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ECOSYSTEMS

The Services-Oriented Architecture: Ecosystem Services as a Framework for Diagnosing Change in Social Ecological Systems

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ABSTRACT

Computational thinking (CT) is a way to solve problems and understand complex systems that draws on concepts fundamental to computer science and is well suited to the challenges that face researchers of complex, linked social-ecological systems. This paper explores CT's usefulness to sustainabiliry science through the application of the services-oriented architecture (SOA), The SOA is a popular organizational framework in information technology that enables businesses to describe the services they offer, including how, where, to whom, and under what terms these services are available to consumers. It provides a straightforward, scalable, and portable way to describe and organize complex business systems, with an emphasis on system controls and component interactions rather than on the system components themselves. Here, we present the SOA as a path to a more mature ecosystem services concept, in support of integrated assessment frameworks such as the Millennium Ecosystem Assessment (MA), With the SOA we capture important interrelationships among ecosystems, ecosystem service consumers, and ecosystem service governance authorities, particularly the effects of their interactions on the viability of ecosystem services. By standardizing the description and relationships involving ecosystem services, the SOA supports a diagnostic approach for evaluating stability and change in ecosystem service use across. both space and time, when influenced by drivers of social, political, and/or ecological change, whether directional or stochastic, planned or otherwise. We present here a prototype of the SOA and illustrate its utility with an example from rural Alaskan communities.

Key words: ecosystem services; computational thinking; sustainability science; service provisioning; governance; Alaska natives; sustainability; millennium ecosystem assessment; SES.

INTRODUCTION

There is an overwhelming consensus that the pursuit of long- term sustainable outcomes for human societies requires insights from a new 'sustainability science' based on the coupling of human and natural systems (Berkes and others 2003; Turner and others 2003). It remains unclear, however, what that sustainability science must look like, that is, its unifying frameworks, principles, and philosophies (Ostrom and others 2007;

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Walker and others 2006). It is unlikely that any single conceptual, theoretical, or modeling framework will emerge as a panacea that universally captures the emergent, synergistic patterns of linked social-ecological systems (SESs), particularly as they diverge from the operations of their constituent social and ecological components (Clark 2007; Ostrom 2007, Walker and others 2006. Yet, without a common frame of reference for assessing SESs, particularly with respect to how they experience change, we have no legitimate basis for evaluating and making decisions regarding the consequences of our actions (Brock and Carpenter 2007; Lee 1999).

With the goals of enabling scientists and policymakers to match resource governance strategies to localized needs and challenges, the effectiveness of sustainability science will depend largely upon its capacity to identify the social, political, and ecological factors that drive path dependence and agency in a system (Ostrom 2007; Scoones 1999; Vemuri and Costanza 2006). A strong, interdisciplinary sustainability science therefore needs the ability to differentially diagnose the patterns of interactions and outcomes among a host of nonlinear and conceptually contrasting variables, such as resource use (and overuse), the implementation of policy, the distribution of infrastructure and wealth, conflict, directional change, and surprise (Mahoney 2000; Ostrom 2007). This calls for a forensic approach to studying change, and requires tools with the capacity for pattern recognition and process identification within and across these systems. Such an approach would enable researchers to capture a time sequence of stability and change in systems, for instance, at pre-. peri-, and post-perturbation states, as influenced by internal system dynamics as well as external influences, whether directional or stochastic, planned or otherwise.

The Millennium Ecosystem Assessment (MA) offers an integrated assessment framework for doing this kind of sustainability science (Figure 1). It was designed to capture how groups of people interact with and rely on ecosystems, and how changes to those ecosystems, either as the result of natural process or of human actions, influence individual and community well-being (MA 2005b). Its language is not specific to natural resources, but instead to the different modes by which ecosystems support human well-being, that is, through regulating, supporting, provisioning, and cultural services. This functional abstraction from ecological resources to 'ecosystem services' allows the MA to focus on the linkages between ecosystems and society; support multi-scale and multi-stakeholder

