

Commentaries

Ecosystem Health and Sentinel Species: Adding an Ecological Element to the Proverbial “Canary in the Mineshaft”

The time has come to improve the “canary in the mine-shaft” proverb. At one level, the proverb conveys a clear “cause and effect” message of the value of a health indicator species. At another level, when the proverb is applied to ecosystem health scenarios, the power of the message seems diminished when used to describe outcomes in more complex systems where multiple stressors and cumulative impacts are at play. It is a given that nonhuman proxies for discerning human well-being have been used for human health assessment and evaluation through the ages; ethnography and anthropology are replete with examples. As the field of ecosystem health grapples with evaluation and assessment, it should reassess its utilization of the canaries in the mineshaft concept. At the more basic level, the health indicator species concept should be a pillar of ecosystem health assessment. When marine mammals succumb to emerging infectious diseases and mass mortality events occur, why does this not send a clear message that the marine environment is threatened and that people are equally threatened, especially those people who depend on marine resources?

The weakness of the “canary in the mineshaft” proverb is its simplicity when applied to complex systems. The canary of 19th century British coal mines was utilized outside of its own natural ecosystem. While methane gas was the hazard of concern in coal mines, the hazards in ecosystems are often multiple, cumulative in nature, and undefined. Within ecosystems, the search for canaries must understand the delicate ecological balance that is derived from species interactions. An environmental disturbance can ripple through trophic levels as cascade events, altering abundance and distribution of species. Disease outbreaks may only be a minor manifestation of diminished ecosys-

tem health, while large alterations in predator and prey relationships may be more symptomatic (such as the cod-fish–dogfish trophic imbalance in the North Atlantic or the killer whale–sea otter–kelp–urchin imbalance) (Estes et al., 1998). In the end, the linkage between the impact on a species and that of the ecosystem must be defined and made as clear as possible; otherwise, information discerned by using sentinel species will be confounded and thus useless.

In this issue of *EcoHealth*, a special section of articles is presented to advance the study of identifying and monitoring sentinel species, a form of health indicator species that serve as nonhuman proxies for ecosystem health. Surprisingly, this realm of knowledge is a collection of stovepipe studies of specific species–disease interactions that individually appear to be metaphorical canaries but collectively do not define the health conditions in the mineshaft. As such, the sentinel species concept put forward here attempts to add an ecological component to our old proverb and, as a consequence, improve upon it.

Three convergent themes emerge among the articles in the study of sentinel species: 1) observations of disease manifestations in specific wildlife populations; 2) examination of focal species studies as potential health indicators; and 3) description of ecosystem parameters that impact species health.

This special section includes articles on several concerns related to sentinel species including the importance of marine vertebrates as bioindicators of health in selected marine ecosystems. Jessup et al. illustrate the case of sentinel species using the endangered sea otter (*Enhydra lutris*) in California. The species is in slow and steady decline and serves as a key indicator of the degraded

