Enhancing the resilience of Puget Sound recovery

A path through the maze of resilience thinking

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Summary

In systems management (including ecosystem recovery) it makes sense to maximize the chances that desired outcomes will endure future challenges and changes, anticipated or not. In other words, it makes sense to maximize the 'resilience' of desired outcomes. 'Resilience thinking' has exploded in recent decades to become a sprawling discipline, complete with debates and inconsistencies (hence the 'maze' in the sub-title), and literature to match. To illustrate, the following are selected quotes about systems resilience (in italics; sources are given in the narrative). All are true.

- Resilience is *an idea that is necessary for inter-generational survival*.
- Resilience is *the capacity of an ecosystem to resist, absorb, or rebound from disturbance or stress, and continue to operate in the face of change* ... also … *the capacity of a social-ecological system to sustain human well-being in the face of change* … There are many definitions of resilience, and their implications can conflict with each other.
- Resilience has become *a central theme of research, policy and programs, across disciplines and sectors, all over the world, from community to global scales*.
- Resilience has become *loosely structured in common use, open to interpretation, and only obtaining meaning in a particular context … a vague and malleable…communication tool across…scientific disciplines*.
- 'Resilience thinking' *is not attractive to nor easily integrated with social science thinking*, nor founded on consistent and substantiated theory.
- The core tenet of 'resilience thinking' remains deceptively simple: for desired states of any system, the more resilient the better.

Prompted in part by the perception that resilience enhancement may be under-attended in Puget Sound recovery, this article is intended to help recovery practitioners become active resilience enhancers (beyond what they already achieve incidentally), without having to wade through (all) the literature. It is intended to help answer the question *How would YOU make the Puget Sound ecosystem more resilient?* It does this by:

- sketching salient parts of the history and conceptual theory of resilience;
- offering perspectives on the prevalence and limitations of 'resilience thinking';
- summarizing some of the approaches and practices used to enhance and measure system resilience;
- providing examples of how resilience of Puget Sound has been enhanced, and may further be;
- availing some of the primary and most useful literature for further reading.

This article will succeed if resilience thinkers, and resilience enhancement, become more prevalent among efforts to recover Puget Sound. It will succeed, of course, if recovery outcomes endure future challenges and changes, anticipated or not.

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Rationale

In the 2018 edition of the *Action Agenda*, which "charts the course to recovery" of Puget Sound, the terms 'resilience' or 'resilient' appear 41 times, but most cogently on page 23, as follows (underline added):

> *… We envision a future in which generations can hear the calls of whales, witness the spawning of salmon, taste locally harvested shellfish, swim in clean water, and experience the unique cultural fabric that ties our region together. Our vision includes a resilient ecosystem—one that can adapt to the impacts of climate change and the pressures of a growing human population, while meeting the needs of its native creatures.*
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> *…We pledge to make this vision a reality. We will do so by challenging ourselves to pursue ambitious action, secure needed funding, seek supporting legislation, apply our resources and legal tools, and hold ourselves accountable for implementing all actions needed to make Puget Sound resilient.*

It is Implicit that the terms 'resilience' and 'resilient' are understood, and in their generic sense no doubt they are. But resilience also has specific meaning – depending on context – that has been evolving for over 50 years[1]. Today, resilience has become "a central theme of research, policy and programs, across disciplines and sectors, all over the world, from community to global scales" (Helfgott 2018). If this is news to you, or even if you are not quite sure of your answer to the question *How would YOU make the Puget Sound ecosystem more resilient?* this article may help. Salient selections from the literature are combined to form an impression of what resilience means in the context of ecosystem recovery, focusing ultimately on Puget Sound.

This follows recent attention to the meaning of resilience in a (Nov. 2017) workshop convened by the PSP Science Panel. The workshop was prompted in part by the perception that 'resilience thinking' may be under-attended in Puget Sound, compared to recovery strategies elsewhere. This is not a review of resilience (of which there are many: Holling 1973, Gunderson 2000, Folke et al. 2004, Folke et al. 2005, Martin-Breen and Anderies, 2011, Chaffin et al. 2016). Nor does it cover the many other 'flavors' of resilience, such as to natural disasters and of disaster management, although these are alluded to. The briefing is intended to 1) sketch the history, principal concepts, and theory of resilience; 2) offer some perspectives on the prevalence and limitations of 'resilience thinking'; 3) introduce some of the approaches and practices used to enhance and measure ecosystem resilience; 4) provide examples of how resilience of Puget Sound has been enhanced and may further be; and 5) provision some of the primary and most useful literature for further reading.

The briefing will 'succeed' if, as a result of reading it, more participants in and practitioners of Puget Sound recovery become active enhancers of its resilience, both individually and collectively (that is, beyond what their ongoing work might achieve incidentally). It will succeed if applications of 'resilience thinking' and measurement are made more explicit to, and prevalent among ongoing recovery efforts in the Puget Sound region.

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[1] In this article, resilience referring to the specific sense is written without quotes.

Ecological resilience

The term resilience has been in use since at least 1430, when it appeared "as a juridical term…for the restoration of the original legal situation" (Hellige 2019). By the 18th century the term was well-established in reports of physical properties of materials, describing the inverse of their brittleness. The same sense of the term was later applied to *systems*[2], specifically, to physiological, engineering, and public health systems, long before it was applied to ecological and social-ecological systems. In general, two different manifestations of system resilience are recognized: capacity to absorb or resist disturbance, and speed of recovery from disturbance. The latter is more commonly used in engineering contexts, where resilience, say of cell phone infrastructure to earthquakes, is measured by the time taken for the system to resume normal operations.

