

Seasons of Stress: Understanding the Dynamic Nature of People's Ability to Respond to Change and Surprise

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ABSTRACT


Climate change is impacting coastal communities in rural Alaska in multiple direct and indirect ways. Here, findings are reported from ethnographic research done with municipal workers, community leaders, and other local experts in the Bristol Bay region of Alaska, where it is found that climate change is interacting with local social and environmental circumstances in ways more nuanced than are generally captured by frameworks for vulnerability analysis. Specifically, the research herein shows the importance of the temporal dimension of vulnerability to environmental change in rural Alaska, both in terms of temporal patterns that emerge from climate-driven stressors and also with respect to how, and under what conditions, people in rural communities may design or manage effective responses to change. There are multiple factors that play into how rural communities will be affected by some climatic or environmental stress; ultimately, the impacts of climatic and environmental stressors will differ depending on where, when, and how frequently they occur. To capture these interactions, two analytical concepts—community capacity and cumulative effects—are discussed and then incorporated into a visual tool for improved planning and vulnerability analysis.

1. Introduction

In September of 2007 in the community of Red Salmon,¹ Alaska, coastal erosion caused a wastewater lift station to fail, releasing untreated waste water onto the beach adjacent to the Red Salmon river. The sewage main runs along the river; whereas it was formerly completely buried, parts of it were uncovered and left

exposed as a result of weather-driven erosion. The failed lift pump in particular was exposed to high water levels, weather, and continued erosion. Municipal workers were able to respond to the failure quickly enough to limit the extent of environmental contamination, but in interviews local managers expressed how fortunate they were that the failure did not occur during the height of the salmon fishing season. For one, the wastewater system would have likely been running at 150% of its designed capacity due to a seasonal increase in population from fishermen, cannery workers, and other seasonal residents. Second, a coordinated response by community workers would have been difficult at this time because some local workers would have been fishing themselves. Finally, the prospect of releasing untreated wastewater into a river when it is full of highly valued salmon raises human health and safety issues; an event such as this could have had devastating impacts on the reputation of these commercial fisheries

¹ A pseudonym, for confidentiality.

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FIG. 1. Map of Bristol Bay, Alaska, with major communities highlighted.

and on the economy, health, and well-being of Red Salmon and the region as a whole.

This anecdote highlights important social and ecological dynamics that enter into how communities experience the impacts of changing weather and climate, and whether they are able to effectively respond. Specifically, we see the importance of the timing of events, fluxes in human resources, and other drivers of short-term variability in a community's vulnerability to some event or surprise. Below, we discuss these dynamics in greater detail as they relate to the many challenges facing coastal communities in rural Alaska, where both climate change and life in general have strong seasonal dimensions. We propose a framework for capturing these nuanced aspects of how communities are impacted by change, one based on the concepts of cumulative effects and community capacity (CEQ 1997; Beckley et al. 2009). We pair these concepts with a visual decision calendar framework (see also Corringham et al. 2008; Kim and Jain 2010; Ray and Webb 2016), which we then operationalize with the data on climate and weather impacts gleaned through interviews with municipal workers and other local experts in rural Alaska in order to illustrate how these concepts provide an informative framework to help determine whether or not people are able to effectively manage environmental challenges.

Our study is thus situated within the general area of vulnerability analysis, which has emerged as an important and popular framework for thinking about the

impacts of climate change (e.g., Cutter 1996; Adger 1999; Turner et al. 2003; Adger 2006; Ford et al. 2006; Gallopin 2006; Smit and Wandel 2006; Hinkel 2011; Haalboom and Natcher 2012). As we discuss below, vulnerability analysis and other analytical frameworks that attend to climate change do not always specifically address the nuanced temporal dynamics highlighted in the story above (Ray and Webb 2016). The decision calendar framework we present here provides both a vocabulary and a compelling visual tool for examining the place-based complexities of how communities experience and respond to change (Parris et al. 2016).

2. Methods

This paper was developed from ethnographic research done primarily with municipal workers, community leaders, and other local experts in the Bristol Bay and region of Alaska (Fig. 1). This type of research is necessary for understanding how local experiences of climate change are embodied and acted upon (Krieger 2001), with a goal of capturing richer stories than simple measures of vulnerability and adaptive capacity provide (Ford et al. 2010). At the core of this work are informal interviews and participant observation in six remote communities, ranging in population from 50 to more than 2400 people. Note that we do not identify these communities by name as a matter of research subject confidentiality. This study is further informed by more

TABLE 1. Sample questions for each category of the community inventory survey tool employed in six remote communities.

