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ORIGINAL ARTICLE

A science of integration: frameworks, processes, and products in a place-based, integrative study

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Abstract Integrative research is increasingly a priority within the scientific community and is a central goal for the evolving field of sustainability science. While it is conceptually attractive, its successful implementation has been challenging and recent work suggests that the move towards interdisciplinarity and transdisciplinarity in sustainability science is being only partially realized. To address this from the perspective of social-ecological systems (SES) research, we examine the process of conducting a science of integration within the Southcentral Alaska Test Case (SCTC) of Alaska-EPSCoR as a test-bed for this approach. The SCTC is part of a large, 5 year, interdisciplinary study investigating changing environments and adaptations to those changes in Alaska. In this paper, we review progress toward a science of integration and present our efforts to confront the practical issues of applying proposed integration frameworks. We: (1) define our integration framework; (2) describe the collaborative processes, including the co-development of science through stakeholder engagement and partnerships; and (3) illustrate potential products of integrative, social-ecological systems research. The approaches we use can also be applied outside of this particular framework. We highlight challenges and propose improvements for integration in sustainability science by addressing the need for common frameworks and improved contextual understanding. These insights may be useful for capacity-building for interdisciplinary projects that address complex real-world social and environmental problems.

Keywords Collaboration · Co-production of knowledge · Integrative research · Science of integration · Social-ecological systems · Sustainability science · Transdisciplinary science

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Introduction

The need to develop a new way of conducting science to enable effective, results-based research that addresses complex problems and societal needs is increasingly recognized (Castán Broto et al. 2009; Jahn et al. 2012; Holm et al. 2013). In particular, sustainability science touches upon a range of human, biophysical, and environmental phenomena that are broader than disciplinary approaches and reflect the real-world messiness often present in coupled social-ecological systems (SES) (Liu et al. 2007; Alessa et al. 2009). Despite numerous discussions of the importance of integration in landscape and sustainability research (Jakobsen et al. 2004; Morse et al. 2007; Tress et al. 2007; Bergmann et al. 2012; Lang et al. 2012; Brandt et al. 2013), there remain relatively poorly defined approaches (Schoolman et al. 2012; Brandt et al. 2013). We suggest that a primarily rhetoric-based approach, rather than a systematic one, as well as the uncertainty in how to apply frameworks have slowed the development of a science of integration—where the science of integration refers to team-based interdisciplinary research that uses SES concepts, and partnerships with stakeholders, to co-produce knowledge for solving real-world problems.

The goal of this paper is to describe an approach that improves integration in sustainability science and provides insight into contextual factors (Lang et al. 2012) for practical applications (Jakobsen et al. 2004). To this end, we draw on a large test-bed project, the Southcentral Test Case (SCTC), and present our integrative research framework, processes, and products. We begin by reviewing the literature that addresses challenges and progress in the science. We then build on a diverse set of integration tools to apply and enrich components of a broad-based integration framework utilized in the SCTC project (Bergmann et al. 2012; Bammer 2013). Throughout our discussion, we apply 'integration to encompass transdisciplinary and interdisciplinary research applied to complex real-world social and environmental problems (Winder 2003; Tress et al. 2005b; Bammer 2013). To conclude, we assess the integration framework used for SCTC using the Bammer (2013) five-question diagnostic (Table 1). Our approach may be useful for projects setting foundations for integration and accommodating unknown outcomes, and for facing the general challenges of reorienting integrative research plans as a project proceeds. With this framework, we hope to improve the capacity for integrative research not only within our SES project, and our community partners, but also the broader scientific community.

Background

Integration and sustainability research: challenges and progress

As a core principle of sustainability work, integration operationalizes insights by crossing disciplinary boundaries (Hirsch Hadorn et al. 2006; Jerneck et al. 2011; Holm et al. 2013). This process can be challenging to define and implement—integrative researchers encounter challenges with a multiplicity of definitions and methods, a lack of empirical examples, and the nature of team-based integrative science. Important factors for the success of integrative studies include: minimizing interpersonal and organizational barriers, reducing time demands, and overcoming the compartmentalization of academic disciplines (Tress et al. 2007; Bergmann et al. 2012). Some strategies for enhancing success in integrative work include: integration implementation plans, small projects, more time for finding common ground, regular meetings, and conservative planning of deliverables (Tress et al. 2007; Bergmann et al. 2012; Bammer 2013). However, such ideal and prescribed conditions are often difficult to implement in practice.

