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The Primacy of Openness in Ecological Complexity Theory

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THE PRIMACY OF OPENNESS IN ECOLOGICAL COMPLEXITY THEORY

DISSERTATION

A dissertation submitted in partial fulfillment of the
Requirements for the degree of Doctor of Philosophy in the
College of Arts and Sciences
At the University of Kentucky

By

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ABSTRACT OF DISSERTATION

THE PRIMACY OF OPENNESS IN ECOLOGICAL COMPLEXITY THEORY

Five principles are at the foundation of complex systems theory: emergence, openness, contingency, historicity, and indeterminacy. Of those five, the principle of emergence is easily the most prevalent. Simply put, emergence refers to the idea that some wholes cannot be properly accounted for by appealing to individual explanations of the parts that compose it. In ecological complexity theory, the principle of emergence is strongly associated with the self-organizing feedbacks that often identify the structural framework of ecosystems.

Within the last half century, the intense focus on the principle of emergence has engendered the development of many conceptual distinctions that have importantly contributed to explanations of ecological patterns and ideas about environmental management and restoration. I argue, however, that ecological complexity theory has become somewhat stagnant and myopic in its devout commitment to the principle of emergence.

This dissertation highlights the issue of ecological complexity theory's overreliance on the principle of emergence by investigating the role of the principle of openness. I argue the reverse of what is typically maintained in the literature – the principle of openness possesses metaphysical, epistemological, and ethical primacy. By beginning with the principle of openness and working towards the use of the principle of emergence in explanations of ecological phenomena, I urge greater appreciation for an ecosystem's complete causal narrative and a reconsideration of the formulation and carrying out of future management and restoration practices and policies.

Keywords: Complex systems theory, emergence, openness, island biogeography theory, resilience theory, ecological restoration ethics

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

Complex systems theory, regardless of where it is used, represents an alternative to the Newtonian worldview. Rather than drawing analogies to rigid machines and grounding explanations in terms of Humean causation, complex systems theory embraces the complexity of organic systems interacting across scales. Instead of seeing the world as linear chains of cause and effect, complex systems theory tries to make sense of causation that goes in both directions, bottom-up and top-down, which makes reductionism less tenable as a ground for broad knowledge claims and the attribution of constant or universal properties too simplistic to be either accurate or helpful. From the point of view of complex systems theory, it is not the case that all sciences are reducible to physics. Instead, each science is unique and must be treated as such with its own set of units of organization to study (Mitchell 2009).

Of all the sciences to incorporate complex systems theory, perhaps ecology has utilized its rich conceptual framework in the most diverse contexts. A lineage of developments in ecological complexity theory is traceable beginning with discussions related to plant succession theory (1910's-1970's). Clements posited the superorganism model that regards climax communities as self-organized entities that as an example of top-down control from start to finish direct the plant succession leading to them. Others, like Gleason and Whittaker, objected to the teleology engrained in the superorganism model. They argued that bottom-up causal interactions between individuals are better predictors and explainers of a plant community's development. Another notable era in ecological complexity theory's history, still underway, involves catastrophe theory and resilience theory (1960's-present). Theorists such as Holling and Scheffer have called on concepts like basins of attraction and hysteresis to explain how ecosystems can adaptively change and recover from disturbances of varying degrees. Especially now that climate change, habitat loss, and overexploitation have stressed many ecosystems to their brink, new conceptual frameworks utilizing both top-down and bottom-up viewpoints have been integral to devising sustainability strategies (Solé and Levin 2022).

Historically speaking, a number of potential intellectual starting points can be identified for complex systems theory. One is Darwin's theory of evolution. Evolution suggests that the natural world is filled with a sort of creativity that does not support the notion of natural kinds, life is always multiplying rather than staying constant. Another possible starting point is Boltzmann's principle. Entropy as the arrow of time suggests that at least some natural phenomena are irreversible. History matters, and contingency is everywhere. Further contributions from the likes of Einstein, whose theory of relativity rivaled Newtonian interpretation of gravity, and Whitehead, whose scientifically informed process ontology provided a novel way to abandon the idea that substances are primary, offered equally important developments. By the early- to mid-20th century, complex systems theory really started to take shape with the rise of studies in cybernetics and information theory, open-system dynamics, and dissipative structures (i.e., far from equilibrium thermodynamics) as propagated by scholars such as Wiener, Bertalanffy, and Prigogine respectively. Since the mid-20th century, philosophy, too, has drawn inspiration from complex systems theory and has helped refine aspects of it to address topics related to metaphysics, epistemology, and applied ethics (Simon 1962; Popper 1982; Wimsatt 1997; Mitchell 2009; Potochnik 2017; Dupré 2021).

To act in a complex world requires an interpretation of causation and an awareness of the limits of understanding. Emphasizing different causal principles, in the present case openness and emergence, to different degrees has far-reaching consequences. To explain a complex phenomenon, some generalization of causal factors is necessary to be able to detect patterns. However, consistently relying on a single set of generalizations jeopardizes the pursuit of robust explanations. It also seemingly attempts to isolate the causal principles from one another, thereby removing many of the factors that generate complexity. Despite their significance, complex systems theory does not appear interested in investigating the exact usage of these causal principles or their interrelatedness. In effect, this dissertation attempts to show why the literature should take an interest.

Most explanations of ecosystems prioritize the principle of emergence, which signals a deep connection to complex systems theory, the science of emergence (Waldrop 1992; Kauffman 1995; Holland 1998; Morowitz 2002; Bedau 2008; Jensen 2023). My contribution to the literature is that I defend the importance of a second causal principle, openness. Openness is the possibility of matter and energy moving between a system and its environment. Complex systems theory acknowledges openness as one of the central structuring principles of systems, but less attention has been paid to how openness constrains emergence. It also matters what those constraints imply about developing practices to prevent the collapse of ecological systems. In four chapters, my dissertation analyzes the metaphysical, epistemological, and ethical dimensions of a conceptual approach directed at practical ends that emphasizes the principle of openness.

Chapter one outlines complex systems theory's history with the concept of emergence. Different accounts of emergence have been offered over this history, from the merely epistemological to the genuinely ontological. Epistemologically, some wholes cannot be explained by means of reduction to their simplest compositional parts. Ontologically, some wholes possess properties that their parts lack and, in virtue of possessing those properties, are unique ontological entities. Conceptual understanding of openness, on the other hand, has not progressed beyond its original definition – the possibility of movement of matter and energy between a system and its environment. I argue that complex systems theory struggles to agree on a single account of emergence (Simon 1963; Bertalanffy 1972a; Chalmers 2006; Bedau 2008; Gillett 2016) because it has undertheorized openness. Chapter one explains all this and calls for a metaphysically robust account of ecosystem dynamics that gives parity to the two structuring principles, openness and emergence.

One reason that complex systems theory has been so enamored with emergence is its use of idealized topological modeling techniques. By topology, I am referring to the mathematization of system dynamics. In ecology, topological accounts often take the shape of network analyses. Following from the conclusions of chapter one, chapter two argues that topography (i.e., relations in physical space), not topology, is the appropriate dimension for interpreting openness. In actual ecologies, topographical features function as regulators of species dispersal and the mobilities of abiotic conditions and resources, potentially resulting in ecological communities hovering around steady state numbers of species. I utilize MacArthur and Wilson's (1963; 1967) equilibrium theory of island biogeography (ETIB) to illustrate this idea. Moreover, I argue, the island biogeography literature in the decades following the postulation of the ETIB offers a conceptual narrative for uniting openness and emergence. I explain how Simberloff and Wilson's (1969; 1970) conclusions from their controlled island experiment in the Florida Keys indicate that systems follow an ontogenetic trajectory in which they begin as predominantly open and become increasingly emergent and closed-off as time passes. These discussions from the island biogeography theory literature reveal a general trend in the field of ecology, namely, that the sudden development of topological-emergence representations of system dynamics meet with criticism from those who stress the effects of topographical variation on organizational patterns. As such, the conceptual account defended in this chapter of the relationship between openness and emergence reappears in the following chapter.

Chapter three investigates interpretations of resilience in the ecological literature. The ecological resilience concept maintains a high profile in ecology literature because of its rich philosophical undertones as a theory of adaptive change (Holling, Gunderson, and Ludwig 2002). It asks one of the most basic questions with the furthest reaching consequences: how does an ecosystem adapt to environmental fluctuations while retaining its structural integrity throughout the process? As previously noted, catastrophe theory and resilience theory form areas of research that explicitly incorporate the conceptual framework of complex systems theory. Most interpretations of resilience emphasize emergent self-organization alone without any mention of open-system dynamics. I argue for an ontologically flexible account that integrates topographical considerations related to openness with topological ones related to emergence in a single ontogenetic narrative that (1) conceptually sorts out the varied elements that contribute to resilience and (2) reveals an ecosystem's shifting causal dynamics. I show that explanations of resilience oftentimes depend on openness more than emergence and, furthermore, that ecological management practices affiliated with sustainability should employ a site-specific approach that successfully draws on both principles. While the site-specific approach to ecological management has long been recognized as an important element of successful practice (Holling and Meffe 1996), I articulate in philosophical terms how, specifically, the tension between emergence and openness brings out the importance of attending to spatial and temporal details. This analysis implies that the prevalent way of theorizing management practices from a purely emergentist perspective neglects relevant spatial details that could significantly impact the long-term efficacy of these practices.

My last chapter examines the role of the concept of resilience in environmental management from the perspective of environmental ethics. I do this to show how an overreliance on the principle of emergence leads to a general attitude toward humanity's relationship with nature that appears morally questionable and can even negatively impact the efficacy of management practices. Much of the final chapter investigates the environmental management practice of ecological restoration. Ecological restoration is a kind of environmental management that attempts to return nature to some original state (that typically existed after human destruction). Although ecological restoration might seem, prima facie, acceptable in all cases since it repairs damage done to the environment from anthropogenic causes, the justifications cited for particular ecological restoration strategies reveal that not all motivations have nature's best interests in mind. This is not only disingenuous but also, I argue, problematic for achieving practical goals. Katz is one such environmental ethicist who prominently challenges the foundations of ecological restoration. He argues that ecological restoration is carried out under false pretense: it claims to achieve restitutive justice on nature's behalf when, in fact, it is an attempt by humanity to dominate nature. I agree with Katz's view but show how resilience theory obviates Katz's argument when restoration is framed in a way (through adaptive cycle models) that place greater emphasis on the principle of openness as opposed to a way (tipping point explanations) that only captures emergence. Management, including restoration and conservation, that is carried on from the perspective of emergence seeks to control the internal dynamics of ecosystems so as to keep them fixed within a desirable stability band. Openness, on the other hand, values natural development and adaptation – neither of which have proper ends but are simply the mechanisms through which nature persists – within a particular site. This emphasis on openness has far-reaching ethical implications beyond restoration. For example, predictions of planetary tipping points and emergent cascades of global ecosystems are often made without the capacity to comprehend the way in which openness operates over such broad expanses as to connect ecosystems to one another in a dynamic patchwork wherein each ecosystem plays a supportive role to the others in times of disturbance.

The purpose of this dissertation is to expand upon precepts in complex systems theory, but from a perspective that emphasizes the principle of openness without necessarily denying the importance of emergence. As I claim in each of the chapters, the principle of emergence is essential to explaining some key features of ecosystem dynamics. However, by emphasizing the principle of openness, I demonstrate the merit of a complementary perspective that is often overlooked, one that contributes to a more pluralist understanding of the repertoire of complex systems theory (Mitchell 2009). By expanding upon the metaphysical, epistemological, and ethical dimensions of ecological complexity, my dissertation also calls for greater philosophical scrutiny of actions undertaken by society in response to environmental degradation and to predictions and observations of rapid environmental change.

Chapter 1: Topographical Openness in Addition to Topological Openness: How the Environment Influences Emergence

Introduction:

> "Matter or mind, reality has appeared to us as a perpetual becoming. It makes itself or it unmakes itself, but it is never something made" – Bergson ([1907], p. 296)

Complex systems theory proposes a new way to answer an old question: How do things stay the same even if they perpetually change? Blending science with process ontology, complex systems theory studies how networks of processes become integrated with one another such that a system in a near-equilibrium state emerges. The system never achieves absolute stability, and all the parts composing it eventually get cycled out so that no one part remains within the system forever. In this way, complex systems theory posits a world filled with interconnected becomings that constantly remake themselves in order to persist over extended periods of time.

Emergence has served as the guiding principle for complex systems theory since the very beginning. Typically, it offers the clearest evidence that complex relations exist. In this chapter, I propose starting from a different principle, openness, and working towards emergence. Complex systems theorists typically so define openness thermodynamically that a system openly exchanges matter, energy, and/or information with its environment. I refer to this as "topological openness." Topological openness balances some of the stronger metaphysical claims emergence introduces into complex systems theory. However, topological openness makes it impossible to analyze the effect the environment has on a system. Thus, I posit another kind of openness, topographical openness. Topographical openness is more simple than topological openness; it tracks the movement of material bodies (whether or not they are bound up in a system) across physical space. Defining openness topographically allows for the analysis of an environment's influence on (1) inputs into a system, (2) potential adaptations coming from outside the system, and (3) the formation of propensities within the system's dynamics.

In the first part of the chapter, I motivate complex system's theory's adherence to an emergence-first approach. I look at how complex systems theory defines individuality in a way that allows it to identify an emergent phenomenon with a specific configuration of processes. Then, I briefly discuss how Aristotle prompted a whole body of literature that complex systems theory incorporates, focusing particularly on the distinction between strong and weak emergence. In the second part of the chapter, I redefine openness topographically after evaluating topological openness. In the end, I argue that defining openness topographically undergirds a productive analysis of the ways in which topographical features influence patterns both before and after systems emerge.

Emergence:

Emerging Individuals:

Emergence always results in an individual. Logically, it must; a distinct thing must emerge. Thus, emergence designates a specific phenomenon that acts or behaves as a unit. Often times detecting emergence is easy, defining the limits of the individual that emerges is not. One of the greatest benefits of complex systems theory is that it provides a somewhat measurable means to distinguish the individual that emerges.

Individuality has long been a popular topic because it carries weighty metaphysical implications.[1] Generally, the imprecision of the term "individual" complicates the metaphysics of emergence. In one sense, "individual" can imply something with a great deal of metaphysical baggage, an identity or a bare particular, like Aristotle's ὑποκείμενον. In a much less rigorous sense, "individual" corresponds to any countable thing (Dupré and Nicholson 2018, p. 12). For the purposes in this chapter, "individual" identifies an ontological unit that meets the parameters set forth by complex systems theory.

For complex systems theory, it is clear what constitutes an individual, a system. "An 'individual' can be defined as a centralized system" (von Bertalanffy 1968, p. 71). Systems differ from the more common things considered individuals due to their dynamism. The individuality of static objects largely goes unquestioned because they possess observable limits. Dynamic systems, by contrast, constantly gain and lose the stuff that makes their existence possible (the most extreme case of the Ship of Theseus paradox). For this reason, complex systems theorists like von Bertalanffy appeal to progressive centralization and progressive individualization.[2] von Bertalanffy states:

> Thus strictly speaking, biological individuality does not exist, but only progressive individualization in evolution and development resulting from progressive centralization, certain parts gaining a dominant role and so determining behavior of the whole. Hence the principle of *progressive*

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[1] Many attempts have been made to identify the criteria for individuality in the philosophy of biology (Buss 1987; Maynard Smith and Szathmáry 1995; Wilson 1997; Queller and Strassman 2009; Folse III and Roughgarden 2010; Clarke 2016; Dupré and Nicholson 2018; Nicholson 2018; Austin 2020; Dupré 2021). In complex systems theory, Krakauer et al. (2020) attempt to use information theory to produce a gestalt approach to individuality.

[2] By "centralization," Von Bertalanffy does not mean that a system possesses an actual center (in physical space) that all the processes revolve around. Instead, "centralization" means that a system turns its processes inwards on itself such that a loop forms. Another term for this is "centripetality" (Ulanowicz 1997, pp. 47-50; 1999, pp. 134-135).

> *centralization* also constitutes *progressive individualization*. An individual is to be defined as a centered system, this actually being a limiting case approached in development and evolution so that the organism become more unified and "indivisible" (1968, p. 73).

Complex systems theory could rightly be called a science of near-individuals. No perfect system exists, so nothing perfectly exemplifies individuality. A perfect system would be a machine. But systems are organic, not mechanical. Bergson puts the matter nicely when discussing the individuality of biological units:

> For the individuality to be perfect, it would be necessary that no detached part of the organism could live separately. But then reproduction would be impossible. For what is reproduction, but the building up of a new organism with a detached fragment of the old? Individuality therefore harbors its enemy at home. Its very need of perpetuating itself in time condemns it never to be complete in space. The biologist must take due account of both tendencies in every instance, and it is therefore useless to ask him for a definition of individuality that shall fit all cases and work automatically ([1907], p. 16).

To complicate the matter further, individuals compose individuals. Organizational hierarchies appear throughout the natural world. Depending upon the level of observation, certain individuals come into focus. As Boulding states:

> [A] phenomenon of almost universal significance for all disciplines is that of the interaction of an "individual" of some kind with its environment. Every discipline studies some kind of "individual" – electron, atom, molecule,

> crystal, virus, cell, plant, animal, man, family, tribe, state, church, firm, corporation, university, and so on. Each of these individuals exhibits "behavior," action, or change, and this is considered to be related to the environment of the individual – that is, with other individuals with which it comes into contact of some relationship. Each individual is thought of as consisting of a structure or complex of individuals of the order immediately below it – atoms are an arrangement of protons and electrons, molecules of atoms, cells of molecules, plants, animals and men of cells, social organizations of men. The "behavior" of each individual is "explained" by the structure and arrangement of the lower individuals of which it is composed, or by certain principles of equilibrium or homeostasis according to which "states" of the individual are "preferred." Behavior is described in terms of the restoration of these preferred states when they are disturbed by changes in the environment (1956, p. 201).[3]

Complex systems theory has tasked itself with studying these multiscalar hierarchies and their causal relations.

In the end, complex systems theory defines an individual system based on how the parts interact with one another. A system is not a mere collection of different things within proximity of one another; the parts of a system must stimulate one another such that the whole possesses characteristics or abilities the parts do not for it to count as an individual (i.e., an ontological unit). Dupré puts this into context:

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[3] Boulding seems to be blurring objects and processes. I make no serious attempt to determine what belongs in a process ontology (objects and processes, processes only, etc.); however, it is a reasonable concern. Simons (2018, pp. 52-53) nicely lays out the metaphysical landscape for process and substance ontologies by identifying five positions in the literature: (1) only continuants (i.e., objects) exist, (2) only occurrents (i.e., processes) exist, (3) both continuants and occurrents exist but continuants are prior, (4) both continuants and occurrents exist but occurrents are prior, (5) both continuants and occurrents exist and both are equally basic.

> Biological individual is a broader category than organism. My liver, a cell in my liver, or a pride of lions are biological and are individuals. By their being individuals I mean at least that there is some integration of their parts and some differentiation from other entities that are not parts of them. So the mereological sum of my nose and my sister's cat do not constitute an individual. More than merely integration, an individual should be expected to do something, to interact as a whole with other parts of the world. The contents of my desk drawer though they may be roughly integrated – the drawer is very full – and separated from other things – by the structure of my desk – do not do anything as a unit (2021, p. 38).

To summarize, complex systems theory regards systems as individuals. Individuals, especially biological individuals, never become rigid due to their endless engagement with the natural world. Systems retain their individuality through progressive individualization, a kind of interminable becoming. Even as processes continue to cycle, the system remains the same individual. In order for a collection of processes to constitute a system, the parts must interact with one another such that the whole possesses at least one characteristic or ability that the parts do not.

Aristotelian Roots:

von Bertalanffy asserts:

> Aristotle's statement, "The whole is more than the sum of its parts," is a definition of the basic system problem which is still valid (1972a, p. 407).

Prigogine and Stengers add:

> Ever since Aristotle…, the same conviction has been expressed: a concept of complex organization is required to connect the various levels of description and account for the relationship between the whole and the behavior of the parts (1984, p. 173).

A single passage in *Metaphysics* H.6 has been enough to grant Aristotle a place among the first emergence thinkers. In this passage, Aristotle discusses the concept of unity (τὸ ἓν). He acknowledges a difficulty with defining a unity where the several parts composing it do not result in a simple additive hodgepodge. A previous passage, in *Metaphysics* Z.10, clarifies the two types of unity Aristotle has in mind with examples for each. On the one hand, the account (λόγος) of a circle does not include an account of each of the parts composing it. An infinite number of segments compose a circle just like an infinite number of points exist between any two values on a number line. If an infinite number of segments make up a circle, no account can be given that takes into consideration all the potential segmentary lines at once, yet a circle possesses a definite limit. On the other hand, an account of a syllable can be constructed by simply adding together the accounts of the letters composing it (1034b25-27). For instance, "h + a" accounts for the syllable "ha."[4] In the passage at *Metaphysics* H.6, Aristotle is concerned with circles, not syllables.

With respect to non-simple sum unities, Aristotle states that "the whole is something beyond the parts" (ἔστι τι τὸ ὅλον παρὰ τὰ μόρια) (1045a9-10). The phrase carries with it considerable metaphysical force because of the "to be" verb. Read ontologically, Aristotle seems to recognize real instances of emergence in which the whole possesses some formal characteristic that none of its parts

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[4] Based on later passages in *Theatetus*, Plato seems to have a different appreciation for the mereology of syllables.

possess. The proceeding passage in *Metaphysics* H.6 lends some credibility to this reading of the phrase since Aristotle introduces matter and form as well as potentiality and actuality to further explain the nature of unity.

However, other passages from *Metaphysics* cast doubt on Aristotle ‘s commitment to what today would be a conventional notion of emergence. Aristotle discusses unity in *Metaphysics* Z.16 as well. There, he clearly states that unity, like being (τὸ ὂν), does not qualify as substance (οὐσία) (1040b21-24). The explanation for why revolves around the generality of unity.[5] Since Aristotle's substance ontology regards substances as its metaphysical primitives, reason suggests that Aristotle does not recognize the kind of genuine emergence that complex systems theorists want to attribute to him. Aristotle seems to intend a logical, not an ontological, causal unity.

Still, this does not close the door on emergence for Aristotle. After all, logic (specifically the syllogism) forms the basis of his metaphysics. Thus, the passages on unity can easily be read as if Aristotle countenances a weaker view of emergence according to which the parts are fundamentally real but the whole still exists in some respect, too. This view, in effect, nears the view posited by the vast majority of contemporary complex systems theorists, and it sets up the discussion to follow. For, von Bertalanffy states:

> The meaning of the somewhat mystical expression, "the whole is more than the sum of parts" is simply that constitutive characteristics are not explainable from the characteristics of isolated parts. The characteristics of

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[5] Why a unity does not qualify as a substance is both complicated and unnecessary for the purposes of this chapter. Suffice it to say, Aristotle seemingly contradicts himself in *Metaphysics* Z by stating on separate occasions (1) substance is form, (2) forms are universal, and (3) universals are not substances (Lesher 1971).

Aristotle reiterates his point about "being" and "unity" existing merely as genera dependent upon the particulars in *Metaphysics* H.6 (1045b5-7).

> the complex, therefore, compared to those of the elements, appear as "new" or "emergent." If, however, we know the total of parts contained in a system and the relations between them, the behavior of the system may be derived from the behavior of the parts. We can also say: While we can conceive of a sum as being composed gradually, a system as total of parts with its interrelations has to be conceived as being composed instantly (1968, p. 55).

From the quote, the idea is that an emergent system results from the interactions between the parts composing it, which means the system's behavior ultimately owes to the behavior of the parts. In other words, the system does not emerge as something causally or ontologically detached from its parts. This explains why von Bertalanffy uses the language of "appearance" to characterize emergence. Still, due to the complexity of the interrelations, the system must be "conceived" as an instantaneous collection of interactions happening together. This gives emergence more of an epistemological, rather than ontological, flavor.

In conclusion, Aristotle seemingly lit a torch that contemporary philosophers carry to this day. Emergence combats the strong reductionist tendencies spawned out of the Modern scientific period. Reducing everything to the simplest parts does not very often yield an adequate explanation of a given phenomenon. Complex systems theory goes beyond Aristotle's simple emergence. Different kinds of emergence are required for different kinds of phenomena. One definition of emergence does not do it, which is why complex systems theory has spent much of its time on the subject. As Mitchell puts it:

> The concept of 'emergence' is one that poses itself in direct opposition to reduction. Aristotle has been attributed with saying, 'The whole is more than the sum of its parts,' from his discussion of part-whole causation in

> the *Metaphysics*. Since then, philosophers have worried much about what 'is more than' means and what 'sum' means. There are different senses of emergence that counter the different senses of reduction (2009, p. 24).

Strong vs Weak Emergence:

Emergence clearly functions as the cornerstone of complex systems theory. As Bedau writes:

> For anyone interested in understanding emergence, two things about complexity science are striking. First, it aims to explain exactly those natural phenomena that seem to involve emergence; the range of phenomena covered by complexity science are about as broad as the examples of apparent emergence in nature. Second, the models in complexity science are typically described as emergent, so much so that one could fairly call the whole enterprise the science of emergence (2007, p. 155).[6]

Bedau formulates a helpful distinction between strong and weak emergence. Strong and weak emergence carry different ontological and causal implications.

To begin, Bedau identifies two hallmarks that describe how macro-level emergent phenomena relate to their micro-level bases in any instance of emergence.[7]

1. Emergent phenomena are "dependent" on underlying processes.

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[6] On this point, Bedau cites Kauffman (1995) and Holland (1998) who both posit a thesis that the fundamental concern of complex systems theory is emergence.

[7] Bedau posits similar hallmarks in a previous paper, *Weak Emergence* (1997, p. 375). I cite Bedau's more recent paper, although most of the points raised here can be found in both.

2. Emergent phenomena are "autonomous" from underlying phenomena (2008, p. 155).

On the surface, 1. and 2. together seems like a metaphysical impossibility. As Bedau points out:

> Taken together, the two hallmarks explain the controversy over emergence, for viewing macro phenomena as both dependent on and autonomous from their micro bases seems metaphysically problematic: inconsistent or illegitimate or unacceptably mysterious. It is like viewing something as both transparent and opaque. The problem of emergence is to explain or explain away this apparent metaphysical unacceptability (2008, p. 156).

Bedau's way of solving the controversy entails differentiating between strong emergence, on the one hand, and weak emergence, on the other.[8]

Strong emergence requires that "emergent properties are supervenient properties with irreducible causal powers" (Bedau 2008, p. 158). Thus, the causal and ontological implications of strong emergence could not be greater. Strong emergence produces "ontological novelty" (Bedau 2008, p. 159). The macro-level emergent phenomenon exhibits properties the micro-level bases do not possess, thereby signaling that the macro-level emergent phenomenon effectively qualifies as a genuine individual; an independently existing individual composed of independently existing individuals.[9]

Despite the ontological and causal demands of strong emergence, defenses that it exists occur in the literature, especially historically. As Chalmers states:

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[8] Bedau discusses a third, "nominal emergence," but this kind of emergence only states that some macro-level properties cannot be micro-level properties (2008, p. 158). Also, Bedau recognizes that his list of types of emergence is not exhaustive; more types of emergence exist in the literature (2008, p. 157).

[9] Gillett (2016) posits "ontological emergence" as another type of emergence that concerns the realization of properties at different levels. He states that sometimes writers use "strong emergence" when they mean "ontological emergence" (2016, p. 187). This might be one of those cases. However, I do not think this has any serious impact on my present discussion.

“Strong emergence is the notion of emergence that is most common in philosophical discussions of emergence, and is the notion invoked by the British emergentists of the 1920s” (2006, p. 244). However, most contemporary philosophers distance themselves from strong emergence as much as possible. As Gillett states: “A large number of philosophers deny that [strong emergence] even represents a viable option” (2016, p. 188). Chalmers himself argues that only one type of phenomenon qualifies as strongly emergent, consciousness (2006, p. 246).

However, totally rejecting strong emergence might be too extreme. Plenty of examples seem to qualify as strong emergence. For instance, mitochondria depend upon the entirety of the eukaryotic cell for a continued existence. That has not always been the case, though. Mitochondria once existed as independent organisms, apart from the other organelles. Over time, mitochondria lost their independence, and became locked within the cell membrane. Subsequently, eukaryotic cells exert downward causal influence over mitochondria (Maynard Smith and Szathmáry 1995, pp. 137-142). A basis for strong emergence exists in the social sciences as well. In *Social Emergence*, Sawyer presents a reasonable argument for a form of sociological realism that posits strong emergence (2005, p. 72).

Weak emergence strips away much of the metaphysical force of strong emergence that complex systems theorists worry about, which explains why complex systems theorists gravitate towards it. Unlike one of a strongly emergent phenomenon, an explanation of a weakly emergent phenomenon appeals to the micro-bases instead of positing any independently existing macro-entity. “The complex consequences of myriad non-linear and context dependent micro level interactions” result in some emergent phenomenon not explainable by simply adding all the micro-level bases like discrete individuals (Bedau 2008, p. 160). Something about the connectivity between the parts produces nontrivial, emergent qualities.

Weak emergence satisfies the two hallmarks. On the one hand, weakly emergent phenomena clearly depend upon coordination between their micro-level bases. This means that weakly emergent phenomena do not possess any sort of ontological independency. Similarly, the causal powers of a weakly emergent phenomenon can be accounted for by “the composition of context-dependent micro causal powers” (Bedau 2008, p. 160). In other words, micro-bases act differently based on the context of their interactions with one another, so causal fundamentalism still holds. On the other hand, weakly emergent phenomena possess “explanatory autonomy.” This is not the kind of metaphysical autonomy strong emergence associates with emergent phenomena. “Explanatory autonomy” is epistemological, and it refers to “our inability to follow through the details of the complicated micro causal pathways” (Bedau 2008, p. 179). Chalmers reaches a similar conclusion: “Even if weakly emergent phenomena do not require the introduction of new fundamental laws, they may still require in many cases the introduction of further levels of explanation above the physical level in order to make these phenomena maximally comprehensible to us” (2006, p. 246). Thus, weak emergence achieves three important goals strong emergence does not: “it is metaphysically innocent, consistent with materialism, and scientifically useful, especially in the sciences of complexity that deal with life and mind” (Bedau 1997, p. 376).