Community inventory survey category	Sample questions
Human capital	How many funded municipal employees are currently trained on water/wastewater management, monitoring, and infrastructures? How many years' experience does each of the primary employees have working on these areas?
Social capital	Does your community/borough have a disaster response plan? Does your community/borough have a climate change adaptation plan?
Financial capital	What are the current sources of permanent funding that support the management of water/wastewater facilities? What grants do you currently receive for water/wastewater issues?
Natural capital	What is your primary source of potable water? What are your concerns with respect to the source water used for the drinking water system?
Built capital	What is the class/configuration of water treatment infrastructure in your community? What percentage of households/public buildings have operational piped water systems?

general observations and community input reported to one or more of the authors prior to engagement with these six communities (see e.g., [Loring et al. 2011](#); [Gerlach et al. 2011](#); [Loring et al. 2016](#)).

Our research involved semistructured interviews and community tours with a total of 12 city managers and planners, public works managers, and water and sanitation infrastructure operators. Interviews were done with individuals and small groups and were informal, guided only by general talking points about the challenges facing community infrastructure, management, and planning. Direct observation of and work with people carrying out their daily duties often took the form of community tours and time spent shadowing participants as they attended to their daily responsibilities. Happenstance encounters with additional individuals in diverse venues such as tribal offices and restaurants were also common and informative.

The core six communities where the research took place were initially chosen based on the types of public works infrastructure in operation for drinking water, sanitation, and solid waste, to provide a representative sample of infrastructure challenges within a single region. Community officials and representatives from regional tribal government consortia and health care providers were then consulted to verify the appropriateness and importance of research in an identified community, and for help in identifying key community research partners. Our selection of Bristol Bay for a strategic case study region is thanks primarily to interest in these issues among our local collaborators.

For the semistructured interviews, we developed a community capacity inventory tool in close collaboration with our community partners to provide talking points and assess the assets (i.e., capital) present in each community, as well as the resources at people's disposal for managing day-to-day concerns (e.g., infrastructure operation and maintenance) and surprises such as a

severe winter storm or an infrastructure failure. The survey was divided into five sections based on the Department for International Development livelihood assets ([DFID 1999](#)): human capital, natural capital, financial capital, physical capital, and social capital. For any given section, the aim was to identify where the capacity to respond to change and surprise exists, and when and why that capacity would be diminished. [Table 1](#) identifies a sample talking point for each survey section.

Our research approach also remained flexible, given the need to adapt to local needs and concerns. Depending on the community member consulted or even the community itself, we used judgment to determine when and how data were collected ([Huntington 1998](#)). Simply put, we employed a "listen first, question second" approach. The process was particularly useful when consulting with members of the communities who are not normally contacted by researchers (e.g., water treatment plant operators). Where appropriate, the community capacity inventory was used as a source of talking points for interviews. For each community, one complete survey was compiled as an aggregation of all the responses recorded.

The theoretical placement of our research design is phenomenological, with the assumption being that the experiences of key individuals in these sorts of positions provide an important and informed window into the nature of climate and weather challenges at the community works and infrastructure level. This is in contrast to research aiming to be "representative" or "generalizable" regarding people's opinions; as such, reporting quantitative aspects of our data (e.g., "three people said ...") would be misleading. In a phenomenological frame, each expert's experience is considered to be equally informative with regard to the nature of the phenomena being investigated. It is worth noting here two additional features of this approach: first is that the

amount of information collected differed for each community depending on who the researcher was able to communicate with, their knowledge, or, in some cases, simply the information kept by the community (this was particularly true of financial information); and second is the surplus of valuable but sometimes “anecdotal” information. Alongside explicit answers to the questions described above, we recorded local evidence of climate change, people’s opinions of state and federal agency practices, and general comments about the practicalities of living in rural Alaska through happenstance interactions, all of which progressively inform how we interpret and report these data (Vayda 1983; Agar 2013).

3. The seasonality of climate change and life in rural Alaska

Climate change is already affecting people in Alaska and the rest of the circumpolar North through a variety of meteorological and environmental changes in annual precipitation; the form and patterns of precipitation (i.e., rain vs snow); snow and winter frost depth; the distribution, movement, and quality of nearshore sea ice; and growing season length (Markon et al. 2012). The frequency, intensity, and seasonality of marine storms are also increasing, and these bring both heavy waves and water level surges that can worsen coastal erosion (Atkinson et al. 2011). Land cover changes are also occurring, including permafrost thaw, expansion of shrubs in the tundra, and a northward and westward drift of the arctic tree line (Markon et al. 2012). Along with other impacts, continuation of these trends could increase water loss due to evapotranspiration and result in overall drier seasonal and annual means for Alaska in the future (SNAP 2011).