Alaska EPSCoR Southcentral test case: study in integrative research

The Experimental Program to Stimulate Competitive Research (EPSCoR), a National Science Foundation supported the initiative to boost research capacity in less competitive US states, supports a 5-year Alaskan funding program titled Alaska Adapting to Changing Environments

Table 1 Integration framework questions and test case approach (based on Bammer 2013)

Integration framework questions	Approach for test case application	Results from test case application
What is the integration aiming to achieve and who is intended to benefit?	Social-ecological systems thinking (Liu et al. 2007; Alessa et al. 2009) Soft systems methodology (Checkland and Scholes 1999; Checkland and Poulter 2010)	Comprehensive understanding of the simultaneous social, physical, economic, and biological components to serve collective decision-making through co-management
Which knowledge is synthesized, and aspects of policy and practice targeted?	Public participation and organizational management (Schlossberg and Shuford 2005; Bryson 2004; Schilling and Kluge 2009; Brandt et al. 2013)	Disciplinary scientists in different components; integrative scientists in a Coordination, Integration, Synthesis group; community residents and stakeholders through scenario-based engagement
How is the integration being undertaken?	'Means of integration' (Pohl and Hirsch Hadorn 2008a, b; Altaweel et al. 2010a, b)	Mutual understanding, theoretical concepts, shared models, and products, especially iterative scenario-based stakeholder engagement
What is the context for integration?	Social-ecological systems (Tress et al. 2001; Newell et al. 2005; Alessa et al. 2009; Angelstam et al. 2013	Time/logistics, past experience, cohesion, career factors, relevance, funding
What are the outcomes of the integrative approach	The integration process and co-developed knowledge (Tress et al. 2005a; Pohl 2010, 2011; Alessa et al. 2015)	Lessons and directions for adaptive capacity that emerge from the iterative stakeholder engagement process

(ACE) which was conceived and designed by two of the authors. Alaska ACE is an interdisciplinary project that seeks to quantify the factors contributing to the adaptive capacity of human communities to effectively respond to environmental and economic change. The SCTC is one of three test cases within Alaska EPSCoR and the focus of this paper. The integrative framework for SCTC employs the landscape as a place in which the dynamics of hydrological, landscape, and aquatic ecosystem changes are expressed and manifested for local communities. Place is a "central, organizing principle" (Cheng et al. 2003; Epstein et al. 2013) that builds on field research to support systems modeling, geospatial analysis, and visualization approaches for integration (Manson and O'Sullivan 2006; Wu 2013).

The SCTC employs an array of methods, linked to address landscape/hydrological changes and societal connections in the Kenai River watershed. The watershed is located on the Kenai Peninsula, approximately 200 km south of Anchorage. The area is subject to multiple drivers of change, including global and regional temperature and precipitation changes (Wiles et al. 1998; McGuire et al. 2006), salmon population variations (Mantua et al. 1997), a fluctuating tourism industry (Kenai Peninsula Economic Development District 2015), resource extraction infrastructure, recreational pressure from outside the region (Degernes 2003), shrinking wetlands and successional change (Klein et al. 2005; Dial et al. 2007), spruce beetle outbreaks (Berg et al. 2006), forest fire (Lynch et al. 2002), increasing population (United States Census Bureau 2010) and urbanization. These multiple interacting factors form the basis of a 'messy' social-ecological system (Alessa et al. 2009) and necessitate response and adaptation by watershed communities. The test case goals are to identify factors contributing to the ability of Kenai River communities to respond to hydrological, landscape and associated social changes on the Kenai Peninsula. Decision support tools are included in the intended research outputs. Evaluating multiple drivers of change and understanding impacts on social-ecological systems within the test case requires an integrated approach consistent with the core principles of sustainability science (Kates et al. 2000).

Integration framework, processes, and products for the Southcentral test case

Integration framework

Our overarching aim in this article is to contribute to a science of integration by presenting our framework, processes, and products, in the context of the SCTC (Bergmann et al. 2012; Bammer 2013). Since we are developing partnerships that will involve local, non-academic participants in project decision-making roles our approach needs to provide a reflexive, place-based assessment to inform decision-making processes and contribute to community capacity to deal with change.