Weak emergence has a firm basis in the history of complex systems theory. I mentioned von Bertalanffy above. Simon, too, seems to define emergence weakly. He states:

> Roughly, by complex system I mean one made up of a large number of parts that interact in a nonsimple way. In such systems, the whole is more than the sum of the parts, not in an ultimate, metaphysical sense, but in the important pragmatic sense that, given the properties of the parts and the

> laws of their interaction, it is not a trivial matter to infer the properties of the whole (1962, p. 468).

Simon continues:

> [T]he theory assumes no teleological mechanism. The complex forms can arise from simple ones by purely random processes (1962, p. 471).

Simon denies the "metaphysical sense" of emergence. Instead, emergent phenomena result from the "properties of the parts and the laws of their interaction," which arises from "purely random processes." These comments closely match Bedau's.

Furthermore, the kind of epistemological autonomy weak emergence countenances has a long-standing tradition extending back to cybernetics. Wiener used the term "black box" to be able to talk about systems as if they are discrete entities with discernable functional capacities because, even though the relationships between the parts of a system may be unknown, certain inputs into a system yield regular outputs (Fig. 1.1). Black boxing represents an "external description:"

> In *external description*, the system is considered as a "black box"; its relations to the environment and other systems are presented graphically in block and flow diagrams. The system description is given in terms of inputs and outputs (*Klemmenverhalten* in German terminology); its general form are transfer functions relating input and output. Typically, these are assumed to be linear and are represented by discrete sets of values (cf. yes-no decisions in information theory, Turing machine). This is the language of control technology; external description, typically, is given in terms of

> communication (exchange of information between system and environment and within the system) and control the system's function with respect to environment (feedback), to use Wiener's definition of cybernetics (von Bertalanffy 1972b, p. 418).

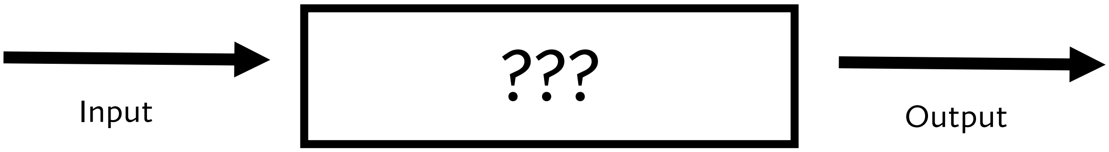

Figure 1.1. Black box explanation: An input goes into a system. The relationships between the parts are unknown (represented by "???"), but the system produces regular outputs to match the inputs. Thus, the system behaves as a functional entity such that claims can be made about the whole system without knowing exactly how the parts interact with one another.

In most cases, an exact understanding of how the system takes the inputs and produces its outputs may lay beyond the limits of observation; however, that does not inhibit an observer from generating reasonable predictions about how the system will behave as a whole. Over time, as new modes of observation open up, a clearer picture of a system's internal dynamics might reveal itself. In this way, "[e]verything is a black box because we can never have complete knowledge of how anything operates; all we can easily observe are those inputs and outputs that can affect and perceive" (Petrick 2019, p. 588).

Despite the support it receives in the literature, a problem still plagues weak emergence that Bedau does not successfully explain away, downward causation. Bedau argues that weak emergence does not preclude downward causation. To him, weak downward causation "is nothing but the iteration of the aggregate micro causes" (Bedau 2008, p. 178), Something like a wave crashing over a sandcastle and dislocating the grains of sand composing it constitutes weak downward causation on his account (Bedau 2008, 177). The wave may possess an ontological status and causal efficacy insofar as the water molecules making it up individually possess ontological status and causal efficacy, but all the water molecules aggregated together as a wave cause the sandcastle to dissolve. This interpretation of weak downward causation preserves ontological and causal reduction (Bedau 2008, p. 178).

Bedau's account of weak downward causation dodges the real issue, though. Complex systems theorists do not question whether aggregates possess causal powers over and above those possessed by their parts. Zeno's grain of millet paradox comes to mind, dropping a single grain does not make a noise but dropping a ton of grains together does. In the wave and sandcastle example, the causal interaction occurs between two individuals, the wave and the sandcastle. The aggregate of micro causal powers that make up the wave can dissolve the sandcastle by overpowering the aggregation of micro causal powers holding the sandcastle together. The real issue at stake for complex systems theory, though, is whether a weakly emergent phenomenon exerts downward causation on its own micro-level components such that higher levels of organization influence the operations of lower levels of organization within the totality of a single hierarchical arrangement. Complex systems theory wants to say that different organizational levels possess different causal powers and that different levels causally interact with one another in both directions. Weak emergence simply does not carve out a conceptual space that handles such multidirectional causal dynamism. It seems that some version of strong emergence is needed to account for multilevel causal interactions within one hierarchy of systems.

Consequently, scientists find themselves in a bind. On the one hand, they do not want to smuggle more metaphysical baggage into their accounts than needed. Weak emergence offers a nice safe haven for them. On the other hand, sophisticated modelling techniques and data analysis present a case for strong emergence. Higher levels of organization do appear to exert a measure of constraint on the parts composing them.

Complex systems theory's whole foundation rests upon the idea that no "one size fits all" approach ever properly accounts for the natural world. Ultimately, both kinds of emergence have a place in scientific explanation. Nothing prohibits some phenomena qualifying as strongly emergent while others qualify as weakly emergent. Complex systems theorists might hedge their bets and say that more times than not a phenomenon will exhibit weak emergence. However, shutting the door on strong emergence entirely seems like an obvious mistake.

The more interesting question, and one that the literature does not seem to consider, revolves around why multiple accounts of emergence exist. What counterbalances emergence ontologically? I think the literature already has the answer, openness. The rest of this chapter evaluates two kinds of openness; one is topological, the other is topographical. Each represents different statistical moments used to characterize a system and its environment. In the end, I argue openness is more fundamental than emergence.

Openness:

Topology vs Topography:

Complex systems theory represents a revolutionary scientific and philosophical endeavor for a variety of reasons. Of those reasons, one involves the incorporation of topological analysis to explain stable phenomena. Whereas topographical space is three-dimensional and primarily concerns itself with fixed points, topological space is n-dimensional and concerns itself with movements. Each degree of freedom (i.e., the variable factors that can lead to changes in state) a system possesses is assigned a dimension. All the dimensions are combined to construct a phase space that maps trajectories of development towards distinct basins of attraction.[10] Complex systems theorists of all sorts evoke concepts from thermodynamics such as bifurcations, symmetry-breaking cascades, limit cycles, thresholds, and hysteresis to explain why different phenomena behave the way they do.[11]

In the literature, "topology" more commonly references mathematical patterns of exchange recurring over periodic time cycles. Cybernetics and information theory are used to systematize these sorts of topological flows into networks of interactions. Wiener refers to the effect caused by systematic constructions like these as "control by informative feedback" ([1948], p. 113). Many fields of study have adopted information theory to explain phenomena topologically in this manner via positive feedback loops, and rightfully so.[12] In most cases, positive feedback loops provide the most comprehensive overview of a system's composition and the causal interactions that give rise to it.

Interesting enough, though, Shannon (1956), one of the patriarchs of information theory, inventor of Shannon entropy, wrote a one-page opinion titled "The Bandwagon." In it, he openly cautions against information theory's rampant application to all domains of study. He argues that cybernetics and information theory were developed as mathematical theories, as "deductive systems" (1956, p. 3). Their applications to more practical affairs that demand inductive practices like chemistry, biology, ecology, psychology, and social systems are much more tenuous. However, enough practical applications of information theory in different sciences have been sufficiently successful to date to warrant its continued use, still Shannon's worries should not be disregarded (as I intend to demonstrate below).

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[10] Noteworthy examples of this in biology and ecology include Prigogine and Nicolis (1971), Holling (1973), and May (1977).

[11] Prigogine and Stengers (1984) offer a comprehensive account of how all these concepts get used in complex systems theory.

[12] Noteworthy examples of this in biology and ecology include Patten (1959), von Bertalanffy (1968, 1972b), Odum (1971), Kauffman (1995), and Ulanowicz (1986, 1997).

Complex systems theory resists topographical depictions of systems because the boundaries of a system do not typically map to any fixed points in physical space. Instead, a system's limits are properly defined by its ability to continuously carry out processes that keep it in a stable state (Dupré and Nicholson 2018, pp. 13-14). As von Bertalanffy puts it:

> Any system as an entity which can be investigated in its own right must have boundaries, either spatial or dynamic. Strictly speaking, spatial boundaries exist only in naïve observation, and all boundaries are ultimately dynamic (1968, p. 215).

Ultimately, I agree with von Bertalanffy (and other complex systems theorists) that systems, as individuals, are best represented by topological means (e.g., basins of attraction and autocatalytic cycles). However, topological depictions of systems fail to capture any meaningful details about how a system's environment influences the system's ability to emerge and persist. They reduce the environment to a homogenous set of boundary conditions acting equally on all parts of system. Of course, that is inaccurate; systems occupy heterogenous environments. The heterogeneity of a given environment, as I argue below, plays an important regulatory role in a system's ability to achieve and maintain a steady state. A system may be fundamentally dynamic such that topological patterns emerge, which gestures towards a system's individuality; but hiding in those topological patterns are topographical features influencing the direction and speed at which processes unfold. My argument moving forward is that the topology of a system and the topography of the environment are somewhat inseparable. Accounting for the emergence and persistence of a system in a steady state requires both kinds of explanation. Ultimately, I conclude that a system is embedded in its environment.

In the next section, I outline and evaluate complex systems theory's topological openness. Most important, topological openness offers insights into how a system successfully maintains a steady state for extended periods of time after it emerges. Additionally, it provides a conceptual basis for interpreting the context-specific characteristics of a system. However, topological openness depicts a system as an abstraction emerging out of its environment; the environment is essentially unanalyzable. To remedy this blind spot, I posit a kind of topographical openness. Topographical openness maps onto semi-fixed physical features that characterize an environment. The boundaries of a system may not perfectly coincide with fixed points in physical space, but topographical features do have a measurable effect on them by (1) regulating inputs into the system, (2) regulating access into the system by outside groups, and (3) facilitate the regularity of propensities characterizing a system. In this way, topographical openness identifies how the environment imposes "soft limits" on a system. Both kinds of openness represent different statistical moments. When considered in conjunction with one another, topological openness and topographical openness serve as an important benchmark to better understand emergence.

Topological Openness:

As early as Bergson, process ontology has grounded its account in the primacy of matter and energy. Bergson writes that energy takes what is heterogeneous and unstable and makes it homogenous and stable ([1907], pp. 265-266). "Heterogeneous and unstable" refers to the flux of matter, stuff moving in different, uncoordinated directions. "Homogenous and stable" refers to the becomings that emerge from the organizational movement of energy through matter. Matter serves as the basis for both becoming and flux, stability and instability. The difference between becoming and flux owes to how energy moves through the matter.

Below, I provide several citations demonstrating how “openness” commonly gets used in complex systems theory:

> “However, we find systems which by their very nature and definition are not closed systems. Every living organism is essentially an open system. It maintains itself in a continuous inflow and outflow, a building up and breaking down of components, never being, so long as it is alive, in a state of chemical and thermodynamic equilibrium but maintained in a so-called steady state which is distinct from the latter” (von Bertalanffy 1968, p. 39).
>
> Open systems are “systems exchanging matter with [the] environment as every ‘living’ system does” (von Bertalanffy 1972a, p. 412).
>
> “An open system is defined by the fact that it exchanges matter with its environment, that it persists in import and export, building-up and breaking-down of its material components” (von Bertalanffy 1972b, p. 21).
>
> “Catalysis alone, however, is not sufficient for life. All living systems ‘eat’: they take in matter and energy in order to reproduce themselves. This means that they are what is referred to… as open thermodynamic systems” (Kauffman 1995, p. 50).
>
> “Ecosystems [as complex systems] are necessarily open, meaning that they exchange material and energy with their surroundings” (Ulanowicz 2004, p. 322).
>
> Open systems are “systems in which energy, information, or matter flows between the system and its environment” (Sawyer 2005, p, 17).

> “[A]ll living systems are *open* thermodynamic systems, taking in matter and energy” (Kauffman 2019, p. 18).

Fundamentally, topological openness appeals to Boltzmann’s second law of thermodynamics that says entropy necessarily increases over time. Systems exist in near-equilibrium states such that the matter and energy they lose through work and dissipation returns to them via inputs from the environment. As such, three features characterize topological openness. Topological openness:

1. Concerns a system’s relationship with its environment.
2. Involves the movement of matter, energy, information, or some combination thereof.
3. Enables a system to stave off entropy.

On the surface, this definition seems to offer very little: a system must refuel itself from the environment’s pool of resources to overcome entropy. However, a richer metaphysics operates within this framework. The definition in effect acts as a refutation of the Modern mechanistic worldview associated with Newtonian physics. Systems are not closed machines characterized by linear causal relations of inputs and outputs between the composing parts. Instead, systems are networks of interactive processes unlimited in their connections with one another and/or other networks.

Ulanowicz’s ascendency model best accounts for the larger metaphysical consequences of topological openness as it relates to emergence. Autocatalytic feedback loops serve as the foundation for Ulanowicz’s (1986, 1997) ascendency model.[13] Autocatalytic feedback loops emerge when the processes of various groups stimulate one another. The result is an emergent network of processes

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[13] Ulanowicz designed the ascendency model for the sake of studying ecosystems, but the same principles apply to other kinds of complex systems, too.

that maximizes the retention of material, energy, and/or information. Over time, systems exhibit a tendency with each work cycle they complete to improve the efficiency, or “ascendency,” of topological connectivity between the different groups composing them (Fig. 1.2).

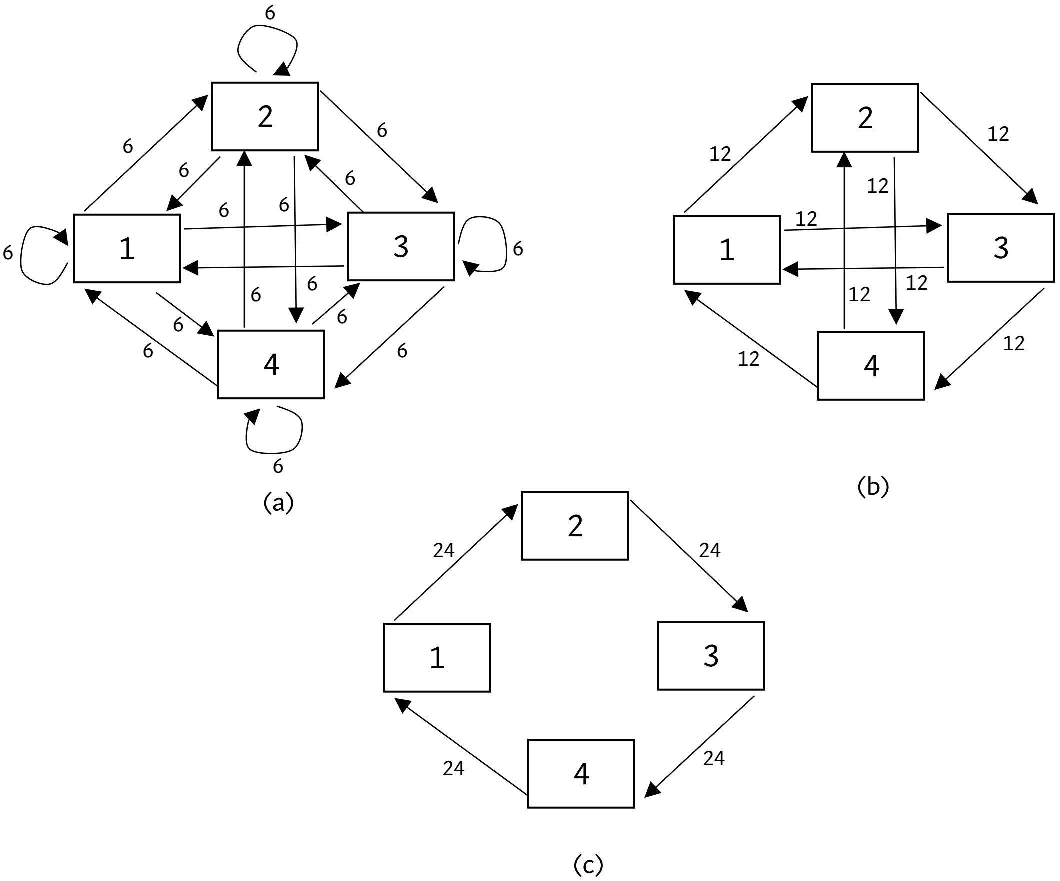
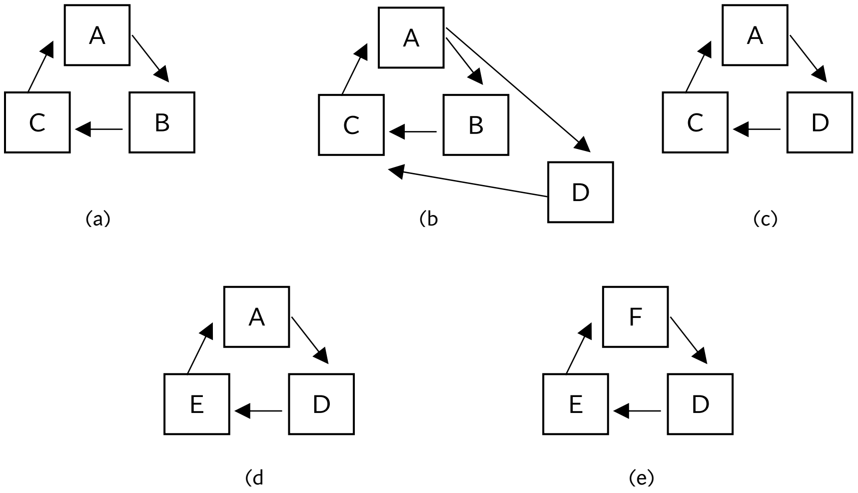


Figure 1.2. A hypothetical network that grows more efficient (“ascendent”) over time from (a) to (b) to (c). The values along the lines connecting the different groups (1, 2, 3, 4) represent the amount of information shared. A higher value indicates a stronger connection than a lower one. Average mutual information (AMI) is a logarithmic index from information theory that is supposed to be a functional measure of organization (adapted from Ulanowicz 1997, p. 74).

A system rarely (if ever) achieves maximum ascendency ((c) in Fig. 1.2), though. Systems always possess a measure of errancy. Ulanowicz identifies four different sources of errancy (“overhead” or “encumbered complexity”) in the topological structure of systems: (1) inputs, (2) exports, (3) dissipations, and (4) pathway redundancy (1997, pp. 82-86). Each of the four sources cause a system to be more “porous,” meaning the network of processes leaks some of its material, energy, and/or information. Outside groups gain access to the network via these leaks. If new groups improve autocatalysis, they can replace old ones (Fig. 1.3). According to Ulanowicz, this sort of porosity is “openness,” and it “is absolutely essential if evolution and/or development are to proceed (2009, p. 56).”



(a) (b (c)

(d (e)

Figure 1.3. A hypothetical instance in which an initial network (A, B, C) exchanges one or more groups over time (from (a) to (b) to (c) to (d) to (e)). The outside groups (D, E, F) are more autocatalytic, which allows them to supplant the weaker groups that were already established in the network (adapted from Ulanowicz 1997, p. 49; 2009, p. 73).

From this basic setup, Ulanowicz’s ascendency model provides a useful means for talking about a system’s ontology. It helps address two topics: (1) how emergence and openness balance one another (i.e., strength of downward causality versus degree of adaptability) and (2) the formation of a system's propensities to behave in a given way.

First, Ulanowicz identifies adaptability as a balance between emergence and openness. A maximally ascendent system is essentially maximally emergent because its processes have become so integrated with one another that production reaches its limits. Such a system, though, easily succumbs to even minor disturbances because it lacks adaptability. When no outside group can find an entry point into the system and production is pushed to the limit, the system becomes fragile. If even one of the groups within the network fluctuates too much (resulting from an outside disturbance), the whole system collapses due to the heightened interdependency. This same principle informs von Bertalanffy's conception of "progressive mechanization:"

> Organisms *are* not machines; but they can to a certain extent *become* machines, congeal into machines. Never completely, however; for a thoroughly mechanized organism would be incapable of reacting to the incessantly changing conditions of the outside world" (1968, p. 213)

More generally, von Bertalanffy states:

> The more parts are specialized in a certain way, the more they are irreplaceable, and loss of parts may lead to the breakdown of the entire system (von Bertalanffy 1968, p. 70).

Connecting topological openness with emergence is the greatest strength of Ulanowicz's ascendency model because it can adequately respond to some of the concerns involving strong and weak emergence previously discussed. With respect to Bedau's second hallmark, Ulanowicz identifies the factors influencing the degree of autonomy exhibited by a system. No system possesses full autonomy because full autonomy would contravene “either the second law of thermodynamics or Goedel’s prohibition against logical self-sufficiency” (1990, p. 44). Instead, autonomy corresponds to a system’s ascendency, which can be measured using a combination of average mutual index (AMI) and total system throughput (TST) (Ulanowicz 2009, p. 86). Higher ascendency reduces the impact a fluctuating environment has on the system’s integrity. Net zero ascendency applies to simple causal chains that depend entirely upon the environmental context they are situated in. Such linear causal chains do not possess any autonomy whatsoever (Fig. 1.4). Systems exist somewhere between full autonomy and no autonomy based on the strength of the topological connections holding between the constitutive parts of a system.[14]

Furthermore, connecting topological openness with emergence introduces a way to explain downward causation within a hierarchical structure without committing itself to any strong metaphysical claims. As previously mentioned, systems compose systems, but not every system operates at the same scale level of organization. Each system indexes to its own level of organization. Depending upon the system under consideration (i.e., the focal level), other systems at different levels of organization can appear as either an efficient cause or a final cause. Ulanowicz states the matter clearly, saying:

> I [argue] that when a feedback loop is apparent at the focal level of the hierarchy, one perceives it as a formal cause. When an autocatalytic loop is acting at a fine scale, it will appear to the observer, along with manifold other agents, in the guise of an efficient cause. Conversely, when the focal system is but part of at least one larger cybernetic loop, that unseen

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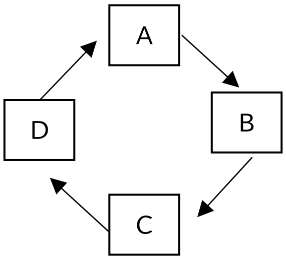
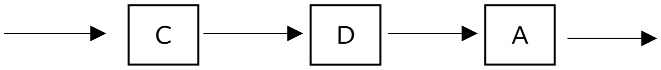
[14] Not surprising, Ulanowicz connects autonomy with emergence, stating: “If autonomy is one aspect of a feedback loop’s essence, then its epistemological counterpart is emergence” (1990, p. 44).

> autocatalytic behavior will impress itself on the object of the system via the boundary conditions. That is, its influence will be perceived at the focal level as final in nature (1990, p. 45).



Autonomous
(a)



Non-Autonomous
(b)

Figure 1.4. (a) An ideal, wholly autonomous causal loop. (b) A strictly non-autonomous chain of cause and effect (adapted from Ulanowicz 1990, p. 43).

So, how does this escape the hairy metaphysical baggage associated with strong emergence? Complex systems theorists are weary of strong emergence because it just reverses the old mechanistic dogma that causality flows in a single direction. Instead of bottom-up, strong emergence emphasizes top-down causal relations. Ulanowicz's ascendency model avoids this issue because it does not attribute causal supremacy to any one system within the hierarchy of systems. In fact, Ulanowicz opts for "top-down influence" rather than "top-down causality" language to avoid committing himself to the primacy of one or the other (Ulanowicz 2009, pp. 95-96). As Ulanowicz conveys in the passage above, systems at higher levels of organization (final causes) harmonize with systems at lower levels of organization (efficient causes). Thus, the causal relations running through any given system are held in check by each level of the hierarchy it is nested within (Fig. 1.5).[15]

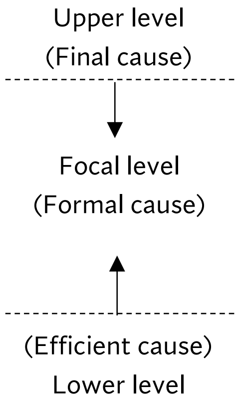


Figure 1.5. The triadic view of causalities as they affect a system. Formal cause arises at the focal level, whereas efficient cause operates from below. Final causes are impressed from above (adapted from Ulanowicz 1997, p. 52).

In addition to providing a measurement for the strength of emergence, topological openness helps to explain why systems behave the way they do. Ulanowicz, following Popper (1982; 1990), extends topological openness to include a type of ontic-causal openness. As Ulanowicz states:

> The universe in general, however, is *open*. In accounting for the reasons why some particular event happens, it is often not possible to identify all the causes, even if we include all levels of explanation: there will always remain a small (sometimes infinitesimal) open window that no cause covers. This openness is what drives evolution (1997, p. 37).

The type of topological openness Ulanowicz's ascendency model describes allows for randomness to creep into a system. Randomness breeds indeterminacy. So, in

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[15] Apropos, Whitehead remarks: "One task of a sound metaphysics is to exhibit final and efficient causes in their proper relation to one another" ([1929], p. 84).

lieu of properties, systems possess "propensities."[16] Properties correspond to fixed qualities of being that apply necessarily regardless of the context they are situated in (what substance ontology values most of all). Propensities differ in that they "never occur in isolation, nor are they inherent in an object" (Ulanowicz 1999, p. 133). Instead of being context-independent, like properties, propensities are always (at least somewhat) contingent upon their context. Ulanowicz states: "Propensities are the tendencies that certain processes or events *might* occur within a given context... inherent in a situation... agencies that populate the causal realm between the 'all' of Newtonian forces and the 'nothing' of stochastic infinitesimal" (1997, p. 37-38).

As propensities grow entangled with one another, it becomes increasingly likely that new propensities will emerge out of the interference, thus amplifying this sort of ontic-causal openness (Ulanowicz 1999, pp. 133-134). Bergson posits something similar:

> A perfect definition applies only to a completed reality; now, vital properties are never entirely realized, though always on the way to become so; they are not so much states as tendencies. And a tendency achieves all that it aims at only if it is not thwarted by another tendency ([1907], p. 16).

This sort of causal meshwork makes sense, especially considering Ulanowicz's notion of autonomy. Ulanowicz introduces a metaphor, "the fabric of causality," to put ontic-causal openness in perspective. He suggests that causality is like a fabric in which propensities are the threads holding everything together. Between those threads are holes of various sizes, which represent openings for chance events to occur (Ulanowicz 2009, p. 56). Autocatalysis strengthens the fabric, reducing the possibility for chance events to occur within the system, but at

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[16] Austin (2020) makes a similar appeal to propensities.

the expense of reducing the fabric's malleability, which has the adverse effect of increasing susceptibility to disturbances (Ulanowicz 2009, p. 78). In other words, the system becomes progressively mechanical (*sensu* von Bertalanffy) the longer it remains unperturbed. As the processes that bind the different groups of a system together become less and less susceptible to error, the closer the probability that the process will successfully take place just as it has done over previous iterations nears 1.0.

Again, topological openness (as outlined in Ulanowicz's ascendency model) offers a variety of benefits that help to qualify claims about a system's emergence. However, something is obviously missing from this sort of account, the environment. Complex systems theory has a tendency to focus so intently on the topological analysis of systems as individuals that it reduces the environment to some homogenous set of boundary conditions similarly experienced by every part of a system, which is, of course, not the case. Complex systems theory homogenizes the environment to the point where it is almost entirely unanalyzable. Still, this does not mean that complex systems theory misrepresents systems when they model them topologically. It just means that topological analyses of systems lack a certain dimension of detail. All models must remove some details in order to show patterns, otherwise the model functions as an exact copy of reality. The question, though, is this: does removing details about the environment cause complex systems theory to lose the ability to reach certain conclusions about a given system's ontology? I argue that it does.

In the next section, I try to recapture some of that missing detail by introducing a definition for openness fundamentally rooted in the topography of physical space. It lacks as strong of a connection to emergence as topological openness, but it does identify soft spatial limits for systems. I argue that identifying the soft spatial limits for a system makes it possible to evaluate and measure the environment's influence on a system's ability to achieve and maintain a steady state.

Topographical Openness:

Similar to topological openness, topographical openness fundamentally concerns distribution of matter and material things. This is why topological openness and topographical openness are best regarded as separate statistical moments rather than two incompatible definitions for the same principle. One type of openness does not preclude the other; they simply represent different lenses to view the movement of stuff (i.e., matter, energy, constitutive parts/groups) in to, out of, through, and independent of a system. Whereas topological openness seats itself within the individual system, topographical openness applies to the environment irrespective of an emergent system. Thus, topographical openness does not establish as strong of a connection with emergence as topological openness does. However, I argue that topographical openness provides a practical means for interpreting the influence of the environment on a system's ontology. A system's boundaries might be dynamic, as von Bertalanffy states, but, as I argue, spatial features still impose soft limits on systems by (1) regulating the flow of matter and energy into a system, (2) regulating access into the system by outside groups, and (3) influencing the propensities characterizing a system (i.e., propensities are built around the topographical layout of a system's environment).

Topographical openness pertains generally to the movement of stuff across physical space. This is the same general principle of topological openness, but instead of limiting movement to exchanges between environment and system (which presupposes the existence of a system) I delocalize movement such that it concerns a material body's movement from one point in physical space to another. In this way, topographical openness redefines openness less as a relational property between two discrete things (i.e., as a system is open in relation to its environment) and more so as a characterization of the state of affairs given the features of physical space and a material body's position within it. Topographical openness does not presuppose an inside or an outside. Sometimes a material body's movement will coincide with topological openness (i.e., movement will be from outside the system to inside the system) but it need not always be the case.

Two types of "stuff" move across physical space, (1) basic needs a system utilizes as fuel (e.g., matter and energy) and (2) possible components of a system. Topographical openness equally applies to both types of stuff.

To explain what topographical openness is exactly, I suggest the following hypothetical situation. Imagine a ball resting on a perfectly level, perfectly smooth, maximally frictionless surface (Fig. 1.6). The ball is just as likely to go in one direction as another. If energy gets put through the ball, the ball will move the direction of the force exerted on it. Such a situation constitutes "absolute topographical openness" because every direction the ball can move is equally likely until energy is exerted on it.

In the real world, a material body's movement across physical space (on massive objects like planets) is limited, so absolute topographical openness never effectively characterizes the environment that material bodies find themselves in. Two features of physical space impose limitations on the movement of material bodies: (1) barriers and (2) texture. Barriers and texture impose limitations on material bodies by impacting the directionality and speed of movement respectively.