Although the Canadian ecologist Crawford S. Holling is correctly credited with introducing the term in an ecological context, Hellige (2019) recounts how he "found primary elements of the ecosystem resilience theory to be already available."[3] Holling (1973) defined the term as *a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables*. Holling's key observation was that, within systems comprised of interacting species, population sizes vary, but within limits, such that, following disturbance, the system tends to recover to the same species makeup and dynamics that persist over time, as if the system was in the grip of an 'attractor.'[4] Examples typically featured production 'regimes' benefiting humans (now referred to as ecosystem services), such as fisheries or grazing systems. These were 'resilient' if, following harvest, they maintained or reverted to the same (or at least functionally equivalent) species composition, relative abundance, dynamics, and productivity.

Many of these systems were also 'commons,' and thus vulnerable to overexploitation, often with long-lasting impacts, manifested as persistently low catch per unit effort in fisheries, or predominance of unpalatable plant species in grazing systems. A disturbance that exceeded a regime's resilience (over-fishing or over-grazing) would, by definition, cause the regime to 'shift' to another with a different combination of species, or with different dynamics, likely diminished in its useful productivity to humans. Often, the new regime was itself resistant to reverting to its former, more desirable state, despite drastic remedial measures (thus, *undesirable* states can also have resilience, which has to be overcome to regain the desired state). Sometimes, the original regime could only be regained by a different combination or sequence of extrinsic 'disturbances' to the one that caused the original regime change ('hysteresis'). A well-known example features overfished cod (*Gadus morhua*) in the Baltic Sea (Mollmann et al. 2015). Even when fishing pressure is reduced, over-fished cod sometimes do not recover from low densities (but not always; more on this below).

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[2] A set of parts interacting mechanistically, or as a network.

[3] Hellige (2019) adds: In 1940, Paul L. Errington had "introduced both the resilience notion and the 'threshold concept' into the ecosystem discourse, as an independent approach to the 'carrying capacity' … anticipating views that are often assigned solely to Holling … Resilience became a corridor for the intensity of use of the natural productivity and a research instrument for optimizing ecosystem services. [T]he key person in this paradigm shift, C.S. Holling, … was the first to integrate them, from 1965, in several phases to obtain a closed system (that is, process model) and integrated strategy concept for resource management. Through this work, he became one of the conceptual founders of ecological economics, which to a great degree has shaped the socio-ecological – and even the general – understanding of resilience up to the present day."

[4] Wikipedia: from the mathematical field of dynamical systems, an attractor is a set of numerical values toward which a system tends to evolve, from a wide variety of starting conditions.

Unlike physical systems, whose responses to stress are predictable and can be tested, ecosystems are usually too unpredictable to be 'engineered.' Mechanisms of ecological regime change can be understood, but typically only in retrospect. The mechanism usually involves direct and indirect effects of ecological processes and properties that are familiar – such as predation, competition, apparent competition, time lags, and refuge effects – but are operating under unusual or unprecedented stressor combinations and intensities. In the Baltic cod system cited above (Mollmann et al. 2015), the causal mechanism preventing recovery from overfishing was ultimately fathomed, and it turned out to be intricate: the cod's fish prey, released from predation, lived longer, grew larger, and outcompeted juvenile cod. In another overfished cod population in the Gulf of St. Lawrence, predation by a growing population of grey seals (*Halichoerus grypus*) was found to be the principal factor preventing recovery (Neuenhoff et al. 2018). With so much resting on contingency, causality of regime change in each system is likely to be unique. Understanding the mechanisms of ecological resilience and regime change typically requires close familiarity with, and detailed monitoring of focal systems (Maciejewski et al. 2018).

Key concepts, therefore, were that ecological systems can exist in more than one locally stable state, not all of them desirable (useful to humans), but each likely to exhibit some resilience to change or reversion. Most important, if system resilience can be exceeded, it can also be enhanced.

Social-ecological systems

Despite Holling's original foresight[5], and considerable effort since, the intrinsic unpredictability of ecosystems impeded development of a formal theory of ecosystem resilience (theory exists, but largely for *metaphors* of resilience; e.g. Scheffer et al. 2015). It did not impede exploration of how the concept may be usefully applied to ecosystems and their management, quite the reverse. Unfettered by formal theory, elaborations of the concept escalated in recent decades. Initial focus on ecological systems disturbed by humans expanded to coupled 'human-ecological' or 'social-ecological' systems with humans defined as the beneficiary (as in *the capacity of a social-ecological system to sustain human well-being in the face of change*; Biggs et al. 2015, Folke et al. 2016). Many saw social-ecological systems

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[5] Further quotes from Hellige (2019) show how much of our current approach to ecosystem recovery was already apparent in Holling's thinking: "Holling's "famous [1973] article 'Resilience and stability of ecological systems' … signaled the reorientation towards the development of a scientific, planning and management concept for a strategic linkage of the resilience of ecological and social systems … The aim was to create a 'resource science'… and a 'new science of ecological management/engineering'…, which aimed at giving recommendations to companies and governmental and societal decision-makers: 'We offer, as an alternative, the process of adaptive environmental management and policy design, which integrates environmental with economic and social understanding at the very beginning of the design process, in a sequence of steps during the design phase and after implementation'.

