A primer on forest health for SNAMP scientists

Draft submitted for comment/review/revision
Sep 8, 2009
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Disrespect for nature means applying a single approach to forest management and forest harvesting over forests that vary in their ecological characteristics.

Kolb, Wagner and Covington 1994

There is no objective or scientific measure of an ideal forest condition that is uninfluenced by human desires, norms, or needs.

Warren 2007

The terms “healthy forest” and “forest health” are used often in natural resources, yet rarely are they qualified or standardized. The confusion surrounding the term forest health is understandable, as there is no single, scientifically derived definition. However, there are some recurring themes in the literature that create a basis for understanding the many existing definitions.

Cultural values vs. scientific scrutiny

Forest health is not exclusively a scientific concept (Kimmins 1997). Forest health is often defined by the social, cultural or economic values of a specific audience. For example, those with an interest in forest products and sustained local economies may define forest health as a sustainable, actively managed forest that is free of disease, with a diversity of tree species for future product markets (Lankford and Craig 1994). This definition is largely concerned with trees and trees alone. However, an audience interested in maintaining vigorous wildlife populations may insist that the definition be expanded beyond tree health to include the capacity of a forest to maintain viable populations of native species and retain biodiversity of flora *and* fauna (Dellasalla et al. 1995). The first definition measures disease and species diversity of trees, and the second measures wildlife populations. Both definitions of the “forest health” may mean opposite management regimes. Ultimately, forest health becomes a social construct, defined not by an inherent, “scientifically correct” state (Warren 2007) but by variables society considers most important.

Utilitarian vs. ecosystem perspectives

Many definitions of forest health fall under the general term “utilitarian”: a forest is healthy if its condition does not threaten management objectives, current or future (Kolb, Wagner and Convington 1994). While it is easy to diagnose an unhealthy forest under this definition (i.e., a forest is threatening management objectives), the concept can suffer from its own circular logic, where a “forest health” is defined by meeting management objectives, yet “forest health” *is* the management objective.

In contract with anthropocentric utilitarian definitions, forest health has also been defined by specific types and rates of ecological processes- quantitative information. Unfortunately, this definition comes with its own set of management problems; quantitative rates and data are not widely available for many ecosystems (Kolb, Wager and Covington 1994), and there is no gold standard for all rates and processes. Using historical rates and patterns is also tricky. Changing climate and land uses by humans make the selection of the desired parameters difficult, and even if parameters were chosen, it is unlikely that our knowledge of past ecosystem processes is sufficient to design a management regime (Wagner et al. 2000).

Resilience and sustainability

Often in the literature, a forest is considered healthy if is resilient or sustainable. Under this guise, a healthy forest is “one that is resilient to changes” (Joseph et al. 1991); “resistant to catastrophic change and/or ability to recover after catastrophe” (Kolb, Wagner and Convington 1994) and has “sustained ecosystem functioning” (Wagner et al. 2000). This definition is also troublesome because resilience is very difficult to measure. The resilience of a forest remains a relative unknown until exposure to catastrophic disturbance or stress.

Scale

The concept of “forest health” is difficult to apply to landscape-level processes because its origins lie at the individual level. Ecosystem health is a metaphor borrowed from human health (Kimmins 1997) and is problematic when applied to whole ecosystems, just as human health is difficult to apply to whole populations (Raffa et al. 2009). A dead or dying single tree is inherently unhealthy, but a dead or dying stand is more difficult to diagnose. Kolb, Wagner and

Covington (1994) define an unhealthy stand as only unhealthy if the rate of mortality exceeds the capacity for stand replacement, but this may not necessarily apply at a forest or landscape level.

FFEH approach

For the SNAMP project, we have built on the idea that tree survivorship is an essential component of forest health. It is also a parameter that we think we can quantify the impact of landscape treatments at a relevant management scale (i.e., the fireshed). We acknowledge that canopy tree survivorship does not encompass the totality of the forest ecosystem. But at the same time, it is hard to envision classifying any forest as "healthy" with an abundance of dead and dying trees. In short, we are arguing that tree survivorship is a necessary but not sufficient condition of forest health. Determining a sustainable level of tree mortality is an important question but given our BACI design, we have narrowed our question to:

> Does forest management in the treated firesheds significantly shift the tree vulnerability profiles relative to the changes observed in the reference firesheds?

See attached perspective for details.