Many of the changes expected in high latitudes, including but not limited to the ones mentioned above, pose risks for rural and urban communities in these regions, and in many cases, these changes and their associated risks are playing out with a distinctive seasonal signal. Strong fall storms are the norm now; seasonal sea ice cover can protect coastal communities from these storms by buffering wave action, but declines in sea ice extent and changes in the timing of freeze up can make communities more vulnerable to surge and erosion (Overeem et al. 2011). Likewise, the timing and duration of rapid and often dramatic “break up” and “freeze up” seasons, that is, the period of time during which coastal or river ice is transitioning from open to frozen or vice versa, is also changing. In recent years uncertainty about break up and freeze up timing has complicated shipping and travel along rivers, and in many cases has resulted in large ice dams and severe spring flooding (Hopkins 2013; Friedman 2013).

Many aspects of life in rural Alaska are also marked by a distinct seasonal pattern. These remote rural communities are peopled by cultures very familiar with the highs and lows of seasonal resource productivity and seasonally mobile lifestyles. Historically, indigenous people across Alaska moved from summer fish camps to fall hunting and spring trapping camps (Nelson 1969, 1986). Today, hunting, fishing, and the country food harvest remain very important to local culture and food security although people are less mobile and trips are often shorter than in the past (Loring and Gerlach 2009; Gerlach et al. 2011). Other seasonal aspects of life in coastal communities include winter constraints on shipping; in communities where sea ice or river ice is a factor, barge service may only be available for a few months per year. Commercial fisheries, sport fisheries, and other tourism activities also contribute a seasonal rhythm to life in many coastal communities. Finally, many men from these communities also take seasonal employment, working in summers for firefighting crews or mining companies, for example. As we discuss below, many of these seasonal aspects of life in rural Alaska factor directly into how climate and weather impacts are experienced.

4. Results

Given the various seasonal facets of life in the north, it is perhaps not surprising that people reported to us in this research that their ability to respond to climate and weather-driven challenges varies seasonally (see also Corringham et al. 2008). Indeed, interviewees provided information to us about a number of seasonal challenges that they regularly cope with and that impact their ability to respond to climatic change in one or more ways (Table 2). In winter, for example, interviewees explain that extreme cold and extended darkness can make it difficult or impossible to work outdoors on failed infrastructure. Another seasonal stress reported in multiple villages is the seasonal influx of nonresident laborers for jobs in fisheries, mining, and other industries such as hospitality and tourism. These spikes in local population put extreme but short-term stress on community infrastructure; as we describe below, this is generally at times when community offices are understaffed because local people are busy with subsistence activities or commercial fishing. Similarly, some respondents noted how increased severity of winter weather and reduced sea ice cover impacts the summer window during which supplies, equipment, and fuel can be reliably shipped to rural communities. One particularly high-profile example of this involved unseasonably early sea ice blocking the coastal community of Nome and interfering with the winter’s shipment of fuel oil (DeMarban 2011; Burke

TABLE 2. Description of the seasonal stresses that are impacting rural Alaska water systems based on community reporting.

Seasonal stress	Description	Challenge
Wastewater treatment system	The calendar identifies the seasons when usage is highest due to seasonal population increase (Jun–Sep), and when effluent quality is lowest (Oct–Nov) as a result of high use during the summer months. The high use season overwhelms and degrades the treatment process.	Seasonal increases in population stress community infrastructure, particular water systems, and result in regular breakdowns. Because of increased usage, treatment system effectiveness is reduced, which reduces the resultant effluent quality. In some communities effluent did not achieve regulatory standard
Subsistence activities	This refers specifically to a typical salmon fishing season	The coincidence of increased local population, regular breakdowns of public infrastructure (see above), and absence of workforce members who are themselves fishing. The net effect is that responses to breakdowns are slow.
Winter weather	Season when exposure to severe winter weather storms is greatest and thus most negatively impacts operational ability and efficiency	Severe winter weather can prevent community members from responding to surprises. Further, if equipment or materials are needed they cannot be delivered by barge during the winter. Instead expense airfreight is used, further challenging capacity.
Strategic planning	Season when communities typically complete planning, do, resource allocations, or have community elections.	Much like the challenges stemming from subsistence activities, planning activities tie up community members during the short season where yearly maintenance can occur. Without planning, though, communities may not get the grants that sustain many of the public systems.
Community funding activities	Season in which many agency funding application deadlines are situated	Much like the planning activities, paperwork activities reduce the capacity of the community to attend to surprises or attend to improvement projects.
Coastal erosion	Season when exposure to coastal erosion is greatest	Many community public infrastructure pieces (i.e., sanitation lagoons) are located near coast/shore lines. Fish camps are likewise located in areas challenged by erosion. A significant erosion event that threatens infrastructure or property will be attended to ahead of everything else challenging the community.

2012). Multiple interviewees also noted how disruptions in shipping can delay important municipal projects for one or more years because of important supplies being stuck in Seattle or elsewhere, diminishing their ability to respond to unexpected and unplanned for infrastructure failures during the winter (see also Gerlach et al. 2011).