A SES systems framework for integration

Systems thinking, particularly a SES approach, is used as a foundation for the integration framework (Fig. 1). This is based broadly on general systems theory (von Bertalanffy 1968), that a system as a whole is understood by its composite parts and the dynamic interrelationships between these parts, and more specifically that a SES is an integrated system of humans within the environment, including the linkages, flows, and feedbacks between human behaviors/actions and ecosystem processes (Alessa et al. 2009). We developed a conceptual social-ecological systems model (Fig. 1) to understand the complexity in this test case. Our conceptual model highlights three related SES dynamics: changing environments of the SES; the societal implications of this change, and; adaptive capacity of local communities to respond to the change. To summarize, the objective of the SCTC is to generate co-produced knowledge among researchers, practitioners, and stakeholders for identifying adaptive responses by local communities to landscape and hydrological change in the Kenai River Watershed using SES thinking and applied science (Fig. 1).

Integration processes

To effectively integrate knowledge and data in the SCTC, we need to understand the collaborative processes connecting system components. In the SCTC, we identify collaboration and the co-development of knowledge as recursive and strongly dependent on constructive interaction between researchers, practitioners, decision-makers, and community groups (Argyris and Schön 1978; Folke et al. 2009)—this recursive or iterative nature is also referred to as learning loops. In the context of the SCTC, we identify iterative learning and adaptation in the research process as occurring at three levels: system, target, and transformational knowledge (after Pohl and Hirsch Hadorn 2008a, b; Hirsch Hadorn et al. 2006; Bergmann et al. 2012) which map to the three SES dynamics for the SCTC—change, societal implications, and response and adaptation (Fig. 2).

1. System knowledge querying the empirical aspects of the SES including: fresh water, salmon, landscape change, perceptions of change and socio-economic data on the Kenai Peninsula.
2. Target knowledge addressing current technologies, management, and institutions, including: Kenai Peninsula water use and treatment technologies, institutional