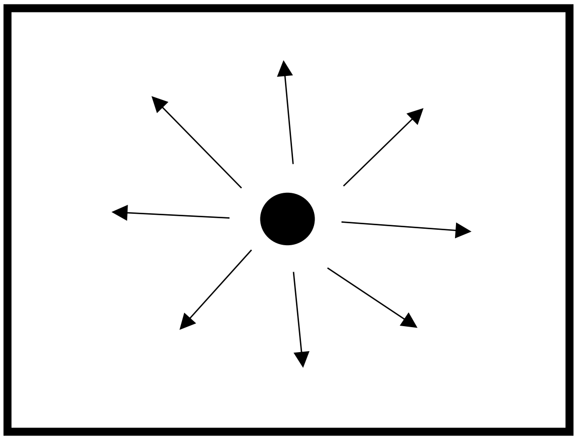

Figure 1.6. A ball resting on a perfectly level, perfectly smooth surface, maximally dense surface. Before energy is exerted on the ball. Each direction of movement is equally probable. The weight of each arrow reflects equiprobability that the ball will travel in a particular direction. In reality, the possible directions the ball can travel are infinite and the probabilities of each of the infinite directions are equal.

Direction pertains exclusively to changes of position by material bodies in the environment. The environment influences the direction of movement via barriers. Barriers occur in a variety of ways at all scales and with respect to all systems. For example, mucous membranes act as a barrier against infection; a mountain range acts as a barrier against the wind; stanchions act as a barrier that funnel people in a particular direction so as to prevent cutting in line. Of course, barriers rarely result in the absolute prevention of movement in a given direction. Cells still get infected; wind carries over mountains; people hop over velvet ropes. However, barriers significantly influence the probability that movement will happen in a specific direction. Probabilities play themselves out many times over, and this sometimes, but not always, results in distinctive movement patterns taking shape (Fig. 1.7).

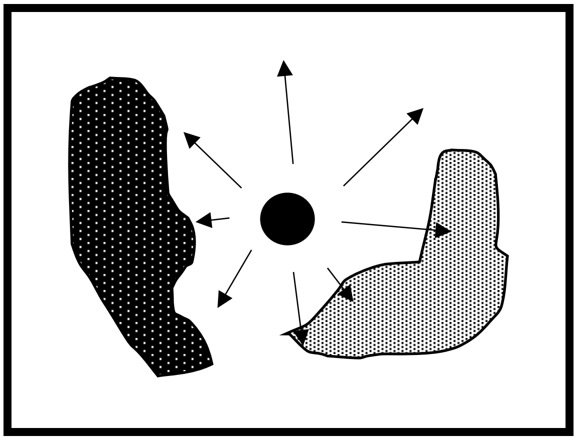

Figure 1.7. The same figure as before but with two shapes inserted to represent two different barriers occurring in the environment. The length of the line indicates the probability that the dot would move in one direction rather than another. Shorter arrows mean less likely; longer arrows mean more likely.

In addition to the tendency of material bodies to move in a particular direction based on the topographical profile of an environment, topography influences the speeds at which they move. The texture of an environment explains the variable speed material bodies travel at. By “texture,” I mean the density, or compressibility, of the surface that movements gain traction from. A texture impacts speed like a drag coefficient. Again, examples abound, running on sand compared to running on an Olympic track, swimming across a river versus walking over a bridge, mucus moving along ciliated as opposed to a nonciliated cells. The environment’s texture varies from place to place, thereby arranging physical space into patches that enforce different speed limits on the movement of material bodies (Fig. 1.8).

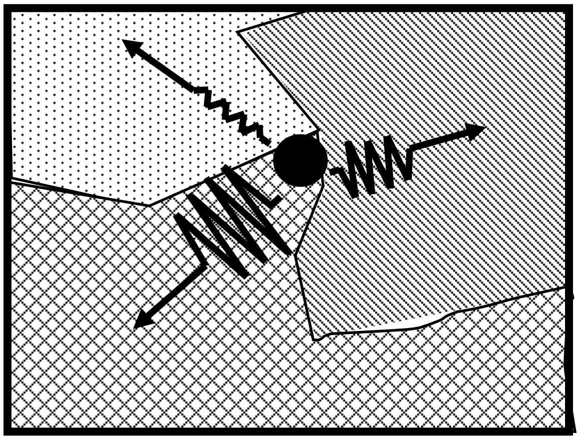

Figure 1.8. The same figure as before but with three zigzag arrows showing movement across three different types of textured terrains (represented by the different patterns), The narrower the zigzag, the faster the movement. Conversely, the wider the zigzag, the slower the movement.

Just as Ulanowicz's account of topological openness is statistically measurable (i.e., AMI and TST), so is topographical openness. With respect to a material body's movement, a lower probability to move in a specific direction reflects lesser topographical openness than equal probabilities in every direction. A statistical measure of topographical openness with respect to directionality can be determined by doing simple mean deviation calculations. A higher mean deviation suggests lower topographical openness; a lower mean deviation suggests higher topographical openness (e.g., an open grass prairie versus a cavernous ravine). (Of course, this requires that the probabilities associated with each direction be known.) Additionally, the speeds associated with various textures of physical space can be combined with the directional probability of a material body to determine the likelihood that a material body will reach a certain destination in a given amount of time. This has a practical implication in any situation where movement of a material body from one place to another is time-sensitive (e.g., getting produce to a grocery store before it spoils, individuals from a rescue population dispersing to a region before the colonizing population goes extinct, epinephrine making its way through the bloodstream before an allergic reaction closes the windpipe).

Taking stock, topographical openness may seem like a simple way to detect distribution across physical space, but it reveals three sorts of influence the topographical profile of an environment has on emergent systems: (1) the regular movement of matter and energy into a system, which act as efficient causes, (2) the accessibility of a system by outside groups, which are sources of adaptation, and (3) the environmental context propensities design themselves around. Below, I go through each of these separately.

1. Matter and energy are one kind of "stuff" that moves across physical space. In many ways, matter and energy act as the ontological primitives of systems for reasons previously discussed (i.e., a system's stable existence as a perpetual becoming depends upon the cycling of matter and energy). Although systems require semi-regular supplies of matter and energy, it is not as if every unit of matter and energy finds itself cycling through a system. Topological openness can only account for matter and energy moving into or dissipating out of a system. Topographical openness is under no such constraint.

The criteria a collection of processes have to meet to qualify as a system is pretty difficult to satisfy, which explains why no other planet in the solar system comes close to matching the number of systems found on Earth. Per Ulanowicz, only processes that organize themselves in an autocatalytic way qualify as a system because only an autocatalytic cycle arrangement possesses the sort of autonomy associated with systems behaving as an individual unit (somewhat) independent of its environment. Most movement of matter and energy across physical space occurs non-autonomously as linear causal chains, though. Something Ulanowicz does not acknowledge in his account is that linear causal chains are not necessarily stochastic; some occur regularly and predictably. In fact, if the delivery of matter and energy through linear causal chains did not happen at least semi-regularly, systems could not possibly exist. Ulanowicz considers lower-level systems within a hierarchy as efficient causes, but these inputs as linear causal chains from outside the system represent an equally important kind of efficient cause. Without them, the system would burn through its resources in a very short period of time.

Topological openness only offers the system's perspective, so the inputs from the environment appear as simplistic steady flows. When viewing openness topologically, the inputs from the environment are unanalyzable. No explanation can be derived about where the inputs come from or what causes their regularity. Topographical openness allows for the analysis of these inputs from the environment. The probability for material bodies (as both matter and energy) to move in a general direction can be calculated using the methods detailed above. The topographical features of physical space influence those probabilities such that regular patterns of movement do occur. This is evident in both natural and social systems. Rainwater flows downwards, into plains, rivers, and lakes, which fuel ecosystems. The number of lanes making up a road as well as what material the road surface is composed of influences traffic patterns, which cities use to create algorithms for their traffic light systems. If the topographical conditions change, if a plot of land is leveled off or a bridge into town is closed, topological openness could only detect it insofar as the system would suffer some disruption in its inputs. Topological openness could not explain how or why a hiccup in inputs occurred. Topographical openness could because it maps directly onto physical space.

Even though a system's ontological limits are dynamic (as von Bertalanffy suggests), systems still possess spatial limits albeit not rigidly defined. A person could never point and say, "the system ends here," but I cannot imagine anyone would want to say that systems are spatially boundless. Surely, no ecologist would say that the tropical rainforest ecosystem of Borneo extends to Lexington, Kentucky. Variations in the regularity of matter and energy's movement across physical space are the likely culprit for explaining why a system does not possess infinite extension. The tropical rainforest ecosystem on Borneo does not share the same sort of inputs as the temperate forests of Lexington, Kentucky. Topographical openness can help to identify these sorts of soft spatial limits by detecting patterns showing matter and energy's consistent movement into particular regions. Tracing those patterns can provide a useful benchmark for explaining the rough spatial limits of a system. This represents probably the greatest strength of topographical openness.

2. Outside groups that can potentially access a system represent the other kind of "stuff" that topographical openness tracks across physical space. Unlike matter and energy, outside groups that successfully access a system do not provide fuel but instead represent different catalyzers of processes. Thus, new groups that access a system act as causal influences with the potential to affect the system's internal dynamics. The way Ulanowicz uses topological openness in conjunction with emergence to explain adaptation is exceptional. His ascendency model adequately explains why one group may be incorporated by a system and why one group might even replace another. It all boils down to how well the different groups composing a system work together to effectively catalyze one another's processes.

Lacking in Ulanowicz's account of adaptability, though, is a recognition of how spatial features of an environment influence whether or not a new group becomes integrated within a system. The topographical profile of an environment influences groups accessing a system in two important ways. On one hand, in order for new groups to be incorporated within a system, the group must first be able to successfully access the spatial region the system occupies. The best catalyzers for a particular system might possess a significantly low probability to ever reach it. In such a case, it does not matter how good of a catalyzer the group is because it will never make its way into a system. Thus, topographical openness identifies important filter effects on the movement of potential groups across physical space.

On the other hand, it matters where within the soft spatial limits of a system a new group positions itself. If a new group cannot penetrate deep within a system, if it establishes itself on the periphery of a system's spatial limits, it will never become incorporated as a regular catalyst. This means it will never replace any of the groups already composing the system. Imagine a new restaurant coming to town. It may offer the best seafood around, but if it sits on the outskirts of town, it will never make enough money to relocate or franchise (reproduce). The restaurant may make enough money to keep up with its lease and offer a slight profit for its owner, but it will never drive any of its competitors out of business because people will opt for a closer, less tasty but still satisfactory option. This demonstrates an important point taken for granted by topological depictions of systems: groups must reside within proximity of one another to exchange matter and energy with one another (i.e., perform catalysis), and location matters. At some point the amount of matter, energy and time it takes to reach a group to interact with is simply not worth it.

Space is an important buffer regulating the rate at which processes are carried out. If groups are too close to one another, they might accelerate their interactions with one another to explosion. If groups are too far away from one another, they might interact too infrequently to maintain their near-equilibrium states. Some systems can create their own spatial divisions (e.g., an organism's body separating itself into different organs and systems) while others depend upon their environment for assistance (e.g., ecosystems). Either way, the spatial relationships within a system obviously matter for the sake of a system's ability to achieve and maintain a steady state.

3. Finally, Ulanowicz correctly points out that systems achieve a measure of autonomy by organizing their processes in an autocatalytic fashion. However, he misrepresents this sort of autonomy as an escape from the environmental context a system is situated within. On his account, the strength of the propensities characterizing a system resides almost entirely with the topological exchanges between the groups comprising a system. This seems like too strong of a claim, though, for at least two reasons.

For one, a system clearly cannot fully remove itself from the context of its environment because the environment directs the non-autonomous. linear causal chains of inputs into the system. As discussed above, Ulanowicz rightly distinguishes between the two sorts of causal arrangements. Linear causal chains are "non-autonomous" because they depend entirely on the context of their environment. If a system is sensitive to fluctuations in inputs from outside the system and those inputs depend entirely on the context of the environment, it seems rather obvious that the system remains causally bound to the context created by the environment, at least in terms of receiving regular inputs.

Additionally, I would argue, the internal dynamics of a system are built around the context of the environment. Systems do not "escape" their environment; they "embed" themselves in it. Spatial relations within a system ensure that processes carry out with a certain degree of regularity such that they qualify as propensities. This is frequently the case in ecosystems. Mice use long grass, rocks, and leaves as a means to hide from predators. An environment with these sorts of components (i.e., long grass, rocks, and leaves) decreases the probability that a predator will successfully catch a mouse. Removing those components from the environment such that the mice have little to no coverage to hide under would likely swing the probability in favor of the predator finding and catching its prey. The depopulation of mice within the system would, in turn, have an effect on any of the other groups that depend upon the sorts of processes mice carry out for the sake of the system. This example highlights how removing habitats from the environment can ultimately influence the dynamics of an ecosystem by either increasing or decreasing the probability that a given interaction will take place. This applies similarly to social systems, which explains why governments and businesses invest significant amounts of capital in designing spaces and infrastructure that fulfill their needs (i.e., carry out their processes in an efficient and timely manner).

In sum, topographical openness offers a practical means to evaluate the influence the environment has on a system. When used together, topological openness and topographical openness provide a useful benchmark for studying emergence. Emergence takes effect only after openness has been sufficiently limited. Too much topological openness causes a system to dissipate into nothingness. Too much topographical openness and a system will never receive a steady input of matter and energy to maintain its near-equilibrium state. Instead of starting with emergence, I suggest working chronologically to analyze the threshold conditions that must be met before a system truly emerges. Doing so would force complex systems theory to reevaluate the role the environment plays in shaping a system.

Conclusion:

In this chapter, I presented and evaluated two different ways to define openness, topologically and topographically. Topological openness identifies the degree in which a system exchanges matter, energy, and/or information with its environment. As Ulanowicz shows, a higher degree of topological openness (overhead) coincides with a lower degree of emergence (ascendency) and vice versa. More specifically, topological openness provides a causal explanation for why new groups can enter a system and supplant old ones. If a new group enters a system and better catalyzes interactions than another group already established in the system, then eventually the new group will work itself into the system and the old group will be worked out of the system. Additionally, topological openness, in conjunction with emergence, explains why regular propensities characterize a system. The stronger the interactions between groups composing a system, the more the system creates its own context, thus escaping the fluctuating conditions occurring within the environment.

Topographical openness is more basic than topological openness. It identifies the movement of material bodies across physical space. Whereas topological openness posits a system against its environment, topographical openness makes no such presupposition; material bodies can move across physical space whether or not they are bound up in a system. Defining openness topographically has three distinct advantages over topological openness. For one, it allows for an analysis of the inputs into a system as non-autonomous causal chains entirely dependent upon the context of the environment. Those inputs act as efficient causes. Without regular inputs from the environment, a system slowly dissipates. Additionally, topographical openness provides added detail to adaptation events. Adaptation involves more than being a better catalyzer for a system. A group must first be able to breach a system's spatial limits and establish itself in a favorable place to properly interact with the other groups composing the system. Topological openness provides the better causal explanation for adaptation, but topographical openness provides further insights into the conditions that need to be met in order for adaptation to occur. Finally, topographical openness suggests that a system's propensities blend themselves with the environment. Instead of "escaping" its environment, a system "embeds" itself into the environment. A system engineers its own context to escape the unpredictability of the environment to a degree, but a system also takes advantage of the predictability afforded by the environment. Why would it not? Strong evidence for this comes from the fact that changing the topographical profile of an environment directly affects the topological relations characterizing a system.

In the end, both kinds of openness provide important ways to analyze a system. Each represents a different statistical moment. One reflects the relationship a system has with its environment, the other applies more generally to physical space itself.

Starting from openness, rather than emergence, represents a new direction complex systems theory can, and should, take moving forward. For too long, complex systems theory has been an emergence-first study. In some respect, this makes sense because emergence serves as the best indication that complex interactions exist. However, complex systems theory has found itself locked into the question of individuality because of it. Does this collection of processes function as an individual? What qualities does this individual system possess that the groups composing it do not? How does this individual system create a set of contingent causal conditions for itself? Can the historical lineage of this individual system be traced? These are the questions complex systems theory seemingly restricts itself to. They are good questions, but it neglects much of the natural world. Not everything exists as a system, and non-systems (as environment) play a significant role in explaining the emergence and continued existence of systems.

Chapter 2: Topographical Openness and Its Relation to Topological Emergence: Philosophical Reflections on Island Biogeography Theory

Introduction:

Emergence is so central to the philosophy of complex systems theory that the whole endeavor has been referred to as “the science of emergence” (Bedau 2007, p. 155) It has been the anchor in the literature for some time now (Kauffman 1995; Holland 1998; Bedau and Humphreys 2008; Hooker 2011; Nicholson and Dupré 2018). Although emergence is certainly an important property of complex systems, it has an equally important, less examined, ontological counterpart, openness. In this chapter I posit a revised account of openness, relevant to ecology, that can be paired with emergence to explain ecosystem dynamics and development. Through the unique biogeographical insights afforded by island settings (cf. Wallace [1880], p. 229), my goal is to offer an ontogenetic account of ecosystems that connects openness with emergence in such a way that realizes the full potential of complex systems theory’s foundational process ontology. I argue that complex systems theory is not “the science of emergence” but rather “the science of becoming,” from openness to emergence.

First, I outline von Bertalanffy’s distinction between primary and secondary regulations as they relate to open-system models (OSMs) and cybernetic system models (CSMs) respectively. The distinction is helpful because it places openness and emergence on opposite ends of an ontological continuum. The simplest complex systems are open systems. Open systems exhibit a steady state existence due to the constant importation of matter and energy from the environment. von Bertalanffy terms the features responsible for this initial steady state “primary regulations.” Over time the component parts of a system become increasingly specialized. Feedback structures emerge as “secondary regulations,” which causes the system to grow isolated from its environment.

Second, I apply the theoretical framework gleaned from von Bertalanffy to a practical example in ecology, the number of species composing an island community as predicted by MacArthur and Wilson's classic equilibrium theory of island biogeography (ETIB). The ETIB is a dynamic equilibrium model of biotic immigration and extinction based on two parameters, an island's distance from the mainland and its area. I convey how the ETIB captures the properties of OSMs in which distance and area, two topographical features, function as primary regulations and induce a steady state where the number of species stays about the same.

In the third and fourth sections, I extend von Bertalanffy's ideas about secondary regulations within refinements made to the ETIB's general narrative in the years immediately after its introduction. I demonstrate how the topographical nature of openness influences the emergence of topological patterns among species in later stages of an island ecosystem's development. In sum, primary regulations set limitations that the emergent secondary regulations never entirely overcome. This reading of the ETIB and its refinements through the concepts from von Bertalanffy illustrates how ontogenesis occurs in ecosystems that encompasses topographical details of the landscape as well as topological structures within the network of species interactions. It also conveys how openness and emergence can be more equitably incorporated into philosophical frameworks of complexity.

Finally, I briefly define openness as a system property and identify its function within complex systems theory's process ontology. I distinguish my account of openness from other common uses of the term. The chapter ends with a petition for an ontogenetic approach that bridges openness with emergence for the benefit of both theoretical and practical endeavors that apply complex systems theory to ecology.

This chapter is intended to set the groundwork for the following chapter on resilience. Resilience is an important concept in ecology, one that complex systems theory has a longstanding tradition with. The same general argument I make in this chapter applies to resilience specifically. Complex systems theory depicts resilience as an emergent property owing entirely to topology. I will argue that openness factors into resilience, too. Topographical features play an important role in assisting an ecosystem's return to a steady state by facilitating or restricting movement back into it after disturbance. Thus, like the ecosystem itself, an account of resilience requires both openness and emergence, topography and topology, to the point where one model will not do.

von Bertalanffy's Primary and Secondary Regulations:

Complex systems are not all the same. Different systems possess different features that perform a multitude of functions in maintaining a dynamic equilibrium. This is the thrust behind von Bertalanffy's distinction between primary and secondary regulations. Primary regulations are general features of an open system that actively regulate equifinal steady states resulting from the constant importation of matter and energy from the environment. Secondary regulations correspond to structural features within the network of interconnections (i.e., feedbacks) that make flow pathways between component parts more unidirectional and efficient. In ontological terms, primary regulations relate to a system's openness whereas secondary regulations relate to a system's emergence and the associated closedness that accompanies it becoming more integrated. The identification of primary and secondary regulations allows complex systems to be classified along a spectrum of developmental stages.

von Bertalanffy credits himself as being one of the first to develop an open-system model (OSM) of the organism after finding himself dissatisfied with biology's unwavering commitment to the mechanistic approach that reduces everything to unidirectional causal chains (1968, pp. 12-13). The OSM is quite simple. A one-sentence definition resurfaces throughout von Bertalanffy's work: open systems continuously exchange matter and energy with their environment (both importing and exporting) resulting in the system attaining a "steady state" (von Bertalanffy 1952, p. 127; 1968, p. 141; 1972b, p. 21). von Bertalanffy frequently names metabolism as an example of an open system. Organisms consume resources and produce waste. The breaking down of resources through metabolic activity yields energy and nutrients so that a steady state is achieved.

The OSM captures some characteristics often observed in complex systems beyond the predisposition to be open with respect to the environment. For example, open systems are irreversible. Closed systems are reversible because every process that occurs within a closed system is entirely determined by the initial conditions of the system and the natural laws of chemistry. Open systems differ in that their initial conditions do not determine their developmental trajectory. Changing one of the parameters acting on an open system does not necessarily mean that the system will undergo a significant, qualitative change. As a result, the developmental trajectory of an open system is often described as equifinal. Equifinality is the principle that in open systems a given end state can be reached by many potential means. Neither changes in initial conditions nor disturbances to an open system deter it from reaching a time-independent steady state. The developmental trajectory of an open system might follow different routes as indicated by "overshoot" or "false start" (Fig. 2.1), but the system returns to its steady state as the flows between the system and the environment equilibrate with one another.

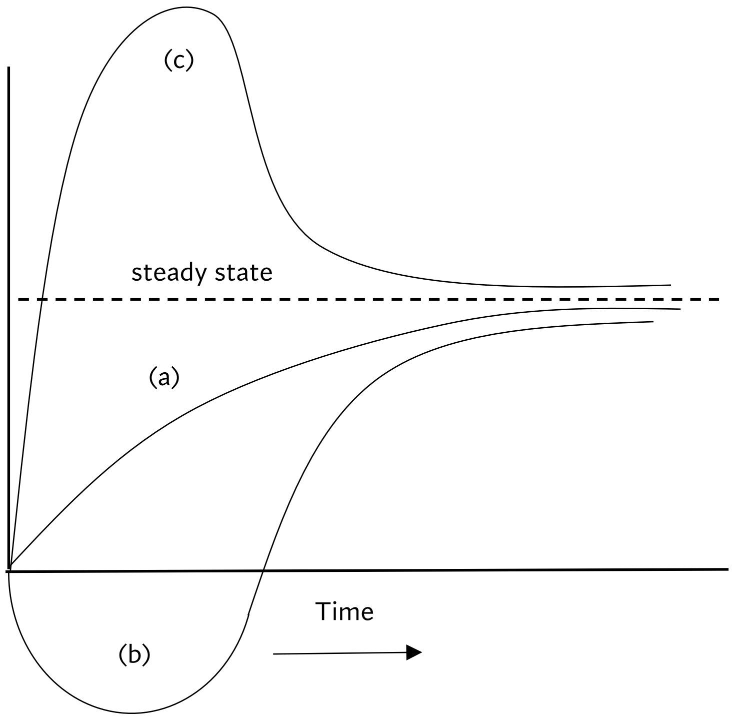

Figure 2.1. Adapted from von Bertalanffy's depiction of an open system following one of three developmental paths towards a steady state: (a) steady approach, (b) false start, and (c) overshoot (1968, p. 143).

Most important, open systems defy the second law of thermodynamics. Instead of progressing towards higher degrees of entropy, open systems progress towards "higher degrees of differentiation and organization" (Prigogine 1965). As with embryological development, an organism starts out as a handful of undifferentiated cells. New structures periodically emerge throughout embryogenesis. These structures start out simple and end up complex. By the time an organism reaches maturity, it possesses a whole assortment of differentiated parts that perform specialized functions for the purposes of maintaining a dynamic equilibrium.

The OSM is a baseline model of the organism. By “baseline,” I am implying that the model serves as a starting point for understanding why an organism exists in a dynamic equilibrium. The OSM is on one end of the continuum. But as with most simplifications, the OSM does not explain everything. Complex systems tend to exhibit greater degrees of complexity as evidenced by their self-regulatory powers. Whenever this is the case, feedback loops are detectable somewhere within the system’s network of interconnected component parts. The study of these feedback loop structures is the chief concern of a different model, the cybernetic systems model (CSM), at the other end of the developmental continuum.

Under the CSM, the goal is to identify structures that grant systems increasing stability as well as the ability to control the direction of flows between component parts. As previously mentioned, these structures take the shape of feedback loops. Feedback loops follow a basic processual pattern. First, some stimulus strikes a receptor connected to the system. Once stimulated, the receptor transmits a message to the control apparatus (i.e., a collection of structural arrangements within the system controlling the direction of processes). After the message is formulated in the control apparatus it passes through an effector and two products result, (1) a response by the system and (2) a feedback loop that cycles back as a new stimulus acting on the receptor (Fig. 2.2). The neuroendocrine system is an example of a biological feedback loop. Glands detect changes to hormone levels in the blood and either turn on or turn off hormone production depending on the detected levels to maintain a threshold. A thermostat is a technological example.

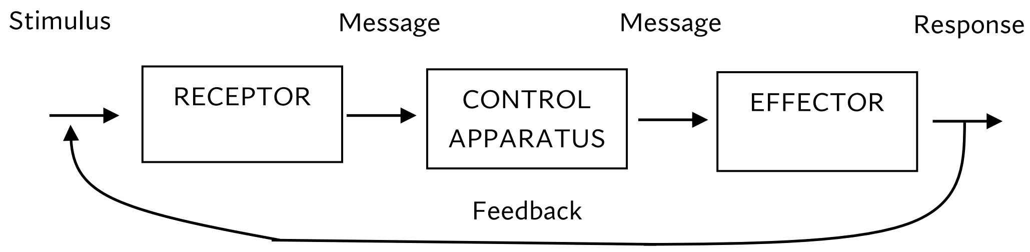

Figure 2.2. A simple feedback loop (adapted from von Bertalanffy 1968, p, 43). "CONTROL APPARATUS" in von Bertalanffy's diagram is a black-box representation of the network connections holding between the component parts of the system responsible for regulating the steady state. Each "message" represents a movement of information.

Feedback loops are measured by the movement of information within a system's network of connections. Information is a statistical measure of connectivity between component parts that, overall, determines the degree of organization characterizing a system. In exact terms, information reflects uncertainty within a system. A network in which each component part is connected to every other component part will possess a low degree of organization because it is uncertain which direction the movement of matter or energy will go from one component part to the next. Conversely, a network held together by a series of single, unidirectional flows from one component part to the next will exhibit a high degree of organization because the transfers between component parts are guaranteed to follow certain paths.

One thing that clearly distinguishes the CSM apart from the OSM is this use of information as a measurement tool. The OSM only captures the movement of matter and energy, not information. The equifinal steady state of an open system is maintained in virtue of constant material inputs from the environment.

A cybernetic system, on the other hand, is "*open* with respect to information, but *closed* with respect to matter and energy" (von Bertalanffy 1968, p. 163). This does not mean matter and energy do not flow in or through a cybernetic system. They do, but feedback structures optimize the retention of matter and energy by maximizing the probability that flows of matter and energy follow specific pathways. In effect, the system becomes increasingly isolated from its environment as its internal dynamics become increasingly unidirectional and self-sufficient. In theory, matter and energy follow a perpetual cycle of transformational repurposing within a feedback loop. In practice, of course, no system is perfectly self-sufficient, which explains why no absolute cybernetic system exists. Every cybernetic system must remain, fundamentally, an open system to some degree.

The characteristics accounted for by the OSM remain attributable to the systems analyzed by the CSM. However, the presence of feedback loops introduces additional characteristics not found in the more primitive open systems. For instance, cybernetic systems are marked by homeostasis. Homeostasis occurs when a system reacts to fluctuating conditions. The system responds to changes by adjusting the flows between component parts so that a target dynamic equilibrium is maintained. von Bertalanffy refers to this as "the seeking of a goal" (1968, p. 46). Homeostasis, thus, points to a second characteristic associated with the CSM, teleology. Feedback loops minimize chance within a system by increasing the likelihood that flows between component parts will follow specific pathways (i.e., the most efficient ones). Over time, the system undergoes "progressive mechanization" in which the component parts of a system become gradually more specialized, losing their equipotentiality to perform multiple functions within the system (von Bertalanffy 1968, p. 44). In short, a system becomes rigid as more of its potentialities become fixed realizations.

For comparison, Ulanowicz's ascendency model is a CSM for studying ecosystems. Autocatalysis among different functional groups cause feedback loops to form. Many of the same characteristics von Bertalanffy associates with cybernetic systems are also identified by Ulanowicz. Ulanowicz compiles a list: (1) growth, (2) selection, (3) asymmetry, (4) centripetality, (5) competition, (6) autonomy, (7) emergence, and (8) agency under the guise of an Aristotelian formal cause (1997, p. 53).[1] Each of these characteristics signals that a mature ecosystem, due to the arrangements of feedback loops among its component parts, possesses self-regulating powers over and beyond those that would be found in a nascent community (an OSM), and even more so if compared to a purely random community. According to the ascendency model, ecosystems that possess feedback loops react to fluctuations in internal conditions and external disturbances via selective adaptations to grow more efficient over time. Autocatalysis strengthens the interconnections between species, causing trophic flows to become unidirectional and codependent, thereby maximizing the ecosystem's retention of matter and energy and minimizing the chance of outside invasion.