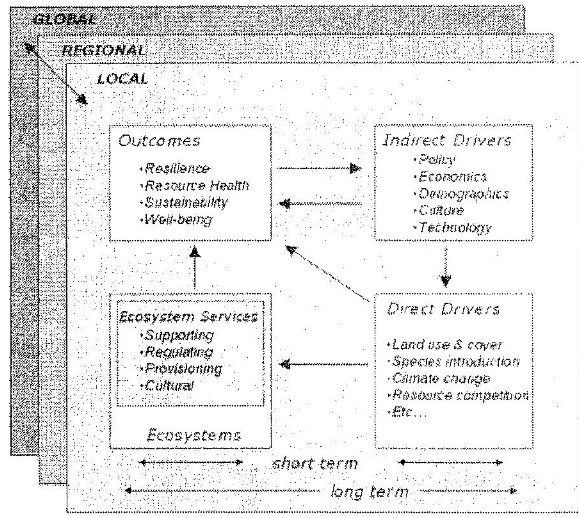

Figure 1. The MA assessment framework. The MA framework is designed to assess the consequences of changes in ecosystems to human well-being. Changes in factors that indirectly affect ecosystems, such as resource governance policy, economics, technology, and culture (*upper right corner* of figure), can lead to changes in factors directly affecting ecosystems, such as land use patterns (*lower right corner*). The resulting changes in the ecosystem (*lower left corner*) cause the ecosystem services to change and thereby affect SES outcomes (*upper left corner*). These interactions can take place at more than one scale and can cross scales. For example, a global market may lead to regional loss of forest cover, which increases flood magnitude along a local stretch of a river. Similarly, the interactions can take place across different time scales. Adapted from MA (2005b).

comparisons; and organize and cross-reference SES assessments conducted at many different geographic and temporal scales, ranging from local communities to the entire planet, and from months or years to decades or centuries (MA 2005b). But what the MA fails to provide is a standardized organizational framework for describing and evaluating the mixture of ecological. social, political, cultural, and economic controls over the provisioning and consumption of ecosystem services (the arrows in Figure 1), as they converge at a specific scale to influence consumer behavior. Nor does it allow us to describe explicitly how ecosystem services overlap and interrelate, both within and across sets of consumers, to create patterns of outcomes such as resilience, vulnerability, resource depletion, and sustainability.

Computational thinking *(CT)*, an approach to understanding complex systems that draws on the principles of computer science, is particularly suited to the study of complex social-ecological systems and can offer significant guidance to the further development of MA-like assessments into mature diagnostic frameworks (Schweik and others 2005; Wing 2006). CT makes complex systems more tractable, both with computational tools and (more importantly) with problem-solving concepts like abstraction, decomposition, recursion and nesting, and pattern recognition (Wing 2006). These principles can guide how we do sustainahility science research, by helping us better understand our research questions so that we know when to abstract or synthesize and when to couple or decouple systems for effective study /management/design (for example, Ostrom 2007; Villa 2007) In this paper, we draw on one particularly pertinent organizational framework from computer science that incorporates these principles-the services-oriented architecture (SOA). The SOA is a 'services-based' approach to representing the internal function of complex systems, which has been very productive in the business realm of information technology (IT) (MacKenzie and others 2006). It is conceptually similar to the ecosystem services concept but places its emphasis on system controls and component interactions rather than on the system components themselves. In the sections that follow we explore the fundamental principles of the SOA and show how they guide diagnosis of factors that create emergent patterns of behavior and outcomes in an SES.

THE SERVICES-ORIENTED ARCHITECTURE

The SOA is a meta-model created to describe complex business systems, via the relationships that exist among their functional/organizational units, for example, accounts receivable, accounts payable, different customer groups, and so on. Many businesses use the SOA to conceptually organize the interactions between these business units as a set of services, defining how and where each of these services is provided and consumed, and the policies that govern their use (MacKenzie and others 2006). By establishing a common vocabulary and semantic framework for describing service interaction and the controls over their provisioning and use, the SOA enables computer software architects to create and customize computer software applications to support specific business needs. The resulting architecture transforms geographically distributed business systems and applications that are characterized by heterogeneous, incompatible computer applications and hardware into easily navigable networks of linked and interdependent service providers and service consumers-analogous to the linkages between multiple ecosystem services and multiple stakeholder groups.

THE SOA PROTOTYPE FOR ECOSYSTEM SERVICES

The concepts presented in the following sections (in italics) originate from the SOA reference model developed by MacKenzie and others 92006) but are adapted to be compatible with the ecosystem services concept as defined by the MA (2005a). In the spirit of computational thinking, the SOA is not simply recommended as yet another new model. but instead as a set of unifying, concepts, axioms, and relationships that are relevant to the integrated assessment of ecosystem services and social-ecological systems at large. Thus, we stress the relationships that this prototype establishes, and how these can inform our analyses, rather than a specific set of terminology, which can and should be expected to vary in practice across disciplines, theoretical perspectives, and even real-world scenarios.