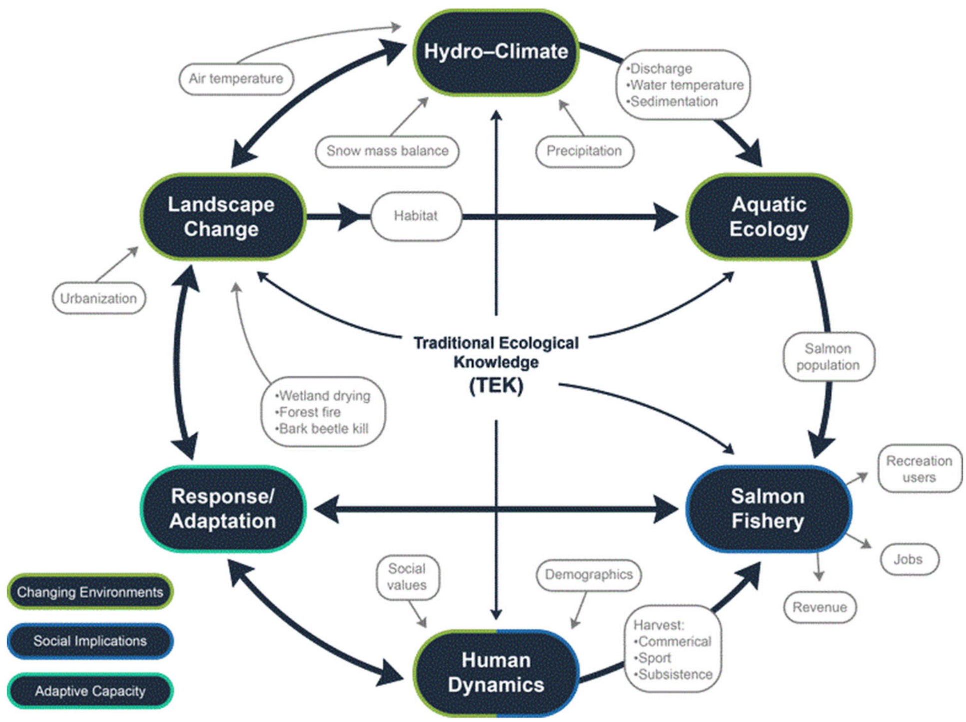

Fig. 1 Social-ecological systems conceptual model of the Southcentral testcase

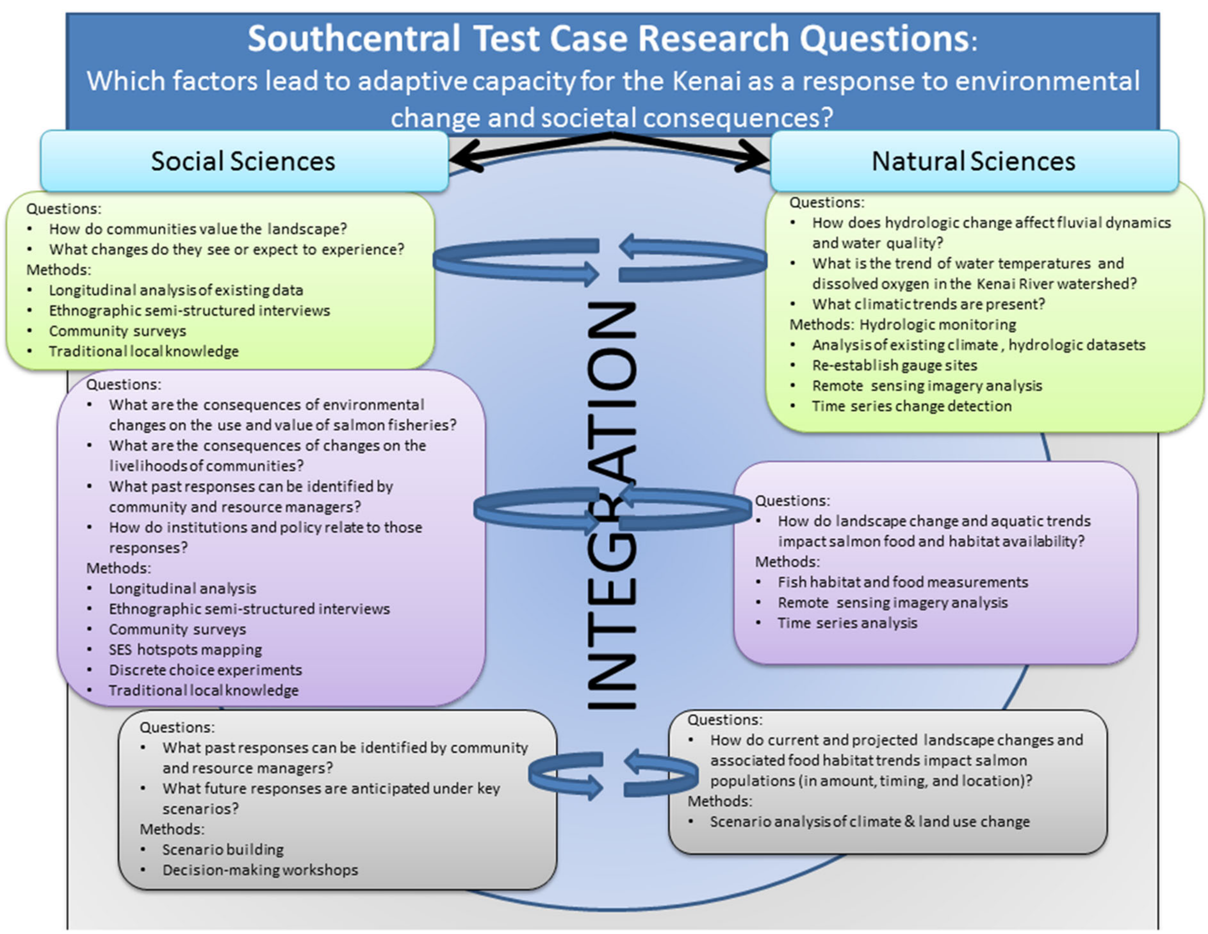

Fig. 2 Diagram showing the iteration between social sicence questions and methods, and natural or ecological science questions and methods for the Southcentral test case, Alaska

policies, connections between land/water and local livelihoods, drivers of change, and policy development.

3. Transformational knowledge Governance and institutional structure, including: interpreting gaps between perceptions of environmental and social dynamics and measured changes in the context of Kenai Peninsula communities and institutions, through the evaluation of adaptive capacity, and a structured scenarios/alternative futures process.

During the process of integrative science, adaptive learning occurs iteratively by individuals and groups within the research team. From an organizational perspective this learning can be viewed as a consequence of the roles that individuals fill as agent types within informal networks (Alessa and Kliskey 2012), also important are the dynamics between agents—for example the level of trust between researchers, and stakeholders. Trust, in this case, becomes a critical, and tangible, determinant of the collective cohesion of an interdisciplinary science team.

