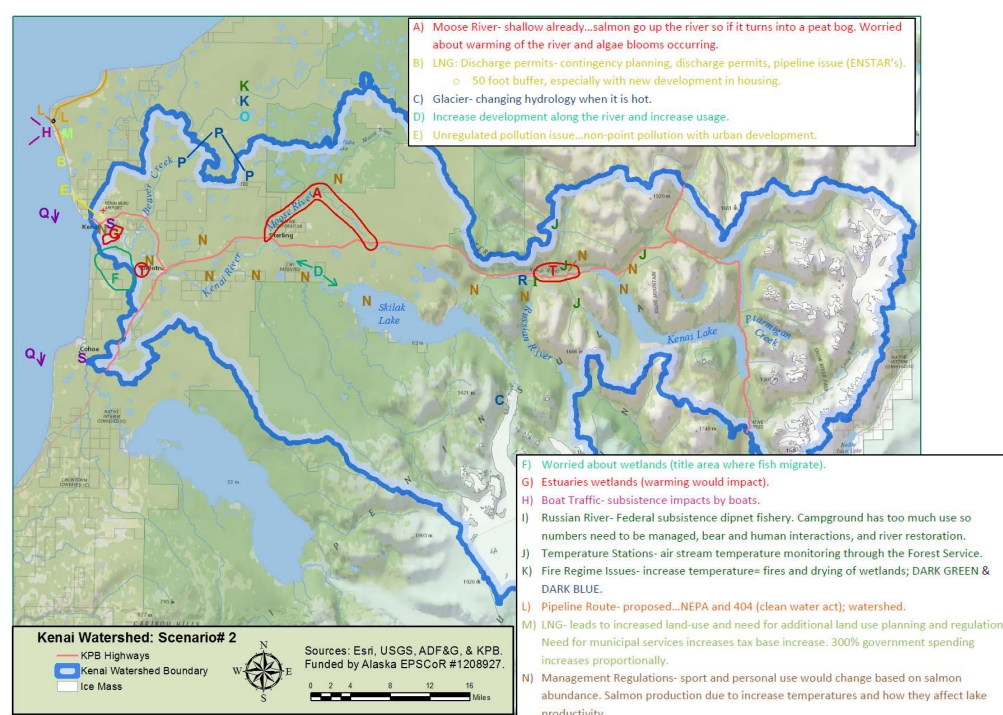


Figure 4. Example of mapping the implications of Scenario 2 (later named Industrial Boom). Letters correspond to notes taken on the nature of the impact, while different colors represent the agency(ies) who would be responsible for managing that impact.

4. Discussion

Our goal was to explore the interdependencies of current and future decisions along with the uncertainty of future environmental conditions and social contexts so that managers and stakeholders will have a better understanding of the food–energy–water social–ecological system of the KRW. Through scenario narratives, based on the best available data and iterative refinement by the stakeholders, we explored five alternative futures for the KRW (Table 1). This represents the first attempt to integrate the various social–ecological stressors facing a key food resource, salmon, on the Kenai into actionable opportunities for change.

Of the six critical uncertainties, three represent stressors well outside the KRW and are considered much harder to manage: climate change, economic competition and ocean conditions. The other three critical uncertainties represent factors that are either managed or manifested locally: local population increases, personal use fishery and sportfishing user days. This dichotomy between external and local uncertainties is important, as decisions are often misdirected when trying to sequentially solve these types of pressing issues. If, for example, all attention and effort by a management agency is focused on mitigating climate change, then they may not have the resources to mitigate against energy development or sportfishing pressures. This is why it was important to specifically address each critical uncertainty in every scenario so that managers can begin to think about these other stressors and how they might interact in a more integrated way.

In most cases, data were readily available to begin to quantify the rates of change associated with these critical uncertainties (Figure 3). However, ocean conditions represented a critical uncertainty that was conceptually and practically very hard to assess. Stakeholders were unsure of how to characterize the threat of changing marine conditions, primarily because of limited disciplinary expertise and lack of accessible data. Thus, we largely treated it in terms of its impact on the relative abundance of salmon in the future (i.e., increases or decreases in relative abundance before the fish enter freshwater systems). Given the uncertainty in the Pacific Decadal Oscillation and how it could impact ocean productivity,

this seemed to be a satisfactory way to treat this uncertainty, although substantial future work is certainly needed [60].

Previous research has shown that the KRW is a highly connected social–ecological system [20,55,59], so it is no surprise that many of the stakeholders had worked on similar issues raised in this scenario process. For example, no stakeholder or member of the research team was surprised that climate impacts to freshwater ecosystems was the top critical uncertainty. However, once some of the more obvious uncertainties were discussed, conversations about the less obvious uncertainties and the interactions among uncertainties created some very meaningful dialog. For example, exploring the changes expected in the sport fishery, commercial fishery and personal use fishery helped to highlight the gaps in stakeholder understanding of who makes decisions about fisheries management, how to engage those decision-makers and what opportunities there might be in the future to coordinate efforts based on other changing conditions. Given that the personal use fishery is open to all Alaska residents and only requires an additional permit, the uncertainty associated with the personal use fishery was the most difficult to quantify based on the lack of knowledge of how to limit access in a fair and equitable way.