The following three quotes from respondents exemplify the various ways that local people communicated to us the importance of timing and seasonality in the challenges they face operating and maintaining their community infrastructure.

“If something’s going to fail, it’s going to happen when it’s coldest, or during a bad storm, in either case at a time when it’s hardest to get out there and fix it. Water only freezes in the winter, you know? Things break at 40 below if you even look at them funny.” City Manager

“There’s only a relatively small window each year that we can barge equipment here from [Seattle]. If something

happens and the barge doesn’t sail, we may be waiting until next year, even for something as simple as a part for our backhoe.” City Water Manager

“I feel like I’m always on my back foot and when it rains it pours. Trouble seems to cluster, and I think that’s because when things happen out there they happen fast. We have maps of how the river bank has eroded, and it’s a lot each year, but I tell you that happens in a matter of weeks.” City Planner

Another way that seasonality presented itself in these interviews included comments by interviewees regarding administrative challenges and mismatches among fiscal calendars, reporting, and grant deadlines, which can create gluts of desk work for local municipal workers during a short period of time. One city manager explained that in times of stress or crisis the first activities to be “sacrificed” are planning and grant writing, and that this causes complications for them in the future

by impacting their ability to obtain new funding. Another puts the challenge this way:

Why the state [of Alaska] makes us submit these in summer I have no idea. We have to write our grant proposals and reports when people are out on the land. They know what life is like out here, so why they don't let us work on these things in winter I have no idea.

A final way that timing emerged as an issue is with respect to people's ability to respond to climate change impacts; while this is not exclusively a seasonal signal, it still involves limits to human resources, a perceived or real tendency for surprises to cluster, and the generally high level of effort it takes for local people to keep old and failing community infrastructure running under even normal circumstances (Loring et al. 2016). "I'm always standing on my back foot," explained one city manager, "... it takes most of my day and all of my employees' time to keep [things] running."

Indeed, in every community we visited we encountered a similar challenge, where one or a few people were already working at, near, or beyond their capacity to maintain just the day-to-day status quo. In many cases, this was because they were coping with infrastructure that is old or inadequately built for the nuances of the remote north, especially during times of rapid and unplanned for shifts in climate and weather. In others, it was simply a matter of staff shortages or inadequate training to work with unnecessarily complex systems. In one community, we observed a "top priorities" list on a city manager's whiteboard that listed items such as training, equipment repairs, and so on. The last space on the list was empty, and the city manager explained that he leaves it empty because some issue emerges nearly every day to fill the spot:

I try to keep an empty space on my whiteboard for whatever new breakdown is going to happen, but take wintertime, for example. Winters don't go by without water problems. That's when we can't get new parts if we need them, so it doesn't matter if my list is empty or full.

Taxed as they are with this baseline level of work for simple operation and maintenance, several interviewees also reported feeling unequipped to attend to a surprise or crisis. More than one interviewee also shared a similar sentiment regarding climate change in general, namely that while they know climate change is important, it is nevertheless in some ways the least of their problems:

I have a lot of things going on here, a lot of things on my to-do list. Climate change is not on there. We see it here better than most people. We just do not want to be [focused on] climate change because we have a lot of other things to be working on.

5. Discussion

A comprehensive framework for understanding how communities will be impacted by climate change needs to account for the experiences described above. The role of timing, seasonality, and human resources issues all interact in these communities in complex ways that as we argue must be explicitly accounted for in order to effectively assess climate change vulnerability at the community or regional level. Below, we discuss how the concepts of cumulative effects and community capacity can improve vulnerability approaches to these issues.

a. Vulnerability

There are numerous extensive reviews available of the concept of vulnerability (e.g., Cutter 1996; Adger 1999; Turner et al. 2003; Adger 2006; Ford et al. 2006; Gallopin 2006; Smit and Wandel 2006; Hinkel 2011; Haalboom and Natcher 2012). In general, most vulnerability frameworks employ a set of three independent concepts for describing a system's vulnerability: exposure, sensitivity, and ability to respond. The first, exposure, relates to a community's proximity to a hazardous location or activity (Dow 1992): are people in the path of a storm or flood, for example. The second variable, sensitivity, relates to the extent to which communities would experience harm if exposed to that stressor. Sensitivity is generally determined by preexisting social, economic, and environmental conditions (Kelly and Adger 2000; Oliver-Smith 2013). Sensitivity can also depend on whether or not a community is already experiencing or coping with some other condition. For example, a community may be more sensitive to a severe storm if they only just recently experienced another severe storm or catastrophic event. Finally, the third component of vulnerability is the system's ability to respond to harm or disruption (Ford et al. 2006). This has been described as both resilience (ability to recover) and adaptability (ability to respond in a way that reduces future vulnerability).