Building system knowledge requires social and natural scientists to develop an understanding of social-ecological system dynamics, by collectively evaluating findings from empirical analyses (Fig. 2). Target knowledge considers which values and norms are used to frame the goals of the integrative approach in the SCTC. For transformational knowledge, evaluating the overall social-ecological system processes, employing recursive integration of research components to distill complex systems and clarifying elements essential to system function strongly interconnects the social and environmental components to direct the SCTC research questions and SES methods toward the complex salmon fisheries problems in the Kenai River. These questions concerning landscape and hydrological change, societal implications of those changes, and adaptive responses to that change, along with interdisciplinary and integrative methods are presented to stakeholders for evaluation, contributing to improved policy decisions. Ultimately, the interdisciplinary team identifies how realistic the application of knowledge is on the ground.

System, target, and transformational knowledge in the Southcentral test case

Each component of the SCTC involves integration of knowledge both within a component, and especially between components. Each of these involve integration operating at the three levels of system, target, and transformational knowledge.

Hydro-Climate: examines the consequences of climate-induced changes in air temperature and precipitation, as well as landscape changes on the Kenai River watershed. The primary consequences that are considered are changes in river discharge, water temperature, and sediment discharge. We utilize existing United States Geological Survey and Kenai Watershed Forum hydrological monitoring on the main stem of the Kenai River and we reactivated hydrological monitoring on three tributaries—Beaver Creek, Russian River, and Ptarmigan Creek.

Landscape change Examines the consequences of anthropogenic and natural landscape disturbance in the Kenai River watershed on the hydrological signature and on aquatic habitat. Anthropogenic disturbance includes the human footprint on Kenai River watershed resulting from urban development, road construction, and resource exploration and extraction. Natural disturbances include spruce bark beetle kill, forest fire, and wetland drying and succession.

Aquatic ecology Examines the consequences of hydrological change and landscape change on aquatic habitat in the Kenai River watershed, particularly for sockeye and Chinook salmon rearing. Although the focus is on salmon rearing habitat, this is considered within the context of Kenai River salmon populations, socio-economic factors, and the potential effects for salmon fisheries.

Salmon fisheries Examines the consequences of changes in salmon habitat on the sockeye and Chinook fisheries in the Kenai River, including subsistence, sport, and commercial fisheries. Consideration is given to monetary consequences (harvest size, revenue, jobs, user numbers) and non-monetary consequences (social values). Although the focus is on salmon habitat this is considered within the context of endogenous factors, such as the local and state oil and gas sector, and exogenous factors, such as the global nature of commercial fisheries.

Human dynamics Examines the consequences and effects of hydrological change and landscape change, to communities in the Kenai River watershed, and subsequent effects on salmon habitat, salmon populations, and salmon fisheries. Social factors considered include social values, perceptions, human demography, and Kenaitze traditional knowledge, with a view to understanding community response and adaptive capacity.

These represent a transition from primarily system knowledge and to a lesser extent target knowledge (Hydro–Climate change, Landscape change, and Aquatic ecology), to increasing target knowledge (Salmon fisheries), to primarily transformational knowledge (Human dynamics).

Community engagement

A key aspect that informs and enriches integrative research (Wickson et al. 2006) is connecting with people and institutions beyond the project researchers. We view our community participants as co-developers of the science, so their knowledge is essential, and it is they who can alter the applicability of the test case outcomes (comparable to Schlossberg and Shuford 2005, Sieber 2006). Reviews of integrative projects have identified community interaction occurring in transdisciplinary research, including problem structuring and implementation. While this varies by project type, we submit that building upon community participation supports research implementation and may reduce participant bias in social surveys, interviews, or focus groups that are used to elicit perceptions and attitudes of stakeholders and other community members. Participant bias occurs when participants act in ways they believe corresponds to what the researcher is looking for (e.g., French and Laver 2009). Thus, the participant may not be acting in a natural or typical way. Reducing participant bias can be particularly important when research involves politically charged issues (Fischer 2000 in Siebenhuner 2004), such as salmon fisheries in Alaska. In the context of the SCTC, participant bias is potentially reduced by our community engagement efforts because careful facilitation of the participants and the engagement process occurs using a professional facilitator, a neutral position with respect to possible management goals and outcomes is stressed, and the use of project outcomes by the local community is emphasized. The co-development of science must occur at the initiation of a project and must balance the needs of communities on the ground and the advancement of science.