…"For use in planning and management, the resilience framework was operationalized by means of dynamic models, ecological indicators, approaches to measurement concepts and standards for the evaluation of economic and social costs and the efficiency of environmental protection measures… [T]he socio-ecological system design was intended to work towards ensuring that future events could be absorbed 'in whatever unexpected form they may take. 'The resilience concept' he envisioned in the face of unexpected perturbations, 'provides a way to develop a planning framework that explicitly recognises the area of our ignorance rather than the area of our "knowledge."'

as central to resilience: "people embedded in and interacting with the biosphere in multiple ways to shape ecosystems at local to global scales" (Parsons and Thoms 2018; see also Colding et al. 1998). Indeed, the resilience discourse only makes sense if human behavior and impacts comprise most of the calculus. Social-ecological systems were seen to behave as 'complex adaptive systems'[6] because they can self-organize, are characterized by nonlinear dynamics, and adapt in response to changing conditions (Gunderson et al. 2012). In social-ecological systems, regime shifts became *long-lasting…changes in the structure and function of social-ecological systems that occur abruptly relative to the temporal dynamics of the system* (Scheffer and Carpenter 2003). In some later conceptions, however, regime shifts were not a necessary feature of resilience. Change was seen as an inherent characteristic of social-ecological systems, and maintaining useful functionality in the face of change as the principal challenge (Biggs et al. 2015). It is worth noting that inclusion or not of regime shifts in the conception of resilience amounts to a substantial difference. Since such contrasts are not uncommon in resilience thinking, it is always important to be aware of context and assumptions.

An adaptive explosion of resilience concepts

In recent decades, resilience concepts and applications have proliferated, not only within social-ecological systems, but to other systems as well. Google Scholar citations to 'social-ecological resilience' increased from 6 between 1995-1999 to 5,430 between 2015-2019. Several volumes on the subject were published, some by organizations dedicated solely to 'resilience thinking' (e.g. the Resilience Alliance https://www.resalliance.org/). The Resilience Alliance was influential in defining the resilience perspective held by the Stockholm Resilience Centre (https://www.stockholmresilience.org/), which focuses on social-ecological systems. Definitions of resilience also multiplied, both within and among systems (Table 1). For example, the Stockholm Resilience Centre defines resilience as *the capacity to deal with change and continue to develop* (Schipper and Langston 2015). Béné et al. (2013) embellished their resilience definition to emphasize desirable system properties (underline added): *the capacity of a system to absorb shocks and disturbances and to catalyze renewal, adaptation, transformation, and innovation*.

Table 1. Some commonly used definitions of resilience in different systems (from Quinlan et al. 2016).

System	Definition	Emphasis	Key references
Ecological	A measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables	Buffer capacity, withstand shock, persistence, robustness	Holling (1996)
Engineering	System's speed of return to equilibrium following a shock	Return time to recover, efficiency, equilibrium	Pimm (1984)
Social-ecological	(i) Amount of disturbance a system can absorb and remain within a domain of attraction; (ii) capacity for learning and adaptation (iii) degree to which the system is capable of self- organizing	Adaptive capacity, learning, innovation	Carpenter et al. (2001)
Social	Ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change	Social dimensions, heuristic device	Adger (2000)
Development	Capacity of a person, household or other aggregate unit to avoid poverty in the face of various stressors and in the wake of myriad shocks over time	Vulnerability, robustness	Pasteur (2011) and Barrett & Constas (2014)
Socioeconomic	Socioeconomic resilience refers to the policy- induced ability of an economy to recover from or adjust to the negative impacts of adverse exogenous shocks and to benefit from positive shocks	Economic response capacity	Mancini et al. (2012)
Community	A process linking a set of adaptive capacities to a positive trajectory of functioning and adaptation after a disturbance	Adaptive capacity, disturbance, social	Norris et al. (2008)
Psychological	An individual's ability to adapt to stress and adversity. Resilience is a process and can be learned by anyone using positive emotions	Coping, adaptation, process	Tugade, Fredrickson & Feldman Barrett (2004)

[6] A system in which a perfect understanding of the individual parts does not automatically convey a perfect understanding of the whole system's behavior (from Wikipedia).

The common-sense principle that benefits can accrue from making the desired state of a system more resilient to challenge and change has been widely applied to managed systems of all types. This includes physical systems, such as infrastructure, as well as less predictable systems, such as emergency and public health systems, and business management systems (e.g. Martin-Breen and Anderies 2011), to list a few. Applied to social-ecological systems, resilience has become “a way of thinking about sustainability and stewardship, an approach to living with, managing, and adapting to change, complexity, and uncertainty” (Parsons and Thoms 2018).

Perspectives

Such expansive growth did not come without reservations and criticism. The mutability of meaning and interpretation was seen by some as a major weakness. By the early 2000s, skeptics charged that resilience was “a relatively poorly defined concept not yet operational for policy and management” (Klein et al., 2003), that had “gained currency in the absence of philosophical dimensions and clarity of understanding, definition, substance” (Manyena 2006). By 2007, the concept of resilience had become “loosely structured in common use, open to interpretation, and only obtaining meaning in a particular context. Resilience had evolved to “a vague and malleable…communication tool across…scientific disciplines” (Brand and Jax 2007). Definitions had become so diverse, a typology was warranted. Brand and Jax (2007) classified and contrasted 10 types of definition, each with sub-classes (see also Winderl 2014). Resilience could refer not only to a *property* (a system’s ability to absorb or recover from disturbance without changing state), but also to an *approach* to managing social-ecological systems. More recently, Tanner et al. (2017) highlighted the multiple and sometimes conflicting ways in which resilience is interpreted.