SNAMP approach

Although forest health is not easily defined and can be problematic under scientific scrutiny, it remains an important link between scientists and non-scientists in communicating shared values from forest management (Kolb Wagner and Covington 1994, Patel et al. 1999). It is likely to be a featured aspect of USFS forest management goals in the future. SNAMP has the opportunity to inform the definition, interpretation, and measurement of forest health. It is important for us to consider how to incorporate the full spectrum of our data, results, and perspectives.

Annotated Bibliography

The following papers provide a basic understanding of the many definitions of "forest health" and surrounding controversies:

Dellasalla, D.A., D.M. Olson, S.E. Barth, S.L. Crane, S.A. Primm. 1995. Forest health: moving beyond rhetoric to restore healthy landscapes in the inland Northwest. Wildlife Society Bulletin 23(3): 346-356

Kimmins, J.P. 1997. Biodiversity and its relationship to ecosystem health and integrity. The Forestry Chronicle 73(2): 229-232

Kolb, T.E., M.R. Wagner, W.W. Covington. 1994. Utilitartian and ecosystem perspectives: concepts of forest health. Journal of Forestry 92(2): 10-15

Lankford, L. 1994. Forest health on nonindustrial private forestland: ecosystem forestry from the ground up. Journal of Forestry 92(2): 26, 28-29

Patel, A., D.J. Rapport, L. Vanderlinden, J. Eyles. 1999. Forests and societal values: comparing scientific and public perception of forest health. The Environmentalist 19: 239-249.

Raffa, K.F., B. Aukema, B.J. Bentz, et al. 2009. A literal use of "forest health" safeguards against misuse and misapplication. Journal of Forestry 107:276-277.

Wagner, M.R., W.M. Block, B.W. Geils, K.F. Wenger. 2000. Restoration Ecology. Journal of forestry 98(10): 22-27

Warren, W.A. 2007. What is a health forest? Definitions, Rationales, and the Lifeworld. Society and Natural Resources 20(2): 99-117

These papers examine forest health in terms of catastrophic fire regimes and pest and pathogen outbreaks:

Filip, G.M., H. Maffei, K.L. Chadwick. 2007. Forest health decline in a central Oregon mixed-conifer forest revisited after wildfire: a 25-year case study. Western Journal of Applied Forestry 22(4): 278-284

Tiedemann, A.R., J.O. Klemmedson, E.L. Bull. 1999. Solution of forest health problems with prescribed fire: are forest productivity and wildfire at risk? Forest Ecology and Management 127: 1-18

Hain, F. 2006. New threats to forest health require quick and comprehensive research response. Journal of Forestry 104(4): 182-186

Steele, R. 1994. The role of succession in forest health. Journal of Sutainable Forestry 2(1/2): 183-190

The following papers each advocate the use of forest health indicators (e.g. presence of woodpeckers, lichens, ants, etc.):

Drever, M.C., K.E.H. Aitken, A.R. Norris, K. Martin. 2007. Woodpeckers as reliable indicators of bird richness, forest health and harvest. Biological Conservation 141: 624-634

O'Laughlin, J. and P.S. Cook. 2003. Inventory-based forest health indicators: implications for national forest management. Journal of Forestry 101(2): 11-17

Randolph, K.C. and J.W. Moser, Jr. 2004. An evaluation of changes in tree crown characteristics to assess forest health in two Indiana state parks. Northern Journal of Applied Forestry 21(1): 50-55

Stephens, S.S. and M.R. Wagner. 2006. Using ground foraging ant (Hymenoptera: Formicidae) functional groups as bioindicators of forest health in northern Arizona ponderosa pine forests. Environmental Entomology 35(4): 937-949

Thormann, M.N. 2006. Lichens as indicators of forest health in Canada. The Forestry Chronicle 82(3): 335-343

Zarnoch, S.J., W.A. Bechtold, K.W. Stolte. 2004. Using crown condition variables as indicators of forest health. Canadian Journal of Forest Research 34: 1057-1070.