In SCTC we engage with communities at different levels or 'intensity of involvement' (Brandt et al. 2013) through introductions, reporting, asking for input and feedback, and active partnerships (comparable to Bryson 2004). Some connections involve feedback, where we communicate findings and receive suggestions, while other relationships may be unidirectional, such as for reporting or information gathering. We connect with various types of community members in "different sectors (and) levels of governance" (Angelstam et al. 2013), including elected officials, agencies, universities, educators, research groups, conservation organizations, community groups, local businesses, and individuals (comparable to Schlossberg and Shuford 2005). We have strength in our formal agreements with decision-making, research, and education groups, including a network of universities, colleges, and local research and education programs. Local context informs our social science research methods, shaping how our connections will develop and evolve in the next project phases. Strong ties to community groups and various consumptive and non-consumptive resource users, as well as connections with agencies, local government, and the general public invest stakeholders with a sense of ownership and invest them in the science such that they are willing to implement and manage adaptive actions themselves.

Integration products

Integration products include co-produced knowledge, models, and tools that are developed through collaborative approaches such as common group learning, deliberation among experts, and integration by a subgroup or individual (Pohl and Hirsch Hadorn 2008a, b). As we investigate adaptive capacity in a place-based study, our integration involves (1) collaborative engagement and learning, (2) shared models and (3) decision support tools—all interrelated and developed through partnerships.

Co-produced knowledge

In practice, co-produced knowledge takes place through in-person meetings, presentations, workshops, and teleconferences as well as long-standing informal relationships with trusted individuals. There is also substantial individual work towards broadening our understanding, such as reviewing new literature or methods and approaches from other disciplines. Integration through mutual understanding is particularly dependent on community interviews and surveys, in which capacity building is as important an outcome as the data collection. Understanding also links strongly to researcher brainstorming meetings, which promote exploration of innovative methods for integration while bringing all team members up-to-speed with interdisciplinary approaches in sustainability science. A critical avenue for mutual understanding are the stakeholder workshops used for presenting test case scenarios of future change and eliciting stakeholder response to scenarios (Voinov and Bousquet 2010). Alessa and Kliskey (2012) demonstrated that stakeholder networks consist of types of agents, defined by their social roles, which affect community response to environmental change. In the SCTC we incorporate stakeholder relationships to each other relating to the issues in our study area. In addition, Elzinga (2008) has called for integrative research to incorporate power connections to participation and resource access. Incorporation of power, values, and resources could be useful for our adaptive capacity component.

The stakeholder workshops generate the information needed to define the scenarios and parameterize the impact assessments, targeting multiple levels of decision makers and non-governmental organizations. The workshops encourage co-production of knowledge with exercises that encourage small-group work as well as workshop-wide voting on key decisions, uncertainties and implications. Stakeholders are identified through a variety of mechanisms. For the decisions and uncertainties workshop, stakeholders were derived from a social network analysis (SNA) generated by interviewing over 40 decision makers on the Kenai Peninsula. Results from the SNA were presented to the workshop participants to facilitate co-production of knowledge (Krupa 2016). The co-production of knowledge generated during the scenario workshops is evaluated by performing another SNA after the scenarios and alternative futures have been finalized and presented to the public.

Co-produced models and tools

Models and tools for integration involve the use and evolution of geospatial analyses, integrated system modeling, and scenario development and simulation as a sequential process guided by the conceptual model (Fig. 1). The biophysical and social data will be integrated through a series of complementary activities (Fig. 2). For example, the SES hotspots mapping is used to depict landscape social values of residents so that these can be overlaid with commensurate measures of the physical landscape to produce social-ecological landscapes (Alessa et al. 2008a). Other system modeling efforts include data mining (Altaweel et al. 2010a), agent-based models (Altaweel et al. 2010b; Bone et al. 2011), and genetic algorithms (Manson 2005). In the SCTC a temporal analysis in SES landscapes is being prototyped using 2001 and 2014 landscape values surveys which in turn support the integrative modeling. Other geospatial analyses include physical, biological, hydrological, and cultural landscapes change detection. Integrated system modeling incorporates a suite of coupled models including landscape, hydrological, aquatic system, and agent-based models. The modeling products in turn support the virtualization of social-ecological system landscapes for developing scenarios of projected change (i.e., alternative futures (Steinitz et al. 2003)), to be represented and visualized as a forum for stakeholder engagement. Additionally, scenario narratives serve as an integration platform, as they synthesize the co-produced transdisciplinary science to qualitatively describe the future condition. The development of *SalmonSim*, a virtualized world of the coupled landscape-hydrological-aquatic-stakeholder system, lies at the core of this stakeholder engagement effort (Anderson et al. 2016).