An ecosystem service characterizes how a particular set of users, or *service consumers,* derive some benefit from ecosystems, either via direct interaction with the ecosystem or via some provisioning authority *(service providers).* A service can be classified by its five major components (Figure 2): the service *definition-basic* information regarding a service, including its service *type;* the service *interaction-details* of the behavior that occurs during service consumption between the consumer and provider; *viability-the* mix of circumstances that make this interaction possible or impossible, which includes physical circumstances as well as social. cultural. and economic policies and constraints on the use of or access to an ecosystem service (for example, via its governance system); the *execution context-one* or more snapshots of service interactions as they happen for certain groups of stakeholders or at a particular scale or scales of interest; and finally the *outcomes-both* direct (for example, food, shelter) and indirect (for example, sustainability, resource depletion, conflict). These are explained further, with examples, in the following sections.

Service Definition and Service Types

The first step to modeling services is to create a working *definition* of that service. For ecosystem services, a definition would include physical locations. description of ecological processes and resources

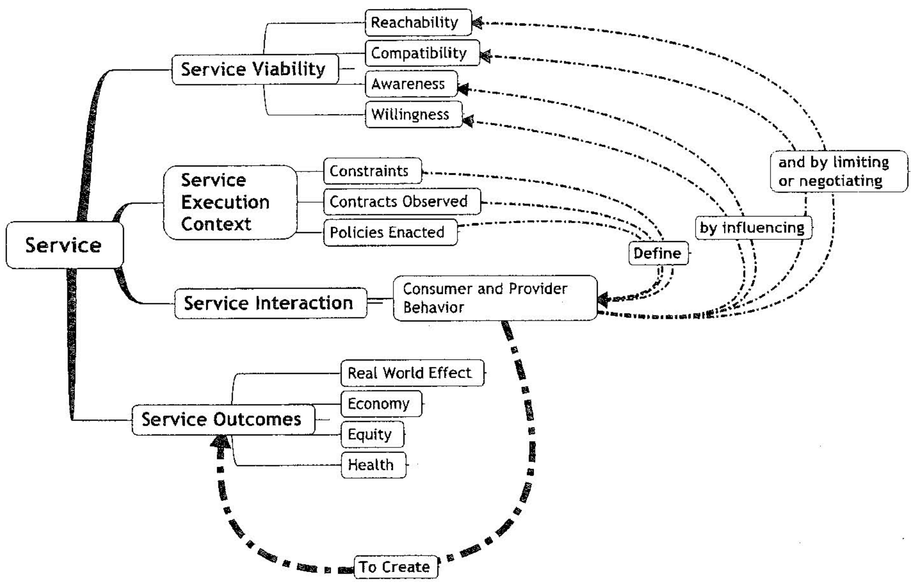

Figure 2. Factors that guide agency and path dependence in ecosystem service use. Consumer behavior is influenced by a service's viability, which is limited by constraints to a service's reachability and compatibility, both physically and through regulatory structures that levy policies and contracts. Consumers, in this context, act based on their awareness of the service, of the rules governing the use of service, and on their willingness to either observe these rules or ignore them and accept the consequences.

involved, lists of relevant stakeholders (users of the service), and references to peer-reviewed papers, maps, diagrams, and economic valuation. One example of components that might be included in a service's definition can be found online in the Ecosystem Services Database, located at http://esd.uvm.edu (De Groot and others 2002; ESD
The information included in the service definition is largely a matter of the agenda/scope of analysis and should be represented explicitly in terms of the research questions pursued and other pertinent context-specific information regarding the SES in question.

A good portion of the service's definition relates to its *type.* Typing is a fundamental concept of CT in general and is an important aspect of the SOA. It describes how the framework supports analysis of complex systems through hierarchical decomposition, allowing us to distinguish between classes and subclasses of ecosystem services. Consider, for example, the similarities and differences between a professional chauffer and a taxi service: both provide types of transportation services, which share a number of conceptual features, such as flat rate versus per-mile rates, service areas, and usage restrictions. But the two differ in many ways as well. One type is specific to a common property resource and the other to a private one: when hailing a cab you are competing with others at the same intersection, whereas with a private chauffer you retain exclusive access to his services. Typing also allows us to represent how the same set of resources are used differently by consumer groups. The same fleet of taxis, which provide a transportation service to the public. may also provide a type of advertising service to an advertising agency. Typing allows these very different services to be compared at their shared dimensions, and contrasted where they differ, to get a more holistic picture of resource use.