These two papers describe the impacts of certain management regimes on forest health:

Jurgensen, M.F., A.E. Harvey, R.T. Graham, D.S. Page-Dumroese, J.R. Tonn, M.J. Larsen, T.B. Jain. 1997. Impacts of timber harvesting on soil organic matter, nitrogen, productivity, and health of inland northwest forests. Forest Science 43(2): 234-251

Woods, A.J. 2003. Species diversity and forest health in northwest British Columbia. The Forestry Chronicle 79(5): 892-897

A perspective: Forest health and tree mortality in the Sierran mixed conifer forests

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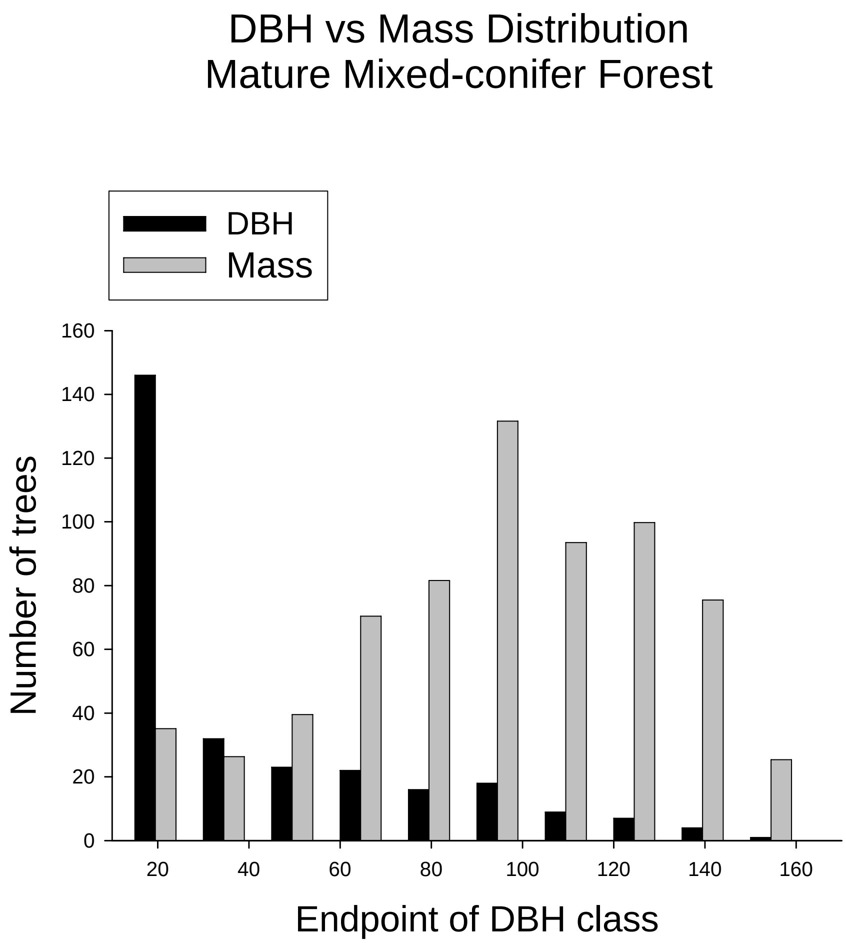
Sep 8, 2009

Premise: The annual survival probability of adult trees in a population is an indicative and quantifiable measure of forest health.