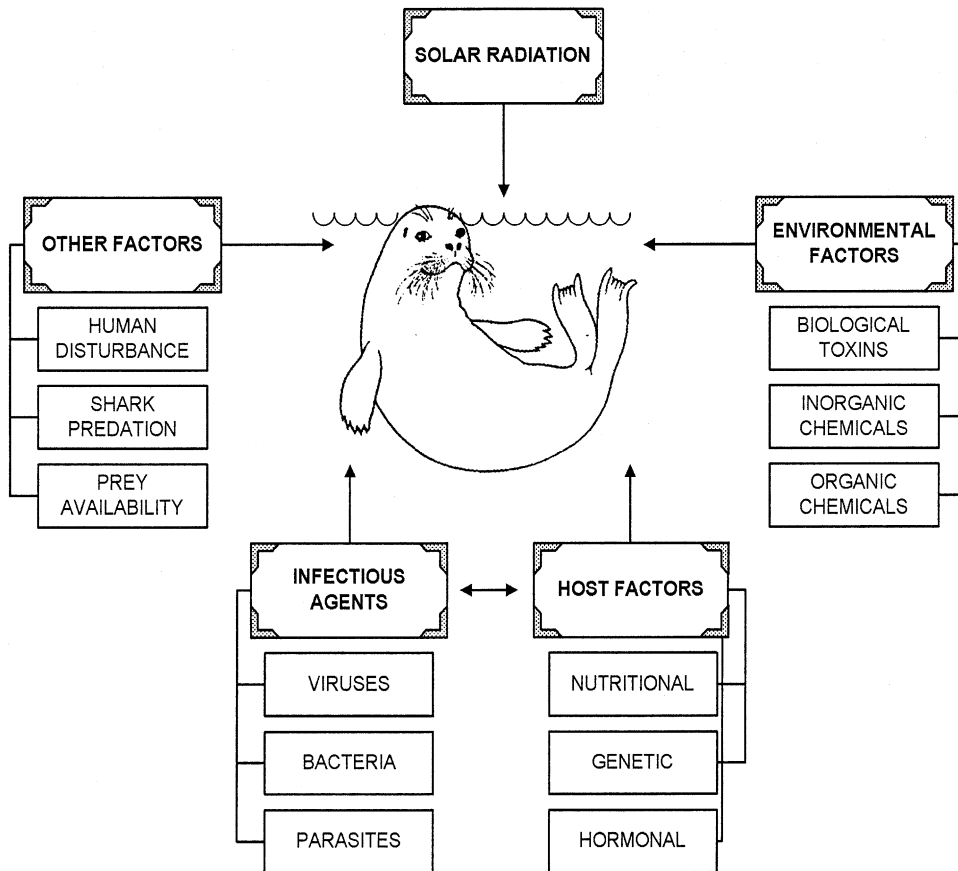


Figure 1. A sentinel species provides the perspectives and methodologies to tease apart the complexity of marine ecosystems. Processes can work in both directions for sentinel species—stressors can impact at both the population biology level and the individual health level. It is necessary to have multiple populations/species to be able to make ecosystem level inferences; we need a portfolio of case studies to address a particular problem. Modified from Aguirre (1991) and Fowler (1987).

California coast; emerging pathogens and pollutants and the decline of prey availability may be the factors causing the population decline. Wells et al. describe the long-term health assessment and monitoring program of several generations of bottlenose dolphins (*Tursiops truncatus*) in the Sarasota Bay ecosystem in Florida. The development of health indicators and techniques to assess the status of sentinel species is fundamental for health assessments from the individual to the ecosystem level. Bonde et al. address the benefits and drawbacks of using the manatee (*Trichechus manatus*) as a sentinel species. Although the manatee's most direct threat is human impact from speedboat use, the species represents a good case study to approach monitoring of sentinel species, including the detection of emerging diseases and pollution and their impact on seagrass bed ecosystems. Burger and Gochfeld discuss the role of seabirds as sentinels and bioindicators of marine pollution, describing case studies on common terns (*Sterna hirundo*) and herring gulls (*Larus argentatus*) with lead in the New York bight and the effects of mercury in fish-eating birds at Barnegat Bay. Finally, Aguirre and Lutz discuss the benefits of using sea turtles as sentinel species, focusing on fibropapillomatosis, a disfiguring

and often fatal epidemic affecting sea turtles worldwide and linked to heavily polluted areas, warm water temperatures, and areas of increased human density along coastal ecosystems.

It is clear with the examples presented herein that the techniques used for ecosystem health assessment and monitoring using sentinel species have just begun to develop. The old proverb may not be useful in the short-term, but as we improve and develop new techniques and build on the "snapshots," species by species and ecosystem by ecosystem, we may achieve a better understanding of the complexity of the marine environment. The sentinel species concept may bring new alternatives for conservation and policy.

Sentinel species may assist in increasing monitoring efficiency at the ecosystem level. They can be utilized during rapid risk assessments to provide information on the environmental conditions of an area. Sentinel species can be selected for their ability to reflect environmental perturbations (Caro and O'Doherty, 1999). Based on their life history and physiological attributes, selected species can provide insight about environmental changes at various spatial, temporal, and trophic scales. Given the complexity

of ecosystems, sentinel species should be thought of as being specific to particular environmental conditions. In some cases, an assemblage of species may be suitable for providing an “umbrella” effect in monitoring the cumulative impacts of multiple environmental variables (Fig. 1).

The development and refinement of environmental and physiological health assessment techniques and monitoring protocols represent the next step in evaluating the unique use of sentinel species. Health assessment within an ecological system in the context of sentinel species provides the tools to determine the responses to naturally fluctuating environmental variables. The establishment of normal values for sentinel species is already occurring for bottlenose dolphins, Hawaiian monk seals (*Monachus schauinslandi*), bowhead whales (*Balaena mysticetus*), Northern fur seals (*Callorhinus urcinus*), and other marine mammals and sea turtles (Aguirre et al., 2002). Health assessment and long-term monitoring is also occurring in several marine bird populations (Schreiber and Burger, 2001). The development of testing protocols, identification of suitable diagnostic procedures and tests, identification of laboratory support, development of a quality control/assurance plan for laboratory results, and the development of data management and data analysis plans are all required to conduct a thorough assessment (Tabor et al., 2001).

Diagnostic laboratory testing can play an important role in monitoring the health of sentinel species and their ecosystems. The results of diagnostic testing are most useful when used to complement thorough field-based ecological research. Ecological studies provide the necessary context for any results concerning disease dynamics and can even discern certain physiological responses due to stress imposed upon populations by environmental change (Hofer and East, 1998).

Diseases, species, and ecosystems form the triad that is essential in the understanding of sentinel species usage. Emerging from these articles is the realization that the complex processes that define ecosystem health can barely be encapsulated by one health indicator species alone. Such a canary would surely be a *rara avis*. This may be the case with wild crow mortality events foreshadowing the West Nile virus outbreak (Lanciotti et al., 1999; Rappole et al., 2000). More commonly, a suite of sentinel species representing various taxa, or trophic levels or ecological processes can better indicate the health status of an ecosystem. Thus, our canaries look more like a menagerie of species, closely linked to the environment in which they are measured as

well as each other. Through this new lens, which still requires better precision, we can then advance and refine the study of sentinel species for indicating ecosystem health.

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