There are four general types of ecosystem services: supporting, provisioning, regulating, and cultural services (MA 2005a),These types are not descriptive of the ecosystems or the specific resources themselves; rather, they describe specific contexts of human - environment interactions (Costanza and others 1997). Like the example of the taxi fleet the same aspects of an ecosystem are likely to be experienced by people in more than one of these ways simultaneously. Ecosystem services are therefore inevitably interrelated: they can overlap and be nested hierarchically (Costanza and others 1997; De Groot and others 2002; Ostrom 2007). A forest stand, for example, most likely provides cultural (aesthetic) and provisioning services (through timber harvest) to one group, while providing all four categories of services to an indigenous community of hunter/gatherers. And different groups of service consumers need not just be people; the ramifications of human competition with other species are also legitimate cuncerns for resource management. An endangered wolf population may use the same set of woods for habitat (a supporting service), and compete with the local human inhabitants for wild game (a provisioning service). Thus, ecosystem services do not merely describe "resources" in the conventional sense (for example, Ostrom 1990). Instead, they allow us the potential to represent ecosystem structure and function from a plurality of perspectives within the same analytical framework, as opposed to frameworks that limit the scope of our analyses to the needs and uses of a single set of users, or to the purview and philosophy of a specific resource management regime.

Which type or types of service we choose to describe a set of ecosystem functions depend wholly on the research questions being asked. Indeed there is no conceivable limit to the number of ways ecosystem services may be characterized and nested. It is useful therefore to have a set of conceptual sub-types, as in the transportation-service examples above. De Groot and others (2002; their Table 1) suggested a good generalized classification of ecosystem service sub-types for the four primary types listed, but sub-types can also be customized on an ad hoc basis to specific scenarios. For example, in the case study we describe later we create a 'country food' service type, a composite sub-type of both provisioning and cultural services that is specific not just to the ecology but also the cultural. economic and resource governance contexts of rural Alaskan communities.

Service Interactions and Service Viability

When a service is consumed, some *interaction* occurs between the service consumer and provider (ecosystem component or provisioning authority), although these interactions can vary from completely passive to active. For this interaction to occur, it must be viable (Figure 2). Service *viability* is an emergent property. Each service's viability results [rom the interacting influences of social, political, economic, and ecological circumstances of the service consumer(s) in question. It results from the interaction of four independent variables: *compatibility, reachability, awareness,* and *willingness*. First, a service's viability requires that the service's *interfaces,* that is, resource harvest and/or delivery methods are *compatible,* or usable by the consumer; ecosystem services are useless to a segment of society if they do not accommodate the specific physiological and psychological consumer requirements. A wall outlet is a familiar technological analogy of compatibility: unless the wall outlet is of the appropriate configuration (voltage, amperage, connector type), the electricity is inaccessible. For ecosystem services, interfaces might include public infrastructure, the harvest of crops, the act of hunting, or something as simple as a viewing area for rare species or iconic landscapes. At a finer ecological scale, interfaces might include different physical or even chemical processes that link ecological service providers and consumers.

Reachability is similar to compatibility, but is concerned with the practicality of access rather than the possibility of use and is determined by a combination of both natural and human influences. The reachability of an ecosystem service depends also on the constraints in place, both physical and as levied by governance structures, which can limit or promote access to or availability of the service. Physical limits include ecological limits and thresholds such as the maximum rate of carbon sequestration per hectare of wetland or the maximum sustainable yield of a fishery. Landscape structure and built infrastructure such as dams or road systems also commonly influence the reachability of ecosystem services. Reachability is also dictated by a resource's governance system, through *policies,* socially and culturally levied constraints on the use of ecosystem services such as fishing quotas and cultural taboos. Similarly, reachability is also influenced by any *contracts* established between service providers and consumers, by establishing policies and terms of lise. How these policies and contracts vary across different stakeholder groups is a key factor in the evaluation of matters such as equity and justice.

Awareness and *willingness* are the last two components of service viability and characterize different aspects of the service consumer's behavior. Awareness of a service is as limiting to a service's viability as are its physical constraints; it involves knowledge of the service and of how to access it. Whether or not a consumer has this information is often a matter of behavior on the part of a producer and, viewed across stakeholder groups, this can reflect differences of equity that manifest in the distribution and availability of information. In cases where ecosystem service consumption involves choice, the consumer must also be willing to behave in the appropriate way, which may involve cultural standards and rituals, and to agree to the policies and contracts that are in place. Willingness to participate, therefore, is reflective of the value consumers place on a service through the tradeoffs (pollution, resource degradation) they are willing to make.