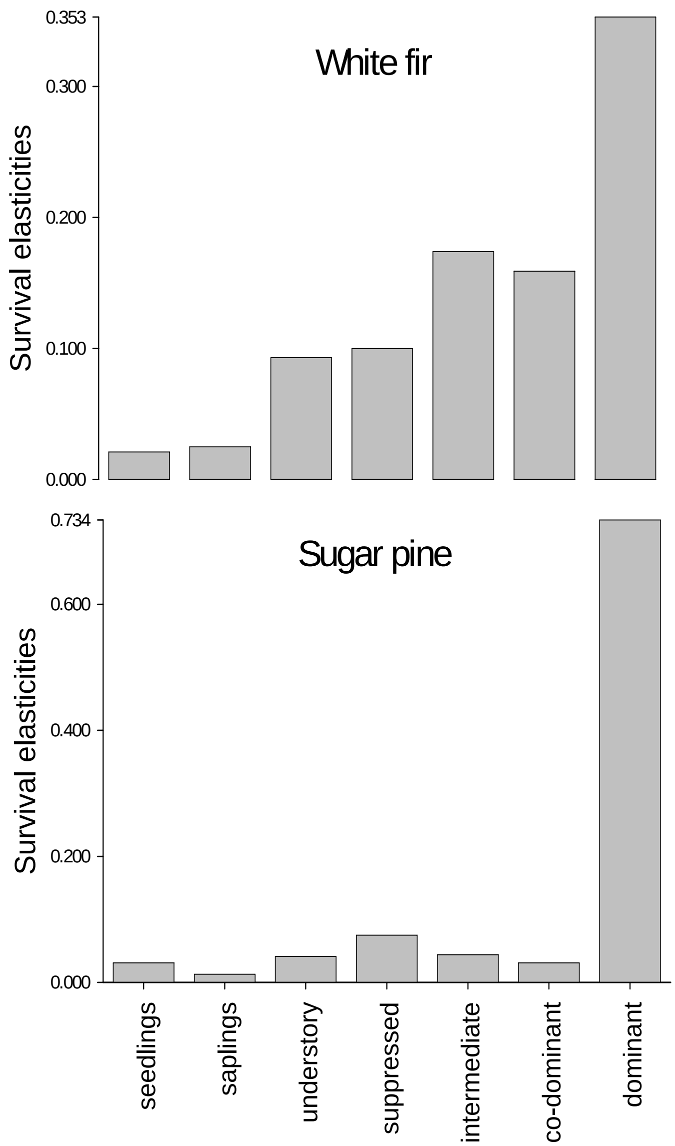
Support

1. Adult trees (dbh >19.5cm) account for the vast majority of forest biomass and are the major engines of energy, water, and nutrient cycling.



2. Tree population growth is most dependent on survival rates of adults.

Survival elasticities for matrix transition models



3. Forest decline is potentially a positive feedback process.

Loehle. C. 1988. Forest decline: Endogenous dynamics, tree defenses, and the elimination of spurious correlation. Vegetatio **77: 65-78.**

4. Minor changes in tree death rates translate into major changes in ecosystem structure and function.

Stepheson, N, and P. van Mantgem. 2005. Forest turnover rates follow global and regional patterns of productivity. Ecology Letters 8: 524-531.

Corollary 1: Any measure of forest health based on tree mortality must recognize key aspects of this demographic process.

Community level implications

Theoretical and applied models of tree mortality share a common perspective. Mortality is divided into two components one predictable and the other stochastic. Estimating the predictable component takes various forms but essentially it is the result of competition. The slower growing or smaller trees are killed as resources becoming limiting and the more vigorous, larger trees co-opt these scarce resources. Familiar implementation include mortality algorithms that depend on the 3/2 power "thinning law" and ones that depend on an inverse relationship between recent tree growth and the probability of mortality. The unpredictable component encompasses all other causes of mortality and is most commonly explained as tree deaths due to rare, abiotic events (lightening strikes, windstorms, soil instability). It is a density independent process in contrast to the strong density dependence in competition mortality. In every implementation I have seen, the predictable component of mortality is the dominant process with the unpredictable component limited to little more than background demographic noise.

Population level implications

The risk of mortality is dynamic and changes over the lifespan of an individual tree. It stands to reason that the drivers of mortality change over the lifetime of the tree. Just about any biotic or abiotic stress can kill a young germinant. In contrast, it often requires a suite of mortality agents acting in concert to kill a mature tree.

Table 1. Demographic information for white fir and sugar pine. Built from BFRS database and BFRS demography information. Values in parentheses are assumed.

Size-Stage	White fir				Sugar pine		
	growth	survival	source		growth	survival	source
YOY	–	0.197	1		--	0.220	1
seedlings	0.045	0.720	2		0.074	0.949	2
saplings	0.040	(0.75)	3		0.35	(0.75)	5,6
understory	0.035	0.943	4		0.022	0.045	4,7
suppressed	0.047	0.962	4		0.038	0.975	4
intermediate	0.023	0.976	4		0.013	0.917	4
co-dominant	0.028	0.976	4		0.064	0.939	4
dominant	--	0.990	4		--	0.983	4
adult fecundity	149 germinants/tree		1		9 germinants/tree		1

Individual level implications (adapted from Das et al. 2007).

Trees are long-lived organisms and like all long-lived organisms (e.g. humans), their prospects for the future depend on their past. The idea that tree death can be a life-long accumulation of injuries (sensu Mangel and Bonsall 2004) was implicit in Franklin *et al*.'s (1987) landmark paper. They presented a conceptual model based on Manion's (1981) disease spiral to characterize the events that eventually lead to the demise of a tree. The key insight was that past events that reduce vigor increase future susceptibility to mortality agents. These mortality agents can include competition, biotic attack, and environmental stress that contribute either independently or synergistically to the death of a tree (Franklin et al. 1987, Keane et al. 2001).

