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A conceptual framework for ecosystem management based on tradeoff analysis

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A B S T R A C T

Three dimensions (natural, social and economic factors) in tradeoff analysis have not been focused in ecology. It is necessary to consider the multi-dimensions through a tradeoff analysis of disturbances to find their positive and negative effects (referred to as two-sidedness). We proposed an 11-step approach to integrate the concepts, methods and examples to understand ecological two-sidedness. We recommend that: (1) ecological complexity and large-scale systematic perspectives need to be integrated; (2) disparate disciplines should be integrated to classify the two-sidedness indicators; (3) models should be adopted to define the characteristic metrics of disturbed ecosystems; (4) researchers need to reconsider evaluation standards and for each indicator with marginal changes; and (5) initial decision-making should refer to the two-sidedness value and that final decision-making should be subject to debate. This approach has great significance for ecosystem management because decision-makers can obtain the superiority and inferiority of disturbance strategies and select optimal strategy.

1. Introduction

One of the universal phenomena is disturbance which may occur naturally (e.g., hurricanes, typhoons, cyclones, forest fires, volcanoes) or be introduced by humans (e.g., deforestation, exploitation, pollution, global warming) (Franklin et al., 2002; Mori, 2011), and the ecological consequences of disturbances depend on their type, spatiotemporal extension, frequency, duration, and intensity (Pickett and White, 1985). After ecosystems are confronted with disturbances, ecosystem structure and functions might be extremely complex, yet additions of natural, social, and economic dimensions to understand ecosystem-disturbance interactions further increase this complexity, creating a new frontier in ecology (Holling, 2001). More importantly, the complexity of natural, social, and economic systems might become a management guideline for ecosystems (Abelson et al., 2015).

Besides the above complexity related to disturbances, in the process of ecosystem management, ecologists have paid attention to the "tradeoff" that has been focused in ecology, such as the tradeoffs between growth and mortality rates when mediated by foraging activity (Werner and Anholt, 1993), ecosystem service tradeoff analysis in marine spatial planning (Crow et al., 2012), a tradeoff between growth or defense in grassland plant species (Lind et al., 2013), and a tradeoff between adaptation to malnutrition and susceptibility to food-borne pathogens (Vijendravarma et al., 2015). However, the emphasis of three dimensions (natural and social and economic factors) in tradeoff analysis have not yet become the mainstream in ecology, and the quantification of these positive and negative (i.e., two-sided) effects of three dimensions in tradeoff analysis has not been explored. Based on this point, we argue that there is no hope for the development of ecology if the socioeconomic factors were not permeated into ecology.

In fact, in tradeoff analysis, positive and negative effects from natural, social and economic dimensions are important events

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(Table 1), which indicate that the two-sided consequences are universal in both terrestrial and aquatic ecosystems. Up to now, there have been the reports on the quantification of positive and negative effects in tradeoff analysis from disturbances such as browse damage of herbivores (Riginos and Young, 2007), the introduction of exotic *Spartina alterniflora* (Wan et al., 2009b) and resource monopolization of competitors (Claar et al., 2011). However, to quantify and qualify the two-sided consequences of tradeoffs between natural and socioeconomic factors for complex ecosystems has not been explored.

One of the most important goals of tradeoff analysis is to make decisions for ecosystem management in which natural and socioeconomic factors should be paid attention to. However, regretfully, few methodologies have been proposed to integrate such multi-factors into the two-sided consequences although there are the documents of ecosystem management related to the integration of social, economic and ecologic factors (Fox et al., 2009). Thus, we propose a methodology that combines negative and positive effects from disturbances to form a foundation in ecosystem studies, as well as for management. Specifically, we propose an integrated framework to promote our understanding of how two-sidedness may be applied in basic and applied research, including qualitative/quantitative methods, as well as their applications in pubilc management. In this paper, we first present how disturbances result in two-sidedness and then summarize the current methods of modeling ecological two-sidedness. Finally, we demonstrate

Table 1
Collected documents for the two-sided effects of disturbances on ecosystems.

Disturbance type	Disturbance factor	Disturbance ecosystems	Negative effect	Positive effect
Natural disturbances	Prairie and forest fires	Prairie and forest ecosystem	Reducing local air quality (Sastry (2002))	Improving biological productivity (Farina (1998))
	Drought	Arid area ecosystem	Limiting plant survival (Talbi et al. (2015))	Promoting accumulation of H_2O_2 and NO and inducing antioxidants defenses in plants (Talbi et al. (2015))
	Volcanic eruption	Basaltic ecosystem	Producing harmful substance (e.g., volcanic ash and sulfur dioxide) that pollutes environment	Producing geothermal energy and mineral resources (Larsen et al. (1979))
	Earthquake	Terrestrial ecosystem	Destructing buildings and infrastructure and causing serious casualties (Potter et al. (2015))	Enhancing people's cohesive force and the ability of disaster relief (Zhou et al. (2015))
	Tsunami	Marine ecosystem	Damaging coastal ecosystems of the Indian islands of Andaman and Nicobar (Velmurugan et al. (2015))	Eliminating decades-long conflict between Free Aceh Movement (GAM) and the Government of Indonesia (Gaillarda et al. (2008))
	Hurricane	Marine ecosystem	Significant decline in oyster population at Cedar Point Reef (Park et al. (2014))	Benefiting seagrass beds in flushing toxic metals and replenishing essential elements (Whelan et al. (2011))
	Sand and duststorm	Terrestrial ecosystem	Degrading human health and increasing air pollution in the source region (Chung et al. (2003))	Forming Loess Plateau and effectively neutralizing the acid rain in China
Anthropogenic disturbances	Deforestation	Mediterranean ecosystem	Causing soil erosion and desertification (Gates and Ließ (2001))	Making more furniture to benefit human well being
	Use of private cars	Urban ecosystem	Emitting carbon dioxide (Spalding (2010))	Facilitating transportation
	Grazing	Grassland ecosystem	Causing loss of vegetation coverage (Fujiki et al. (2010)) and reducing pool sizes of topsoil organics (Giese et al. (2013))	Promoting plant productivity and biological diversity (Louhaichi et al. (2012); Fuhlendorf and Engle (2015))
	Chemical fertilizer	Lake ecosystem	Creating non-point source pollution (Wesström et al. (2014))	Increasing crop yields
	Chemical pesticide	Paddy ecosystem	Enhancing pesticide residence, and the resistance and resurgence of pests (Wan et al. (2013))	Killing pests and ensuring crop yields (Wan et al. (2013))
	Human trampling	Forest ecosystem	Decreasing the genetic diversity in a clonal woodland plant (Rusterholz et al. (2009))	Recovering four montane heath communities in Cairngorm, Scotland (Bayfield (1979))
	Mining exploitation	Desert ecosystem	Destroying ecological environment (Carvalho et al. (2005))	Booming economy from mineral resources
	Invasion of Asian carps	Mississippi River basin ecosystem	Causing disorder in ecological balance and destruction of local environment (Kocovsky et al. (2012))	Providing fish food and biofiltration of sewage; contributing to aquaculture research (Kocovsky et al. (2012))