Example: The Electric Company

An electric utility company is often used to illustrate the SOA and is a good example of service viability and provider-consumer interactions (MacKenzie and others 2006). The utility company (a provisioning authority) generates and distributes electricity (a provisioning service) from coal (the actual service provider) to residential and business areas; and consumers of this service access the electricity via a wall outlet (service interface) in their home. To use the electricity, a consumer's home must be on the grid (reachability). and the consumer needs to understand what type of plug to use (compatibility), the voltage of the supply (service constraints), and possible limits to the load (service policy). A residential or business user must open an account with the utility to use the supply, and the utility will meter usage and expects the consumer to pay for use at the agreed-upon rate (service contract). The consumer values living with power highly enough to accept the negative long-term effects of coal-burning power plants (a trade-off), and so commits to the constraints and polices specified within the service contract (willingness) to receive electricity. Their service is maintained as long as the electricity distribution grid and house connection remain intact (a surprise event like a storm knocking down power lines could disrupt distribution). and as long as both parties continue to behave in the manner specified in the service contract. Had the consumer known that they had the choice to purchase some of their power from a farm of windmills and/or to refit their home with energy-efficient appliances, solar panels, and so on, they might have chosen to power their home in a different manner (awareness).

Service Instances and the Execution Context

Another important aspect of CT that is found in the SOA is the object-instance relationship, how we differentiate between the definitions of an ecosystem service in general terms, and the actual *instances* of that service's consumption by users, Instances are defined by their *execution context:* a set of 'real-time' scenario data that describes how a specific consumer or group of consumers experience the service in question. These allow us to distinguish between different instances of the same service. In our earlier example, we defined the electricity provisioning service provided by an electric company; each household's use of that service would be considered an instance of that service, each with their own specific execution contexts, which would capture details of service contracts, access methods, use levels, regional pricing and ability to pay, proximity to the publicly maintained power grid, and so on. Execution contexts are not limited to one side of the interaction; rather they capture the totality of the service interaction, providing a snapshot of all the aforementioned parameters as they are enacted by providers and consumers. Depending on the intent and scope of analysis, instances can be used to represent consumption at this finest level of resolution (one household), or more broad categories of data that are common to an ecosystem service for a group of stakeholders (a community).

In practice, these instances of ecosystem services function as indicators of SES health-revealing the extent to which specific needs are being met for a set of stakeholders (MA 2005b). An MA-style integrated assessment will likely include several services and service instances, with execution contexts that reflect multiple scenarios of providers and consumers at multiple scales. These will invariably be cross-referenced and nested, for example, in cases where cultural services are linked to provisioning services, or multiple, competing interests are being represented. The goal is to use these as indicators to diagnose and understand the patterns of outcomes, or cumulative *real-world effects* of ecosystem service use, for instance, how needs satisfaction stratifies across groups or results in patterns like stability and resilience or resource overuse and conflict. as well as how ecological and/or sociopolitical drivers of change further interact with these pa rterns.

THE COUNTRY FOOD SERVICES OF ALASKA

In this section we begin with the observa tion of trends in a particular set of SESs in Alaska, and show how an ecosystem-services-based assessment, using the concepts of the SOA, allows us to diagnose the circumstances that are driving those trends (Figure 3). Indigenous communities across the Arctic are undergoing a rapid restructuring process, including economic, social, demographic, and ecological changes like community decentralization and out-migration, environmental degradation and pollution, and a dietary transition from wild or country foods to store-bought, industrially produced foods (ACIA 2005; Gerlach and others in press; Huskey and others 2004; Kuhnlein and others 2004). These restructuring processes pose significant implications for the health of people and their communities and are accompanied by epidemic trajectories of diabetes, heart and respiratory disease, malnutrition, alcoholism, and depression (for example, ADHS 2000; AMAP 2003; Caulfield 2002; Degal and Saylor 2007; Graves 2004; Krupa 1999; Kuhnlein and others 2004). A diagnostic approach to understanding these system pathologies and trajectories begins by selecting a research