Perspective on this sprawling diversity is aided by a few observations. First, throughout its growth, the core tenet has remained deceptively simple: for desired states of any system, the more resilient the better. Second, a radiation of approaches intended to enhance resilience was inevitable, because one approach (and definition) could not fit all systems. Third, much of this growth amounted to exploration of the principle’s breadth, depth, and potential. Given that any part of any system can be made more resilient, the potential is essentially limitless. Accordingly, the breadth of resilience applications has become expansive, and is still growing.

Fourth, the depth and validity of ‘resilience theory’ remain problematic, or at least unconfirmed. For example, despite nominal focus on social-ecological systems, Olsson et al. (2015) showed that resilience has thrived in ecological and environmental sciences but not in social sciences. They offered three reasons why resilience “is not attractive to nor easily integrated with social science thinking”: (i) the ontological presupposition [in resilience but not social theory] to see reality as a system with equilibria, feedbacks, and thresholds; (ii) the principle of self-organization [in resilience] overshadow[s] agency, conflict, and power[7]; and (iii) the notion of function [is] foundational to resilience theory [but has] lost its centrality in the social sciences.” This highlights a fundamental dislocation between ecological and social systems theory that warrants scrutiny.

[7] A conflict arising when people (the agents), entrusted to look after the interests of others (the principals), instead use the authority or power for their own benefit…It is a pervasive feature of practically every organization whether a business, church, club, or government. Modified from: http://www.businessdictionary.com/definition/agency-problem.html.

An example is provided by ‘transformative governance,’ a leading edge in the development of resilience thinking. Chaffin et al. (2016) described it as “an approach to environmental governance that has the capacity to respond to, manage, and trigger regime shifts in coupled social-ecological systems (SESs) at multiple scales. The goal of transformative governance is to actively shift degraded SESs to alternative, more desirable, or more functional regimes by altering the structures and processes that define the system. Transformative governance is rooted in ecological theories to explain cross-scale dynamics in complex systems, as well as social theories of change, innovation, and technological transformation. Similar to adaptive governance, transformative governance involves a broad set of governance components, but requires additional capacity to foster new social-ecological regimes including increased risk tolerance, significant systemic investment, and restructured economies and power relations.” If the ‘social theories of change’ that are foundational to transformative governance have been superseded by advances in the social sciences, validation of resilience theory awaits reconciliation with those advances. (See Stone-Jovicich 2015, and Stone-Jovicich et al. [2018], who introduced a series of papers on this topic; also see Biesbroek et al. [2017], on how the field has largely been unsuccessful in capturing the complexity of governance processes, in particular cause-effects relationships.)

While these critiques have not slowed the rising tide of resilience thinking, they highlight that much of resilience thinking is not founded on consistent and substantiated theory.

Enhancing social-ecological resilience

Foregoing sections cover some of the history and theory of resilience, but this section turns to its most important aspect: practical application. Until the Anthropocene, attributes such as prey switching by predators (e.g. Post et al. 2000, Campbell and Butler 2010), and portfolio effects among populations (e.g. Griffiths et al. 2014) conferred resilience on ecological systems over evolutionary time. Today, ecological systems are changing rapidly in response to novel stressors imposed by humanity (they are sometimes referred to as ‘novel ecosystems’[8]). The persistence of valued ecosystem components will depend largely on the extent to which their resilience can be retained, recovered, and enhanced. This is not easy. Recall that enhancing resilience entails not just managing complex systems (which are by definition hard to predict[6]), but managing *an emergent property* of complex systems. Accordingly, it would seem prudent to act on only the most robust expectations of how a focal system will respond.

Theory and practice are contrasted in Parsons and Thoms’ (2018) account of how resilience has been operationalized in river systems. They say resilience science “is about the complexity of systems and their resilience, adaptation, and transformability in an uncertain and changing world. Many applications of resilience science exist…all of which attempt to develop resilience-led solutions to a range of problems characterized by complexity, uncertainty, and multiple actors.” A wide-ranging discourse on how resilience of social-ecological systems can be enhanced under uncertainty was distilled into seven generic principles by the Stockholm Resilience Center (Simonsen et al. 2015 refers to an entire volume; its summary is available online, and in the attached collection of papers).

[8] Novel ecosystems are anthropogenic landscapes that cannot be returned to their original ecological status (from: Collier 2015)

The titles of the seven principles capture their intent, and they were sorted according to their principal areas of influence into an instructive 2x2 matrix by Quinlan et al. (2016; reproduced in Figure 1). This helps to show how the task can be spread among multiple actors.

Figure 1. The Stockholm Resilience Center's seven principles for building resilience in social-ecological systems, arranged (after Quinlan et al. 2016) as a matrix separating the focus of management (vertical axis) from system attributes (horizontal axis).