An additional and broader level integration product is the representation of the difference between instrumented measures of hydrological and landscape change, and perceived change in these phenomena by stakeholders—referred to as *P* (perceived) delta *I* (instrumented) or $P\Delta I$. $P\Delta I$ provides a qualitative measure of the correspondence between what people think is happening (*P*) and a critical and quantitative measure of change based on instrumentation. A high degree of correspondence represents individuals or communities that may be more aware of environmental change and may be better positioned to enact appropriate responses (Alessa et al. 2010). The $P\Delta I$ integration can be considered a meta-level analysis since it is has been developed by the coordination, integration and synthesis (CIS) group, toward a higher order integration effort in Alaska EPSCoR ACE and cuts across all three test cases, not just SCTC.

Another SCTC integration product considers the importance of utilizing paleoecological analysis to measure change in past salmon abundance and relate this to the archeological record and Indigenous (Kenaitze Indian) oral history. Our analysis shows a prolonged reduction or elimination of salmon runs to Upper Russian Lake, one of the Kenai River's primary sockeye salmon nursery lakes, from approximately 100BC to 500AD. This period coincided with the decline of the Riverine Kachemak culture in the archeological record and, subsequently, a shift to the Sedentary Dena'ina who utilized coho salmon rather than sockeye.

A final integration product is the application of adaptive capacity assessments using the Arctic Water Resources Vulnerability Index (AWRVI; Alessa et al. 2008b). AWRVI, one of the few SES specific adaptive capacity indices in use, also provides meta-level analyses for the CIS group since the assessments can be undertaken across all three test cases. These products of integration are undertaken in our project by the majority of the test case team, in collaboration with local Kenai Peninsula experts and stakeholders.

The integration framework, processes, and products of the SCTC provide an example and set of lessons for other projects and researchers. From our experience with this process, the emphasis on co-development of knowledge, the identification and quantification of interconnections between stakeholders, and the use of an integrative systems-based framework to synthesize knowledge is essential.

Assessing the SCTC integrative framework

For the SCTC we apply the five-question diagnostic (Bammer 2013) as a standard integration assessment of the extent to which the framework developed for the SCTC adequately achieves integration (Table 1).

Table 2 Disciplinary and interdisciplinary expertise of the Alaska Southcentral Testcase

Physical science	Social science	Biological science	Integrative science
Climatology	Archeology	Aquatic ecology (×2)	Complex systems
Hydrology (×2)	Behavioral geography	Salmon biology	Computer modeling
Paleoecology	Cultural anthropology (×2)		Geospatial analysis
	Demography		Landscape ecology (×2)
	Fisheries and regional economics (×3)		Scenarios/futures
	Sociology		Visualization and virtualization (×2)

For what and for whom?

The objective of the SCTC integration and the intended beneficiaries (Question 1, Table 1) are ("Integration framework"): "an approach agreed upon by researchers, practitioners, and stakeholders for identifying adaptive response by local communities to landscape and hydrological change in the Kenai River Watershed using transdisciplinary guidelines." The emphasis on co-development of knowledge in this objective contributes to the importance placed on collaborative processes in SCTC including the central role of iterative scenario-based stakeholder engagement.

Which knowledge?

The disciplinary and stakeholder knowledge that is synthesized (Question 2, Table 1) in the SCTC is guided by the SES conceptual framework (Fig. 1) and principally involves: hydro-climatological; landscape change; aquatic ecology; socio-economics of fisheries; human dynamics, values, and perceptions, and; adaptive capacity of stakeholders. These knowledge components provide a focus on addressing the research goal of determining the interactive effects of landscape change and hydrologic change on aquatic ecology of salmon and the ecosystem services supported by salmon fisheries. An explicit aspect in the understanding of human dynamics is documenting and comparing the core values of multiple stakeholders, including those of the different salmon fisheries interest groups—commercial fishing, recreational sport fishing, guided sport fishing, Alaskan residential fishing, Kenaitze Indian subsistence fishing, and fishery managers. The SCTC team comprises 24 disciplinary and interdisciplinary areas of expertise spanning biological, social, physical, and systems science (Table 2). Since the integration framework (Fig. 1) is an open system, boundary setting is necessary to constrain the project by considering the aquatic system, but not extending this to the important marine component of the salmon lifecycle.

How to integrate?