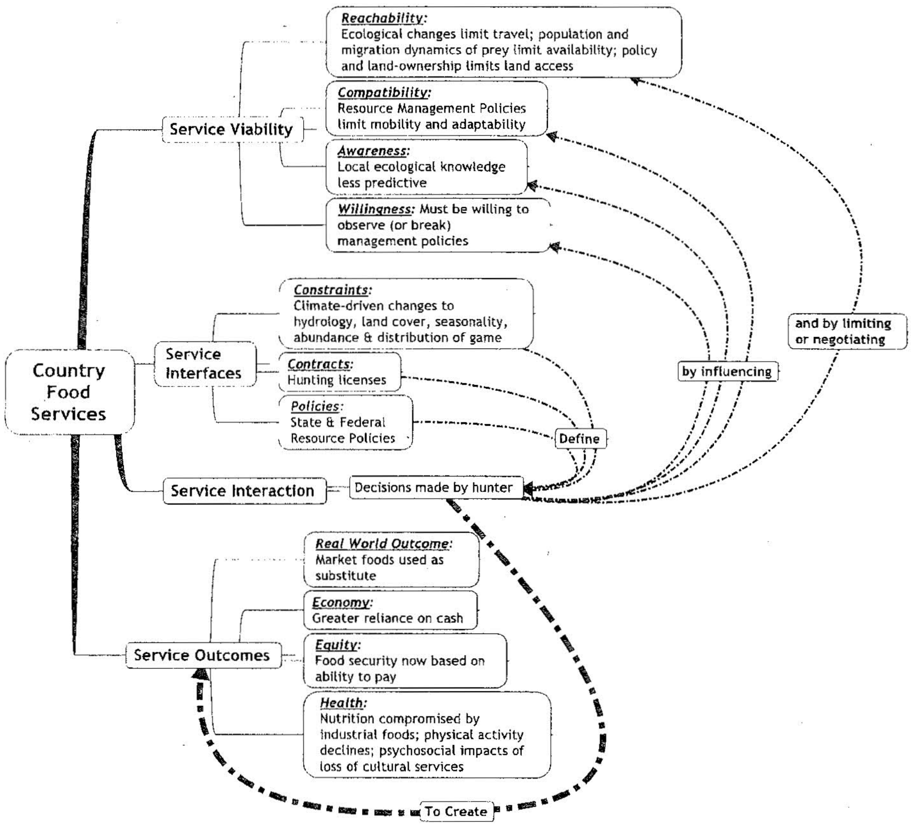

Figure 3. How the viability of country food services influences hunter behavior and outcomes. Alaska Natives communities who make their living on country food services face a problem of those services' viability. Specifically, the intersection of new and unpredictable ecological constraints with the current set of political, legal, and economic policies and contracts that are in place severely limit the reachability and compatibility of wildlife resources for Native communities, and force the hunter to choose between hunting out of season or substituting market foods for country foods. The trade-off of market foods, which continues to proliferate throughout rural areas of Alaska, leads to a host of negative well-being outcomes.

question, for instance, "what are the drivers behind the transition away from locally available country foods toward market foods?", a trend that is present in rural communities statewide but to a significantly varying degree. The concepts of the SOA allow us to deconstruct the political, social, and ecological circumstances, which operate at a variety of scales, as they translate at the individual and community *level* to limit the viability of those country food services when compared to the alternate provisioning services offered at the store.

What we call country food services (Table 1) vary across communities and can include sea mammals, ungulates like moose, caribou, and musk ox. fresh and saltwater fish, miscellaneous waterfowl. berries and other botanical resources. The use and harvest of these resources provide Alaska Native communities with both provisioning services (food) and a variety of cultural services, many of which contribute to an individual's sense of role, responsibility, and identity. *Even* under the best conditions, the availability of these services is highly variable. Nevertheless, Alaska Natives have subsisted on country food services for thousands of years, relying on extensive local knowledge (awareness) and livelihood strategies of mobility, adaptability, and economic diversity (compatibility) that allowed them to respond to the services' natural variability (Campbell 2004; Krupnik and Jolly 2002; Loring 2007; Nelson 1986; Spencer 1976).

Although ecological variability has always been part of the execution context of country food ser*vices,* new and unprecedented down-scale manifestations of climate change on the ecology of Alaska are limiting the viability of these services in new and unpredictable ways (Chapin III and others 2006; Gerlach and others in press) (Table 2). Changes in precipitation, the timing of break-up and freeze-up of rivers and lakes, fire regime and changes to successional trajectories, individually and in tandem, create terrestrial obstacles to transportation across landscapes, and cause difficulties accessing traditional harvest areas because of water levels and coastal or river bank erosion (limits to reach ability) (Chapin III and others in press; White and others 2007). Changing land cover, weather, and seasonality are also modifying the abundance and migration patterns of terrestrial animal populations, both spatial and temporally (more ecological constraints that limit reachability). Similarly, lower water levels can also affect both the timing of salmon runs and their spawning