Vulnerability analyses are often spatially explicit, representing comparatively the vulnerability of nations, regions and/or communities (e.g., Allison et al. 2008; Himes-Cornell and Kasperski 2015). With respect to the temporal dimension, however, most vulnerability frameworks are more limited, attending primarily to pre-, peri-, and postimpact states, treating communities as generally static at the time of "impact," and emphasizing the nature of the hazard or crisis over local societal processes and trends (Fazzino and Loring 2009; Oliver-Smith 2013). That is not to say that the temporal aspect of vulnerability has not been discussed; Ford and colleagues, for example, describe it thus:

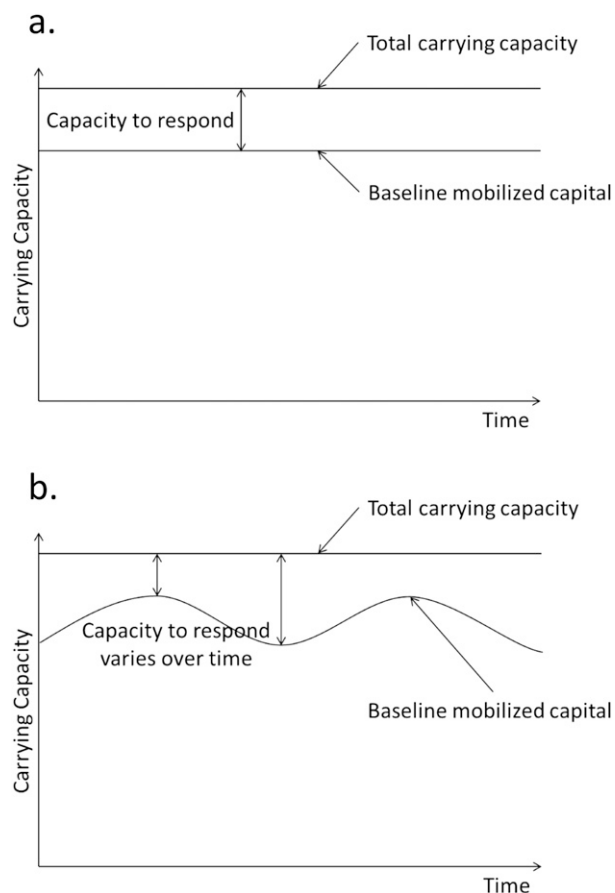


FIG. 2. (a) A schematic representation of community carrying capacity. The area mobilized capital demonstrates the extent of the total carrying capacity that is currently employed by the community in some way to manage an existing need or challenge. The capacity that is available beyond this baseline represents the capacity to respond or, in operational terms, the ability to respond. Putting time on the x axis allows for the visualization of how capacity changes over time. (b) A schematic representation of community carrying capacity. The area representing the capacity to respond—between mobilized capital and total capacity—is temporally dynamic and changes over time in ways that are often seasonal.

Climate-related conditions include magnitude, frequency, spatial dispersion, duration, speed of onset, timing, and temporal spacing of conditions. ... In Arctic communities, different species will be harvested in different locations at different times of the year on account of individuals' knowledge of the environment, past experience, differential time constraints, and access to technology. ... Exposure-sensitivity is clearly dynamic, changing as the community changes its characteristics relative to the climatic conditions, and changing as the stimuli themselves change. (Ford et al. 2006, p. 147)

Other work on climate change and vulnerability identifies the importance of the temporal dimension (Sönmez et al. 2005). Yet, as Ray and Webb (2016) note,

writing specifically about the needs of communities facing climate change, “many analytical frameworks lack a temporal dimension of use of products and information” (p. 29). Our goal in the sections that follow is to offer a decision framework for capturing the temporal dimension, focusing specifically on how a community’s ability to respond changes over time as a result of myriad local social and ecological circumstances and processes.

b. Community capacity

Whereas vulnerability analyses are generally oriented to the system-level responses to change and perturbations, they also often emphasize the importance of a community’s capacity to respond to change—the capabilities and resources that actors in communities can draw on for the practice of managing environmental systems and needs (Scoones 1998; Beckley et al. 2009; Speranza et al. 2008; Loring et al. 2016). Sometimes called “community capital” (DFID 1999), capacity-oriented frameworks have also been used for some time in the international development policy literature. Community capacity as we use it here is borrowed as a metaphor from the ecological concept of carrying capacity (Brush 1975) to describe the cumulative abilities of people in a community to manage their day-to-day lives and responsibilities (Fig. 2a), while also coping with external stresses and disturbances as a result of social, economic, and environmental changes (Loring et al. 2013).