Management and Governance of the Social Ecological System	6. Broaden participation 7. Enhance polycentric governance	4. Foster complex systems understanding 5. Encourage learning and experimentation
Social Ecological System	1. Maintain functional and response diversity 2. Manage connectivity	3. Manage slow variables and feedbacks
	System Structure	**System Dynamics**

Many authors agree that resilience enhancement in a given context should begin with specific answers to the questions *Resilience of what? To what? And for what purpose?* (e.g. Carpenter et al. 2001). It also helps to be specific about the target system or systems, and to ensure that all relevant systems are considered. Focusing on community resilience, for example, Helfgot (2018) argued that the questions *Resilience for whom? By when?* should also be addressed, to ensure that goals are commensurate. In effect, this is an appeal to ensure that, if the goal is to enhance (say) social-ecological resilience, outcomes should account perspectives and interests of *all* affected communities (see National Academies of Sciences, Engineering, and Medicine 2018).

In *Resilience Practice,* Walker and Salt (2012) divided practical resilience enhancement into three steps (quoted from Parsons and Thoms 2018). "First, *describing the system* involves bringing together stakeholders to determine the components that make up the system and how they are connected. Second, *assessing resilience* investigates the dynamics of the system by evaluating specified resilience (alternative states and thresholds), general resilience (diversity, modularity, feedbacks, openness, and capital), and transformability (options for change). Third, *managing for resilience* involves the development of an adaptive management and adaptive policy program in which interventions are considered as experiments." The book complements a set of workbooks intended to guide resilience assessment, produced by the Resilience Alliance (2010). Also see Quinlan et al. (2016) for a good description of the rationale for and process of resilience assessment.

Actions intended to enhance resilience can be more focused and specific when change is predictable. Climate change is an obvious example, given that temperature, ocean pH, sea level, etc. will change in predictable directions (population growth and its corollaries provide another example of predictable change). Timpane-Padgham et al. (2017) reviewed the literature on biological, chemical, and physical attributes that confer resilience to climate change in ecological systems. From 170 articles, 45 attributes were identified that confer resilience at five levels (individual, population, community, ecosystem, and 'processes') via six principal mechanisms (connectivity, biological diversity, adaptability, habitat variability and condition, presence of refugia or support areas, and natural disturbance history). They provided a decision-support tool "to assist restoration practitioners in identifying appropriate resilience attributes to measure and monitor within particular systems".

Resilience enhancement is rarely prescriptive. While much can and should be learned from approaches designed for other systems, strategies must be individually tailored to each system. The process requires collaborative participation by those familiar with the system, and with experience in designing resilience applications. Success will depend on their creativity. It is likely to be a recurrent and adaptive process, improving over time. It should also be a measured process.

Measuring and monitoring resilience

As in other facets of ecosystem management and recovery, best practice for resilience enhancement entails monitoring of progress indicators. Given that resilience is an emergent property of complex systems, however, it is rare that resilience itself can be measured. Rather, surrogate variables are usually identified, along with conceptual models of how they enhance resilience (theories of change).

Scheffer et al. (2015) reviewed quantitative approaches that have been used to monitor ecological resilience, focusing on univariate indicators of change in the dynamics of focal systems over time or space (e.g. characteristic changes in variance, kurtosis, or autocorrelation at lag 1 within time series; see the list provided in Table 1 of Scheffer et al. 2015; see Carpenter et al. 2011 for examples). For example, recovery following perturbation often becomes characteristically slower when a system approaches a tipping point to a different regime, a phenomenon known as 'critical slowing down.' This feature raises the potential for identifying 'early warning' indicators of regime change. Monitoring such changes typically demands long-term records sampled at temporal and spatial scales relevant to the dynamics of the studied system (i.e. requires a lot of data). That such patterns reveal changes in resilience (as opposed to some other trait) is not always clear, but is more likely if multiple indicators show similar patterns (i.e. requires a lot of analysis). However, using laboratory yeast populations, Dai et al. (2015) showed that indicators of critical slowing down can become unreliable when multiple environmental drivers change simultaneously. Gsell et al. (2016) found early-warning indicators of critical transitions to be unreliable in long-term data sets of five freshwater ecosystems that have experienced sudden, persistent transitions, and for which the relevant ecological mechanisms and drivers are well understood.

These studies point to limitations of univariate indicators for detecting change in ecosystem resilience. Eason et al. (2016) tested a multivariate approach to detect critical transitions in ecosystem dynamics based on Fisher's Information index (or FI; see Ahmad et al. 2016 for a step-by-step example on how to compute FI). Using published time series, Eason et al. (2016) found that FI tracked changes in ecosystem dynamics (in this case: phosphorous concentration in a model lake) better than univariate indicators. Again, large (multivariate) data sets and long time series are needed to implement this approach, for which affirmation awaits additional case studies.

Quinlan et al. (2016) summarized approaches designed to assess and measure resilience for (mostly) social-ecological systems (their Table 2). They found that "resilience assessment and measurement can be complementary. In both cases it is important that: (i) the approach aligns with how resilience is being defined, (ii) the application suits the specific context and (iii) understanding of system dynamics is increased." They also cautioned that "measuring and monitoring a narrow set of indicators or reducing resilience to a single unit of measurement may block the deeper understanding of system dynamics needed to apply resilience thinking and inform management actions." Hills et al. (2015) provided guidelines for tracking and reporting changes in resilience of components of agricultural programs.

Measuring resilience has probably advanced furthest in the context of community disaster preparedness (judging by the number of reviews, e.g. Winderl 2014, Bahadur et al. 2015, Schipper and Langston 2015).