Table 1. Country Food Service

The Moose country food service		
1. Definition	1.1 Description	Provides food (energy) to humans and other animals on the landscape • Nelson (1986) provides an excellent description of moose hunting by Athabascan communities in genera • Stephenson (2004) and (Gasaway and others 1992) and (Boertje and others 1996) are good reports regarding the ecology of moose in the region • Andrews and Napoleon (1985) is the most recent demographic review of Native moose harvest in the region
	1.2 Service type(s)	• Provisioning (food) • Cultural (identity, community, spiritual, learning)
	1.3 Harvest method	• Hunting • Scavenging
2. Viability	2.1 Constraints	Factors of abundance and distribution, for example, animal birth rate, predation pressure, and compensatory mortality. Also landscape cover, river water levels, and forest fires
	2.2 Policies	• State and federal policies may limit take or access • Social and cultural institutions may dictate/limit take, or require take at certain times for ceremonial reasons
	2.3 Contracts	The Alaska Department of Fish and Game assigns licenses to hunters, some on a first-come or lottery basis. Hunters agree to harvest the prescribed number of animals. Contracts for moose management can also exist between agencies and tribal corporations for moose management, access to state/federal land, and so on
	2.4 Compatibility	Natural ecological variability requires mobility and adaptability of harvest strategies
	2.5 Reachability	Must have access to landscape where resources are present and be available/capable of harvesting them • Practical hunting range is limited by living in fixed communities • Access can be limited by changes in weather, landscape, fire, legislation, land-ownership • Ability includes time and resources, for instance, if the hunters' circumstances influence them to take a wage-earning job during hunting season, or if they cannot aord gasoline to power a snowmobile
	2.6 Awareness	Must have local knowledge as to harvest areas, wildlife movement, and must have the appropriate hunting skills
	2.7 Willingness	• Ritual may dictate certain procedures before, during, and after the hunt • Must be willing to accept risks of travel across landscape where there may be danger • Must be willing to observe policies and enter into appropriate contracts with resource managers and land owners (or be willing to accept the consequences of not doing so)

An SOA analysis of the services provided by the land to an Alaska native family, including the physical, political, social, cultural, and economic aspects of the services use. The SOA meta-model brings together a variety of down-scale influences that are relevant to understanding the viability of an ecosystem service for a particular set of consumers.

success (Fleener and Thomas 2003 NRC 2004; Schindler 2001).

These new ecological constraints to the viability of country food services are often aggravated, rather than mitigated, by state and federal regulatory structures that govern the use of wild fish and game (policies and contracts). State- and federal-level resource management agencies such as the Alaska Department of Fish and Game, the Bureau of Land Management, and the National Park Service, all exercise extensive control over the use of country food services, both geographically and temporally, through wildlife reserves, game management units, open and closed hunting seasons, quotas, area closures, and so on. The result is a barely navigable patchwork of land management with little regulatory consistency, even for communities separated by less than 100 miles (Gerlach and others in press). Additionally, which wild resources and resource-harvest techniques (behav-

Table 2. Country Food Execution Context

A country food service instance	
Provider/setting	The Minto flats wildlife refuge
Consumer	Alaska Native Family in Minto, AK
Harvest method used	Hunting
Constraints	• Size of moose population is dependent on predation and predator control policy • Water level is low and new beaver dams cut o access to most productive area, both down-scale impacts of warming • Global oil prices are high, and gasoline prices in the village can limit boat travel • Wage-paying job taken by hunter limits time for huntin
Policies enforced	• The enforced hunting period is out of step with the seasonal behavior/migration of the moose, making local available numbers low • Competition for resources is high because Minto flats wildlife refuge is an extremely popular sport-hunting destination and state policy does not provide rural (local) users with preference
Contracts observed	Hunter receives license from state agency to take 1 moose during the prescribed season
Consumer behavior	Hunter does not have enough money to purchase boat fuel during hunting season, but if they do following the close of season they may choose to hunt out of season
Real world effect	If Hunter chooses to hunt: • Hunter is caught hunting outside the season, and must prove 'ceremonial use' to avoid costly fines. The so-called ceremonial use requires that a potlatch ceremony be held and the moose meat consumed all at once, not preserved/stored for the family's use through the winter months If Hunter chooses not to hunt: • The cultural services that the activity provides are sacrificed. The hunter gives up an opportunity to share traditional hunting areas and practices with a child. The lack of engagement in the activity can have physical health eects (less exercise) as well as psychological ones (role fulfillment). The family must also rely on more store-bought foods. These all converge to negative physical and psychosocial health outcomes

The execution context for the users of one particular rural community, Minto, AK. Within the last two decades, but most intensely within the last 2 or 3 years, significant changes have been observed in the distribution, availability, and migration patterns of harvested resources such as moose, ducks, and fish (Andrews [illegible]; Andrews and Napoleon [illegible]; Reed [illegible]; Smith [illegible]). In concert with gasoline prices exceeding $7 a gallon (necessary for boat and snowmachine transportation), short hunting seasons, and competition with sport- and tourist-hunters allowed by state laws which prohibit rural priority for resource use, the use of country food services is effectively being abandoned (DCA [illegible]; Loring [illegible]). Indeed the viability of country food services in the region is so undermined that their willingness to accept substitutes supercedes their continued preference for wild foods. The ready access and relatively low pricing of market food services (because Minto is on the road system, unlike the majority of Alaska Native communities) is subsidizing the trade-off such that the transition is happening faster here than elsewhere in the state.

ior) are considered by law to be "customary and traditional" and therefore allowable for country food services, and what role the foods play in local economies (that is, subsistence use versus for-profit) are limited by legal definitions and institutional interpretations of Alaska Native culture (Gerlach and others in press: Berger 1985). By nature, these regulatory structures cannot respond as quickly as change is occurring on the ground, making it difficult for hunters to effectively adapt and alter their harvest strategies to the changing ecological constraints (Gerlach and others in press: Natcher and Davis 2007).