Ulanowicz's ascendency model is consistent with von Bertalanffy's progressive mechanization concept and the teleological implications that result from it. One point Ulanowicz makes clearer than von Bertalanffy does, though, is how highly efficient feedback loops imply greater system emergence. As the component parts undergo specialization their existence becomes entwined with the whole's existence. For example, mitochondria once existed as free-living prokaryotes but now cannot exist without other organelles and the cellular environment (Smith and Szathmáry 1995, pp. 137-142). To make an even stronger

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[1] In a previous paper, Ulanowicz identifies only six of these attributes: (1) autonomy, (2) emergence, (3) growth enhancement, (4) selection, (5) competition, and (6) formality (1990, p. 44).

claim, a system organized by strong feedback loops, having undergone progressive mechanization, appears to qualify as an individual in the ontological sense.[2]

On these grounds, Ulanowicz (1990; 1997; 1999; 2009) is justified in returning to the language of Aristotelian formal and final causality to explain different characteristics of ecosystems. These are not traditional Aristotelian formal and final causes, but they elicit a similar worldview. Mature ecosystems have a patterned structure, a form, as evidenced by network depictions of trophic interactions. An ecosystem's continued existence can be confirmed by its maintenance of a particular topological structure. In terms of final causes, ecosystems result from self-regulating processes, the ones that improve autocatalysis. The strength of autocatalysis can impose constraints on the species that compose the ecosystem such that the success of individual species is tied to the success of the whole. According to the ascendency model, the species in a mature ecosystem interact with one another in such a way that they fulfill an end, namely the stabilization of the ecosystem. Although I can understand how Ulanowicz derives this philosophical perspective, my position moving forward is that this kind of thinking is ultimately problematic because it denies the importance of openness by making the natural world seem like a place of isolated individuals instead of constant flux. The former worldview suggests a process ontology that secretly aspires to substance ontology ideologies whereas the latter represents a commitment to process ontology wholesale.

It is not simply the case that the OSM and the CSM represent different ways to model a complex system. The OSM and the CSM highlight regulatory

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[2] No system perfectly meets the criteria for individuality based on the traditional realist concept. Instead, as von Bertalanffy posits, systems undergo "progressive individualization" (closely related to "progressive mechanization") so as to approach individuality yet never fully attain it (1968, p. 73). However, individuality remains an important concept to complex systems theory. Krakauer et al. (2020) recently developed new techniques in an attempt to measure various types of individuality using information theory.

features that dominate different stages of development. They thereby provide the basis for explaining a system's ontogenesis from a mere collection of causal chains to an organized structural arrangement of reinforcing interactive processes. Following von Bertalanffy, features can be classified as either primary or secondary regulations.

Primary regulations are of greater relevance to the OSM. They account for the regular movement of matter and energy into a system from the environment. The result is a steady state characterized by equifinality. von Bertalanffy does not provide a more precise account of primary regulations. This imprecision is not necessarily problematic, though, because it aligns with the generality of the model. Again, the OSM is a foundation to build on; it needs to be filled out to apply in particular domains. The exact features responsible for primary regulations likely differ depending on the nature of the system under consideration. In my view if a feature regulates inputs and outputs of matter or energy that contribute to a steady state, it qualifies as a primary regulation.

A large number of open systems organized by primary regulations possess additional structure that improves the system's overall stability. These are secondary regulations, and they are accompanied by the emergence of semi-fixed arrangements of directed pathways (i.e., feedback loops) (von Bertalanffy 1968, p. 150). It is important to note that secondary regulations do not replace primary regulations. Instead, they are "superposed" on them (von Bertalanffy 1968, p. 44). So, a system possessing secondary regulations simultaneously possesses primary regulations. Secondary regulations strengthen as the components of a system become specialized and the pathways connecting them become more deterministic. Thus, the emergence and growing influence of secondary regulations signals progressive mechanization.

Bridging the OSM and the CSM appears to be von Bertalanffy's ultimate goal. The duality of the OSM and the CSM, von Bertalanffy asserts, "is a modern expression of the ancient antithesis of *process* and *structure*” that “will eventually have to be resolved dialectically in some new synthesis” (1968, p. 163). The primary regulations studied by the OSM account for the equifinal steady state that results from constant material input from the environment. The secondary regulations studied by the CSM focus on the feedback structures within the network of interactions between component parts that grant a complex system greater control over its homeostatic state. As a concept, progressive mechanization links the two sets of regulations to provide an ontogenetic account.

In the end, the OSM and the CSM expose something significant about complex systems theory’s philosophical foundations. von Bertalanffy defends the OSM as the proper starting point of an explanation rather than the CSM because every cybernetic system is necessarily an open system. Starting from the OSM is not required, though. In fact, most of the complex systems theory literature does not. It instead follows Ashby, a contemporary of von Bertalanffy (cf. von Bertalanffy 1968, pp. 94-95), and starts from the CSM. Even though one approach is not more veridical than the other, selecting has its consequences. I do not at all deny the value of cybernetic accounts. But I do find myself siding with von Bertalanffy. Openness is more primitive in comparison to emergence. Naturally occurring complex systems may start to close off from the environment as their self-regulatory powers grow, but it is undeniable that they remain inherently connected to and dependent on it at some basic level.

The domination of CSMs and the introduction of network analysis tools like information theory has engendered a topology-centered approach to the study of ecosystems (e.g., Ulanowicz’s ascendency model). These approaches account for important secondary regulations within ecosystems but make no attempt to identify the primary regulations responsible for their emergence. In the next section, I use MacArthur and Wilson’s equilibrium theory of island biogeography (ETIB) to demonstrate that topographical features function as primary regulations determining the extent to which an island community is open prior to and after the formation of ecological interactions (e.g., competition and predation). I intend to show that the relationship between these sorts of primary and secondary regulations in island communities reveal an asymmetry. Changes to the primary regulations cause changes to secondary regulations but not the other way around. This asymmetry seemingly confirms openness' primacy over emergence and the need to supplement topological analyses with topographical details to draw out causal dependencies within networks of interconnections.

MacArthur and Wilson's Equilibrium Theory of Island Biogeography (ETIB):

Islands are well-recognized for the visibility they give to ecological and biological concepts like endemism, relictualism, insularism, niche specialization, adaptive radiation, and biodiversity. This is due to the geographical characteristics of islands. The present section focuses on the single most prominent feature of island biogeography theory: the factors determining the number of species found on a given island.

MacArthur and Wilson published *The Theory of Island Biogeography* (1967) around the same time as von Bertalanffy's *General System Theory* (1968). In it, Macarthur and Wilson expand on a theory they first introduced in a previous article (1963), the equilibrium theory of island biogeography (ETIB).[3] The ETIB posits that for every island the number of species found reaches an equilibrium as immigration rates intercept extinction rates (Fig. 2.3). The number of species

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[3] Although there have been many refinements of the ETIB over the last half century, I employ the ETIB here as it is more commonly employed today, as an equilibrium concept from which departures from it can be compared in a manner similar to how the Hardy-Weinberg principle works in biology. The predictions of the basic ETIB are not universally true. However, the ETIB is the starting point for assumptions about the species richness of an ecosystem until more contextual detail is obtained. As I convey below, the initial formulation of the ETIB, and the challenges and refinement of it that followed, support the argument I am making about the prioritization of openness over emergence.

found on an island remains relatively unchanged when the number of species entering equals the number of species exiting the community.

According to the ETIB, immigration and extinction rate curves are each influenced by different topographical parameters. The impact of two such topographical parameters, distance and area, on the number of species present at equilibrium is fairly straightforward. First, immigration rates change as the distance between landmasses changes. Different species have different dispersal powers. Birds are more successful at crossing wide expanses of water than large mammals are, which explains why birds are found on almost every remote oceanic island and large mammals like elephants are not found on any. The closer an island is to the mainland the steeper its immigration rate curve because more species possess sufficient dispersal powers to reach it. Conversely, the further away an island is from the mainland the flatter its immigration rate curve is since fewer species can successfully make the trip and colonize. Second, extinction rates change as island area changes. The ETIB only predicts the number of species present at equilibrium; it makes no prediction about the size of the species' populations. However, a commonly accepted ecological premise is that smaller areas sustain smaller populations. In turn, smaller populations are more prone to extinction due to chance disturbances, ecological pressures (e.g., competition and predation), or unsuccessful reproductive periods. When species have access to a larger area their population usually grows and the possibility of going extinct decreases. Therefore, extinction rates are higher on smaller islands and lower on larger islands. Together, distance and area yield a number of species expected once an island reaches equilibrium (Fig. 2.4).

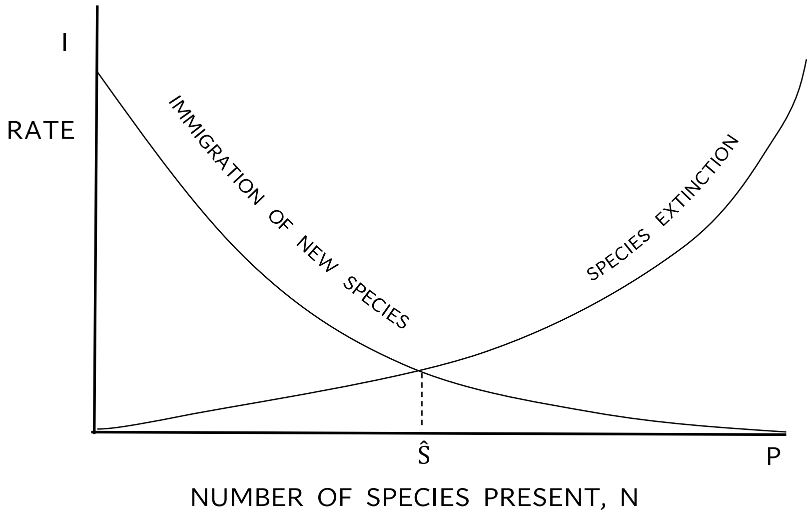

Figure 2.3. Simple representation of the equilibrium reached as immigration rates intercept extinction rates. [Immigration rates = I; species pool = P; number of species = N; number of species at equilibrium = Ŝ] (adapted from MacArthur and Wilson 1967, p. 21).

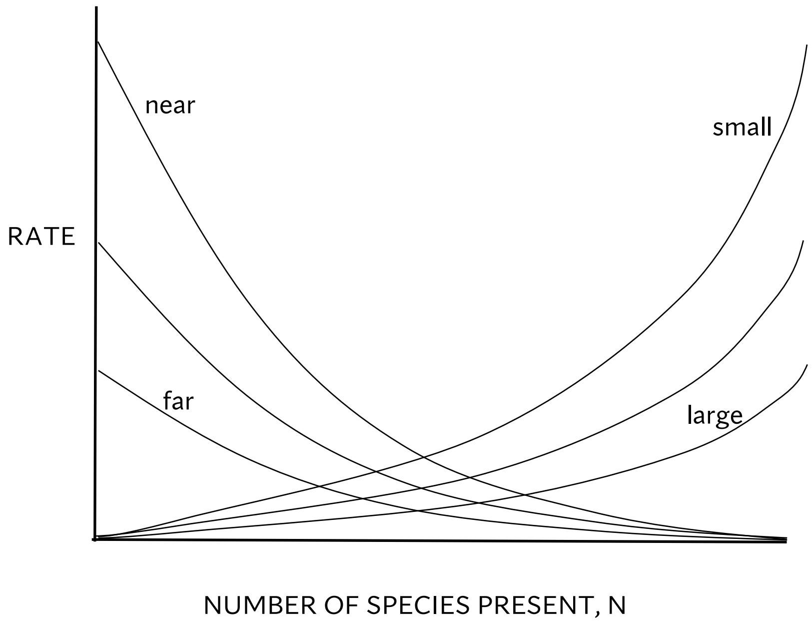

Figure 2.4. A graph depicting different intercepting immigration rates and extinction rates based on changes in distance and area (adapted from MacArthur and Wilson 1967, p. 22).

Once an island reaches its equilibrium number of species, immigration and extinction do not suddenly halt. A dynamic turnover occurs. New species continue to immigrate to the island. There are three possible ways for the newly arriving species to establish once an island has reached its equilibrium number: (1) the immigrant species drives an island species to extinction through competition ("taxon cycle") (Wilson 1961), (2) the immigrant species forces some other island species to seek a new niche elsewhere ("assembly rules") (Diamond 1975), or (3) a previously established species goes extinct due to some unspecified cause (e.g., disturbance, progressively diminishing population size due to difficulty in finding mates, etc.), leaving a vacancy for some new species to fill. In all these situations species numbers do not immediately change in a one-for-one fashion. The ETIB is intended to generate general, realist predictions of island colonization dynamics at the expense of precision (Levins 1966). In other words, the number of species found at equilibrium on any particular island is not exact. Instead, the species number at equilibrium converges toward but may fluctuate around a particular number.

As I argue here, the precepts of the ETIB, in its formulation as an equilibrium-based theory involving immigration and extinction as a function of mainland distance and island size, are similar to those of the OSM. The number of species found on an island at equilibrium is produced by two dynamic processes (immigration and extinction) interacting with one another as shaped by the topographical properties of distance and area.[4] Immigrations are inputs into the island community from outside sources. Extinctions are losses owing to species' individualized chances of surviving the conditions on the island. The ETIB assumes no cybernetic structure holding the island community together. Two further

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[4] von Bertalanffy claims, similar to the ETIB, that biocoeneses (i.e., ecological communities) can be conceptualized as open systems balancing continual immigration and emigration (1968, p. 138).

points are salient to the idea that the original formulation of the ETIB is an OSM with respect to island colonization.

First, the ETIB does not identify which species immigrate to an island or which go extinct. Immigration and extinction rates are a generalized representation of the overall species pool. Again, the ETIB only predicts the number of species at equilibrium; it claims no predictive power concerning the composition of species present at equilibrium. The immigration and extinction rates assume equiprobability distributed throughout the species pool. Not differentiating between species seems inherently problematic in an ecological study, which is why an early criticism from Sauer (1969) focuses on this point. Sauer takes issue with the fact that MacArthur and Wilson treat species as interchangeable units (cf. Berry 1979). Species differ from one another in a variety of meaningful ways that impact the probability of colonization.

The second point to support the ETIB as an OSM is that immigration and extinction rates assume no ecological basis for colonization. In other words, the ETIB does not acknowledge any ecological interactions between colonizing species like competition or predation when calculating the immigration and extinction rates for a given island. In the model, immigration and extinction rates are individualized, meaning they are non-interactive measures of species' ability to reach an island, colonize it, and persist. This forms the basis of Lack's recurring critique of the ETIB (1969, 1970, 1976). Lack disagrees with the individualized nature of MacArthur and Wilson's immigration and extinction rates. According to him, such rates are not the effect of distance on each individual species but rather the collective effect of remoteness on the system as a whole. Lack posits that islands reach an equilibrium once they become "ecologically full" as determined by niche vacancies in open habitats (1970, p. 29).

Sauer's and Lack's criticisms do not defeat the ETIB, as the many subsequent refinements of it illustrate. Instead, their criticisms should be taken to apply to more developed island ecosystems, the kind of ecosystem possessing both primary and secondary regulations. The ETIB only captures primary regulations.[5] At early stages of an island ecosystem's development primary regulations account for the observed dynamic equilibrium, which is why equifinality seems to form the conceptual basis of the ETIB. In fact, MacArthur and Wilson make an indirect appeal to equifinality later in *The Theory of Island Biogeography*, mirroring aspects of von Bertalanffy's own account of the OSM. Immigration and extinction rates are typically expressed as monotonic functions (i.e., functions with either always-increasing or always-decreasing slopes). Immigration rates are monotonic because the distance between an island and a source area does not fluctuate in any appreciable way over ecological time. Extinction rates, on the other hand, do not always function monotonically. During early stages of an island ecosystem's development extinction rates can fluctuate due to unsuitable abiotic conditions for first arrivals (increasing the extinction rate) or greater spatial and resource availability (decreasing the extinction rate). Over time the extinction rate returns to a level to meet the immigration rate as species unfit for the island's conditions are filtered out and island occupancy nears its limits. This demonstrates that overshoot or false start can occur in the island colonization process, but an equifinal dynamic equilibrium results nonetheless (Fig. 2.5) (cf. Heatwole and Levins 1972).

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[5] Diamond (1976) suggests that Lack's theory and ETIB actually complement one another other.

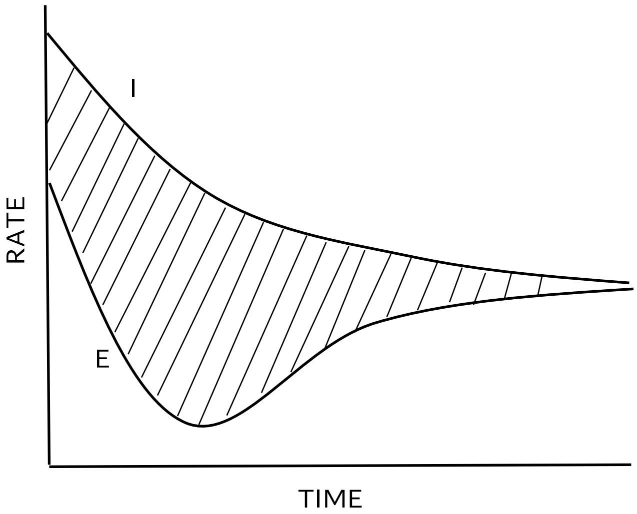

Figure 2.5. This diagram differs from previous ones in that immigration (I) and extinction (E) rates do not intersect. Instead, rate of change corresponds to the y-axis and time to the x-axis. The shaded area demonstrates the difference between rates at a given moment. Over time the two rates will near one another, and a dynamic equilibrium will form (adapted from MacArthur and Wilson 1967, p. 51).

In the ETIB, distance and area function as primary regulations which allow for the total number of species found on an island to develop towards an equifinal steady state. This is where the idea of topography as a causal primitive makes sense. Both distance and area are topographical properties of islands and surrounding regions. Distance reflects remoteness. Species must contend with varying distances when they move from one landmass to the next. Large oceanic expanses represent an impassable barrier to a majority of terrestrial species. Even those with adaptations for long-distance dispersal still get filtered along the way (cf. Carlquist 1965). Area performs a similar filtering function. According to MacArthur and Wilson, area is a simplified measure for diversity of habitats (1967, p. 8). Larger areas have a greater likelihood of exhibiting topographical diversity, which means a greater number of habitats for potential species to choose from and exploit. A topographically complex landscape lessens the severity of competition and allows species to potentially escape from other selective pressures like predation and disturbances. The net effect is a reduction in the extinction rate (Fig. 2.6).

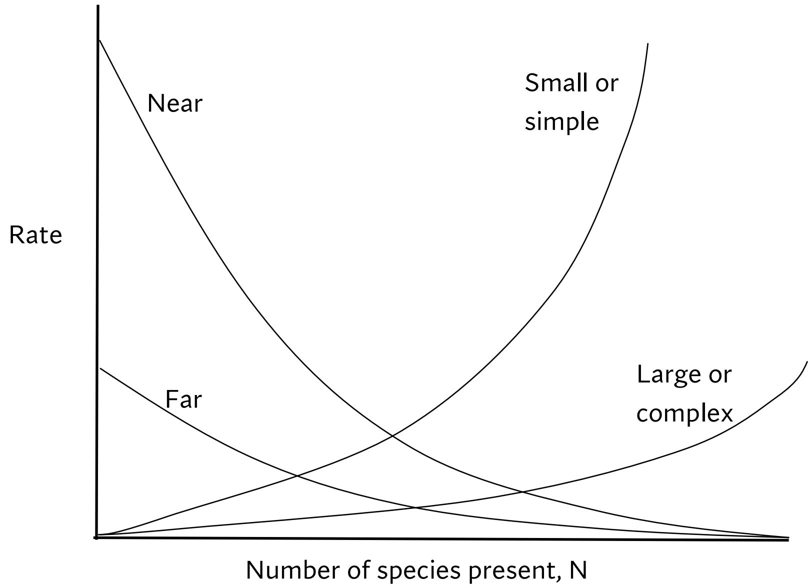

Figure 2.6. A diagram showing how small islands typically possess few habitats (“simple”) and larger islands more (“complex”) (adapted from MacArthur and Connell 1966, p. 183).

MacArthur and Wilson’s *The Theory of Island Biogeography* elicited a huge response in the ecological sciences. Testing, applying, expanding, and criticizing the theory continues to this day. In the next section, I focus on the general narrative unifying different refinements to the ETIB proposed by Simberloff and Diamond. Taken together, they add greater detail to the ontogenetic story of an island community’s progression from a random collection of species organized around an initial dynamic equilibrium (open system) to a self-regulated ecosystem (cybernetic system). My argument stays the same: Topography accounts for the primary regulations that eventually give way to secondary regulations (expressed topologically). An island ecosystem transitions from a state of high openness and low emergence to a state of low openness and high emergence.

An Ontogenetic Account of Island Communities:

The ETIB provides a conceptual basis to understand the existence of steady state communities on islands, but, due in large part to its generality and status as an OSM, much of the ecological details are not incorporated. More realistically, island communities are the culmination of a history of processes. The importance of some processes changes over time. In this section I describe the developmental track of island communities using the language of primary and secondary regulations and of openness and emergence.

Island communities are a combination of dispersal and ecological interactions that initiate on bare substrates upon island formation. Flora and fauna find their way on the island from outside regions through dispersal, and then the flora and fauna interact with one another. Biogeographers have tended to focus on one or the other, which causes island community dynamics to be discussed in somewhat fixed terms where one element is given priority over the others (e.g., climate, topographical heterogeneity, area, distance, ecology, habitat diversity). Moreover, island communities evolve and, so do their dynamics. A point sometimes lost in the ETIB literature is that what explains a dynamic equilibrium early on may very well play less of a determining role later.

Dispersal explains most of the patterns observed in early stages of an island community's formation. Islands start as bare rock lacking any floral and faunal immigrants. Chance has a lot to do with an individual making it to an island (cf. Clark and McInerney 1974). When individuals are taken collectively as species, chance is distributed across the whole set and dispersal probabilities start to reveal themselves. Species success at dispersal depends on a variety of extrinsic (distance and area) and intrinsic factors (physiology and behaviors). Intrinsic factors differ from species to species but are assumed constant for each member of a species. This means that the extrinsic factors, which similarly apply to all species, regulate which species make it to an island and how quick. Species with higher dispersal probabilities tend to arrive on islands first. Even if an individual from a species with a low dispersal probability arrives on the island, the species is still unlikely to establish on the island long-term because its population size will be so small that it will likely succumb to extinction pressures before successfully mating. The disparity between species' dispersal probabilities grows as distance increases, and, to a lesser extent, as area shrinks. In this way distance and area function as primary regulations inducing filter effects.

A nascent island community is often described in stochastic terms because of the significant role dispersal plays in shaping its composition. Any perceivable pattern is the result of individualized probabilities playing out over time. To identify these sorts of patterns, authors in the ETIB literature construct null hypotheses to use in statistical tests of collected data (Simberloff 1978, Connor and Simblerloff 1978, Diamond and Gilpin 1982). The assumptions built into null hypotheses differ from one to the next but, generally, they suppose no ecological basis for species' ability to colonize an island, only dispersal ability matters. Models looking to confirm a null hypothesis are essentially OSMs. They posit that the number of species on an island reaches an equilibrium (steady state) because species' dispersal probabilities interact only with the topographical features of distance and area for an island in a regular way. The composition of the island community is not factored into the modeling of the number of species. Species constantly immigrate from neighboring islands or mainland areas into the island community as other species already established on the island go extinct. In the absence of ecological interactions, arriving species replace the island community's internal losses such that the number of species present reaches and hovers around a steady state equilibrium point.

However, the effects of distance and area on island community composition starts to wane as time passes and population sizes increase. Increasing the size of species populations has a tendency to heighten the effect of ecological interactions between species coinhabiting the island. Wilson and Simberloff's classic field experiment reveals this progression.

Together, Wilson and Simberloff (1969; 1969; 1970) performed the first controlled test of the ETIB. They surveyed six small mangrove islands in Florida Bay of varying sizes that lay in different directions from nearby sources of colonization. Simberloff and Wilson erected tents over the islands and pumped in methyl bromide gas to remove all traces of fauna. The islands were then periodically censused to observe the trajectory of their development and to determine whether an equilibrium happens in the way predicted by the ETIB.

The results of the mangrove island experiments favored the ETIB. During initial stages, Simberloff and Wilson note that propagules were constantly hitting the islands as the ETIB depicts and as Sauer rejects (1969, p. 282). In less than a year the islands appeared to achieve an equilibrium number of species. Simberloff and Wilson cite three lines of evidence in favor of the ETIB. First, the number of species on the control islands did not change much over the first year. Second, Simberloff and Wilson observed that untreated islands of similar area and distance possess a similar number of species. Third, and most convincing, the islands that underwent defaunation returned to a number of species approximately the same as before defaunation. Once the number of species returned to pre-defaunation levels, the number oscillated around the equilibrium as the community structure continued to change rapidly (Simberloff and Wilson 1969, p. 285).

Simberloff and Wilson admit that obtaining absolute immigration rates and extinction rates proved nearly impossible.[6] The only apparent pattern detected in

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[6] Much of the debate over the ETiB arose because CSM perspecitves were being applied to its OSM features. This debate was often acrimonious. Simberloff accused many biogeographers of accepting the ETIB as a paradigm without substantial evidence or distorting data to prove it (1976). Issues surrounding censusing techniques and the imprecision of definitions for concepts fundamental to turnover make confirming the ETIB difficult, which explains why most of the disputes in the ETIB literature concern the nature of turnover (Mayr 1965; Lynch and Johnson 1974; Hunt and Hunt 1974; Simberloff 1976; Gilbert 1980; Williamson 1981; 1989). Diamond (1969;

the observed immigration rates and extinction rates was that nearer islands possessed a higher immigration rate. However, once expected rates for immigration and extinction were calculated, Simberloff and Wilson concluded that the findings were consistent with the ETIB (1969, pp. 287-288).[7]

The original compositions of the mangrove islands started to re-emerge by the second year (Simberloff and Wilson 1970). More interesting is the course of development observed by Simberloff and Wilson. Immigration rates remained constant but something odd occurred with extinction rates. The mangrove islands initially neared an equilibrium number of species. As the number of species neared 75% to 90% of the expected equilibrium value the number of species started to dip (Simberloff and Wilson 1969). Simberloff and Wilson's explanation: The first equilibrium occurs because the colonizing species have not yet accumulated the impacts of ecological interactions like competition or predation whereas the second equilibrium represents a period in which ecological interactions begin to manifest at a level detectable by the researchers. The first equilibrium is termed "non-interactive equilibrium" and the second "interactive equilibrium." The interactive equilibrium does not mark the island's return the pre-defaunated state, though, an "assortative equilibrium" does. An assortative equilibrium emerges as combinations of shorter-lived species go extinct and longer-lived species accumulate. Once the assortative equilibrium emerges the turnover rate on the island decreases meaning the composition of species becomes relatively fixed

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1971), too, acknowledges the difficulties associated with testing the ETIB. These problems lead Connor and Simberloff (1978) to adopt a pessimistic attitude, stating that the best predictor of the number of species found on an island is mostly determined by the number of surveying trips. In a later article, Simberloff calls on biogeography to develop a falsifiable formulation of the ETIB or "the entire equlibirum theory will degenerate into a truism" (1983, p. 1275).

[7] Simberloff also found evidence for the distance effect predicted by the ETIB in the study of the British Isles (Johnson and Simberloff 1974).

(Simberloff and Wilson 1970, Simberloff 1974) (cf. Wilson and Taylor 1967; MacArthur 1972; Heatwole and Levins 1972) (Fig. 2.7).[8]

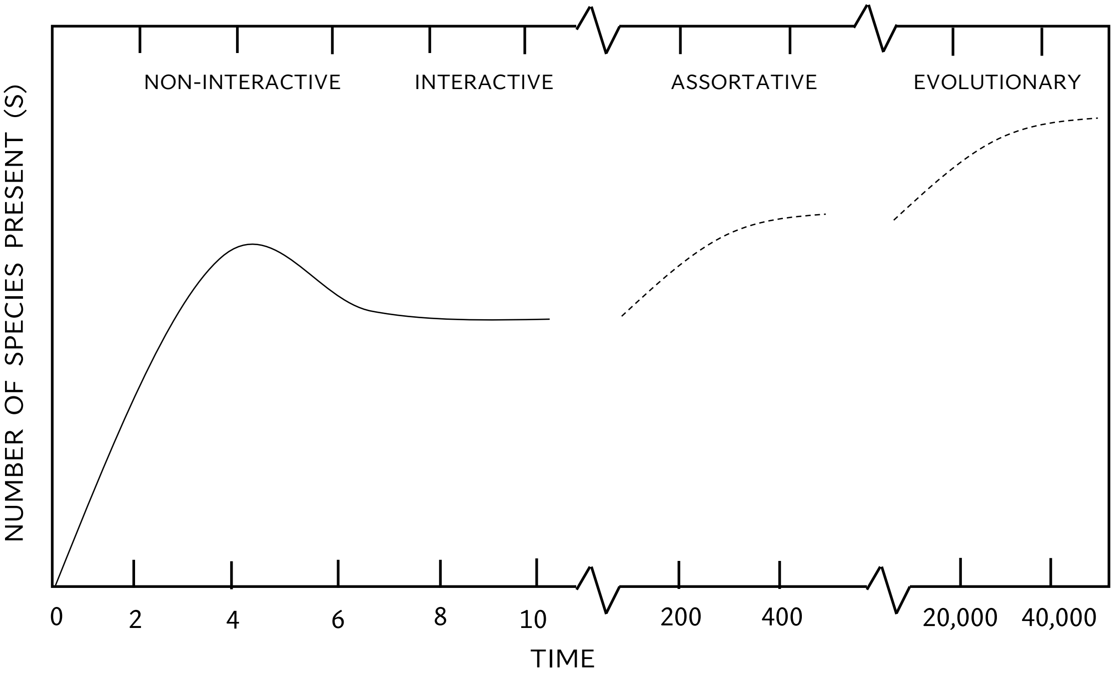

Figure 2.7. A diagram showing a hypothetical island community's number of species through time as it progresses from one equilibrium to the next. The time scale is theoretical. It is only intended to show that long periods of time are required for stages of greater ecological development to emerge (adapted from Wilson 1969, p. 45).

Wilson and Simberloff's field experiment has been called into question because of the small size of the islands (Whitehead and Jones 1969; Slud 1976; Gilbert 1980). However, the same general account can be made for just about any

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[8] The small size of these islands raises concerns about whether Simberloff and Wilson's experiment supports more general biogeographical laws regarding colonization (Whitehead and Jones 1969; Slud 1976; Gilbert 1980). However, it is worth noting that Wilson and Taylor (1967) found a similar kind of colonization dynamic from in their study of Polynesian ant fauna.

type of island where distance is great enough to impose unequal barriers to dispersal on species from source areas.