Community capacity is generally understood to have five dimensions: natural, human, built, social, and financial (DFID 1999). Natural capital describes the environmental resources upon which people rely, resources that include but are not limited to freshwater sources. Human capital represents the ability of people to perform management tasks and to respond to problems, with this measured by experience, expertise, and education. Built capital represents the existing infrastructure with which people have to work when managing the environment, whether water treatment facilities, seawalls, or airports and seaports. Social capital includes organizations for regional collaboration and strategic plans for development or disaster mitigation. Finally, financial capital represents the finances available, and can include local revenues as well as grants and federal transfers that are necessary to manage existing systems and to promote effective responses to change, even if this is too often a short-term approach to both long- and short-term problems.

What the various local experts in the Bristol Bay communities have impressed upon us is that their community capacity is not static (Fig. 2b). For example, when public works employees are absent during subsistence activities there is less capacity to respond to

infrastructure challenges. Similarly, turnover in many community sectors (health, teaching, public works) is high, and while replacements can be employed their level of training, experience, and, importantly, local knowledge can greatly change the capacity available. Community capacity thus changes over time in ways that are seasonal or cyclical and in ways that are directional, especially when small events slowly accumulate over time and erode the capacity to attend to ongoing operation and management issues. One city manager, for example, noted his concern regarding the ways in which a series of wastewater infrastructure failures was impacting community morale; “it’s hard to keep people in jobs where they get [human waste] all over them. Eventually, they walk away.” As we discuss below, these temporal dynamics are an essential component of how we understand the cumulative effects of environmental and climate challenges on communities.

c. Cumulative effects

The cumulative effects framework was originally developed by the U.S. White House Council on Environmental Quality (CEQ) for use in environmental impact assessments associated with the National Environmental Policy Act (NEPA) of 1970. The [CEQ \(1997\)](#) defines cumulative effects as “the impact . . . which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions” (p. v, [CEQ 1997](#)). Cumulative effects as originally written was concerned with predicting the short-term and cumulative impacts and adverse effects (the language at the time) of large-scale development projects (e.g., oil, gas, mining, etc.) and was tied to NEPA, the Antiquities Act, and a variety of federal funding streams. What a cumulative effects approach brings instead to the matter of vulnerability is a holistic perspective that expects that new climate- and weather-driven challenges will interact with one another and with other social and cultural factors, and accumulate, additively or synergistically, over time. The cumulative effects approach also focuses not just on the short-term but also on the long-term impacts, and not only accounts for proximate or immediate causes but also anticipates the accumulation of stressors toward the potential for thresholds and “tipping points” beyond which an entirely new suite of negative impacts may appear ([Natural Resources Council 2003](#)).

Cumulative effects describe the feedbacks that either amplify or suppress vulnerability. Those feedbacks can be connected temporally, such that, for example, a storm in November that knocks out power and requires expenditures to fix could deplete the financial resources necessary to fix the next power outage. In the simplest

terms, cumulative effects arise from single or multiple drivers, whether climatic or nonclimatic, that in combination result in additive or interactive effects on communities. One way that the cumulative effects perspective is complementary to traditional vulnerability approaches is that it provides language for incorporating spatial and temporal crowding of environmental perturbations as well as synergistic effects among the various perturbations:

- Temporal crowding occurs when the interval between perturbations is less than the time required for an environmental system to recover from each perturbation. The rate of temporal crowding may be continuous, periodic, or irregular and may occur over short or long time frames.
- Spatial crowding is analogous to temporal crowding but where spatial proximity between perturbations is smaller than the distance required to mitigate or disperse the effects of each perturbation. Spatial accumulation may be characterized by scale (local, regional, global), density (clustered, scattered) and configuration (point, linear, areal).
- Synergistic effects are those cases where stressors do not merely accumulate in an additive way, but complex interactions among environmental stressors and other local circumstances, whether economic, demographic, or cultural, create outcomes that are often complex, nonlinear, and unanticipated.

With the popularization in the last few years of health impact assessments, uses of the cumulative effects concept have evolved from a focus just on human impacts on the environment to examining how environmental changes impact people through health and food security ([Bhatia and Wernham 2008](#); [Fazzino and Loring 2009](#)). Here, we argue that the concept has important analytical power for thinking about people’s collective ability to respond to climate and weather-driven impacts on their households and communities. The “near miss” anecdote at the beginning of this paper provides an informative example. The people of Red Salmon were fortunate; the cumulative effect of the various circumstances could have been disastrous by comparison had the failure happened during the fishing season and, although a failure could very well occur at any time, it is not unreasonable to expect that failures are more likely when the system is under higher operating load as it is during salmon fishing season (June to September) when a community population can double. Coastal erosion, another process that played a role in the Red Salmon example, is also intensified in the region during spring and fall storm events.