These circumstances influence the hunters' behavior in many ways (Figure 3), New, stochastic down-scale manifestations of climate change, like shifts in seasonality, are making the environmental cues that hunters once used to reliably predict the weather and behavior of animals less effective (a new limit to their awareness). And many of the climate-change-driven changes to land cover pose risks to individual safety when traveling across the land and waterways, which a hunter mayor may not be willing to accept (willingness). Ultimately, however, hunters are faced with the need to provide food for their family. Food sharing across families provides a small amount of country foods to families in the greatest need, but nevertheless hunters are often faced with making decisions to either hunt out of season (break a contract) should they not fulfill their requirements during the allotted period, or make the trade-off decision to purchase more market foods, which meets their provisioning needs but sacrifices the cultural services that country food services also provide. Dependence on market foods also requires the ability to pay, which invariably results in more time spent earning wages than spent on the land harvesting country foods. Not only does this create a positive feedback loop whereby the country food service's viability is further reduced, but it also creates incentives for wage-earners to migrate out of their villages for work and undermines the generational pedagogy that allows Athabascan culture to persist (Huskey and others 2004).

DISCUSSION

The SOA framework enables us to describe a scenario where a mix of new ecological constraints and existing policies converge to make a set of ecosystem services far less viable now than they were historically. The natural variability in the migration, distribution, and density of wild game is only compatible with a lifestyle strategy of mobility and adaptability. With people now mostly geographically fixed by infrastructure to their communities and to sources of wage income and further restricted in their ability to traverse the landscape by the patchwork of unresponsive regulatory structures and private, state, and federal land ownership, the mobility and adaptability that made the country food services compatible with Alaska Native lifestyles are significantly constrained. This is further confounded by habitat alteration caused by oil, gas, and mineral mining development activities (for example, Werhham 2007). Although mobility and adaptability once provided resilience to family economies and contributed to the long-term sustainability of these communities, new restrictive circumstances are translating into increased dependencies on market foods to maintain local food security.

Application

Having now identified some of the primary drivers behind this transition, mitigation. intervention and response strategies can be designed to target appropriate policy directions for resource management and land development. Particularly, management strategies are needed that avoid creating barriers to country food service viability, and instead re-create room for adaptability and mobility in the Native lifestyle. The viability of country foods via hunting (the service interface) has global dimensions (climate change), regional - to - national dimensions (state and federal policies), and local dimensions (hunting licenses, wildlife distribution/ abundance) that define the options available to Alaska Natives. Enhancement of these options therefore requires policy intervention at several levels, and/or adaptation responses that redefine the service interface (for example, development of community gardens). Witbin the present service interface, local actions could enhance service viability through improved access rights (reachability), development of co-management arrangements (compatibility), culture camps that transmit traditional knowledge from elders to youth (awareness), and increased use of summer fish camps to harvest salmon (willingness). Observed changes in service outcomes then provide a basis for modifying the intervention strategy in an adaptive management context (Armitage and others 2007).

CONCLUSION

SES resilience, vulnerability, adaptability, and transformability are all phenomena that emerge from a host of interlaced and often cross-scale dynamics, the fundamental processes of which cannot be captured by secularized descriptive or analytical models. However, taking the next step toward a systems diagnostic approach to the integrated assessment of these phenomena is difficult to attempt, primarily because of gaps in communication across disciplines and differences in mental models of the nature and spatial scale of the critical controls over the dynamics of SESs. Social scientists, for example, are keenly aware of the qualitative importance of path dependence to human agency and of cross-scale interactions (Arthur 1999; Mahoney 2000; Scoones 1999); they often shy away, however, from reliance on systems models that focus on particular temporal and spatial scales of historical and structural processes (Mahoney and Snyder 1999). Although existing assessment frameworks like the MEA admit complexity in the drivers of agency and path dependence, they don't provide a conceptual framework for diagnosing how these interact to create patterns of outcomes. The computational thinking principles of the SOA give us the tools to identify the major factors that influence agency and path dependence at a broad range of temporal and spatial scales. Once these factors are identified, the stage is set to differentially diagnose the mix of specific drivers that lead to emergent phenomena or contemporary trends of change. the result of which points us in the direction of designing more sustainable and equitable strategies and interventions.

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