The most remote islands reflect this ontogenetic pattern. Islands such as Hawaii and the Galapagos are described having a state of "disharmony" arising from ecological interaction involving highly specialized species following long periods of adaptive radiation (Carlquist 1965; 1974).[9] "Where a particular ecological niche in the landscape of an oceanic island remained unfilled, an existing species often adapted itself and its behavior to fill it" (Nunn 1994, p. 306). Darwin's finches, Hawaiian honeycreepers, and various species of weedy, shrubby, and arboreal Asteraceae plants found on islands all over the globe are prime examples of adaptive radiation leading to increased ecological interactions between island community members.[10]

The assortative equilibrium of Wilson and Simberloff draws inspiration from MacArthur's detailed work on niche theory (1969a, 1969b, 1972; Klopfer and MacArthur 1961; MacArthur, Diamond, and Karr, 1972). An assortative equilibrium is a collection of co-adapted species (Wilson 1969; Simberloff 1976). Most relevant is MacArthur's concept of "diffuse competition." MacArthur defines diffuse competition as: "Several competitors can much more easily outcompete and eliminate a species than a single competitor can" (1972, p. 29). This definition chiefly concerns instances in which three closely related species occupy a similar niche dimension on a resource spectrum. The middle species has almost no chance at achieving prolonged success because it experiences intense competitive pressures from species on either side of it. In terms of my ontogenetic argument,

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[9] Some ecologists like Berry (1992) disagree with referring to islands as "disharmonic" because it suggests that other islands are "harmonic."

[10] This chapter is more interested in ecological time scales than evolutionary ones. However, it is worth pointing out that connecting the different time scales is a point of interest in the literature (Losos and Schluter 2000; Heaney 2000; 2007). Additionally, this kind of ontogenetic approach has been posited against evolutionary changes in island topography due to progressive erosion and subsidence (Stuessy 2007; Whittaker, Triantis, and Ladle 2008).

diffuse competition is like a network property that emerges as species within a community develop increasingly regular ecological interactions with one another. It suggests a kind of deepening autocatalysis growing within the community such that each species undergoes a degree of specialization, transitioning from a wide niche to a narrow one, to maximize resource utilization. An added property results from diffuse competition, resistance to invasion. "Resistance to invasion" translates into the island community becoming more closed off and machinelike due to niche specialization.

Diamond's (1975) refinement of the ETIB is similarly built from criticisms that apply to secondary regulations and CSM organization. Diamond conducted many investigations into the distribution patterns of avifauna found in the archipelagos near New Guinea (Diamond 1974; 1975; Diamond, Gilpin, and Mayr 1976; Diamond and Mayr 1976; Gilpin and Diamond 1976; Mayr and Diamond 1976). Diamond shows that species within the same guild seem restricted to a few regularly occurring combinations.[11] Some species within the same guild never appeared together. Other species appeared together only in certain combinations. Like MacArthur's definition of diffuse competition, Diamond also acknowledges that a species may be unable to fit into a community because of diffuse competition (1975, p. 387).

Diamond's assembly rules are based on the observation of checkerboard distributions of species combinations throughout the archipelagoes, and formulated into different combinatory and compatibility rules. Built into the assembly rules is an account of island community development similar to the non-interactive, interactive, assortative, and evolutionary equilibriums of Wilson and Simberloff. Tramp species typically colonize first, employing a range of r-selection strategies. Then, species with lower dispersal probabilities arrive, supplant some of

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[11] A "guild" is a set of species that exploit similar niches within a community (cf. Whittaker 1975, pp. 80-81).

the tramp species by utilizing K-selection strategies, and the island community moves closer to an assortative equilibrium. In his assembly rules, competition is not two species fighting against one another but rather the collective effect of a whole network of interconnections (cf. Diamond 1978). Together, species within the island community utilize resources with a kind of deterministic rhythm and timing that maximizes interconnectivity and efficiency. In short, the island community develops autocatalytically and, as a result, becomes increasingly cybernetic (i.e., closed off and self-sufficient).

<u>The Primacy of Openness</u>:

Null hypotheses and assembly rules, as general concepts, stand in stark contrast to one another. The former concern stochastic dispersal and colonization processes attributable to individual species within an OSM. The latter concern deterministic ecological interactions between island community members taking place in an CSM. Much of the debate in the ETIB literature focuses on proving that either the stochastic or the deterministic model of colonization is the right approach, but such thinking seems to miss the point.[12] For any complex system it is impossible to say if the OSM or the CSM more properly accounts for its dynamics without reflecting on its ontogenetic progression. As such, pluralism is typically the best practice. It is the one Whittaker (1997) defends with respect to the ETIB literature.

Adopting a pluralist approach as Whittaker suggests does little to lessen the stakes, though. Deciding on a model shapes the kinds of claims that can be made about an island community's formation and properties. Complex systems theory tends to favor the more deterministic models, and its application to ecology

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[12] Lynch and Johnson (1974), Simberloff (1978), Connor and Simberloff (1978, 1979), and Gilbert (1980) are among those who argue for stochastic models of colonization and turnover. Terborgh (1973), Power (1975), Diamond (1975), Abbott, Abbott, and Grant (1977), Gorman (1979), Diamond and Gilpin (1982), Gilpin and Diamond (1982) argue for deterministic models.

is no exception. Ecological theories like Ulanowicz's ascendency model and Odum's (1969) strategies of ecosystem development invoke network analysis techniques as a conceptual starting point (Brown 1981, Wright 1983, Schoener 1989). However, a self-regulating network of trophic interactions is not a starting point; it is an end (insofar that an ecosystem even has an end). In my view openness always possesses some measure of causal priority that emergence can never overcome.

Two additional examples can demonstrate how openness is the more operative property explaining an island community's dynamic equilibrium: (1) the changes in geographical conditions over time that cause changes to an island community's composition and (2) disturbances that occur frequently enough to prevent an island from reaching an assortative equilibrium encompassing the entire flora and fauna found on it.

An island's distance from the mainland and its area both change over geological time. During the Pleistocene ocean levels fluctuated due to glaciation, and at times were much lower than the present-day highstand. This exposed even greater island area for inhabitants to exploit as well as land-bridges that facilitated dispersal. Island colonization by species with weak dispersal powers became more possible during this period, changing the composition of many island communities.

Even in the absence of eustatic sea level rise, the size and topography of an island changes through time. Darwin's (1842) theory of volcanic island subsidence explains how a fringing reef transitions into a barrier reef and then an atoll formation as the geological base of an island weathers and erodes over time (c.f., Stuessy 2007; Whittaker, Triantis, and Ladle 2008). Species composition changes as island area shrinks and habitat heterogeneity disappears.

These two scenarios (i.e., global glaciation and island subsidence) demonstrate how the secondary regulations associated with a community's network of trophic interactions are quite sensitive to changes in primary regulations connected with topographical features. Any emergent ecological interactions that select for a distinct combination of species, as predicted by Diamond's assembly rules, degrade as the features accountable for the island's openness fluctuate to the point that the entire island may go underwater.

Disturbance is a key concept in both ecology and complex systems theory more generally. Most of the ecological trends espoused by the ETIB and its refinements seem plausible as long as an island remains undisturbed. Disturbances are frequent enough, though, that most islands will experience a perturbation before achieving an assortative equilibrium state.

Bush and Whittaker's (1992; 1993) work on the Islands of Krakatau, a location marked by a massive volcanic explosion in 1883, and similarly studied by MacArthur and Wilson (1963; 1967), conveys another way in which secondary regulations associated with a community's network of trophic interactions are quite sensitive to changes in primary regulations. Disturbances happen too frequently for that equilibrium to ever manifest fully. So, island communities typically exist in a nonequilibrium state (Whittaker 1995).

Secondary regulations are responsible for safeguarding the structural integrity of the trophic pathways among species. However, secondary regulations cannot return an island community back to its pre-disturbance state when large portions of the species populations are lost. An island community often depends on primary regulations to initiate movement towards a dynamic equilibrium after a disturbance. These topographical properties constrain the introduction of new species or individuals from nearby rescue populations that can replace those lost due to disturbance.

As these closing examples convey, any dynamic equilibrium that an island community achieves depends on the topographical conditions characterizing the region as a whole and the various species occupying staging areas around the island. An island community cannot control for changes to either of those factors because the island itself is fundamentally open. Any emergent properties that an island community possesses owe directly to the primary regulations facilitating and restricting movement from outside to inside its spatial limits. Despite the potency of the secondary regulations holding an island community together the fact remains that they are never strong enough to overcome changes to primary regulations embedded in the region's topography, which is why the stability of the landscape is often the best predictor of an island community achieving and maintaining an equilibrium (Nunn 1994, pp. 305-306).

Conclusion:

In this chapter, I have discussed openness as a system property that captures the movement of matter and energy from the environment into an ecosystem such that an equifinal steady state results. This interpretation of openness is one of flux. Like Dupré (2021), I accept the process ontology of complex systems theory that regards everything as processes. The world is one of processes all the way up and all the way down. Material is transient; it never stays put and, even more, it never stays bound to the same set of processes for too long. As a system property, openness refers to that constant movement of matter or energy between the environment and the system of interest. It assumes some sort of boundary between the two. My motivation for incorporating topographical details into the concept of openness is largely because those boundaries can sometimes, but not always, be observable and, thus, measurable to some degree. Tests of the ETIB offer excellent examples of this.

In my account, "openness as flux" is the principal kind of openness. But other interpretations of openness exist. One could define openness with respect to disturbance. If a system were perfectly insulated from its environment, it could not be disturbed (i.e., knocked out of its dynamic equilibrium). By observation, all complex systems that have ever existed must be open in this way because none have existed in the same state forever. Openness with respect to disturbance, though, is the same as openness as flux just with a very specific event in mind (i.e., a disturbance).

Another kind of openness is one often used in philosophy to account for unforeseeable future states. This kind of openness is actually indeterminacy. Indeterminacy has both epistemological and metaphysical aspects to it. In *The Open Universe*, Popper (1982) posits an account that recognizes instances in which some future state cannot be predicted by scientific knowledge and may even be something genuinely novel. For this reason, Popper (1990) suggests talking in terms of "propensities" rather than "properties." Whereas properties are permanent qualities determined by natural laws of causation inherent in an object propensities are qualities that come to be due to chance, complex causal relations attributable to processes. Stated differently, a property is a quality always expressed and a propensity is a quality that is expressed under different sets of conditions.

Popper's contributions help qualify different behaviors observed in nature. However, this is not openness; it is contingency. The world is not entirely determined. Instead, contingent causal factors interact with one another in unpredictable and unique ways. This leads to the addition of another important property attributable to systems, historicity. Causal interactions are accumulated and internalized by a given system. Thus, how a complex system behaves or responds to changes depends in part on its history (cf. Mitchell 2009). This interpretation of "openness as indeterminacy" is clearly a case where the generality of "open" simply lends itself to many applications. However, in the interest of being precise, it is not openness but really an acknowledgment of contingency and, by association, historicity.[13]

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[13] Ulanowicz (1997; 1999; 2009) fully embraces Popper's contributions on these topics, and he incorporates elements of openness as flux, which is why I find myself so drawn to the ascendency model.

So, why is my view of openness the right one? This question can be answered in two ways, both with theoretical and practical appeal. For one, von Bertalanffy's call for a synthesis between process and structure, between the OSM and the CSM, is the same, long-standing metaphysical distinction between flux and being, or, on my account, between openness and emergence. Resolving the paradox of how a thing stays the same even though it is constantly changing is impossible, but the conceptual distinctions alluded to in this chapter provide further means to approach the matter. One of the aims of science entails finding ways to get models to communicate with one another. The ontogenetic account that von Bertalanffy posits is suited for this. Identifying primary and secondary regulations of a given system connects features of a system attributable to openness with those attributable to emergence to explain a single phenomenon, a system's dynamic equilibrium. Identifying the interdependencies between the two is seemingly the first step in uniting the different approaches. Philosophically, determining the strength of different regulations allows for a given system to be plotted on a continuum between the two properties of openness and emergence. My argument in this chapter has been that the continuum always skews towards openness, especially when accounting for ecosystem dynamics.

Secondly, viewing openness as the ontological counterpart to emergence enables a more nuanced understanding of adaptation. Ulanowicz (2009) posits that the strength of autocatalysis between the species of an ecosystem regulates what becomes incorporated into the network of interactions. An ecosystem marked by weak autocatalysis is open to invaders as long as those invaders promote greater autocatalysis. If autocatalysis between the species is strong, invaders will find it tough to invade. In essence, strong autocatalysis between species implies that the ecosystem is maximally emergent and more machinelike in that it becomes closed off to other species. A "healthy" ecosystem is one open enough that it can "select" its composing species (based on degree of autocatalysis) and, thus, "adapt" to changing conditions (Ulanowicz 1997, p. 126). I find Ulanowicz's account both helpful and correct. Adaptation is only possible in a system that exhibits certain gradations of simultaneous openness and emergence.

Arguing in favor of openness rather than emergence does not require the rejection of CSMs in ecology. Ulanowicz (1997; 2001; 2009) approaches ecology from a process ontology like I do. The only distinction that could be made between Ulanowicz's philosophical view and mine is that Ulanowicz's focuses on emergence (i.e., autocatalysis between species composing a network of interconnections) whereas I focus on openness. Ulanowciz briefly discusses openness as both flux and indeterminacy, but his account of them is not nearly on par with his account of emergence, which is his primary interest. Processes extend beyond the network of interconnections constituting an ecosystem, though, and it is not as simple as moving between nested levels of scales as Ulanowicz (1990; 1997; 1999; 2009) often suggests. Processes like dispersal cannot be subsumed neatly within a hierarchy of complex systems because they are indicative of errancy (i.e., lines of flight). Defining openness topographically as I have argued for in this chapter is a proposed supplement to Ulanowicz's topological approach to ecosystem emergence. Synthesizing the two would yield the sort of ontogenetic account I am championing.

From my point of view, complex systems theory has focused intently on emergence without much investigation into the nature of openness. I have suggested that this is due in large part to the emphasis placed on CSMs. Openness has a profound impact on emergence as evidenced by the way in which the ETIB and its subsequent challenges and revisions can be held together along an ontogenetic continuum of OSMs and CSMs. As such, openness, as a system property, deserves more attention than what it presently receives. In ecology, the health of feedback structures depends on spatial attributes of the landscape that facilitate the transport of matter and energy into the ecosystem from its outside environment. Analysis of the secondary regulations apart from the primary regulations they depend on neglects a big chunk of the story explaining why a complex system exists in a certain state. Good science should be mindful of the whole story and not just the endpoint. Complex systems theory is not so much "the science of emergence" as it is "the science of becoming," which is a decidedly wider scope demarcated by openness at one end and emergence at the other.

This chapter sets the theoretical groundwork for the next chapter examining resilience as an ecosystem property. Resilience is often depicted topologically and defined using concepts such as thresholds, tipping points, and hysteresis. Similarly, the fact that resilience is defined topologically strongly suggests that the principle of emergence fully explains it. Resilience is an emergent property internal to the ecosystem itself. In other words, resilience explains how an ecosystem as a network of interconnected species can remain stable even as the environmental conditions fluctuate. Complex systems theory makes little explicit mention of openness or topography with respect to resilience. I problematize this view. Topographical features play an important role in facilitating and restricting the immigration and dispersal rates of species. Oftentimes an ecosystem must be rescued by nearby populations after a disturbance in order to restabilize. Also, important structure-inducing resources are transported across topographical routes that ensure an ecosystem's stability. Common interpretations of resilience in complex systems theory do not provide the conceptual space for acknowledging these spatial aspects of resilience. Instead, complex systems theory treats resilience as an objective property of ecosystems independent of their environment. I argue for an account of resilience that is ontologically flexible insofar as it can incorporate topographical and topological elements depending on the dimensions deemed relevant by an observer.

Arguing in favor of an ontologically flexible account has practical appeal when it comes to policymaking. Environmental resources are limited. The fear is that the standard topology-centric, hierarchical view of resilience that does not satisfactorily incorporate openness will negatively affect the allocation of resources. If an area is believed to have passed a tipping point based on the standard model, then it may be denied assistance. However, this may be inaccurate. A region may be salvageable and denying it support will cause unnecessary hardships. Therefore, an ontologically flexible account of resilience is advantageous from an ethical standpoint as well.

Chapter 3: The Metaphysics of Resilience Theory: Ecological Resilience is More than an Emergent Ecosystem Property

Introduction:

The concept of ecological resilience is one of the most prominent of several investigations that links complex systems theory to ecology. Not only does it incorporate many of the dynamics introduced by complex systems theory (e.g., feedback loops, hysteresis, basins of attraction) but it also shares many of the same philosophical motivations. The study of ecological resilience is a search for a theory of adaptive change (Holling, Gunderson, and Ludwig 2002), for an answer to the question: In a world of flux, how do some organizations persist? This is a deeply metaphysical question that combines ontology and causation. Like the ship of Theseus, it is a question of how an unchanging identity persists despite its compositional substrate constantly changing. The question itself will likely never reach a conclusive resolution, but it at least demands a working hypothesis.

Although, prima facie, metaphysics might seem foreign to contemporary science, it is simply a way of rationalizing naturally occurring patterns. Science is not just a fact-finding mission but is principally the art of theory-building. Any sufficient metaphysical theory provides science with a conceptual framework with which it can (1) characterize different elements of interest and (2) make causal connections. For example, biological classification between the 18th and 19th centuries drastically changed from a Linnean system to a Darwinian one. Each countenances a remarkably different metaphysics. Linnaeus proposed a closed hierarchy of classification in which each species is immutable. His approach requires the metaphysical concept of natural kinds to explain how species can be similar without sharing a common ancestor. Darwin, on the other hand, posits that species exist in their current forms because of an uninterrupted evolutionary lineage in which natural selection coerces adaptation. Asking why an organism is classified the way it is will elicit two starkly different kinds of explanation depending on who is asked, a Linnean or a Darwinian. The end goal is always the same, to produce a metaphysics that accords with scientific reality. In this way, the whole endeavor is a collaborative effort between philosophy and science to produce consistent and reliable explanations.

This chapter makes the argument that the metaphysics of resilience theory needs revision. On my view, resilience theory already possesses a robust metaphysical foundation, namely the one it inherited from complex systems theory. However, it limits itself to a conceptual framework that does not satisfactorily meet the two criteria of a sufficient metaphysical theory because it fixates on a single structuring principle, emergence. Traditional accounts of resilience are formulated almost entirely in terms of emergent self-organizing feedback loops between biotic and abiotic elements. As I described in previous chapters, this fact leads to a situation in which topological depictions of ecosystems dominate all areas and levels of explanation. Topographical details – at least initially in the evolution of resilience theory – are rendered as secondary, if not superfluous. Recently, however, resilience theorists have realized that topological accounts alone do not sufficiently explain ecological dynamics: spatial elements directly impact an ecosystem's ability to persist and adapt, which are both fundamental to ecological resilience. Those topographical details must be reconciled with the topological ones to produce robust explanations of ecological resilience. Before that can occur, the conceptual framework needs to undergo some reorganization.

Emergence should not be removed from the conceptual framework of resilience theory because self-organizing feedback loops are crucial for explaining persistent ecological patterns. But, I argue, emergence needs to pair or be supplemented with its metaphysical counterpart, openness. Openness already has a place within current resilience theory, so no theoretical additions are needed.

However, a single overarching metaphysical theory that unites them has not yet been advanced. Like with previous chapters, that is the motivation for this chapter. My goal, once again, is to argue that openness often warrants greater attention than emergence once the two are brought under a single ontogenetic account.

This chapter is divided into three sections. The first section describes the traditional emergentist version of ecological resilience. I utilize the ball-and-cup diagram heuristic from resilience theory to detail how ecological resilience has been explained in terms of self-organizing feedback loops. So much emphasis is placed on these feedback loops that it has become common practice among many resilience scholars and those invoking the concept to refer to ecological resilience as an emergent property of ecosystems. The second section challenges this interpretation. Some today argue that the spatial character of ecosystems and the geographical configuration of regions constrain the expression of emergence to a greater degree than previously thought. Self-organizing feedback does not adequately account for these causal conditions of resilience; only open-system dynamics can do so. For that reason, resilience theory needs to recalibrate its metaphysics and carve out a more meaningful role for openness (i.e., the exchange of matter and energy between a site and its surrounding environment). Instead of being an emergent ecosystem property, resilience should be understood more as a feature of ecological space (and time). The final section reconciles emergence and openness. As in my earlier chapters, I propose an ontogenetic narrative that interprets open-system dynamics and emergent self-organization as causally coeval but contributing more or less to the overall explanation during different stages of development. I employ another heuristic from resilience theory, the adaptive cycle, to serve as an explanatory template of the conceptual framework in action.

Emergence Between Internal Dynamics and Environmental Conditions:

Traditional resilience theory gains much of its foundational beliefs from three articles. First, Lewontin (1969) connected ecosystem stability with basins of attraction, defined global stability, and identified the possibility of multiple stable points within nonlinear systems. He defined stability loosely as "a property of the dynamical space in which the system is evolving" (p. 21). Later, C.S. Holling (1973), following Lewontin, discussed ecosystem recovery after disturbance in terms of basins of attraction but distinguished between "stability" and "resilience." "Stability" is "the ability of a system to return to an equilibrium state after a temporary disturbance" "Resilience" is the "measure of persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (p. 14). Whereas stability concerns an ecosystem's return to some fixed equilibrium point resilience is about a system remaining in a qualitatively distinct state amid other possible states. Finally, May (1977) recapitulated Lewontin's and Holling's complex systems theory approaches to resilience and introduced additional concepts (e.g., hysteresis, breakpoint values, and stable limit cycles), examined below, to describe an ecosystem's transition to a different state following the crossing of some critical threshold.

Of the three, Holling is widely regarded as the originator of resilience theory, having dedicated his career to the concept. In another landmark essay Holling (1996) differentiated between two kinds of resilience, engineering and ecological resilience. "Engineering resilience" refers to how quickly an ecosystem can return to a designated equilibrium point. It is often taken to be analogous to Holling's earlier notion of stability. "Ecological resilience" corresponds to how much an ecosystem can withstand before it is forced to restructure itself and the variables and processes that control its behavior (Holling 1996, pp. 32-33).

Engineering resilience emphasizes efficiency, constancy, and predictability. Ecological resilience emphasizes persistence, change, and unpredictability.

The baseline heuristic employed by resilience theory – ball-and-cup diagrams – illustrates the key differences between engineering and ecological resilience. A ball-and-cup diagram graphically represents the dynamics existing between an ecosystem and the range of environmental conditions it could exist under (Fig. 3.1). The state of the ecosystem is depicted by the position of the ball along the surface. The valleys are indicative of the range of qualitatively distinct stable states that the system can settle into (i.e., basins of attraction) given a set of environmental conditions. The hills are unstable states where the ecosystem is likely to tip towards either of the adjacent stable states given the slightest disturbance. Together the valleys and hills form a stability landscape.

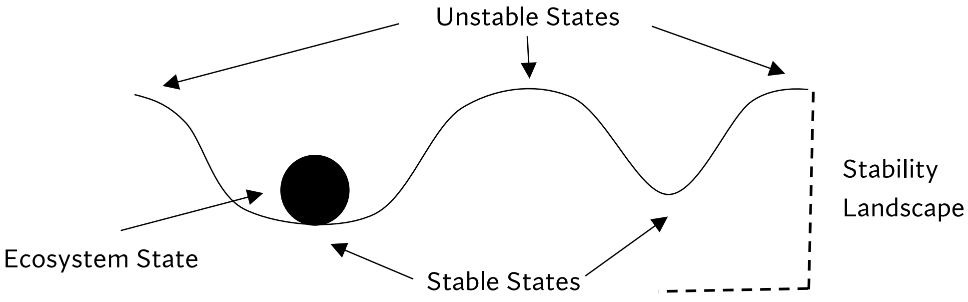

Figure 3.1. A ball-and-cup diagram.

Ball-and-cup diagrams illustrate an important distinction between global and local stability. Global stability posits a fixed stable state for an ecosystem. Regardless of the severity of the disturbance, an ecosystem will eventually return to the same equilibrium state (Fig. 3.2). If all ecosystems exhibited global stability, then engineering resilience would exhaust the resilience concept. The question would not be “whether” the ecosystem returns to its previous state after a disturbance but only “how long” before it does.

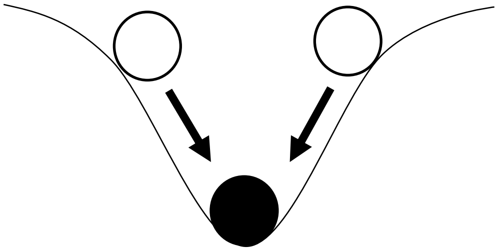

Figure 3.2. A ball-and-cup diagram exemplifying global stability. The white circles represent an ecosystem state post-disturbance. The arrows signify that the ecosystem returns to a fixed equilibrium state. Since the stability landscape exhibits only a single basin of attraction, the ecosystem possesses global stability.

Nonlinearity complicates the idea of a single global equilibrium. With nonlinearity comes the possibility of multiple stable states. When more than one stable state exists within a stability landscape, an ecosystem can be described as locally stable relative to all the possibilities (Fig. 3.3). (Local stability can also be represented three-dimensionally (Fig. 3.4)). Ecological resilience can only apply when more than one locally stable state exists. For if there is only one stable state, no amount of shock can cause an ecosystem to undergo qualitative change.

Not only do nonlinear dynamics exist throughout nature, but they are also what make ecosystems complex systems in the first place. For those reasons, resilience theory tends to prioritize ecological resilience over engineering resilience in their investigations.[1]

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[1] For more detailed representations of engineering and ecological resilience in relation to global and local stability using ball-and-cup diagrams, see Peterson, Allen, and Holling (1998) and Scheffer (2009).

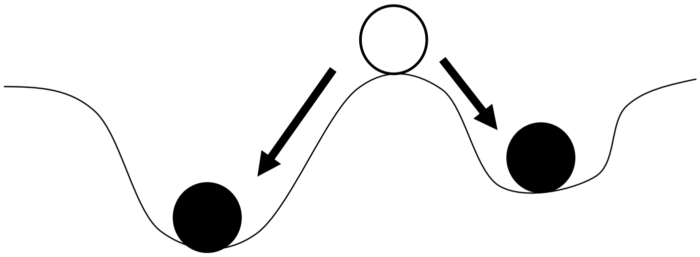

Figure 3.3. A ball-and-cup diagram exemplifying local stability. The white circle represents an ecosystem in an unstable state where a minor disturbance can tip it into either one of the attractors (as indicated by the arrows). Once the ecosystem settles into either of the two attractors, the ecosystem is said to be locally stable.

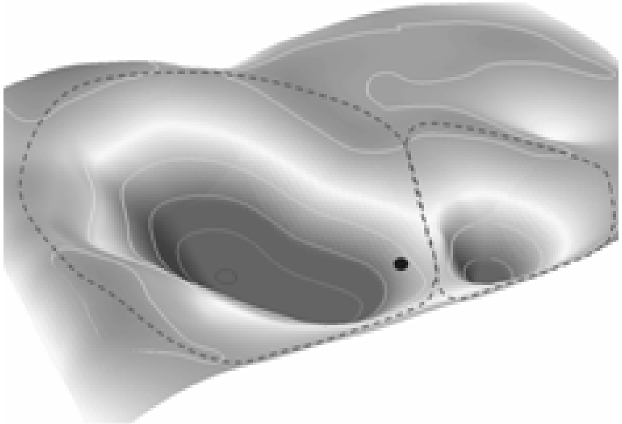

Figure 3.4. An example of a three-dimensional stability landscape with two basins of attraction (adapted from Walker et al. 2004).

It is not as if the system state exists within a static landscape, though. The shape of the stability landscapes themselves are dynamic (Fig. 3.5). The contours can shift in response to interactions among multiple environmental parameters. Changes to the biophysical systems that comprise a given stability landscape alter the depth of a valley and the slopes of its sides (Gunderson 2000; Scheffer 2009).

Shifts in microclimate, soil conditions, or disturbance regimes (e.g., fire) are three examples of such environmental parameters.

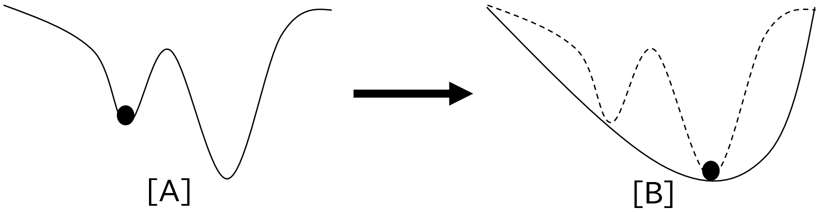

Figure 3.5. An example of a stability landscape changing such that the ecosystem is tipped into an alternative stable point. [A] represents the original stability landscape. [B] is the transformed stability landscape with the original landscape overlayed on top of it (dotted line) to better change in the overall conditions and resources in the system.

Nonlinear stability landscapes introduce the possibility for regime shifts. A regime shift occurs when the ecosystem in question transitions from one qualitatively distinct state to another. Ball-and-cup diagrams are not as well-suited to communicate another potential nonlinear phenomenon responsible for regime shifts, hysteresis. When a system undergoes a regime shift, it is often insufficient simply to return the conditions to how they were earlier to get the ecosystem to switch back to its previous state. Instead, the conditions must be pushed even further in the opposite direction before the ecosystem will abruptly shift back (Fig. 3.6). Because hysteresis introduces irreversibility, other metaphysical principles like historicity and contingency have found their way into resilience theory. The critical values at which the ecosystem abruptly shifts are referred to as “tipping points” (Lenton 2013; van Nes et al. 2016; Dakos et al. 2019) where ecological resilience is effectively zero. In section three, I revisit tipping points and discuss the debates over the likelihood of global-scale tipping and planetary regime change. With the advent of spatial resilience as an area of study, the existence of global tipping points has been challenged, and questions have been raised about how causation is conceptualized in resilience theory more generally.