Additionally, there was rich discussion around the advantages and disadvantages between sport fishing by residents and non-residents, and whether local population increases would translate to increased sport fishing. Stakeholders understood the impact of one pathway (residents of the KRW area increase sport fishing pressure, as in the Retirement Paradise scenario) versus another (sport fishing is driven by people outside the watershed, as in the Fishing Capital scenario).

Exploring comprehensive scenarios, those narratives that explicitly consider different levels of change in all critical uncertainties provide managers the opportunity to have meaningful dialog about the future. Given that stakeholders identified watershed management as one of the top three critical decisions that they will have to face in the future, it is clear that they were already considering integrated management as a solution. However, it was also clear that many of the stakeholders did not know who to involve and were often surprised when they learned about various agency jurisdictions. A participant highlighted this gap by saying, “I enjoyed working across agency borders and ranks.” Prior to the stakeholder workshops, only half of the stakeholders had previously worked with the borough mayor, and only one had previously worked with the Alaska Board of Fisheries, both major decision-makers in the watershed. This was perhaps one of the most important outcomes from these scenario exercises, and shortly after the scenario workshops were completed, an “all hands–all lands” group began, led by one of the Salmon 2050 stakeholders.

One of the primary advantages of scenario analysis is its ability to challenge conventional beliefs and facilitate a new understanding of system dynamics [38,56]. Stakeholder feedback indicated strong approval of both the process and the level of engagement by all relevant stakeholders. Several stakeholders made positive comments about the collaborative nature of the process and felt that the process better prepared them for the future. One comment stated, “The process gave me a broad understanding of potential impacts.” Another participant said, “The resulting data will be telling of many perspectives.” Across the board, stakeholders stated the scenario process was relevant and important to their job and the decisions that they make. As one participant put it, “this has changed the way I think about planning, it is a total paradigm shift for me.” Another result of the workshop came from the Kenai Peninsula Borough, who updated their master plan to include more future-resilient language about permitting.

The application of scenario analysis using facilitated stakeholder engagement provides a form of co-production of knowledge for sustainability planning. One participant noted that the process “seems to be great for use with the general public.” The set of critical uncertainties and the suite of scenarios integrate the perspectives and understanding of stakeholders with the modeling and data outputs of researchers to provide a framing of plausible changes and possible responses in the watershed. However, this also means that identified scenarios can be limited in scope, depending on stakeholder willingness

to think broadly about stressors and actions. Regardless, geospatial analysis, landscape and hydrologic process modeling and scenario analysis executed iteratively and in concert using a SES framework [26] provide a science of integration in support of food, energy and water systems issues at watershed scales. This directly addresses the call for scenario analyses to support contentious planning and policy issues, such as the “Pacific Salmon Wars”, by considering a wide array of assumptions across a diverse set of scenarios [61]. Similar narrative scenarios have been used recently to explore fishery conflicts in the Northeast Atlantic, the East China Sea, the Coast of West Africa and in the Arctic [62].

An emerging global literature on alternative futures is applied to diverse issues (e.g., energy, aquaculture and land use) and in many parts of the world (e.g., Australia, Colombia, Europe) but is predominantly composed of modeling-based scenarios, at very broad geographic scales, which are not the result of co-production efforts with stakeholder groups [63–65]. Our work fills a gap in the global literature on scenarios planning by demonstrating Geodesign as an alternative futures approach at local or watershed scales through engagement with stakeholders.

5. Conclusions

The future of salmon, a key food resource for many in Alaska, in the Kenai is uncertain [53]. However, using scenario analysis, decision-makers in the KRW identified important issues, decisions and critical uncertainties facing the future of salmon so that some of the uncertainty can be addressed. Scenarios were developed to explore different levels of change in the critical uncertainties, which were validated by stakeholders through their knowledge of the implications and management options. The final scenarios provide a narrative describing and quantifying the impact of plausible futures for the KRW. The modified scenario process [56,58] exemplified in the KRW demonstrates the strength of stakeholder engagement in SES [20] as an example of the co-production of watershed knowledge.

Integrated analysis of the food, energy and water resources was a central theme thanks to a diverse stakeholder group that saw value in taking an integrated approach to environmental management. Through facilitation and clear communication, stakeholders considered interactions among critical uncertainties, identified important decision-makers with whom they had not previously coordinated and described possible management conflicts, even though none had experience in this type of exercise before. Our research further confirms that scenario development can be a powerful tool for stakeholders to work collaboratively to anticipate futures [22] and the impacts of their decisions in food, energy and water systems.

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