Created largely by international development agencies and NGOs, 'resilience measurement frameworks' (RMFs) have been defined as *the systematisation of resilience concepts and components into schema to guide efforts aimed at measuring, evaluating, testing and analysing the results of processes to build resilience* (Bahadur et al. 2015). These reviews are useful for our purposes to the extent that RMFs designed for development applications may guide resilience enhancement design for recovering social-ecological systems.

Bahadur et al. (2015) reviewed 43 RMFs, and found them to be almost too diverse to compare. Some measured system *assets* conferring resilience, others measured system *processes* that lead to resilience. "Of those that measured assets, most focused on one or more of the five sets of 'capitals' that make up the Sustainable Livelihoods Framework: human, social, natural, physical and financial (Krantz, 2001). Frameworks emphasising processes tended to suggest changes that are required in policies, protocols, institutional structures, organisational changes and social/political/governance conditions in order for a system to be resilient. Most frameworks underlined the importance of both." For their comparison, Bahadur et al. (2015) assessed each framework on the basis of five attributes (Box 1).

Box 1: The five attributes used by Bahadur et al. (2015) to assess Resilience Measurement Frameworks

1) The degree to which the framework aligned with conceptual understanding of 'resilience thinking' as a way of gauging their internal coherence and rigor.
2) The attention paid to weighing trade-offs between human well-being and environmental services, by acknowledging the ways in which conditions of society (such as human health and livelihoods) may come at the cost of environmental services.
3) How well a framework measured the ability of a system to:
   a) minimize impact of shocks and stresses (its absorptive capacity),
   b) develop alternative strategies of dealing with shocks and stresses based on changing circumstances (its adaptive capacity),
   c) enable structural/systemic change to reduce risk sustainably (its transformative capacity).

   The authors noted that it was often "not clear how well current approaches to measuring resilience lend themselves to gauging these capacities."
4) The extent to which resilience measurements are sensitive to issues of scale, in particular, how well proposed metrics capture the manner in which resilience is being enhanced *at different scales*.
5) How well qualitative vs. quantitative measures of resilience perform, given known pitfalls of quantification, beyond the mere paucity of data. Levine (2014) pointed out "problems with deploying the concept of 'thresholds', difficulties in determining the minimum conditions for resilience, issues of time, scale and geographic scope, and the relationships between risk, resilience and adaptive capacity. In the context of quantification, '...resilience is not a single ability' but rather, 'People are resilient to different degrees depending on the threat or risk being discussed, and in coping with any problem people may rely on many different abilities,' therefore, a static and numerical measure of resilience is unhelpful at best and harmful at worst (Levine, 2014).'"

In their review of 17 frameworks, Schipper and Langston (2015) fashioned assessment criteria using as a starting point Rodin's (2013) five characteristics of resilient systems (Aware, Diverse, Self-Regulating, Integrated, and Adaptive). They ended up with three criteria that covered key 'dimensions' of resilience: *Learning* (about threats faced, and assimilation of lessons into preparedness and recovery), *Options* (to modify behavior, for example, having alternative sources of income, or ability to grow different crops), and *Flexibility* (to maintain opportunity to utilize options). While Schipper and Langston (2015) found that most of the frameworks embraced all three of their assessment criteria, like Bahadur et al. (2015), they found the frameworks themselves too diverse to compare, because “each framework is strongly influenced by its conceptual entry point.”

The prevalence of RMFs in the development sector reflects their earlier adoption, and greater conviction that measuring resilience is worth the effort, compared to the recovery sector. The intricacy of RMFs reflects the complexity of measuring resilience, and the diversity of plausible approaches attests to little consistency or convergence in design. The reviewers’ apparent disappointment of this is perhaps surprising, given that, like definitions of resilience, one measurement framework does not fit all – in fact it only fits one – and each must be tailored precisely to each unique focal system.

In a recent example of a resilience measurement framework designed for biophysical systems, Goodin et al. (2018) developed resilience indicators for five terrestrial and marine ecosystems in the northern Gulf of Mexico. For this framework, Holling’s (1973) definition of resilience was interpreted to correspond to *ecological integrity…the degree to which, under current conditions, the structure, composition, function, and connectivity of an ecosystem corresponds to reference conditions and is within the bounds of natural or historic disturbance regimes*. Goodin et al. focused on ecological resilience as *a measure of the persistence of systems and their ability to maintain ecological integrity and provide ecosystem services while absorbing changes and disturbances*. Their “Ecological Resilience Framework…integrates information on ecosystem drivers, structure and function and ecosystem service provision to make recommendations for a set of ecosystem indicators that should be monitored to assess ecosystem resilience.”

As a guide for designing resilience measurement frameworks for social-ecological systems, two things are worth noting about the framework of Goodin et al. First, a great deal of collective expertise was required (there were 16 authors of the report, which emerged from 8 working groups and 3 workshops). Second, in a world where, increasingly, “history is an unreliable guide for decision making”[9], the utility of ecological integrity as a resilience definition may be short-lived. As Karieva and Fuller (2016) observed “Human activity is dramatically shaping all of Earth’s natural systems, producing unprecedented challenges for people and nature…mak[ing] management difficult. …[R]estrictive and often unspoken mental models of ecological and environmental science are robbing…managers and their institutions of the flexibility required to respond to the Anthropocene’s uncertain changes. The three most profound mental traps are: (1) an undue emphasis on historical reference points; (2) an ecological concept of resilience that fails to reckon with the Anthropocene’s dynamism; and (3) a precautionary bias against new technologies and dramatic interventions. Caught in these mental traps, environmentalists too often reject entrepreneurial experimental approaches that could make them more relevant to policymakers, corporations and other institutions that seek to respond more proactively to impending disruption.” Point taken, but without historical references, managing the resilience of novel ecosystems will be even more onerous.