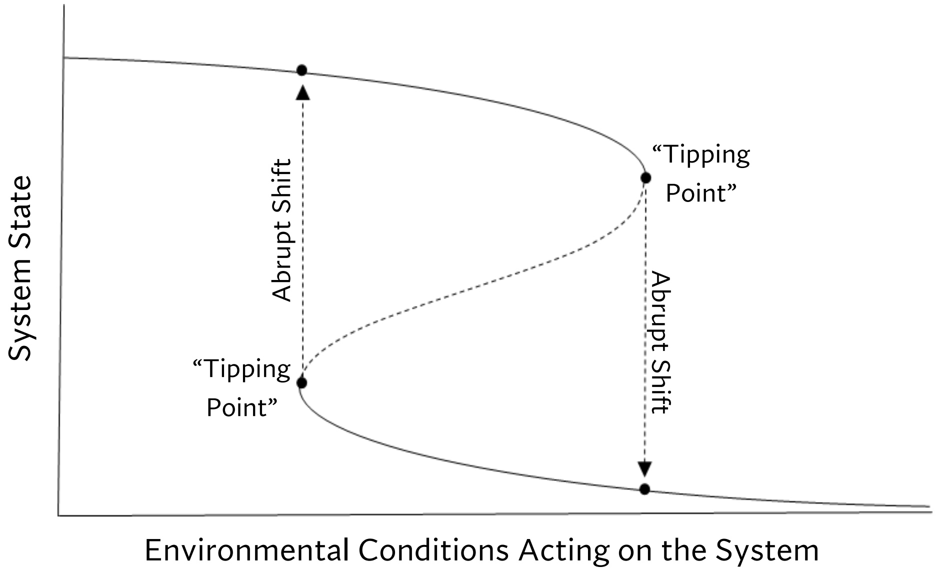

Figure 3.6. A general diagram depicting hysteresis. The solid arcs at the top and the bottom of the graph represent qualitatively distinct states that an ecosystem could exist in. The dots signify critical values where the ecosystem abruptly shifts from one state to the other (as indicated by the arrows). For further explanation see Scheffer et al. (2001).

The ball-and-cup heuristic reveals two of the three basic elements of ecological resilience, (1) internal dynamics and (2) environmental conditions. Internal dynamics concerns interactive feedbacks among groups of species and the environment that generate emergent self-organization. Ecological interactions (e.g., competition, predation, mutualism, parasitism) connect species with one another and the environment. Positive feedbacks accelerate an ecosystem on a trajectory towards a stable state as a few dominant processes set the pace of trophic flows between species and, thus, promote regularity. Once the ecosystem nears a stable state, the runaway positive feedbacks give way to negative feedbacks, which dampen the acceleration and hold other ecosystem properties (e.g., total biomass, transpiration) relatively constant. When minor disturbances occur the internal positive feedback mechanisms respond by accelerating processes once again so that the ecosystem returns back to the same stable state. For instance, after a disturbance, remnant individuals that survive the disturbance function as internal ecological memory that help reconstruct the dominant processes and effectively supply a blueprint for recovery.

It should be reiterated, though, that internal dynamics are intimately connected with environmental conditions, as represented by changes in the contours of the stability landscapes. In some cases, moreover, self-organizing feedbacks can emerge between the network of species constituting an ecosystem and the environmental processes that impose constraints on the ecosystem and how they develop. For example, trees absorb water and release it through the process of evapotranspiration. In dense forests evapotranspiration increases humidity to such a degree that it affects local precipitation. As a result, removing large areas of forest can lead to rainfall reduction because the biological machinery that recycles the water is lost, causing the region to become more arid, which, in turn, initiates a regime shift and the loss of vegetation (Aragão 2012). Additionally, geomorphological processes can sync with biological ones in biogeomorphological systems that exhibit ecological resilience. Riparian environments (Corenblit et al. 2007) and sand dune ecosystems (Stallins and Corenblit 2018) offer clear examples of how feedbacks within biogeomorphic systems emerge and shape the range of states and levels of resilience available to them. A similar dynamism manifests with shifts in the movement of heat between hemispheres associated with annual seasonality. This dynamic can induce frequency locking, or phase locking, in which certain ecological processes speed up or slow down based on the time of the year (Scheffer 2009). Common examples include predator-prey interactions that decrease during winter months in temperate and polar regions when predators go into hibernation and flowering plants that bloom during the spring and provide a spike in food availability for pollinators. All three of these examples illustrate how internal dynamics and environmental conditions can become so interconnected as to produce a self-organizing feedback that ensures ecosystem persistence within a unique stability state.

This internal dynamics-environmental conditions account reflects the traditional interpretation of ecological resilience. Self-organizing feedbacks, networks of trophic interactions, with their ability to respond to and negotiate fluctuating environmental conditions, are regarded as the locus of ecological resilience. In other words, ecological resilience is an emergent property of ecosystems, which explains the persistence of ecosystems as discrete organizational entities amidst environmental fluctuation. As Gunderson states: “Resilience is an emergent property of ecosystems and is related to self-organized behavior of those ecosystems over time” (2000 p. 430) (cf. Peterson 2008).

As I argued in previous chapters, the allure of topology is largely responsible for the reification of this emergentist thinking. Topological analyses help conceptualize and anticipate patterns that escape straightforward observation. They also encourage elaborate quantitative computations that can produce exact mathematical results. In ecology, topological depictions of the internal dynamics of an ecosystem or the relationship between an ecosystem and its environment are commonplace, especially in resilience theory (Scheffer et al. 2012).

To be sure, mechanistic explanations of systems are scientifically attractive, but are they enough to adequately conceptualize ecological resilience? More recent resilience theory literature would emphatically answer that it is not. Topology abstracts away from the finer spatial details of the landscape (i.e., topography), and some of those details are vital for obtaining a robust interpretation of ecological resilience. Recent developments in the area of spatial resilience have decisively made this point. Through a closer examination of the resilience theory literature in the next section, I expand my interrogation of the metaphysics of resilience theory by arguing how openness operates as a structuring principle of equal or greater significance than emergence in producing a robust explanation of ecological resilience.

The Importance of Openness to Understanding External Inputs:

External inputs are the third basic element of ecological resilience. In this section, I argue that the impact of external inputs on ecological resilience deserves as much consideration as the other two elements noted earlier (i.e., internal dynamics and environmental conditions). However, external inputs are not explainable conceptually in terms of emergence. Instead, it is the metaphysical principle of openness, which captures open-system dynamics as opposed to cybernetic system dynamics (cf. chapter two), that best characterizes the causal situation. Put simply, openness concerns the regular exchange of matter and energy between a site and its surrounding environment that results in equifinal steady states. Although an equifinal steady state may appear to share some similarities with emergent self-organizing feedbacks (i.e., prolonged, regulated stability), the causal factors relevant to each are vastly different, and the sorts of details needed to give a full explanation of the phenomenon in question vary considerably.

External inputs are divisible into two kinds. The first kind embraces external inputs of resources. Ecosystems receive minerals and nutrients that replenish what is lost or converted through metabolic processes that help stimulate growth. For example, dust regularly disperses over the Amazon rainforest. Those inputs help sustain the high vegetation density found there.[2] Sometimes external inputs qualify as disturbances, though. For example, nutrient loading in shallow lakes due to runoff can induce a regime shift from a clear state to a turbid one. The nutrients

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[2] Cumming and Norberg refer to these kinds of relationships as “subsidy effects” (2008, p. 261).

accelerate phytoplankton growth to the point that their mass becomes so dense that they block sufficient sunlight from reaching the benthic macrophytes that bind the soil (Scheffer and van Nes 2007).

The other kind of external input embraces ecological agents. Unlike resource inputs, which typically slow down or speed up processes already underway, outside ecological agents play a much more active role in stabilizing or even reconstituting an ecosystem after a disturbance. Disturbances are isolated to certain areas. Individuals in a disturbed area may be lost, but they can be replaced by others from source areas. These are referred to as mobile link species. The more severe the damage, the more important mobile link species are. Mobile link species can fulfill three roles that are not mutually exclusive. They can function as: (1) resource links that bring in nutrients and energy resources from more productive areas, (2) genetic links that move important genetic material for restarting productivity (e.g., pollen, eggs, mycorrhizal fungi, etc.), or (3) process links that facilitate trophic and nontrophic processes as ecosystem engineers. In this way, mobile links are a source of external ecological memory that resupplies a disturbed area (Lundberg and Moberg 2003).[3]

Coral reef recovery provides an example of the importance of external inputs. In coral reefs, prevailing currents affect recruitment rate. Coral larvae are poor swimmers, so much so that their probability of reaching a coral reef formation depends almost entirely on prevailing currents transporting them from one location to next. In addition, other types of mobile links are of vital importance to a coral reef after a disturbance. The return of mammals, fish, and other

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[3] van Nes and Scheffer (2005) question whether mobile links really provide much of a stabilizing influence since such links are just as likely, if not more likely, to drastically alter the dynamics that characterized the ecosystem prior to disturbance. It is worth noting, though, that mobile links are portrayed favorably by an overwhelming number of authors cited in this chapter since they promote ecological resilience through the introduction of diversity (Folke et al. 2004; Scheffer et al. 2012; Cumming, Morrison, and Hughes 2017). The full impact of diversity on ecological resilience lies beyond the scope of this chapter, it cannot be overstated, however, how important it is to reaching Holling's goal of a theory of adaptive change.

herbivorous organisms like sea urchins provide external ecological memory by transporting limiting nutrients and suppressing algae growth (Nyström and Folke 2001; Elmhirst, Connolly, and Hughes 2009; Scheffer et al. 2012).

Post-disturbance island colonization in archipelagoes provides another example. Islands are unevenly affected by disturbances such as hurricanes. After a hurricane passes, islands within an archipelago near to an affected island act as staging areas housing stockpiles of external ecological memory that can, in effect, restore its functional integrity. Consequently, the remoteness of an archipelago or island group and the presence or absence of dispersal barriers greatly affect recovery rate after a disturbance. More remote islands have lower overall connectivity and, thus, take longer to fully recover (cf. MacArthur and Wilson 1967). In short, the movement speeds of immigrating species, which are affected by geographical distance and topographical variability, largely shape the trajectory of recovery within disturbed areas, especially so on islands.

Spatial resilience is the subarea of resilience theory that emphasizes connectivity between multiple spatially extended, self-organizing systems (Nash et al. 2014). Among spatial resilience's focuses are "the spatial arrangement of system compartments (for example, habitat patches or households) and interactions between them, as well as patch or area size, shape, heterogeneity, and the number and nature of system boundaries" (Cumming, Morrison, and Hughes 2017, p. 650). Spatial resilience does not deny the role that internal dynamics and environmental conditions play in promoting ecological resilience but instead highlights the importance of the external inputs and their heterogeneous availability that often go underreported in the analyses of traditional resilience theory. For instance, Cumming states: "Isolated patches have different properties from continuous landscape, resulting in changes in both their internal ecological dynamics and the ways in which organisms disperse, and meet their basic life history requirements" (2011, p. 904). In this way, spatial resilience provides more robust depictions of ecological resilience by embracing the multidimensionality of ecological processes (Kéfi et al. 2019).

Conceptually, emergence does not fully explain the causal dynamics that connect isolated patches in ecologically relevant ways. Dispersal processes do not resemble self-organizing feedbacks. In particular, probabilities of active dispersal are almost entirely determined by an individual's dispersal capabilities relative to the topographical properties of the area it disperses over. The only ecological impetus affecting dispersal seems to be when competitive exclusion makes it difficult for invading species to establish (cf. Diamond 1975). Instead, the effects of dispersal processes on ecological resilience are best explained by open-system dynamics.

Openness, in many ways, is the opposite of emergence because self-organizing feedbacks become progressively closed off from external inputs over time as their homeostatic capabilities grow (cf. chapter two). A tradeoff occurs between the two in ecological systems such that higher rates of successful immigration come at the expense of higher ecological connectivity and vice versa. In section three, I demonstrate how investigations into ecological resilience must be framed in such a way that they incorporate both openness and emergence. Working with one without the other oversimplifies ecological resilience and renders any explanation of it incomplete and potentially misleading.

Now, it is not as if traditional resilience theorists are unaware of the impact that movements across heterogeneous spaces have on ecological patterns. They have become so obsessed with models designed to reveal emergent topological patterns, however, that everything else just appears secondary. Reiners and Driese (2001) make proper note of this fact, citing a list of authors from the 1920's through the 1990's who report the significance of movements across geographical space in their positing of ecosystem patterns. More to the point, they also note that "[t]he 'openness' of ecosystems to energy and matter was a primary attribute" of the accounts given during that period even if it was not always clear (Reiners and Driese 2001, pp. 939-940). Reflecting on the work of Holling and some of his colleagues, like Peterson (2002a; 2002b), they clearly acknowledged the significance of spatial heterogeneity on resilience well before spatial resilience became a specific research area. In his seminal paper, Holling states:

> Variability over space and time results in variability in numbers, and with this variability the population can simultaneously retain genetic and behavioral types that can maintain their existence in low populations together with others that can capitalize on chance opportunities for dramatic increase. The more homogenous the environment in space and time, the more likely is the system to have low fluctuations and low resilience (1973, p. 18).

C.R. Allen, another regular collaborator with Holling and a proponent of treating ecological resilience as an emergent property (Allen et al. 2019), gives an unequivocal endorsement of spatial resilience in an article he co-authored with two notable spatial resilience theorists, Cumming and Folke: "The roles of within- and among-system connectivity are critical to understanding ecological regime shifts and, therefore, resilience" (Allen et al. 2016, p. 628). Even stepping-stone patches without any ecological significance themselves are deemed relevant to ecological resilience insofar as they facilitate the movement of organisms across the landscape (Allen et al. 2016, p. 627).

In sum, the emphasis placed on emergence in traditional resilience theory originated with scientists' tendency to gravitate towards mechanistic explanations that analyze patterns topologically, but not due to any obliviousness to the relevant details of openness. However, by downplaying openness, they force more emergentist metaphysics into the way in which scholars examine environmental change. In part this may be a consequence of the teleological nature of resilience theory. It originated as a way to examine human impacts and to manage resources to fulfill specific purposes. Thus, this directed use of resilience theory may not account for the inherent variability and dynamism of resilience that openness introduces.

How might the tendency to prioritize topological, mechanistic explanations be broken? Reiners and Driese (2001) suggest a different unit of study. They opt for an approach that focuses on environmental space, not discrete ecosystems. "Environmental space" is a "neutral and inclusive term" that refers to the "arena in which the phenomena [being addressed] occur" (Reiners and Driese 2001, p. 941). Operating from the standpoint of environmental space allows for more robust explanations of ecological dynamics that include exchanges of matter and energy between geographical areas. For example, RH Whittaker (1953) proposes a site-specific account of plant succession largely indebted to the conceptual framework of von Bertalanffy (1950a; 1950b; 1951), one of the most prominent advocates of open-system models in the history of complex systems theory (cf. von Bertalanffy 1968; 1972b). Instead of concentrating on feedback dynamics, Whittaker discusses stand development in terms of constant losses and replacements that result in equifinal steady states. He argues for a site-specific approach to studying plant succession that takes into consideration a stand's sensitivity to spatially unique features of the landscape:

> The climax balance is determined by environment of a specific site, and the climax population only has meaning for a kind of site. For the early assumption that climax was independent of site may be substituted the hypothesis that any significant difference in site implies a difference in climax population. As all climax stands occur on sites having some kind of

> topographic relation to other sites, all climaxes are topographic, as well as climatic, climaxes (1953, p. 54).

I find the site-specific approach metaphysically tenable but recognize that some scholars may object to it on grounds that ecological patterns do not correspond neatly with fixed spatial boundaries. Even von Bertalanffy recognizes this:

> Any system as an entity which can be investigated in its own right must have boundaries, either spatial or dynamic. Strictly speaking spatial boundaries exist only in naïve observation, and all boundaries are ultimately dynamic (1968, p. 215).

Although I understand the appeal of ecosystems, as dynamic but discrete entities, serving as the central unit of investigation, it is important to remember that the ecosystem concept is equally naïve. Levin is right to refer to ecosystems as "fictions," "an arbitrary restriction of spatial boundaries rather than a reflection of real thresholds of species change" (1999 p. 71) (cf. Levin 2005). It is not as if neatly arranged positive feedbacks with discernible sets of species occur anywhere in nature. In this way, the topological models typically employed in network analysis posit something that is equally as unreal as fixed spatial boundaries. If both are equally fictions, it only seems right that the position adopted should be whichever one provides the greatest utility in formulating explanations and generating successful predictions. Seating an explanation in terms of environmental space allows for greater explanatory flexibility insofar as it provides even greater metaphysical specificity. It introduces both a third element relevant to classification (i.e., external inputs) and a second causal schema to describe organizational patterns (i.e., open-system dynamics) Conversely, by definition, the ecosystem concept restricts primary explanations to self-organizing networks of feedback processes. Starting from environmental space imposes no such restrictions, and it actually encourages ecologists to incorporate topographical dimensions (e.g., geography) into their topological analyses to yield more robust explanations of ecological pattern formation (cf. Stallins, Mast, and Parker 2015).

The spatial resilience literature has at its aim to develop modeling techniques to capture the effects of spatial correlation, spatial variance, and spatial skewness and their relationships to the persistence of ecological processes and patterns (van Nes and Scheffer 2005; Dakos et al. 2011; van de Leemput, van Nes, and Scheffer 2015; Allen et al. 2016). However, it would be wrong to think that spatial resilience extirpates the roots of traditional resilience theory. Self-organizing feedbacks within sites remain crucial to explaining ecological resilience. And therein lies the metaphysical challenge: to connect topological and topographical details such that emergence and openness function as coeval dimensions of a single causal nexus that engenders persistent yet adaptive ecological organizations. In the next section, I demonstrate how another heuristic, the adaptive cycle, might allow for the reconciliation of emergence and openness into a single ontogenetic narrative. This ontogenetic narrative facilitates the incorporations of both topological and topographical details that are responsible for ecological resilience.

Uniting Emergence and Openness Through the Adaptive Cycle Model:

Ball-and-cup diagrams are one common heuristic that resilience theory employs. They depict the qualitatively distinct states an ecosystem's internal dynamics can settle into against the backdrop of fluctuating environmental conditions. A single ball-and-cup diagram identifies the instantaneous state an ecosystem exists in with respect to the range of possibilities and its proximity to collapse. However, this snapshot provides little insight into the diversity of processes needed to adequately explain ecological resilience. Another heuristic from resilience theory is used is needed to capture those details, the adaptive cycle model. In this section, I employ the adaptive cycle model to illustrate how openness is embedded in resilience theory. In the next chapter I argue that present-day anthropogenic environmental change appeals more to emergentist accounts of resilience, with considerable ethical implications for how management and restoration strategies are designed and carried out.

The adaptive cycle model is a general scheme commonly employed as a heuristic device to describe an ecosystem's ontogenesis (Holling 1992; Carpenter et al. 2001; Holling and Gunderson 2002; Allen and Holling 2008; Holling, Peterson, and Allen 2008; Peterson 2008; Scheffer 2009; Sundstrom and Allen 2019). The simple version of the adaptive cycle model identifies four distinct phases of ecological resilience. Each phase affects ecological resilience by either strengthening the mechanisms responsible for persistence or introducing new ecological agents that promote adaptability. The four phases can be divided into pairs such that one pair constitutes the "forward loop" and the other the "backward loop." The forward loop begins with an exploitation (r) phase during which individuals of pioneer species become established with relative ease in the absence of strong ecological interconnectivity. As ecological interactions strengthen, the ecosystem slowly transitions into a conservation (K) phase. The conservation phase is marked by a high degree of connectedness and efficiency, which actualizes the potential for maximum ecological productivity. Higher efficiency, however, results in lower adaptability (Scheffer 2009; Ulanowicz 2009). A maximally efficient ecosystem loses its ability to adapt to fluctuating conditions and, as such, becomes more susceptible to disturbances. An inevitable disturbance leads to an abrupt collapse, or release (Ω) phase, that marks the transition to the backward loop. Immediately following the collapse, reorganization (α) takes place. The area of disturbance possesses an abundance of natural capital (i.e., free matter and energy) that permits the establishment of novel combinations of species before any significant regulating ecological mechanisms take shape and a new r-phase commences (Fig. 3.7).

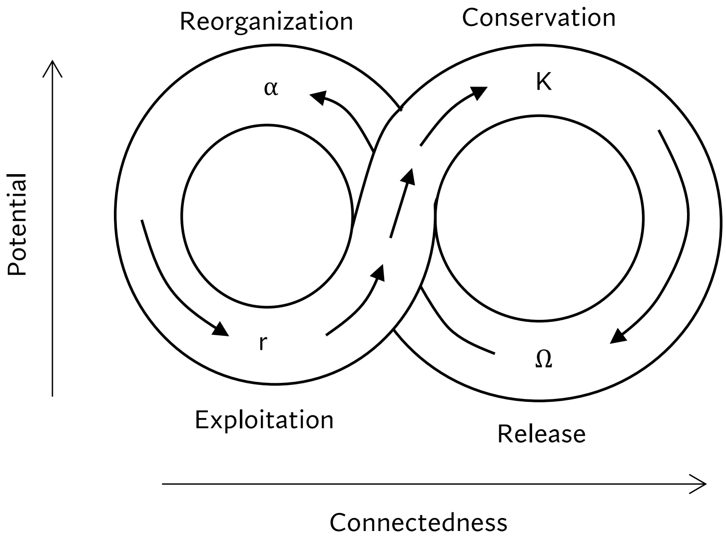

Figure 3.7. A two-dimensional representation of the adaptive cycle model. The y-axis indicates the accumulated potential for ecological development, and the x-axis indicates overall connectedness. The arrows represent the speed of transition from one phase to the next. Longer arrows are quicker whereas smaller, consecutive arrows depict slower processes. For more comprehensive models of the adaptive cycle, see Holling and Gunderson (2002), Allen and Holling (2008), and Sundstrom and Allen (2019).

Not only are open-system dynamics responsible for triggering ecosystem collapses in the first place, but they are especially relevant during the post-disturbance reorganization phase. In this phase, connectedness is low because the feedbacks holding an ecosystem together have broken down. Conditions to enter the area are enticing for many species, and mobile link species most of all take on great significance. The regulatory mechanisms responsible for the arrival of mobile link species are front-and-center, including dispersal routes, staging areas, corridors, and any other ways that geographical or topographical features of the layout of the region impact the movement of species into the disturbed area. It is at this stage of the adaptive cycle where the possibility for novelty and innovation is the greatest.

During the following exploitation phase, the mobile link species and the effects of their presence start to take root or shape. Pioneer species (i.e., r-strategists) prepare the disturbed area for recovery. All the natural capital released by the disturbance is seized on by them. The lack of an overarching ecological structure (i.e., low connectedness) increases the turnover rate and decreases the efficiency of trophic exchange. Over time, as more species cycle through, chances for species compatibility grow and stable combinations begin to emerge. During the exploitation phase emergence is just beginning to be explanatorily relevant. Open-system dynamics still largely govern recovery because without the arrival of species from the outside no new combinations could emerge that increase overall ecological resilience by filling in functional group and functional response vacancies critical to the overall functionality of the slowly emerging ecosystem.

As the adaptive cycle progresses from the exploitation to the conservation phase, regulatory mechanisms corresponding to emergence overtake those associated with openness. Feedbacks engender homeostasis. Turnover rates decrease as the ecosystem becomes increasingly resistant to invaders. More generally, the efficiency of trophic exchanges increases with connectedness, which maximizes the retention of matter and energy flowing through the system. With greater overall connectedness, though, comes a greater susceptibility to disturbances. The components of the ecosystem become so dependent on one another that their fates are tied together: the loss of even one species (or functional group) can lead to the collapse of all the others. A minor disturbance is enough to push the ecosystem into a release phase, restarting the adaptive cycle.

As this and the preceding section show, traditional resilience theorists are acutely aware of the impact dispersal processes have on ecological resilience. But their theories have seemingly stopped interpreting dispersal as a feature of open-system dynamics and instead treat it as an adjunct to emergent self-organization across spatial and temporal scales.[4] Many ecologists now conceptualize dispersal processes as occurring within emergent hierarchies of adaptive cycles. This has led to the proliferation of the panarchy concept within resilience theory (Holling 1992; Allen, Forys, and Holling 1999; Holling, Gunderson, and Peterson 2002; Allen and Holling 2008; Allen et al. 2014; Sundstrom and Allen 2019). In short, the panarchy concept represents different processes operating over different scales. Dominant scale-specific processes entrain others to produce self-organizing patterns linked across scales through nested adaptive cycles (Fig. 3.8). Causality loosely connects the different adaptive cycles of a panarchy so that each adaptive cycle operates semi-autonomously from the others above and below but remains sensitive to significant fluctuations occurring at any level of organization. The resultant cross-scale modularity is important because it offers some insurance against total ecological collapse while at the same time engendering a kind of holistic regulatory apparatus.[5]

According to the panarchy concept, dispersal into an ecosystem at the focal level is subsumed within the adaptive cycle above it by expanding the spatial area and extending the temporal duration. So, instead of conceptualizing dispersal as originating from beyond the boundaries of a site, it just appears as regular movement within a larger self-organizing system.

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[4] In the next chapter, I will insist that cultural aspects endemic to the practice of resilience theory help to perpetuate this mentality. The overall effect, I argue, is negative from an ethical standpoint.

[5] The importance of modularity to resilience theory is accounted for in greater detail by Levin (1999) and more directly by the watchmaker analogy offered by Simon (1962).

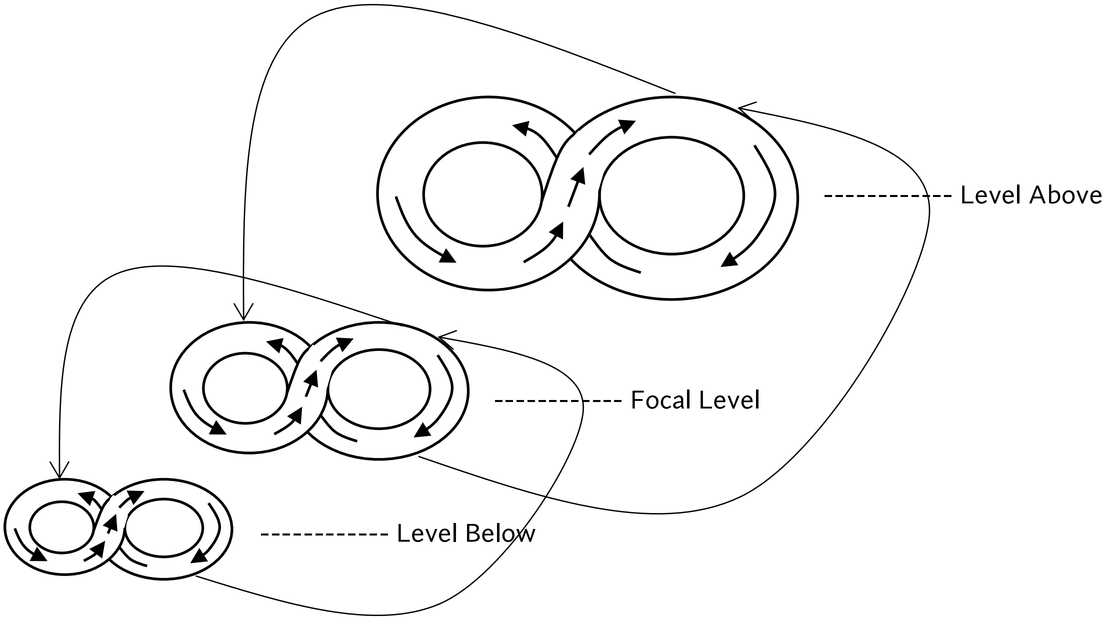

Figure 3.8. A simplified example of a panarchy arrangement based on a diagram provided by Allen and Holling (2008, p. 222). An adaptive cycle in the process of actualizing its K phase imposes constraints on the adaptive cycles below it, most notably as the lower-level adaptive cycle is reorganizing. However, an adaptive cycle that has progressed deep into its K phase is sensitive to collapses (i.e., the release phase) of adaptive cycles below it because any disruption to the constancy of productivity levels produces a cascade effect in an overly efficient self-organization of feedbacks.

Panarchy theory and the wider body of theory in which it is situated, hierarchy theory (Simon 1974; Allen and Starr 1982; O'Neill et al. 1986; Wiens 1989; Levin 1992), are clearly ways to extend mechanistic explanations beyond a single scale yet remain committed to a single conceptual principle, emergence. My job here is not to challenge the existence of various ecological patterns in nature. But trying to understand all these patterns in terms of emergent self-organization is clearly a misconception. Not only does it oversimplify something inherently complex, but it makes investigators susceptible to Maslow's hammer (i.e., if all you have is a hammer, everything looks like a nail). A hammer is not the right tool for every job. Emergence is one conceptual principle; openness is another. Taken together, they provide ecologists with the scope and flexibility needed to approach ecological resilience with greater care and precision.

In fact, of the two principles, openness is typically more central to an explanation of ecosystem recovery, which is significant because it seemingly refutes the common assumption that ecological resilience is best understood as an emergent ecosystem property. A problem with explanations structured by the principle of emergence is that self-organizing feedbacks are not fully realized until the very end of succession, as shown by the adaptive cycle model, and succession is frequently interrupted by disturbances. Take for example the recolonization of Krakatau. Bush and Whittaker (1991) collected data on the colonization patterns on Krakatau and compared it with previous records spanning the period since its catastrophic eruption in 1883. Their analysis found that MacArthur and Wilson’s equilibrium theory of island biogeography is insufficient for describing the island community’s recovery because disturbances often outpace ecological development (Bush and Whittaker 1993). For islands like Krakatau, an “uninterrupted Clementsian march” of succession is pretty much an impossibility (Whittaker 1995, p. 424) (cf. Whittaker 1997). In their words, the formation of ecological organizations often reverts to predominantly open-system dynamics before any potent self-organizing feedbacks can emerge.

Even more, some of the predictions from emergentist thinking have not come to pass. For instance, some worry that the planet is nearing a global tipping point. Barnosky et al. (2012) fear that the biosphere may soon undergo an irreversible global catastrophe. Due to the hierarchical arrangement of feedbacks, a collapse at the highest level would almost undoubtedly lead to the collapse of all the feedbacks below. Or, at least, that is the emergence-centric line of thinking. Spatial resilience theorists, such as Scheffer and van Nes (2007) and Hughes et al.

(2013), disagree. A global tipping point does not exist in the sense that surpassing some critical value will result in the biosphere abruptly collapsing. On the contrary, evidence seems to suggest that the spatialization of ecological, environmental, and social systems reduces the speed of regime shifts. Rietkerk et al. (2021) even go one step further and assert that spatial self-organization is a means by which tipping points are evaded. The openness that exists at the scale of the entire globe is likely to interrupt any emergent synchronization of tipping points. To this end, a growing area of study in resilience theory concerns itself with how localized regime shifts interact with one another through their connectivity (Rocha et al. 2018; Scheffer and van Nes 2018), highlighting the need for more expansive explanations structured around the principle of openness instead of emergence.