Disciplinary and stakeholder knowledge is integrated (Question 3, Table 1) using mutual understanding, models, and products (as outlined in "Integration products"). Critical to this is the development and use of iterative scenario-based, stakeholder engagement that applies the conceptual model (Fig. 1) using geospatial analysis, coupled modeling, virtualization and visualization, and consideration of alternative future scenarios. The 5-year SCTC is entering the 5th, and final, year with exploratory interviews, focus groups, and surveys completed, coupled modeling has been developed and validated, social network data and analysis, visualization tools have been established, two of four stakeholder workshops have been held, and alternative future scenarios are in development ahead of the 3rd and 4th stakeholder workshops. At the 2nd stakeholder workshop in May 2016 one local resource manager commented "I had not thought about future scenarios for the Kenai before or how useful they can be, but I now realize we need to change how we manage".

What is the context?

The overall context of the problem (Question 4, Table 1) for SCTC is established through the SES conceptual view (Fig. 1) including the six sub-components that are examined, the dynamics and feedbacks among these components, and the emergence of adaptive capacity as a feature of system behavior. The context of the SCTC is dominated by the importance of salmon in the Kenai River Watershed—to ecosystem functioning, in providing core ecosystem services, as an economic driver, and pivotal to the core values of residents. As anadromous species salmon provide the dominant biomass in the Kenai watershed ecosystem and essentially establishes the trophic structure for the aquatic system (Rinella et al. 2011). Salmon also provide a myriad of ecosystem services to the watershed, region, and state, not least of which are the economic benefits arising from the commercial fisheries, resident fishery, sport fisheries, and subsistence fishery. Salmon shape the livelihoods, culture, and existence of long-term residents in the Kenai River watershed, not least for the indigenous Kenaitze Indian. Because of the multiple fisheries and multiple species (pink, red/Sockeye, silver/Coho, king/Chinook, Chum/dog) there is a complex set of institutional actors and arrangements governing the management of each fishery—local, state, and federal agencies as well key decision making bodies (e.g., the Alaska State Board of Fish). An important aspect of the SCTC has been identifying the institutional arrangements and the networking among these stakeholder groups.

What are the outcomes?

The most critical implementation outcome (Question 5, Table 1) for SCTC is the integration process, that is, the iterative scenario-based stakeholder engagement. Without this process the level of co-development of knowledge that has been achieved would not be possible nor the engagement of stakeholders and residents. Other outcomes include the coupled SES model suite, the virtualized world of Kenai Watershed (SalmonSim), the paleo-analysis of salmon abundance and use, and the adaptive capacity indices (AWRVI assessments) for communities in the Kenai watershed, which all support the scenario development. Of particular significance for an integrative approach purporting to develop the co-production of knowledge are the management responses from local managers (see "How to integrate?") and the impact for residents including the youth—for example, the Kenaitze tribal youth examined and documented their sense of place and awareness of a changing environment in the Kenai River Watershed (Trefon et al. 2014).

Conclusions: setting foundations for conducting integrative research in sustainability science

The approach outlined in this paper contributes to the development of integrative research in sustainability science by assessing the implementation of the integration framework. The framework allows us to clarify our project integration boundaries and goals and helps us develop a set of actions, implementation plans, and outcomes. As part of this effort, we critically assess the trade-offs in approaches to integration that provided a better understanding of both foundational disciplinary research and synthetic interdisciplinary research, highlighting where we can complement and benefit from work and expertise across the team. The integration framework and components are a shared road map, to facilitate the incorporation of new students, personnel, and stakeholders and to improve our efforts towards integration products. Finally this approach can provide an example that other researchers may draw upon in developing their own integrative research projects. We propose two recommendations:

1. Emphasis on collaborative engagement and processes: Steps towards this could include support for relationship-building, institutional efficiency, incentives for researcher engagement and consequences for impeding it, as well as updated researcher evaluations that reflect the importance of alternative research outputs (i.e., town hall meetings, radio talks, reports, policy briefs, etc.). Regular iterative workshops and discussions with communities, policymakers, and institutions can help assure that products and outcomes are both scientifically valid as well as socially relevant.
2. Innovation in integrative methods: This requires continuing refinement of existing techniques and methods for integration, along with the development of new approaches. For example, a need exists for a community-wide and approved mechanism for archiving integrative sustainability science practices, that is, a best practices archive (Alessa et al. 2015). Such an archive would include the means by which interdisciplinary teams are formed, co-develop, and engage partner communities, as well as the steps and circumstances under which the integration approaches have been effective.

We believe that consideration of these recommendations will improve the development of a science of integration and its practical implementation by encouraging application, shared language, innovative critical design, and the co-production of knowledge.

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