In a broad sense then, mortality can be conceptualized in terms of a cumulative process (Anderson 2000) where the events over the lifetime of an organism influence its likelihood of future survival (Mangel and Bonsall 2004). Temperate trees are particularly amenable to such an approach, as many species record a detailed history of these life events in their annual growth rings. A given tree's growth then can be understood as an integrated measure of the physiological realities that contribute to its likelihood of survival (Kyto *et al.* 1996).

Anderson, J. J. 2000. A vitality-based model relating stressors and environmental properties to organism survival. Ecol. Monogr. **70**:445-470.

Das, A., J.J. Battles, N.L. Stephenson, and P.J. van Mantgem. 2007. The relationship between tree growth patterns and likelihood of mortality: a study of two tree species in the Sierra Nevada. Canadian Journal of Forest Research 37: 580-597.

Franklin, J. F., Shugart, H. H., and Harmon, M. E. 1987. Tree Death as an Ecological Process. Bioscience **37**:550-556.

Keane, R. E., Austin, M., Field, C., Huth, A., Lexer, M. J., Peters, D., Solomon, A., and Wyckoff, P. 2001. Tree mortality in gap models: Application to climate change. Clim. Change **51**:509-540.

Kyto, M., Niemela, P., and Annila, E. 1996. Vitality and bark beetle resistance of fertilized Norway spruce. For. Ecol. Manag. **84**:149-157.

Mangel, M., and Bonsall, M. B. 2004. The shape of things to come: using models with physiological structure to predict mortality trajectories. Theor. Popul. Biol. **65**:353-359.

Manion, P. D. 1981. Tree Disease Concepts. Prentice-Hall, Englewood Cliffs, N.J.

Complications/Opportunities

1. Das et al. (In review. Inferring Process from Pattern: A Biologically-Informed Approach to Studying Tree Mortality. Ecological Monographs) demonstrate that density independent mortality processes account for about half the observed mortalities in an old-growth forest. Clearly the balance between density dependent and density independent processes changes with the development of the forest community.

2. Das et al. (2008. Spatial elements of mortality risk in old-growth forests. Ecology 89: 1744-1756) showed that not all density-independent processes are stochastic. In fact, some can be predicted.