[9] A. Pershing, quoted in https://www.ecowatch.com/ocean-heat-waves-2639711739.html

Resilience of Puget Sound recovery

Most of the Puget Sound lowlands qualify as a novel ecosystem (see footnote 8). Many components of marine and freshwater systems in the region are candidates for regime change, although data are generally lacking to confirm this. Examples include stream benthic invertebrates at some locations, marine basins in which forage fish have declined and jelly fish increased (Greene et al. 2015), some threatened salmonid populations, the southern resident orcas, and systems with increased frequencies of algal blooms. 'Desired states' for most of these components and habitats have been described (e.g. as indicator targets) in numerous recovery strategies.

Attendance to resilience enhancement in Puget Sound is patchy, however. Gaydos et al. (2009) listed principles for designing healthy coastal ecosystems like the Salish Sea that included resilience enhancement. Presidential Executive Order 13653 (November 1, 2013) required that provision be made in federal programs for climate change, including resilience planning. This EO was rescinded on March 28, 2017, but most federal plans still heed that requirement, including recovery plans for threatened and endangered species (see Smith et al. 2018). In 2015 Puget Sound and the Snohomish Watershed received funding from the Resilient Lands and Waters Initiative (2016) to, among other goals, support local resiliency planning, improve stakeholder awareness about resilience, and increase agricultural resilience. Resilience is also covered in best-practice guidelines for federal programs, including forestry (Luce et al. 2012), land use and building codes (EPA 2017), and engineering (USACE 2016). Eelgrass resilience in Puget Sound has been investigated for more than a decade, and found to depend partly on landscape conditions (Thom et al. 2012), with geographic scale playing a dominant role in regional population dynamics (Shelton et al. 2016).

Beyond these, however, explicit attention to resilience may be under-attended in Puget Sound recovery efforts. This is not uncommon. Juan-García et al. (2017) reviewed studies on resilience in the (global) wastewater treatment sector, addressing metrics and actions intended to increase resilience. They found that "to date, no framework for resilience assessment is complete, comprehensive or directly applicable to practitioners."

Of the seven 'completed' Implementation Strategy narrative documents available at https://www.psp.wa.gov/implementation-strategies.php, the term resilience appears in all but one (*Shellfish Beds*), mostly in the context of climate change/sea level rise or 'communities'. Most refer to enhancing resilience, but only implicitly, or state that resilience enhancement will be added to the strategy in future (also see Puget Sound Partnership 2017). To be clear, resilience will likely be somewhat enhanced incidentally, if the goals of these strategies are met. However, the focus here is on actively enhancing resilience for its own sake. Only in the *Shoreline Armoring* IS was resilience enhancement treated explicitly. This is partly because shoreline stressors are so predictable (as impacts of rising sea levels), but also because the authors were well-versed in 'resilience thinking' (Box 2).

It is never too late to add resilience enhancement to a recovery strategy, in fact this can best be done after priority strategies and actions have been defined. This review has attempted to affirm that, while we can learn and borrow from others, resilience enhancement must be tailored explicitly to each application. It would be appropriate for resilience enhancement designs to be added (with indicators) to all Implementation Strategies – or preferably to their syntheses – as part of their adaptive management. In response to a request for input to this briefing, Dr. Julie Watson (Washington Department of Fish and Wildlife, and member of the Habitat Strategic Implementation Lead team), contributed a set of examples in which resilience could, and probably should, be enhanced in the recovery strategy for Puget Sound (reproduced here in Appendix 1).

There is also potential for some currently-monitored indicators of Puget Sound recovery to serve as resilience indicators as well, but a complete list, and the mechanisms by which our current indicators enhance resilience, would need to be made explicit. Conceptually, the assessment and design of resilience indicators should build on explicit theories of change, just as is done for progress indicators. Thus, steps in the process of developing resilience indicators are similar to those used by Puget Sound recovery planners to develop indicators of recovery progress.

Ideally, all participants in Puget Sound recovery would become practiced at enhancing resilience. Over time, the result of individuals and groups making small contributions would amount to a substantial cumulative improvement. Attending to resilience is often seen as an additional cost or as requiring extra effort. Juan-Garcia et al. (2017) saw it as "a means to overcome project uncertainty that could unlock new opportunities for investment." Navigating a path through 'resilience thinking' becomes easier once one relaxes any expectation of consistency (among systems), embraces diversity in definition and approach, and fixates on the outcome (greater resilience of desired states). One experienced practitioner of applied resilience thinking said "when forced to sit down and think through the problem of how to enhance system resilience, one is always surprised at what can be achieved"… or words to that effect.

Box 2: Examples of resilience enhancement in the *Shoreline Armoring* Implementation Strategy

(with thanks to Dr. Jennifer Griffiths and Dr. Julie Watson, Habitat SIL, and Nicole Faghin, Washington Sea Grant)

- A vulnerability assessment was conducted for each of the four recovery (sub-) strategies in the IS, envisioning how forecasted changes to sea level, storm surge, and extreme precipitation could affect their successful implementation. Both existing and new tools, regulations, and programs were identified that could help to abate negative impacts of climate change. (From Appendix IV.a: *Process to develop the Shoreline Armoring Implementation Strategy*. Part 6.1 Assessment Exercise.)