Of course, spatial resilience theorists are also not saying that human beings cannot cause ecological or climatic catastrophe on a global scale. They are simply pointing out that conceptualizing earth systems entirely in topological terms may be too simplistic. More details need to be incorporated to properly explain ecological resilience, especially topographical ones. Ignoring the possibility of global tipping points might be a risk not worth taking (cf. Lenton et al. 2019), but in this case an inadequate theory of causation is a reason to take pause. Potential remedies or further complications might be going unrecognized because so much emphasis is placed on nearness of collapse as opposed to features that regulate openness and improve recovery, which, I argue, are more fundamental to the ecological resilience concept. The stakes are simply too high at this point. If protection against global catastrophe is the goal, reliance should not be placed in emergence alone.

One final note, I am aware that the ontogenetic narrative I am offering here does not fully reconcile open-system dynamics and self-organizing feedback dynamics in a single theory of causation. Maybe some future modeling technique will be able to accomplish this feat, but, philosophically, such a reconciliation is not necessary. The goal is just to improve the conceptual organization of relevant details. As noted, a sufficient metaphysics (1) characterizes different elements of interest and (2) makes causal connections. Joining the adaptive cycle with the ontogenetic narrative not only satisfies both those criteria but it also provides a degree of epistemological guidance. For it predicts what sort of causal factors are strongest and when. If a disturbance has recently occurred, then open-system dynamics and the associated elements (i.e., external inputs) are likely to be most responsible in explaining ecological resilience. If, by contrast, many generations have passed since a major disturbance, then self-organizing feedbacks probably exert stronger causal influence over the formation of ecological patterns, which means internal dynamics and environmental conditions contribute more to explaining ecological resilience. Using the ontogenetic narrative in tandem with the adaptive cycle provides the kind of conceptual scope and flexibility needed to effectively account for the multidimensionality of ecological resilience, which is the purpose of this chapter.

Conclusion:

I have argued that ecological resilience is not a matter of emergence alone. Openness is another dimension of the complete causal picture needed to yield a complete account of the persistence and adaptability of ecological organizations that encounter regular disturbance. Whereas emergence emphasizes topological details, openness emphasizes topographical ones. More to the point, I posited an ontogenetic narrative uniting emergence and openness that both improves the characterization of elements of interest and encompasses the changing causal dynamics responsible for ecological resilience.

As mentioned in the introduction, I do not see this chapter adding anything metaphysically new to resilience theory that was not already present in the literature. My contribution is a defense of the principle of openness in explanations of ecological resilience in light of the wealth of topographical details that are relevant to them. The one point of contention that I introduced was whether a site or an ecosystem is the proper unit of study. I argued that a site-specific approach lends itself to analysis through a combination of openness and emergence, whereas an ecosystem approach wields the principle of emergence almost exclusively and renders anything related to openness largely irrelevant. Many complex systems theorists, including traditional resilience theorists, take issue with the site-specific approach I defend because all boundaries in nature are inherently dynamic (cf. von Bertalanffy 1968). However, I find that the greater access to details afforded by the site-specific approach is more advantageous in crafting explanations than having a discrete unit to study (i.e., an ecosystem) to which properties are attached. If, in the end, fixed spatial boundaries and ecosystems are equally fictions, it only seems sensible that the position adopted should be whichever one provides the greatest utility in formulating explanations and generating successful predictions. Explanations that use environmental space as the unit of study allow for greater explanatory flexibility insofar as they provide even greater metaphysical specificity by including a third element of classification (i.e., external inputs) and a second causal schema to interpret organization patterns (i.e., open-system dynamics).

Up to this point in the dissertation I have approached ecological complexity from the standpoint of metaphysics and epistemology with an emphasis on openness. I have argued that emergence and topology so dominate complex systems theory that meaningful details have been misunderstood. Open-system dynamics and topographical details also need to be recognized. In both chapter two and chapter three, I have posited an ontogenetic narrative that does just that – connect openness with emergence – to demonstrate the advantage of an expanded explanatory framework that covers topographical details in addition to topological ones.

In the following chapter, I tackle a job often assigned to the applied philosopher, viz., constructing an ethics that is mindful of the above complexities. Ecological resilience is not just a theoretical investigation, but also used as a concept to guide management and restoration practices. Katz, a pragmatist ethicist, challenges the ethical foundations of ecological restoration on the grounds that ecological restoration is carried out under the false presumption that it achieves some kind of restitutive justice on nature's behalf. Ecological restoration does not restore but produces an artifact. Indeed, the act itself is really just another attempt by humanity to dominate nature, which he refers to as "the fundamental error." I agree with Katz's general assessment, but I argue that the resilience theorist's viewpoint can escape Katz's criticism if it follows from a metaphysics that values openness more than emergence. The emergentist perspective designs management and restoration practices with the intention of keeping an ecosystem in a stability state for anthropocentric reasons. Just as Katz argues, this is not an act of restitutive justice but an action out of human self-interest to control nature. A site-specific approach, however, avoids Katz's criticism because it does not impose an exact design on the natural state that is to exist. Instead of some desired state like the emergentist thinking pursues, a site-specific approach structured primarily by the principle of openness values progressive development and adaptation regardless of the states that result and their compositions. What it values, in other words, are not specific ends but the specific mechanism through which nature persists. I organize the discussion around the role tipping points have recently played in directing management and restoration.

Chapter 4: A Geographical Environmental Ethics: How Openness Avoids Anthropocentric Ideals in Restoration Practices

Introduction:

In the first three chapters, I discussed the metaphysical and epistemological dimensions of openness and emergence. I argued that both principles are fundamental to explaining ecological patterns found in nature. I took issue, consequently, with accounts that prioritize emergence over or at the expense of openness. In most cases openness appears to be the foundational causal principle upon which self-organizing systems depend on most. In this final chapter, I provide an ethical account that unifies my previous discussions. First, I argue that an emergentist approach facilitates a short-sighted, exploitative command-and-control perspective that seeks to dominate nature and leads to an anthropocentrism some ethicists have described as “dysfunctional” (Katz 2012) and “arrogant” (Rolston III 2020). Second, I show how this anthropocentrism is reinforced by the way in which emergence is invoked to implement strategies and to develop practices in response to tipping points. Lastly, I explain how aspects of adaptive cycles mitigate some of this reification of emergence so as to offer an ecocentric approach to restoration and the responses to rapid environmental change.

As I demonstrate, the use of openness as a conceptual guide for restoration is key to achieving an ecocentric ethics. Practices following from openness aim to increase the resilience of systems without imposing a specific a priori design on them. In turn, the environmental ethics I argue for is steeped in biogeographical principles, which aim to give nature spaces to operate, rather than in more active management strategies that attempt to manipulate processes or alter environmental conditions as to restrict emergence to narrow anthropocentric outcomes. The emphasis I place on these principles lead me to refer to my approach as “geographical environmental ethics.”

The work of environmental ethicist Eric Katz on localized ecological restoration and global geoengineering provides the springboard for my critique of tipping points. The target of his criticisms is the attitude that human technology can improve upon nature. This attitude originates from the idea that humans possess the know-how to fix any destruction they cause to natural places or processes. In Katz’s view, this reflects a kind of anthropocentrism and unyoked hubris that humanity can act without regard to nature because any problem can be solved by human ingenuity. The crux of his critique is that restoration practices and policies are veneered with ecocentrism but are seemingly always indexed to human interests. Although such anthropocentrism is not entirely inescapable in and of itself, it unnecessarily poses significant harms to natural systems and, by extension, the humans that depend on the services provided by those natural systems.

I agree with Katz’s critique and believe that it can be extrapolated to ecological management practices in general. More specifically, I argue that some explanations of system dynamics used to guide management practices and policies, namely, those that are built around the concept of tipping points, are infused with the unavoidable anthropocentrism that Katz is attempting to dispel. At the same time, I also believe that other explanations of ecological complexity promote an ecocentrist ethics that does not jeopardize human wellbeing but replaces control over processes with the facilitation of recovery as the chief end.

Developing a pragmatic ecocentrism seems needed for at least two reasons. First, historically, many of the most prominent environmental ethicists have defended ecocentrism ever since Aldo Leopold’s (1949) land ethic and Naess’ (1973, 1986) deep ecology. Pursuit of ecocentrism shaped many early discussions in the analytic environmental ethics literature (Callicott 1984; Rolston III 1994).

Even those who argued in favor of a pragmatist approach (Weston 1985; Katz 1987; Stone 1988) never truly lost sight of ecocentrism (cf. Weston 1991); they simply realized that environmental ethics could not effect positive change by simply convincing the public that nature possesses intrinsic value. Second, how one ascribes values often affects one's preferred practices. A relatively new conservation ethic has emerged that advocates biodiversity conservation solely with an eye toward human interests. Some worry about the unintended consequences such a mindset can have, such as further habitat destruction when species lack clear and present value for humans (Soulé 2013; Doak et al. 2014). As a result, renewed calls for ecocentrism have been issued in hopes of dissolving the mentality that seemingly justifies these short-sighted and exploitative practices (Piccolo 2017; Piccolo et al. 2018; Taylor et al. 2020).

Given this situation, ecological complexity theory seems like a promising way to construct a practical basis for the ethical evaluation of practices and for policies that blend science and philosophy. For this theory has found a way to portray human interests as entwined with ecological values by shifting the unit of study from ecosystems to socio-ecological systems (SESs) (Folke et al. 2010; Cumming 2011; Cumming, Morrison, and Hughes 2017). Shifting the focus to SESs has the potential of relaxing the anthropocentrism-ecocentrism divide because acting in the best interests of an ecosystem is then also acting in the best interests of social systems, and vice versa. Although I agree with the general framing of this approach, I do not think that it is the best ethical perspective for informing management and restoration practices. As I will show, uncritically implementing a complex systems approach can still lead to a kind of short-sighted, exploitative anthropocentrism that can threaten the longevity of the natural systems involved. I contend that the matter comes down to the emphasis placed on the two primary structuring principles, emergence and openness, in explaining system organization.

To apply Katz's criticism, I return to the two sets of heuristics discussed in the previous chapter, tipping points, which more formally originated from catastrophe theory (Zeeman 1976; May 1977; Scheffer and Carpenter 2003), and adaptive cycles, which are the linchpin of traditional resilience theory. Neither offer an exhaustive explanation of all the relevant causal mechanisms influencing the formation of self-organizing patterns in nature but both help to simplify some of the complex aspects. Tipping points are characteristic of emergentist thinking. Adaptive cycles are more neutral in that they allow openness and emergence to be related to one another ontogenetically. The tipping points heuristic identifies distinct stable states against a backdrop of varying environmental conditions. Managers and restorationists use tipping point designations as a guide to hypothesize about the natural and human processes that regulate the internal dynamics of a system and to try to control or augment the environmental conditions acting on them. This strategy has been useful in closed systems like shallow lakes as one example, but less so in open systems like coral reefs. Both examples are discussed in section two.

The adaptive cycle heuristic does not necessarily identify a target state but is instead concerned with the evolutionary transitions characterizing the development of a system. Evolution is a principal way in which nature exercises its autonomy (to borrow Katz's language). I argue that the adaptive cycle heuristic can provide a basis for developing restoration practices that do not as overtly infringe on nature's autonomy but instead uphold a conservation-focused approach that allows nature to utilize spaces in ways that will lead to naturally occurring self-organizing systems. Although humans like to think that they possess ample knowledge of natural dynamics, that knowledge is never complete and is almost always skewed in one way or another by an epistemological bias towards one or a couple of causal mechanisms – especially feedbacks – characteristic of natural systems. The adaptive cycle heuristic does not single out any one mechanism as most crucial but instead provides a template for the natural progression of systems insofar as it identifies opportunities to enrich ecological insurance. Instead of trying to manipulate processes or conditions to produce desired results, the approach to restoration practices that I defend seeks to provide natural systems with spaces to buffer the effects of disturbances and to determine their own evolutionary trajectories.

Ultimately, conceptualizing natural systems in terms of emergent, self-organizing feedback is not a totalizing dysfunctionality, an anthropocentric arrogance. As I have shown in previous chapters, emergence is essential to understanding causal relations characteristic of ecological complexity. However, I aim to demonstrate how actions guided by emergence alone continue a long history of exploitative views towards nature. Tipping points have often been elevated to prominence in addressing environmental problems partly because they facilitate the technological quick fix that humans typically seek. Instead of addressing the root cause of human-induced environmental problems, namely, exploitative practices, tipping points have created the illusion that crafted emergentist interventions can redirect global system properties. I argue that this illusion is a recipe for disaster in that tipping points are heuristics that fail to account for important open-system dynamics that affect the overall health of a system. They are an ethically problematic framework for restoring ecosystems insofar as they might lead to the violation of nature's autonomy, which does seem both dysfunctional and arrogant.

The pragmatic approach I defend may not lead to a cogent, singular actionable response to the global climate change crisis since ecological and evolutionary timescales for any solution extend far into the future. But this quick fix expectation foisted upon nature is precisely the attitude I am arguing against by introducing Katz's critique. Natural systems should not be made to run on humanity's preferred time schedule and spatial specifications. Not only does doing the latter show a disregard for the value of the non-humans that comprise natural systems, but it is also highly unlikely to work in the long run and even more likely to lead to brittle systems prone to catastrophe.

This chapter is divided into three sections. The first section outlines Katz's ethical criticisms of ecological restoration, as well as a subset of this practice that targets global extents, geoengineering. In the second section, I demonstrate how the very structure of tipping point explanations exemplifies Katz's charge of dysfunctional and hubristic anthropocentrism. Finally, I offer a positive account for an approach to restoration that circumvents the thorniest parts of Katz's criticism by using the adaptive cycle model as a guide. I conclude along similar lines as Holling and Meffe (1996) that the failure of restoration practices from an ethical perspective is rooted in humanity's expectations of fixity in a natural world that is fundamentally fluid and open. From the perspective of environmental management and restoration, the implication is that the inexactness of planetary tipping point explanations makes the prospect of rigid manipulation of system processes to produce desired results untenable. From an ethics standpoint, moreover denial of an anthropocentrism affiliated with tipping point designation thwarts any embrace of a humbler ecocentrism rooted in the principle of openness.

Katz's Critique:

Katz first formulated (1992) and has repeatedly defended (1993; 1996; 2000; 2012; 2015; 2018) his criticisms of other environmental ethicists, for instance Paul Taylor (1986) and Peter Wenz (1988), who believe that ecological restoration accomplishes restitutive justice or moral repair towards nature. His principal target is the mindset that humans can "fix" nature after they have harmed it (e.g., replanting trees after clearcutting a forest). For the purposes of this chapter, I focus on the ineliminable anthropocentrism operating within most restoration and management practices that Katz wants to reveal and dispel. Anthropocentrism, as understood in this context, signifies the prioritization of human interests over those of any non-human. Katz's argument is that, oftentimes, practices and policies are framed as ecocentric, meaning that they claim to act in the best interests of the natural systems concerned, but are actually carried out for the purpose of furthering human interests. These practices and policies purport to "restore" nature, but, on Katz's view, they "create" an artifact.

The distinction between natural and artificial is fundamental to Katz's views on ecological restoration and is largely indebted to the essay, "Faking Nature," written by Robert Elliot (1982). Elliot compares ecological restoration to art forgery. Imagine the following hypothetical. A private collector wants to purchase Leonardo da Vinci's *Mona Lisa* from the Louvre, and the price is unfathomable. The private collector is successful, however, and now the world-renowned painting resides in her home. Many years later, the collector decides to auction it, hoping to get a hefty return on her investment. Unbeknownst to her and everyone else, the *Mona Lisa* painting that the Louvre sold her was in fact an exact forgery by a highly skilled but unknown artist. An art thief commissioned the forgery and substituted it for the original years earlier. Before the painting goes up for auction, the art thief comes forward and fesses up. Although the painting in the collector's possession is an exact copy of da Vinci's, so much so that even the best artists and art dealers around the world could not tell the difference and many tourists admired it in the Louvre, no one is willing to pay anything close to what the collector paid. Why? It is because even though the two paintings are impossible to distinguish the history of the painting affects its value. Even if the unknown painter can perfectly replicate da Vinci's work, that painter is still not da Vinci nor is the painting the one that possesses an enduring history as a publicly adored work of art.

A similar interpretation of value can be attributed to the practices of ecological restoration. Nature is the artist of ecosystems. If an ecosystem is destroyed and then replaced by human intervention, the original is gone, and the replacement cannot duplicate the original's history. It is no longer the ecosystem authored by nature, but a forgery passed off by humans as the real thing. Although Katz (1992) believes that Elliot's art forgery hypothetical is ultimately too fanciful (no one could reasonably expect a land developer to restore a strip-mined natural area back to its original state without anyone noticing the differences) and not of the right sort (art is static whereas nature is dynamic) (1996), it has had a profound effect on his own criticisms of ecological restoration. At the heart of Katz's criticisms of ecological restoration is an ontological distinction between what is artificial and what is natural.

For Katz, the defining feature of an artifact is human intentionality. It follows as a corollary that all artifacts are intrinsically anthropocentric in a loose sense, for which the actual ends pursued are irrelevant. Just as every piece of human technology is designed for a specific application, every artifact is born from an act of intentional design.[1] Thus, the simple fact that artifacts are produced by humans makes them anthropocentric. This loose sense of anthropocentrism seems ineliminable from human activity unless humans stop existing. Accordingly, Katz does not expect to eliminate anthropocentrism altogether. He adopts this loose sense of anthropocentrism as an argumentative foil to show that simply demonstrating that one's actions benefit nature in some respect is insufficient to establish one's actions as ecocentric. Two sets of criticisms, and Katz's responses to them, provide further clarity regarding the distinction between artificial and

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[1] Following Siipi (2008), Katz does not classify side effects of human production as artifacts. For example, sawdust that accumulates from a construction project does not qualify as an artifact, but the project does. Although this raises an interesting ontological question, it does not weigh too heavily on my argument.

natural and how the distinction shapes the ethics of not just restoration but also geoengineering.

The first set of criticisms comes from Yeuk-Sze Lo. In a 1999 essay, Lo first raises a clarificatory objection against Katz's assertion that ecological restoration projects are always anthropocentric insofar as they originate from a desire to further some interest held by humans. She gives the example of restoring bamboo for the purposes of feeding pandas (1999, p. 253). In this example, the restoration project is motivated by a desire to help the pandas rather than produce anything of human value. Thus, on Lo's account, even if ecological restoration produces artifacts, those artifacts are not necessarily rooted in anthropocentrism. She accuses Katz of confusing "anthropogenic" with "anthropocentric" (ibid.).

Katz responds to Lo's initial objections in two ways. First, he does not suppose that natural versus artificial is an absolute dualism. Instead, he argues that the two exist on a spectrum and that restoration projects are a blend of both in varying proportions. Bamboo grows naturally in the wild and pandas naturally evolved over many generations consuming bamboo, so adopting a practice that simply increases the yield of bamboo to ensure that pandas have plenty to consume seemingly demonstrates a kind of non-anthropocentrism. However, it can hardly be denied that human values play a role in the intentional decision to grow bamboo. Designating a plot of land as a bamboo farm and keeping other species of plants out is artificial. So, the act of growing bamboo to feed pandas is a blend of natural (bamboo and pandas consuming bamboo) and artificial (bamboo agriculture). This leads to Katz's second point: restoration design can follow from either a direct or an indirect human interest. Although promoting bamboo growth might seem like it only benefits the pandas, Katz alleges that the real reason humans do so is because of the value humans derive from the pandas. Species like pandas usually gain human protections that other species (e.g., rats) do not because of non-ecological reasons such as aesthetic or cultural values.[2] If humans did not value the pandas as they do, then a restorationist would not think about planting bamboo. Thus, for Katz, restoration projects of any degree of naturalness or artificiality will always be tied to human purposes and goals (2012, p. 77).

Perhaps providing more context for the bamboo example might help to elucidate Katz's points. Imagine a supremely selfless person who decides to demolish her home to provide more area to grow bamboo. Every inch of the property is devoted to growing the plant so that the pandas will not go hungry. Now she is homeless. Furthermore, her reputation has been ruined because the new bamboo forest is an eyesore next to her neighbors' freshly mowed lawns and it has also introduced new pests to the area. The other homeowners are so angry they plan to sue. Intuitively, it might seem reasonable to declare the supremely selfless person's actions as entirely non-anthropocentric. Katz would disagree. If they were entirely non-anthropocentric, then nature would have been allowed to reclaim the area for itself, whether that included bamboo or not. Even though this supremely selfless person put herself in a disadvantageous position by demolishing her home, it does not mean her actions are non-anthropocentric. She would not have demolished her home unless doing so led to pandas being fed. Ultimately, the degree of human determination over how a given space is utilized (e.g., wilderness, parks, cities, agriculture, etc.) decides the degree of anthropocentrism characteristic of the action. This is fundamental to my argument in the third section.

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[2] Similarly, humans actively eliminate species that threaten their interests despite performing important ecological functions. This is most acutely observable in industrial agricultural practices that have caused widespread environmental degradation (Thompson 2010).

It is unclear what, if any, guidance ecocentrism, as an ethical position, provides in determining the correct treatment of species. It does not seem feasible to expect that all species receive equal treatment. That kind of ecological egalitarianism is simply impractical. Luckily, solving this problem is needed in order to emphasize the principle of openness in restoration projects. Openness provides species with room to avoid direct conflict with human interests since they can utilize spatial features within the landscape to maximize flexibility over extended periods of time.

The cause of the disagreement between Katz and Lo is quite clear. As previously noted, Katz operates using a loose sense of anthropocentrism. Since every human action is intentional and pursues some end framed by human values, every intervention by humanity on nature's behalf exhibits a degree of anthropocentrism. Lo, on the other hand, defends a narrow, and more prevalent interpretation of anthropocentrism. The key difference between them is the point of ethical evaluation. Whereas Katz's loose anthropocentrism accentuates the intentions with which people act, Lo's narrow anthropocentrism concerns the ends of actions. In other words, who is supposed to be the primary beneficiary? In the homeowner case, obviously the pandas, which means the homeowner's actions are non-anthropocentric according to Lo.

On the surface, Katz appears to place unreasonable expectations on humans. But I still see merit in judging environmental practices through the lens of loose anthropocentrism. This is because, as the next section demonstrates, the "domination over nature" mentality can easily avoid detection if narrow anthropocentrism is the only hurdle that needs to be cleared in order for a project design to be implemented. In this context, I should reemphasize the motivation for this chapter: to develop a pragmatic ecocentrism grounded in the principles of complex systems theory. Maybe narrow anthropocentrism could identify bad actors when their actions are held up to intense theoretical scrutiny, but, in practice, bad actors are unlikely to be caught in this way. I would contend that carbon offset programs offer one such example. Such programs do less to address active harms committed against nature (e.g., pollution, climate change, etc.) because they pledge to redress those harms by some other means that do less to disturb business as usual. But little consideration is given to nature's interests. Instead, initiatives like carbon offset programs are actually a way to marry current human interests (i.e., fossil fuel dependence) with future human interests (i.e., an amenable climate to ensure consistent access to resources) (cf. Dargusch and

Thomas 2012). Most troublesome is that this kind of argument can easily be bought and sold under the false pretenses of ecocentrism. That is my chief worry, and, I would argue, Katz's, too.

Still, Lo might have an argument to defeat Katz's loose anthropocentrism insofar as blueprints for restoration projects do not necessarily owe their origin to human design. Whereas copies follow a template, or "reference state," designs introduce novelty (Lo 1999. P. 257). By "novelty," Lo means that a design seeks to produce something else, or some kind of functionality, absent from the original. In such a situation, the presence of human intentionality is undeniable. Copies, on the other hand, are as natural or artificial as the template they derive from. Lo states that "when a person produces a copy exactly resembling the template which was originally a novel entity designed by another person, the product will be obviously a copy made by the first person *and* obviously an entity designed by the second" (1999, p. 258, emphasis in the original). If a restoration project seeks to copy the reference state of an ecosystem prior to human meddling, then, on Lo's account, it copies something that does not possess any human intentionality. The template is essentially natural.

Katz rejects the notion that humans can seemingly copy a naturally occurring state without imposing design. He states:

> When restorationists attempt to make a copy of an original *reference state*, they need to have a design, a plan, to accomplish the restoration project. Even if the goal is a copy of a naturally occurring entity or system that was not designed, the copy itself must be designed or planned. Are the actions of ecological restorationists simply random and unplanned? No: they work according to a design. Restoration projects are intentionally planned human activities that follow a design in order to reach a goal, the production of a specific entity or system. This product is an artifact (Katz 2012, p. 80).

Even though the template might be derived from nature, choosing a specific template to implement resides with the restorationist's own intention. In such a world, nature turns into a garden where different patches have distinct functions they are intended to fulfill. Gardens are not natural, they are artifacts.

Although Lo's suggestion of circumventing anthropocentric tendencies by insisting upon reference states to guide human interventions seems reasonable, it clearly neglects something fundamental about nature that I do not believe Katz fully appreciates either – natural systems are connected to one another through space and time. Trying to reconstruct an ecosystem from hundreds of years ago in a site may harm the redundant surrounding ecosystems. Despite the fact that the world is indeed a patchwork of systems operating over multiple spatial and temporal scales, proximal systems have evolved together and, as a result, interact with one another in a way that a transplanted ecosystem could not. The result could be costly, like trying to extensively repair an engine using replacement parts from a completely different car manufacturer. I do not doubt that Lo would expect limits to be placed on which reference states could be implemented. But the fact that she does not outline any guidelines is somewhat problematic from both a practical perspective, in that it could lead to negative ecological consequences for the region, and an ethical one, insofar as nature's autonomy to organize itself across multiple levels of scale simultaneously and seamlessly is impeded.

The Lo-Katz exchange raises another important practical issue that Katz does not seem to fully appreciate: can a restorationist have knowledge of the template produced by nature? It seems like a 21st century Platonic Forms problem. Restorationists must work within epistemological limitations (i.e., inaccessibility to the complete dynamics of a system) that do not apply to nature. From a practical perspective, copiers must take interpretive freedoms simply because they cannot know all the details of the thing being copied: the more dynamic the thing being copied, the more unlike the original the imitation is likely to be. This is central to my overall argument. Closer inspection is needed of the explanatory frameworks used to develop practices because each displays some metaphysical bias. In sections two and three, I attempt to show this by investigating the two concepts – emergence and openness – used to inform restoration practices and how they diverge from one another despite being used to explain the same thing, resilience.

A second set of criticisms against Katz's baseline view and his response to them further elucidate why restoration is not as simple as returning a system to a previous state. Steven Vogel argues that the intentionality of a builder does not dictate how an artifact gets used. He gives the example of someone picking up a stick from the ground to use as a weapon. It is not as if the tree produced a stick with the explicit intention of creating a weapon (2003, p. 155). The idea is that restoration projects can avoid imposing a strict design on nature by implementing a loose schema to jumpstart the regeneration of natural processes. Ultimately, Vogel posits something similar to Lo, stating "the idea is that humans might intentionally produce a situation that is *out of human control,* beyond our ability to plan or to predict, and perhaps one that bears a close resemblance to the situation that existed before we set foot in the area" (2003, p. 157, emphasis in the original).

To make his point, Vogel (2003, pp. 158-159) uses the example of children, which was originally introduced by Katz (1993), to demonstrate how intentionality is a necessary condition in producing an artifact but not a sufficient one. Parents intend to produce a child; however, part of the joy of being a parent is seeing the child grow as an autonomous individual who maneuvers through life on her own. Something similar can be said of restoration. A restorationist can try to install different elements that allow the system to restore itself and control its own trajectory. Thus, Vogel argues, restoration does not necessarily end in an artifact as Katz contends. He uses another example that Katz (1992) cited in his initial critique, Steve Packard's restoration of the oak-savannah plains of the American mid-west, to drive home the point. In an effort to revert the prairie back to a condition prior to the arrival of white European settlers, Packard planted seeds of previously endemic species and cleared out various brush that stood to inhibit growth. The idea was to somewhat reset the conditions, reintroduce the previous species, and let the dominant processes take over again thereby allowing nature the final say as to what occupied the various sites. If the community, then, ends up diverging, that reflects an autonomous trajectory authored by nature.

Katz responds to Vogel's criticism by questioning the merit of the analogy, saying that it is "at the very least, disingenuous, and more likely, flat out incorrect" (Katz 2012, p. 82). Packard's restoration project was designed with the specific intent of re-creating the oak-savannah system that existed prior to the arrival of white European settlers. Many different ecosystems have existed in the American mid-west over many millennia, so why is that specific one chosen? Attempting to redress the harms of Western colonialism, Packard, not nature, is the entity that made the decision. In Katz's opinion, this is contrary to how morally upstanding parents act towards their children. Of course, parents may desire that their children achieve general goals (e.g., happiness, health, productivity), but expecting a child to grow up to achieve specific goals, like becoming a professional athlete or famous musician, reflects "dysfunctional" parenting (2012, p. 83). Katz identifies restoration with the dysfunctional style of parenting because, as he points out, most projects have a specific goal in mind (i.e., a target system), just as the oak-savannah system of precolonial times was Packard's. Thus, Katz concludes: "The idea that in either case we are designing and creating a self-directing entity free of external control is simply incorrect" (ibid.).

I think Katz's intuition is appropriate because even if Packard's dream of perfectly re-creating the pre-colonial oak-savannah system came true and then the ecosystem reverted back to its post-colonial, present state, I imagine the response would be that something went wrong during the initial stages of restoration so the whole project needs to start over. Successful restoration seems to be predicated on achieving the expected outcome; indeed, oftentimes when the expected outcome is not achieved, the project is labeled a failure. As Katz points out those sorts of value claims are a human product. Nature does not “fail” when humans narrow their interference: nature simply enacts its autonomy.

I agree with Katz’s response to Vogel’s remarks here. If a restoration practice is designed to keep a system in some desirable state, then it reflects the kind of “domination over nature” mentality that is at the heart of Katz’s critique. But, to be clear, Katz is not stating that something like Packard’s restoration project is immoral or that it harms nature. Again, Katz is not alleging that an anthropocentrically motivated practice or policy cannot benefit nature. The purpose of his somewhat hyperbolic rejection of contemporary approaches to restoration is to demonstrate how difficult it is to shake the yoke of that “domination over nature” mentality when intervening in natural systems.

Up to this point, the discussion has been restricted to restoration projects. In another article, Katz (2015) expands his ethical critique beyond restoration projects to include ones carried out on a global scale as part of geoengineering projects to address climate change. Before moving into the next section to look at how the structure of tipping point explanations influences the framing of restoration practices, it is worth looking at this version of Katz’s account.