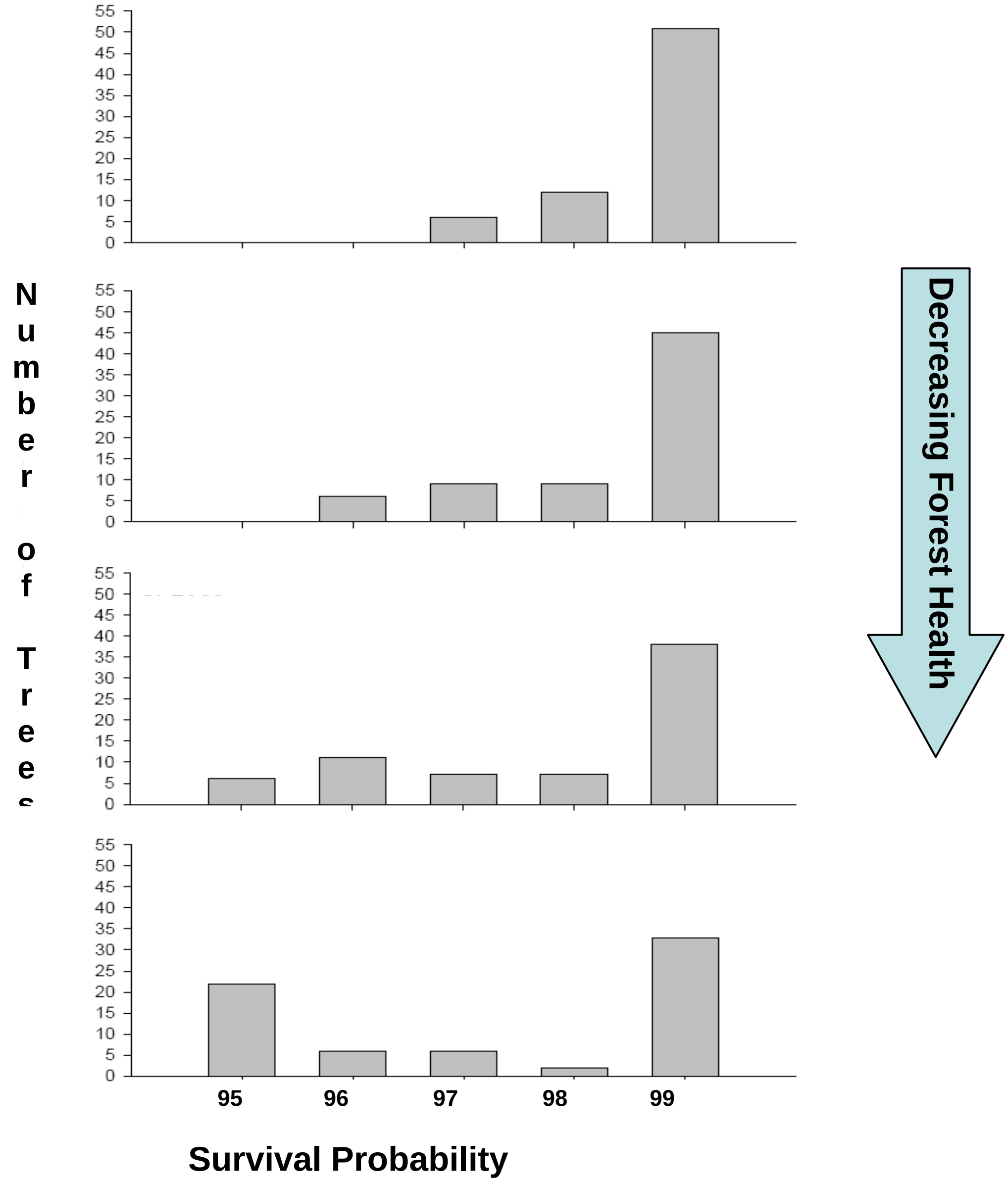
3. Das et al. (2008) also found that the identity of a tree's neighbors mattered to its probability of survival and that these effects were independent of density. For example, a white fir tree surrounded by a given density of neighbors had higher survival if those neighbors were also white fir. In contrast, a pine tree surrounded by a given density of neighbors had lower higher survival if those neighbors were also pine trees.

Corollary 2: The distribution of annual survival probabilities represents the health of the trees in the forest.

Given the complex interplay among community, population, and individual ecologies, the probability of survival will vary among trees in a forest. However the distribution of probabilities represents the status of the forest as a whole. Typically annual mortality rates among canopy trees in mature Sierran forests are < 1%/yr. Thus we expect survival probabilities to be strongly skewed. Most trees will have a very high chance (99% or greater) of surviving. This distribution toward the extremes makes detection of change difficult. Indeed we do not often know we have a declining forest until we start observing increased tree death. Thus our responses, both in terms of management and research, are reactive rather than proactive. However if there were a means to measure the distribution of survival probabilities and a way to detect subtle changes in this distribution, we could enhance both our response time and understanding. We would detect decreases in tree health before trees were dying en masse.

Demonstration: Vulnerability profiles as a measure of forest health.

Battles et al. (2008. Climate change impacts on forest growth and tree mortality: a data-driven modeling study in a mixed-conifer forest of the Sierra Nevada. Climatic Change 87: S193-S213) described an approach to measure changes in forest health by constructing empirically based tree vulnerability profiles (see diagram). Profiles are based on a representative sample of trees where the annual survival probability is predicted using the long term growth record (Das et al. 2007). The sample is then scaled-up to the entire population using inventory information on tree size and species. Repeated sampling is used to quantify changes and a new statistical measure (Menning et al. 2007**.** Quantifying change in distributions: A new departure index that detects, measures and describes change in distributions from population structures, size-classes and other ordered data. Oecologia 154: 75-84) can detect small departures from the status quo.



Challenges

1. Vulnerability profiles require extensive data collection and model development. Practical only in a research context or when forest of interest is of very high value (e.g., giant sequoia groves).

2. Only in pilot stage. First wholesale test is underway as part of the SNAMP project.

3. Predictive equations require long-term growth records and are somewhat sensitive to stand conditions, although we have made progress in calibrating a species model to different conditions.