- The *Habitat Strategic Initiative* funded a project with *Friends of the San Juans*, raising awareness among homeowners about sea level rise, and how removing, setting back, or softening armor may help improve resilience to climate change. That project aligned with the education/incentives strategy within the *Shoreline Armoring* IS (see also: https://sanjuans.org/sealevelrise/).

- Further resources for resilience enhancement include:
  - for nearshore see MacLennan et al. 2013, Raymond et al. 2018, and Miller et al. 2018,
  - for salmon see Herbold et al. 2018,
  - for riparian zones as connectivity corridors see Fremier et al. 2015,
  - for system resilience to bivalve mortality see Guillotreau et al. 2017,
  - for wildlife in the Cascades see Halsey 2017,
  - for coastal habitats see Basso et al. 2017,
  - for urban coasts see Cryan 2018,
  - and for highly modified landscapes see Beller et al. 2018.

Conclusion

We tend to approach restoration as a process of tweaking specific aspects of our environment, behavior, policy and practice. Phasing out brake linings containing copper to enhance salmon survival provides a good example (McIntyre et al. 2012; Chapter 70.285 RCW). This approach assumes that the sum-of-all-tweaks will be sufficient for targeted ecosystem components like salmon to thrive once again. An alternative view holds that we must dramatically alter our way of life, that only fundamental changes will suffice to achieve our recovery goals – in governance, economies, culture, living, you name it. The probable truth is that both lie on a continuum, and solutions will vary depending on context. Resilience thinking offers a way to consolidate advances made towards recovery by the former, as well as identify and facilitate the more fundamental changes that are required by the latter.

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Appendix 1

How resilience may be added to the strategy to recover Puget Sound
(contributed by Julie Watson, on behalf of the Habitat Strategic Initiative).

1. **Resilience of Puget Sound as a Social Ecological System, focusing on the ecosystem: What do protection, restoration, and "recovery" mean from a resilience standpoint?**
   a) This question should be addressed as part of the Vital Sign refresh, Vision 2020 (what is our ideal future state?), and big-picture recovery system (Comp Plan) discussions.
   b) E.g. process-based restoration targets, adaptive governance systems.

2. **Resilience of Puget Sound as a recovery community: How do our environmental communities and institutions adapt to changing knowledge and conditions?**
   a) This question is also a Comp Plan level discussion, including the structure of our Boards and RCWs, including "living" nature of the Action Agenda + content of the Action Agenda.
   b) E.g. What happens when orcas start dying and the governor makes it a top priority? Can our planning and prioritization adapt to social and ecological shifts such as sudden media, public, and political interest in a certain topic?
   c) E.g. What happens when leadership changes? Or if Washington Environmental Council or The Nature Conservancy change priorities drastically? Or if NEP loses funding?

3. **Resilience of the Implementation Strategies (content): How do we ensure we are selecting strategies that will work even if conditions change? Or, How do we ensure that our selected strategies will still work if conditions change?**
   1. This question is <u>very appropriate for IS Leads, ISCTs, and IDTs</u> to address as part of the IS development or adaptive management (AM) process
   2. As part of the development process, during the strategy selection phase and results chain creation and review:
      - Are any of these strategies only going to work in very specific circumstances? E.g. if the same leaders stay in place, if the same people keep running the same organizations, if the same funding decisions are made
      - Are any of these strategies that are hardier, that can work in more situations or keep working without needing a lot of attention and care? (Cactus instead of orchids)
      - How can we improve this strategy to make it work or keep working even if things change? What are the key barriers that make this strategy vulnerable?
        - Example: Shore Friendly was a pretty fragile (not resilient) strategy when it depended entirely upon continued NEP funding. Shifts in NEP priorities or the funding process (from LO to SIL) jeopardized the ability of these programs to continue. We (Habitat SIL) identified this fragility of funding as a key barrier and engaged the ECB to address it. Following the workshop and ECB recommendations, the Shore Friendly strategy is being institutionalized with a more promising funding source (ESRP via the Capital Budget—still room for improvement). This increases the resilience of the strategy and makes it more likely that the programs will continue- because of the institutionalization and better funding- even if circumstances and budgets change.
   3. As part of the AM process (could update IS AM worksheet to better address resilience):
      - Have any of our strategies been halted or derailed by changing circumstances? If so, why? What barriers? How do we improve the strategy so that barrier doesn't stop/derail the strategy?
      - Are any of the strategies proving too fragile (too conditional, too finicky) to be implemented? If the strategy is ineffective (and can't be improved to be implementable any time soon), should we replace that strategy with one that can make progress on the VS target in the next 5 years?

4. **Resilience of the Implementation Strategies (as a process): How do we ensure these are relevant, maintained, and used?**
   a) This is a <u>key question for the ISWG</u>, and may focus on the IS guidance, IS lead agreements, ISWG charter, and PSP support capacity
   b) How might we need to improve IS creation or AM process so it works even if staff change?
   c) How do we deal with handoffs of ownership of the strategy, in case certain work groups evolve, disappear, or lose funding to continue the work?
   d) How do we deal with conflicts when an IS lead fails to finish, manage, or advance the utilization of the IS?
   e) How do we disperse the institutional knowledge about the IS process and content (especially throughout the PSP hierarchy) so that decisions (say, PSP agency policy priorities, Science Panel activities, etc.) are in alignment with the recovery system and IS's?