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Two roles for ecological surrogacy: Indicator surrogates and management surrogates

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A B S T R A C T

Ecological surrogacy – here defined as using a process or element (e.g., species, ecosystem, or abiotic factor) to represent another aspect of an ecological system – is a widely used concept, but many applications of the surrogate concept have been controversial. We argue that some of this controversy reflects differences among users with different goals, a distinction that can be crystalized by recognizing two basic types of surrogate. First, many ecologists and natural resource managers measure "indicator surrogates" to provide information about ecological systems. Second, and often overlooked, are "management surrogates" (e.g., umbrella species) that are primarily used to facilitate achieving management goals, especially broad goals such as "maintain biodiversity" or "increase ecosystem resilience." We propose that distinguishing these two overarching roles for surrogacy may facilitate better communication about project goals. This is critical when evaluating the usefulness of different surrogates, especially where a potential surrogate might be useful in one role but not another. Our classification for ecological surrogacy applies to species, ecosystems, ecological processes, abiotic factors, and genetics, and thus can provide coherence across a broad range of uses.

1. Introduction

In October 2014 a diverse group of scientists from around the world gathered in Australia to spend three days exploring the full scope of ecological surrogacy, primarily trying to achieve a broad, synthetic understanding that would advance the use of this important concept. They ranged from conservation practitioners and scientists who use bacteria and lichens to monitor pollution, to those who try to foster ecological integrity of whole oceans, or try to conserve regional biodiversity by managing representative arrays of ecosystems. The participants soon discovered that, despite a common interest in the use of surrogates for monitoring and managing ecological systems, they did not share a foundational understanding of ecological surrogacy. In particular, those who measure surrogates as ecological indicators found it difficult to embrace the concept of surrogates as alternative foci for management. For example, managing an umbrella species because it is an efficient way to maintain a large set of species did not

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Table 1
Examples of indicator surrogates and management surrogates for five types of ecological components. The example goals highlight distinctions between monitoring and managing. We chose these five classes to show the wide applicability of our concept, not to suggest that they constitute a definitive classification (e.g., one could readily combine ecosystems and ecosystem processes or separate abiotic factors into chemical and physical factors).

Class	Indicator surrogates		Management surrogates	
	Example	Example goal	Example	Example goal
Species	Indicator species	Detect change in target species abundance (*E. coli*, Ashbolt et al., 2001)	Umbrella species	Conserve a large suite of species (*Leadbeater's possum*, Lindenmayer, 1996)
	Indicator guilds	Detect change in function provided by a guild (pollinators, Kehinde and Samways, 2012)	Flagship species	Foster support for conservation (giant panda, Bowen-Jones and Entwistle, 2002)
Ecosystems	Ecosystem extent	Use species–area relationships to predict species richness (Triantis et al., 2015)	Ecosystems as coarse filters	Maintain biodiversity at species and genetic level by conserving a representative array of ecosystems (Hunter et al., 1988)
	Ecosystem structure	Measure structural diversity to quantify habitat for target species (Baril et al., 2011)		
Ecological processes	Ecosystem productivity	Detect changes in biomass accumulation (Culman et al., 2010)	Disturbance regimes	Manage fire regimes to create desired vegetation (Bradstock et al., 2012)
	Biogeochemical cycling	Detect carbon fluxes (Fan et al., 2015)	River flows	Manage flow regimes to restore riverine ecosystem integrity (Beechie et al., 2010)
Abiotic factors	Nutrient concentration	Monitor nitrogen and phosphorous water pollution (Rocha et al., 2015)	Geological and climatic diversity	Conserve diverse environments for biodiversity (Beier et al., 2015)
Genetics	Population structure	Detect functional connectivity (Braunisch et al., 2010)	Genetic diversity	Maintain evolutionary potential (tuatara, Miller et al., 2012)

seem like a form of surrogacy to them, whereas this was a key form of surrogacy for others. This led to many hours of discussion and ultimately we reached a consensus that explicitly recognizes two basic forms of surrogates based on goals: indicator surrogates (which are measured to provide information about ecological systems) and management surrogates (which are managed to achieve a different, often larger, goal such as "maintain biodiversity"). In this paper, we argue that this dichotomy represents a meaningful division in how different groups use ecological surrogacy. We discuss why this schism has emerged, and give examples of how it applies to five types of ecological components: species, ecosystems, ecological processes, abiotic factors, and genetics. We argue that disagreements over surrogate utility typically occur between groups with different goals, and that by explicitly recognizing two overarching goals for ecological surrogacy – providing information about ecological systems and facilitating their management – future misunderstandings can be avoided.

2. Context and definitions

Although ecological surrogacy is a frequently used concept (nearly 50,000 journal articles by one count; Westgate et al., 2014), it has repeatedly defied simple classification. For example, the United Nations (UNCCD 2013), Secretariat of the Convention on Biological Diversity (2014), European Union (BISE, 2014), Australia's State of the Environment Program (ANZECC State of the Environment Reporting Task Force 2000), and the United States Fish and Wildlife Service (USFWS, 2014) have all embraced different uses of surrogates. This lack of consensus amongst academics and practitioners on a shared terminology or scheme of classification remains despite repeated critiques and attempts at standardization (e.g., Landres et al., 1988; Noss, 1990; McGeogh, 1998; Simberloff, 1998; Dale and Beyeler, 2001; Niemi and McDonald, 2004; Caro, 2010; Heink and Kowarik, 2010; Pereira et al., 2013; Lindenmayer et al., 2015; Stephens et al., 2015). We propose to build a simple foundation for ecological surrogacy by recognizing that many seemingly distinct applications of the surrogate concept share common goals: environmental monitoring or informing management. Our focus on goals differs from earlier classification schemes that emphasized differences among organizational scales (e.g., genes, species, or ecosystems; Caro, 2010, Table 1), ecological attributes (e.g., compositional, functional, or structural; Noss, 1990), or distinct types of problem (e.g., environment, ecology, or biodiversity surrogates; McGeogh, 1998).

We begin with a definition of ecological surrogacy to distinguish it from surrogacy in medicine, engineering, and other fields (Forrester et al., 2008; Barton et al., 2014).

> Ecological surrogate: An ecological process or element (e.g., species, ecosystem, or abiotic factor) that is used to represent (i.e., serve as a proxy for) another aspect of an ecological system.

The earliest explicit uses of surrogates focused on measuring one species as an indicator for others: i.e., beginning in 1893, the concentration of *Escherichia coli* was used to indicate the likely presence of other pathogens in drinking water (Ashbolt et al., 2001). This usage is clearly consistent with our definition of indicator surrogates:

> Indicator surrogate: A type of surrogate that provides information about another aspect of an ecological system: for example, measuring the population density of species A because it provides information about the condition of target ecosystem X.

This approach emphasizes a mechanistic, statistical approach to surrogacy that remains popular amongst environmental scientists. However, a dramatic expansion in the use of the surrogacy concept in ecology and conservation biology arose alongside the development of the concept of "biodiversity" in the 1980s. Advocates of maintaining biodiversity realized that it was impractical to address directly all of the elements of biodiversity given the vast numbers of species, especially little-known or undescribed invertebrates and