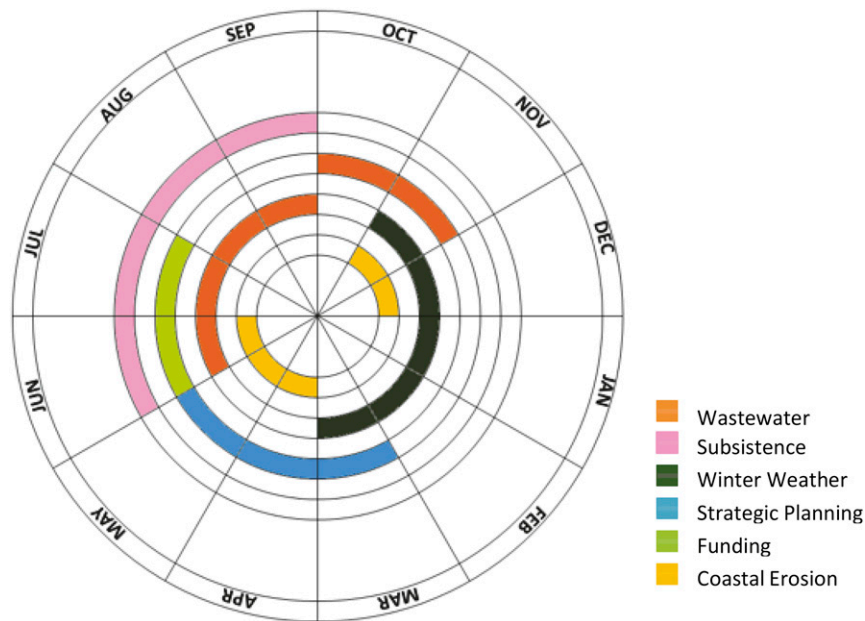


FIG. 3. The seasonality calendar displays the seasons in which climatic and nonclimatic stresses impact a coastal Alaskan community based on stresses reported in Table 2.

d. Developing our seasonal approach

As explained above, a great many aspects of life in rural Alaska have strong seasonal characteristics, and whether and how a community will be impacted by some climatic or environmental stress is related to this temporal dimension. Accordingly, seasonal calendars have emerged as one innovative way for communities and environmental managers to plan for environmental variability and change (Corringham et al. 2008; Kim and Jain 2010; Ray and Webb 2016). In conversations with our community collaborators, we likewise found it informative to adopt a seasonal time scale for our analysis of community capacity and cumulative effects, as it is reflective of the various features of northern life noted earlier: important hunting and fishing activities that take place during certain times of the year, rapid and often dramatic “break up” and “freeze up” seasons, and strongly seasonal weather patterns.

Figures 3 and 4 offer a visual representation of both community capacity and the cumulative effects of multiple climatic and nonclimatic stressors on a seasonal time scale. We adapted the circular visual style from the traditional calendars of subsistence practices that are common for Alaskan Native peoples and indigenous groups around the world (e.g., Attla 1996; Hoogenraad and Robertson 1997). Our goal is to provide a culturally relevant framework and visual tool for capturing and communicating data on the timing and seasonality of potential hazards, as well as sociocultural details such

as planning cycles, fiscal years, and seasonal changes in human resources (Goddard et al. 2010; Dilling and Lemos 2011). Table 2 provides additional detail about how the stresses marked on the seasonal calendar in Fig. 3 are categorically organized.

Especially evident in Fig. 3 is the temporal crowding of challenges reported by interviewees. The cumulative effect of these various factors, for example in the month of June, is evident: public works operators must manage both the increased population for fishing season and the stresses put on the wastewater system, as well as perform triage repairs with reduced staffing because people are away and fishing themselves. Community members have likewise reported to us and to others an increase in both severity and frequency of summer storms and the dramatic effect this can have on river and sea coast lines, leading to challenges such as those described above for Red Salmon (Atkinson et al. 2011). Finally, many state organizations are balancing future budgets at this time, and the community itself is completing the necessary financial planning to ensure continued grant funding. While community managers concede that they have no choice but to respond to these challenges, they recognize that the response required to the accumulation of these stresses often exceeds the various physical, human, and financial resources at their disposal. Managers, too, express concern about the trade-offs and inherent vulnerability in being overcommitted and too often underresourced:

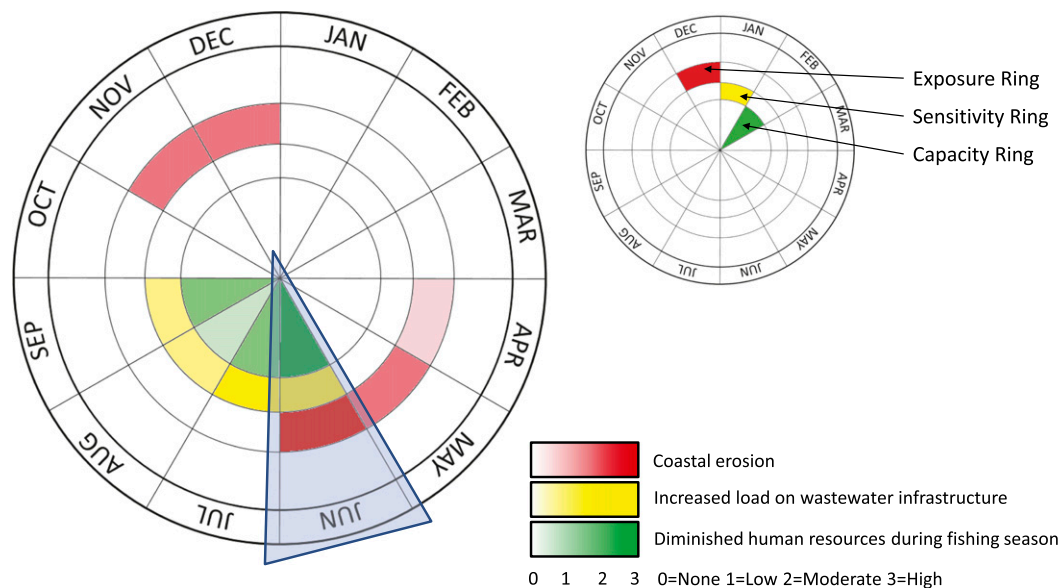


FIG. 4. Simple seasonal stress calendar showing how a vulnerability approach can be given a temporal dimension, focusing on the example of a community's vulnerability to wastewater systems failure and taking into account coastal erosion, usage of wastewater infrastructure, and seasonal variability in human resources. When viewed together, late spring appears to be the time when the community is most vulnerable.

I was asked if we'd want a new water plant here, and sure, why not, why wouldn't you want the latest and greatest? But frankly, that's a headache I just don't have time for. We have clean water. We don't have a working backhoe, though. We barely have enough people to keep the existing water system running in winter time.

Not all activities that a community routinely manages are included in Fig. 3, but these are the most often reported concerns that we encountered through this research. For example, when responding to the question "What keeps you up at night?" one public works manager specified that operating the wastewater system during salmon season (midsummer for most Alaskan communities) was their greatest concern at that time of the year. Clearly, if an additional surprise event occurred people would do what they could to respond, but what must be sacrificed as a result is an important consideration, as is whether people are functioning so far over capacity that they must implement short-term fixes that are not durable, and may even erode their capacity moving forward.

Figure 4 illustrates how the seasonal calendars complement vulnerability analysis through the addition of an explicit temporal dimension, and especially participatory approaches to vulnerability (e.g., Gadams 2013). With the help of local experts, exposure to stress, sensitivity to stress, and the community capacity to respond can be mapped on the seasonal calendar for one or even multiple stressors. The tool could also inform

research, guiding needs assessment interviews, for example, by asking local experts to rate when exposure or sensitivity is highest, or when ability to respond is low. Hence, a community and researchers could use this framework to collaboratively generate an understanding of vulnerability to stress on a local temporal scale.

6. Conclusions

Rural Alaskans are keenly aware of climate change and are actively searching for innovative and effective solutions that complement rather than detract from community plans for development and prosperity (Cochran et al. 2013; Loring et al. 2016). Intuitively, we all understand that people are creative—that they experiment and innovate in different ways, and therefore we should expect that no two communities can or will mobilize resources in the same manner. Our attempt with this paper is to shed further light on how communities mobilize resources and to craft a robust framework for visualizing how communities will be impacted by change or surprise.

One of the most important findings in this research is the importance of the temporal aspect of environmental change in rural Alaska, with this perhaps overshadowing the spatial dimension that is so commonly emphasized in vulnerability research. Indeed, when we started this research, our operating premise was that spatial variation of community vulnerability to climate change would be

pronounced, and we had to abandon this premise rather quickly. To be sure, there are multiple factors that play into whether and how a community will be impacted by some climatic or environmental stress, both spatial and temporal, but in rural Alaska at least, the seasonal pattern is the most visible. The cumulative effects framework employed here draws attention to this temporal dimension; we propose that the seasonality aspect may also be important outside remote high latitudes as well, and other researchers have observed seasonal rhythms in rural livelihoods around the world (Binford 2003; Ulijaszek and Strickland 2009). Regardless of whether the temporal aspects are more dominant than spatial, we argue that a focus on community capacity and cumulative effects significantly improves researchers' and policy makers' toolkit for examining and addressing vulnerability to extreme weather and climate change. The next step with this framework is to evaluate its applicability elsewhere in the North, but also in notably different geographic and decision-making contexts, through participatory action research. Ultimately, the most important indicator of the durable value of this or any framework is whether it presents information in a way that enables people to make informed and successful responses to change.

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