Katz (2015, 2020) argues that geoengineering produces an artifact in the same way that ecological restoration does. Implementing strategies such as solar radiation management,[3] his primary target in the essay, is an active attempt to modify natural processes in order to produce a desired system state. In this way, geoengineering exemplifies anthropocentric motivations that are characteristic of ecological restoration. In particular, Katz takes issue with the scale of human intervention and the desire to manage the entire planet. He concludes:

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[3] Solar radiation management involves increasing the reflectivity of the atmosphere by injecting particles like aerosol sulfates into the atmosphere to mimic the effects of large volcanic eruptions to reduce solar radiation (Katz 2015, p. 487).

> Ecological holists such as myself are not against intervention into natural processes. Ecological holists are not eco-fascists willing to let humans die for the sake of a pure natural environment. There is nothing wrong with intentional human activity to correct the problems we encounter in nature – given the proper scale and the appropriate conditions of the problem (Katz 2015, p. 496).

Katz's argument is that geoengineering, like ecological restoration, attempts to control what systems are present and how they function at higher and higher scales. At some point, every natural system will likely fall under human management if this mentality is allowed to continue. No scale level could be larger than the climate system of the entire biosphere, and, from the perspective of complex systems theory, the systems characteristic of the biosphere function as the context for the systems nested underneath it. Controlling the systems at the highest level allows for greater control of the systems that depend on them. Thus, geoengineering represents a way to exercise domination over nature and to avoid remedying the practices that cause environmental problems in the first place. As is the case with carbon offset programs, cloud brightening or pumping the atmosphere with aerosols are ways to carry on with business as usual. Again, this seems to indicate that what is prompting these practices is the maintenance of long-term human interests (i.e., access to resources). Although this is not necessarily a moral wrong, it is certainly not ecocentrism, and it might not be as controllable as humans may like to believe.

To avoid this exploitative and arrogant mentality, Katz advocates for a more localized approach to environmental interventions. In section three of this chapter I will advocate the same by arguing that the adaptive cycle heuristic functions as an explanatory framework that restoration practices can utilize in a site-specific way so as to facilitate recovery that allows natural systems to determine their own evolutionary development – the basis for an ecocentric environmental ethics on my account.

On reflection, I find Katz's critique of ecological restoration and geoengineering to be powerful but not necessarily persuasive on its own. Katz seems primarily worried about living on an artificial planet where nature no longer has any meaning. Some may be unmoved by this argument and think that whether the planet is natural or artificial makes no difference. For, at this point in history, humanity has little time for a lesson in semantics: humanity should be more concerned about the health and longevity of natural systems persisting into the future than with ecotourists exclaiming, "This isn't *real* nature!" As Soper states: "it is not language that has a hole in its ozone layer" (1995, p. 151). But I also believe that Katz's criticism harbors a more elaborate and revealing point that goes beyond a simple semantic game. Katz thinks so, too. "In short, it is how we use the distinction between humanity and nature – a distinction that our language and conceptual frameworks of the world will not permit us to ignore – that will determine appropriate environmental policies" (Katz 2012, p. 95). I agree with this point and will emphasize the "conceptual framework" aspect of his statement moving forward.

In the wake of scientific advancement, humanity has seemingly assumed the role of chief artificer without much critical reflection as to whether it possesses the necessary capacity and wisdom for the role. Is humanity qualified to make these decisions? In some respects, sure, which is why it can be reasonably asserted that humans have some responsibility to nature, but, by and large, no. As the title of William Wimsatt's (2007) book suggests, *Re-Engineering Philosophy for Limited Beings: Piecewise Approximations to Reality*, humanity navigates the natural world with an incomplete map that smooths over a considerable amount of consequential complexity. Overstepping bounds, asserting domination when humanity clearly does not have a firm grasp on the reins, can compound problems just as overcorrecting a skidding car on an icy road leads to even less control and a more violent crash. That overstep, I argue (*sensu* Katz), is inadvisable. The task now is locating the source, which, I believe, is the conceptual framework from which these practices and policies originate.

The general point of this chapter is to demonstrate how restoration practices are mediated through explanatory frameworks and how each explanatory framework shapes the ethical landscape of the restoration practices it informs. I do not argue that some explanatory frameworks are ethical while others are not. Specifically, I intend to show that the principle of emergence falls victim, when used to articulate restoration goals, to Katz's critique whereas an ontogenetic approach that relates the principles of openness and emergence to one another avoids the distinct kind of "domination over nature" mentality that Katz refers to as "the fundamental error" (1992, p. 240).

The Ethics Inherent to Tipping Point Explanations:

In this section, I plan to analyze how the dependence upon tipping points to promote management practices and policies can lead to the kind of "domination over nature mentality" that Katz critiques. I begin by summarizing the concepts central to tipping point explanations introduced in chapter three (i.e., hysteresis and regime shifts). Then, I explain how tipping point explanations emphasize keeping systems fixed to a particular state preferred by humans. Finally, I discuss how tipping point explanations not only embody the "domination over nature" mentality but also reflect the hubristic notion that humans have access to and can successfully implement a template designed by nature. To demonstrate this latter point, I once again discuss how tipping point explanations fail to capture all the details that spatial resilience theorists have discovered are important to a system's functional integrity and recovery.

As discussed in chapter three, the foundation for the tipping point concept loosely formed in the ecological and mathematical literature during 1960s and 1970s,[4] including the field of catastrophe theory (Zeeman 1976). The tipping point concept and its ties to catastrophe theory are apparent in ecology today through the work of theorists like Martin Scheffer (2009) and his fellow collaborators (Scheffer et al. 2001; Scheffer and Carpenter 2001; van Nes and Scheffer 2005; Scheffer and van Nes 2007; Rockström et al. 2009; Scheffer et al. 2009; Dakos et al. 2011; Scheffer et al. 2012; Hughes et al. 2013; van de Leemput et al. 2015; van Nes et al. 2016; Dakos et al. 2019). Natural systems of all kinds are collections of complex processes defined by their self-organizing feedbacks. Instead of demonstrating simple cause-and-effect relationships, these systems are often nonlinear. At the most extreme (Fig. 4.1), non-linearity means that a given system can exist in the same state despite different environmental conditions. It also means that two systems can be subject to similar environmental conditions yet exist in qualitatively dissimilar stability states.[5]

In catastrophe theory, the term “hysteresis” is used to summarize this extreme in non-linearity that can develop in systems. Hysteresis applies to a type of catastrophic fold that systems exhibit when the complex processes comprising them present the possibility for two distinct stability states under similar environmental conditions. As long as the environmental conditions remain within a certain range, the system stays qualitatively the same. But once the environmental conditions are pushed beyond that range, a threshold is crossed, and the system abruptly changes to the alternative state.

The critical values at which the system abruptly shifts are referred to as “tipping points.” The system is vulnerable, and even the slightest disturbance can

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[4] Three papers mark the beginning of the resilience theory tipping point concept (Lewontin 1969; Holling 1973; May 1977).

[5] I follow Scheffer’s (2009) lead in using “stability states” since it is common practice in the literature even though it is somewhat misleading because complex systems are dynamic.

cause it to move to one stability state or the other (Scheffer et al. 2001; Lenton 2013; van Nes et al. 2016; Dakos et al. 2019). Tipping points and corresponding regime shifts are found throughout nature (cf. Scheffer et al. 2001; Folke et al. 2004). Although systems exhibiting extreme hysteresis may have abrupt transitions upon tipping, non-hysteric systems can also tip albeit less suddenly and with a great potential for recovering the initial state.

For hysteretic systems, it can be insufficient simply to return environmental conditions to how they were at the moment the regime shift occurred in order to induce a system to switch back to its previous state. Instead, the environmental conditions must be pushed even further in the return direction before the system will abruptly switch back. In short, once a system undergoes a regime shift, it becomes increasingly impossible to undo it without careful planning and an immense effort.

Tipping point explanations began with local and regional phenomena but have now been expanded to the entire biosphere. Concerns have been expressed that the rapid loss of the biodiversity that supports ecosystem integrity, fluctuations in nutrient and energy cycling, changes to atmospheric and oceanic chemistry, and pollution on a global scale might soon push the entire planet across some critical threshold in which a set of feedbacks that support life will dramatically alter (Lenton et al. 2008; Rockström et al. 2009; Barnosky et al. 2012; Hughes, Carpenter et al. 2013; Lenton 2013; Mace et al. 2014). Rockström et al. (2009) identified nine such planetary boundaries associated with the potential for widespread catastrophe. Along with identifying the nine different planetary boundaries, they propose values for each that are intended to guide management practices to ensure the evasion of tipping points.

Tipping point explanations essentially set the stage for something like Lo’s defense of practices by appeal to reference states. Hysteresis implies two distinct qualitative states. If the system of interest exists in the upper bound, it is one kind of system, but if it is in the lower one, it is another. Humans assign value to both types of system – in terms of human interests, no less. Once a target state is identified, along with the relevant internal processes and external parameters, the goal is to keep the system from approaching the critical value. Two of Katz's criticisms seem applicable to this sort of approach.

First, humans are obviously the ones assigning value to these systems, not nature. Deserts are naturally occurring biomes that emerge from the autonomy of nature. The transition of a forested system to a dry woody shrub-dominated system is "bad" only in the sense that humans cannot exploit drylands for valuable resources. So, as previously demonstrated with Katz's response to Lo, anthropocentrism still operates heavily within these practices even though humans are working with and for natural processes. The fact that humans favor one set of processes over another is where anthropocentrism reveals itself. It might be asked, however, whether this is an undesirable result. Humans win. The most productive version of nature wins.

This leads to the second of Katz's criticisms, which demonstrates why the narrow sense of anthropocentrism that Lo has in mind with her reference state approach does not necessarily lead to such a satisfying resolution. Tipping point explanations make it possible to act in any way toward nature so long as the tipping point is avoided. It reaffirms the "technological fix" attitude underscoring the "domination over nature" mentality that suggests humans do not need to change their behavior because humans will always have some solution for any danger that looms on the horizon. Cloud brightening and pumping sulphate aerosols into the atmosphere to regulate the planet's temperature, the two practices Katz criticizes, do not demonstrate a respect for nature's autonomy. Instead, they seem like ways to promote both current and future human interests. A consequentialist might take no issue with this since it is not like the many organisms that benefit from humanity reining in carbon emissions will ever become aware of humanity’s intentions. Similarly, given the severity of the current climate crisis, most people would be happy to see positive steps towards remediation regardless of the justification for them. I accept all of this, and I believe Katz does, too. However, tipping point explanations reinforce the attitude of control and domination over nature in the practices they inform. Although the potential results are appealing, significant risks are inveterate to this mentality that, if allowed to operate unchecked, threaten all stakeholders involved, human and non-human alike. Short-term success belies long-term failure. Industrial agricultural provides a clear warning that mechanisms of control (e.g., pesticides, fertilizers, monocultures) may be highly productive for a brief period of time but are unsustainable in the long run, leaving behind ecological and environmental destruction as well as unmet social needs in the form of diminished food production (Thompson 2010).

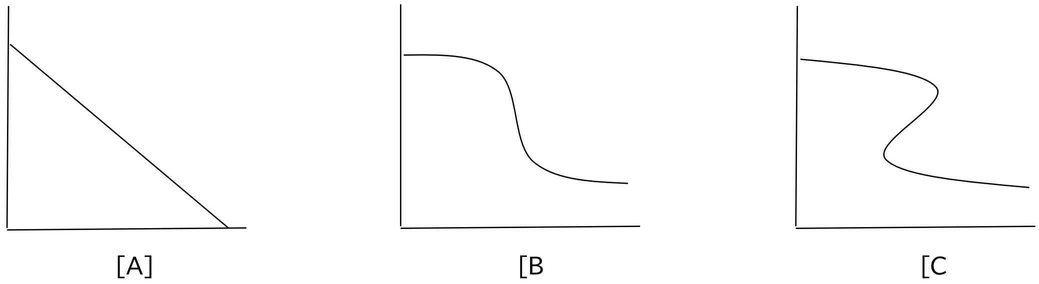

Figure 4.1. The three kinds of responses systems have with respect to changing conditions. [A] reflects a smooth transition. [B] demonstrates a sharp transition at a certain critical value. [C] shows hysteresis (adapted from Scheffer and Carpenter 2003) (cf. Scheffer et al. 2001; Scheffer et al. 2009; Lenton 2013). Although systems can exhibit any one of these responses, hysteretic ones are the chief concern because they are the most surprising, the most challenging to manage, and, typically, the most devastating.

A fundamental problem with tipping point explanations is that they rely on a knowable, stable state of nature. If nature's details are known and stable, an ecocentrism similar to Leopold's land ethic would apply without fail. Unfortunately, nature is very challenging to know in detail and instability is more the rule than the exception (Botkin 1990). However, it is this instability that generates the potential for adaptation and evolution. A plausible ecocentrism needs to be able to acknowledge both stability and instability as essential to nature acting autonomously (Hettinger and Throop 1999). Relatedly, stable efficiency is only one aspect of system integrity and is unable to address environmental problems on its own. As discussed in chapter two, the more rigidly stable a system becomes the more prone it is to abrupt collapse (Ulanowicz 2009). When technological know-how fails, when natural complexity overwhelms humanity's epistemological limitations and the fragile systems humans attempt to control crumble, there better be greater investment in the mechanisms that support quick recovery to escape irreparable catastrophe. Unfortunately, the "domination over nature" mentality rarely puts much thought into these mechanisms. The possibility for unpredictable, abrupt catastrophe means that the "domination over nature" mentality not only raises questions about whether ecocentrism or anthropocentrism should guide practices, but is something that puts all stakeholders at risk, humans and non-humans alike.

Environmental practices and policies that demonstrate how interrupting nature's autonomy to self-organizing and self-regulating is dysfunctional in an inadvisable way, also appear hubristic in how they negate the role of openness, particularly as the popularity of tipping points grows. Tipping point explanations seem to break down as the scale level gets larger. In the following paragraphs, I discuss two examples to illustrate this point, shallow lake systems and coral reef systems. Demonstrating the limitations and shortcomings of tipping point explanations in generating practices and policies, I argue, reveals that the conception of emergence commonly invoked cannot, on its own, form the basis of a functioning environmental ethics, ecocentric or not.

Ecologists have documented how shallow lakes can transition between clear and turbid states using tipping point explanations (Carpenter and Cottingham 1997; Scheffer and Carpenter 2003; Scheffer and van Nes 2007). For a clear lake, nutrient loading from nearby runoff can cause phytoplankton growth to accelerate. If the phytoplankton growth rate cannot be curtailed by the herbivorous organisms within the shallow lake ecosystem, the phytoplankton increase the turbidity of the water as their concentration goes up. The result is that the benthic macrophytes binding the soil on the base of the lake do not receive sufficient sunlight and die, thereby mobilizing sediment and increasing turbidity. The resulting positive feedback of complex processes establishes the new stability state. These eutrophic, turbid lake states have been reversed to clear ones by either removing fish that eat the herbivorous organisms (e.g., zooplankton) that themselves suppress phytoplankton growth (Scheffer 2009) or introducing piscivorous fish (e.g., bass) that consume the fish that consume the herbivorous organisms (Batt et al. 2013). Other approaches to restore turbid lakes to clear manipulate other features of positive feedbacks. Removal of pollutant sources and increased water clarity allow benthic vegetation to establish and stabilize sediments. In effect, lake managers who do either are altering the complex processes principally responsible for emergent self-organization (Fig. 4.2).

Figure 4.2. Depiction of a clear state [A] and a turbid one [B] in lakes. [A] has a greater density of benthic macrophytes compared to phytoplankton and fish that feed on zooplankton. [B] the opposite conditions hold.

Shallow lakes are somewhat easier to manage compared to most other systems because they are, for the most part, closed. However, a wider survey of lake states reveals that they do not so neatly track the emergentist perspective of the two-state outcomes of constitutive positive feedbacks (Scheffer 2009). As managers and restorationists apply this emergentist two-state model of lakes at greater extents instead of a single local lake – an obvious blind spot appears: the accounting for the role of openness in constraining tipping point transitions in lake states. Most natural systems like lakes are not completely closed, which complicates the emergentist picture of system dynamics. In a two-state hysteresis system, the y-axis concerns the internal dynamics of a self-organizing system, and the x-axis concerns the environmental conditions acting on the systems. Nowhere within the explanatory framework is there an adequate description of the spatial properties and characteristics of these internal dynamics and external conditions. Tipping point models and predictions often lack geographical context. Open-system dynamics, in the form of environmental heterogeneities, resource inputs, and mobile links, challenge management efforts that follow the emergentist approach too closely.

Of the kinds of open systems that tend to exist in one of multiple possible stable states, coral reef has also received considerable attention in the spatial resilience literature. Knowlton (1992) identified four potential ecosystem drivers of multiple stable states in coral reef systems. She noted that each arises from some combination of single species interactions, competition, and predation. Taken together, they correspond to the complex processes of a system that produces a self-organizing pattern with the potential for hysteresis (Hughes 1994; Hughes et al. 2010). Changes to the complex processes have the potential to induce a regime change. The degradation of Caribbean coral reefs within the last half century offers a clear example of this.

Beginning in the 1960s, chronic overfishing weakened the functional integrity of Caribbean coral reef systems by reducing the number of herbivores that consume the fleshy algae that curtail coral recruitment. This resulted in an uptick of sea urchin (*Diadema*) populations that also feed on the algae. In 1980, Hurricane Allen caused extensive damage to the coral reefs. Despite the damage, algal blooms were ephemeral in the months following, and the coral reef systems soon recovered. The recovery belied waning resilience, though. Between 1982 and 1984, a pathogen devastated the *Diadema antillarum* population across a significant portion of the Caribbean's geographical area. Without sufficient herbivores, due to overfishing and sea urchin mortality, the coral-dominated system transitioned into an algal-dominated one. Reversing this regime shift and managing these systems has since proved difficult (Hughes 1994; Hughes et al. 2010).

Viewing the entire Caribbean coral reef systems in terms of a tipping point explanation makes restoration practices seem futile. How are self-organizing systems going to be rehabilitated when most of the elements responsible for resilience have either been lost or significantly altered? However, when viewed from a local perspective, another element, related to openness, comes into focus: spatial connectivity. It is not as if the entire Caribbean now exists in an algae-dominated state. Some isolated patches have remained in coral-dominated states. And the connectivity between coral-dominated sites and algae-dominated ones is important for reversing the regime shift since it facilitates the movement of resources and mobile links that increase resilience.

In coral reefs, prevailing currents affect recruitment rate between sites. Coral larvae are poor swimmers, so much so that their probability of reaching a coral reef formation depends almost entirely on prevailing currents transporting them from one location to the next. Fish and other herbivorous organisms like sea urchins function as mobile links and provide external ecological memory by transporting limiting nutrients and suppressing algae growth through grazing activities (Nyström and Folke 2001). Thus, a spatial resilience strategy might actively seek to facilitate the movement of mobile links connecting individual sites that dampen the potential for catastrophic flip.

Spatial connectivity is somewhat of a double-edged sword, though (Simberloff and Cox 1987; Simberloff et al. 1992; Haddad et al. 2014). On the one hand, high connectivity ensures that resources and mobile links can initiate a quick recovery after a disturbance. On the other hand, high connectivity can cause harm to systems by increasing the transmission rate of diseases or invasive species (cf. van Nes and Scheffer 2005), which is especially true in coral reef systems (Elmhirst, Connolly, and Hughes 2009). Of course, low connectivity has the opposite effects on systems. What matters most is that spatial connectivity is an important element to system resilience that tipping point explanations cannot adequately account for. As such, management practices designed based solely on a tipping point explanation are incomplete. Emergentist focus on tipping may overlook the extant openness that may suppress such irreversible changes.

As with the coral reef systems of the Caribbean, the emergentist thinking that accompanies tipping point explanations oversimplifies planetary systems to such a degree that it seems impossible that management practices could successfully avert the catastrophes they are supposed to address. By ignoring the variability and openness that exist, it exaggerates the potential for tipping and the potential ways to offset it. A growing number of investigations have cast further doubt over the interpretation of resilience as simply a combination of internal dynamics and environmental conditions. Strong evidence suggests that spatial patterns impact the connectivity between sites, and the movement rates of ecologically important resources and mobile links, on a global scale to the degree that a system’s shift from one state to another can be slowed (Scheffer et al. 2009; Brock and Carpenter 2010; Dakos et al. 2011; Scheffer et al. 2012; Brook et al.

2013; Hughes, Linares et al. 2013; van de Leemput et al. 2015) or even avoided (Rietkerk et al. 2021).

Thus, not only are practices and policies emanating from tipping point explanations clouded by these metaphysical considerations, but they also instill a false sense of security for those that want to exploit nature to the brink of collapse. Just as Lo and others worry that someone might attempt to use Katz's criticisms against ecological restoration to justify inaction, I worry that someone might abuse tipping point explanations similarly. Single explanatory frameworks rarely suffice with regard to matters of complexity (Mitchell 2009). As Richard Levins states: "The truth is found at the intersection of many lies" (1966, p. 423) (cited in Scheffer and Carpenter 2003, p. 654). However, it is impossible to deny the popularity of the tipping point concept. As the climate crisis continues to receive ever greater media coverage, the term has become a buzzword for many. But, as the Caribbean coral reefs demonstrate, especially when they are generalized over large areas and too many sites, tipping point explanations have serious shortcomings. In the next section. I suggest a different guiding heuristic might be in order.

Emergence and Openness in Adaptive Cycles:

Adaptive cycles provide a heuristic to detail the progression a system goes through after encountering a disturbance. Although both adaptive cycles and tipping points owe their origin to branches of complex systems theory, adaptive cycles are associated with traditional resilience theory while tipping points are a product of catastrophe theory. While resilience theory does recognize dramatic changes of state, it also postulates a processual aspect encompassing emergent phenomena that depends on openness. The adaptive cycle model consists of four phases to which the strength of competing causal dynamics vary. Put together, the phases are supposed to explain the overall resilience of a given system.

Table 4.1 Summary showing how elements of Katz's criticisms connect with elements of tipping point explanations.

Katz's Criticisms	Tipping Points
Reference states (Katz 2012)	Distinguishes multiple stability states for a given system and set of environmental conditions
"Technological fix" (Katz 1992)	Practices can employ a targeted approach to augment individual parameters affecting feedback dynamics
"Domination over nature" (Katz 1992)	Keeping nature fixed in the stability state that best protects long-term human interests rather than allow nature's processes to develop on their own accord

Exploitation is the first phase of the forward loop of the adaptive cycle. It occurs as earlier colonizing species disperse to the disturbed site. During this time, open-system dynamics explain most organizational patterns. Colonization may or may not be successful because of the distance to source areas or stochastic processes that limit survival. Turnover is relatively high since ecological connectivity between inhabitants is low mostly because population sizes are still small. As population sizes grow and trophic interactions become more efficient, feedback loops driving self-organization surpass the open-system dynamics. Invasion by outside is less likely and turnover decreases. This marks the conservation phase, and the end of the forward loop. As the system within the site grows increasingly efficient it loses adaptability. A maximally efficient system is prone to collapse because even a minor change in the trophic flows connecting the different species can cause significant disruption to the whole organizational arrangement. At which point, the system moves abruptly into a release phase, thus initiating the backward loop. After the system collapses, much of the resources used to build the system are freed up. This reflects the reorganization phase, which sets the stage for another exploitation phase to begin the forward loop once again. Throughout the entirety of the backward loop, open-system dynamics account for the causal structure of any patterns that form.

A critical metaphysical feature of the adaptive cycle is that the principle of openness plays a significant role in all the phases leading up to the conservation phase. An input of some kind (e.g., invasive species, disease, excess nutrients) causes the breakdown of a system's feedbacks. After the collapse of the system, the generation of a new system relies heavily on inputs like mobile links and various pioneer species. Turnover is high because open-system dynamics are primarily responsible for the regulation of the organizational pattern. During the conservation phase, emergent self-organizing feedbacks become more powerful. However, the developmental trajectory towards rigid self-organization primes the system for its own demise. Greater network efficiency engenders greater system fragility because everything becomes so streamlined that one setback throws the timing of the whole system off. Management practices that prioritize these effects of openness in adaptive cycles over the potential internal feedbacks and emergentist outcomes related to whether a system will tip or not offer a more metaphysically robust and potentially more ecocentric environmental practices.

Adaptive cycles serve as the appropriate basis for an approach to promoting resilient systems grounded in principles of geography. Management practices already exist, rooted in metapopulation theory and island biogeography theory, that demonstrate the approach I envision. These theories begin with the obvious assumption that natural systems need spaces for their processes to unfold. The quality of a given space matters to these unfoldings since it affects the success of particular processes and may even alter which processes are dominant. This geographical approach to recovery and restoration emphasizes two principles, connectivity and isolation.

Connectivity means that spaces are accessible to one another. It increases the effective size of a site. The size of a site matters because large keystone species often have greater areal requirements. Larger average body mass and spatial range are often strongly correlated (Holling 1992; Allen, Forys, and Holling 1999). In turn, keystone species are important because they drive processes that other species within the ecosystem depend on. As a result, their loss can have a more profound effect on the overall resilience of an ecosystem from the disappearance of passenger species (Holling 1992; Walker 1992). On the other hand, some degree of isolation is equally important to ensure the maintenance of an ecosystem's functional integrity. Connectivity can produce negative effects, as evidenced earlier by the transmission of disease among sea urchin populations in the Caribbean coral reef systems. In effect, isolation functions as a kind of "primary regulation" (von Bertalanffy 1968; chapter two) that assists with emergence of feedback dynamics crucial to ecological resilience.

From a pragmatic standpoint, both connectivity and isolation can be actively managed. Whereas connectivity can be enhanced by the construction of wildlife corridors (cf. Foster and Humphrey 1995; Clevenger and Waitho 2000; McGuire et al. 2020),[6] isolation can be achieved by establishing multiple sites that are separated by greater distances.

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[6] It should be noted that the benefits of wildlife corridors are unanimously agreed upon for reasons similar to the ones illustrated by the Caribbean coral reef systems (cf. Simberloff and Cox 1987; Simberloff et al. 1992; Haddad et al. 2014).

Tipping point explanations aim to prevent system shifts whereas an adaptive cycle approach looks to facilitate system recovery. This characterization nears the position that Katz (2020) eventually arrives at. “Prevention” is concerned with fixity, “recovery” embraces dynamism. At the heart of any true ecocentric practice is an acceptance that natural systems do not strive towards stable endpoints but instead encompasses a never-terminating evolution to which disturbance and change are equally integral causal events. Natural systems constantly evolve from open-system dynamics to novel, and often surprising, emergent feedbacks, and back again. The cycle repeats but the result is never the exact same. Accepting that, I argue, is the basis for genuine ecocentric restorative practices.

Of course, the adaptive cycle heuristic might not completely capture the expectations of ecocentrism. It is possible to imagine the features of a site being manipulated to give some species an advantage, which would be anthropocentric on Katz’s loose interpretation. However, I believe that emphasizing space rather than the systems themselves is the key to a practical ecocentrism that affirms nature’s autonomy while at the same time encouraging humanity to operate within its epistemological limits. From a complex systems theory perspective (Ulanowicz 1990; 2009), system self-organization is the manifestation of nature’s autonomy, so any intentional manipulation of processes to change the internal dynamics of systems will violate nature’s autonomy. Space, on the other hand, is the setting where nature initiates self-organization. Thus, humans facilitate natural self-organization without dominating it by maximizing the variety of spaces that processes have to utilize. Still, additional points merit acknowledgement.

First, my use of the adaptive cycle heuristic to conceptualize management practices is simplified. The adaptive cycle heuristic is enmeshed with other adaptive cycles. They are nested within hierarchies referred to as “panarchies”

(Holling 1992; Allen, Forys, and Holling 1999; Holling, Gunderson, and Peterson 2002; Allen and Holling 2008; Allen et al. 2014; Sundstrom and Allen 2019). Panarchy theory emphasizes emergence over openness, just as do most other approaches in complex system theory (cf. chapter one). The panarchy concept aims to better understand cross-scale causal relations so as to develop more targeted approaches to management practices (Gunderson, Allen, Garmestani 2022); it succumbs to the charge of anthropocentrism that Katz brings against restoration and geoengineering since it involves humanity attempting to control natural systems by manipulating processes to yield desirable system states (cf. Holling and Meffe 1996). In response, I follow Katz (2020) in believing that most management practices (besides global emissions standards) should operate at a local scale rather than a global one. By operating on a local scale, humans return a greater degree of autonomy to nature because larger systems remain free to self-buffer or evolve on their own accord. In effect, this situation lessens the potential for abrupt collapse since the dynamism of nature at higher scales of a given panarchical arrangement is safeguarded.

Second, some might worry that a geographical approach to conceptualizing ecocentric restoration practices might encourage some agents to use its scientific basis to further their own interests at the expense of natural systems, just as is the case with tipping point explanations that in effect bless the exploitation of natural systems as long as doing so does not cause a threshold to be crossed. For example, proponents of the single large reserve in the SLOSS (single large or several small) debate, like Diamond and Terborgh (Diamond et al. 1976), worry that the mere fact that arguments in favor of several small reserves exist might provide ill-intentioned developers with potential justification to do what is easy rather than what is most likely to lead to the preservation of natural systems. The fear is that overseers of environmental practices and policies might seize on the SLOSS debate not because of the accuracy of its predictions but because it provides a way of quantifying what qualifies as “enough space” and thus a way to avoid responsibility if practices and policies fail: if the space turns out to be insufficient for the natural system, that signifies a failure on the scientists’ part, not the politician’s or corporation’s. Mitchell (2009) shares this worry. Unfortunately, I do not see how the geographical environmental ethics I propose can directly address this problem. At the same time, emphasizing dynamic recovery as opposed to fixity as well as the roles space and openness can play in it does not identify any immutable values. Setting quantitative thresholds often gives the impression that harmful actions can be performed towards nature as long as they remain within a certain margin. This mindset, I argue, is untenable as a guide to practices. Instead, management practices should pursue tactics that improve the probabilities of success for the ecosystems involved to progress through the stages of the adaptive cycle without much interruption. This requires a conscious utilization of geographical space.

Conclusion:

In this chapter, I have pursued a spatially-sensitive ecocentrism that can inform ecological management practices. I investigated the contributions that emergence and openness make to framing such practices and policies. I found that management practices based on tipping point explanations – a common conceptual tool employed for just these purposes – tend to aim towards keeping nature fixed in a single, desirable state. This situation evinces the “domination over nature” mentality that Katz identifies as broadly anthropocentric. I argued that natural systems adapt and evolve via open-system dynamics. If management practices are going to be ecocentric, as many environmental scientists and philosophers advocate, they need to emphasize such dynamics. To bridge practice with ethics, I suggested drawing on the adaptive cycle heuristic so as to pursue aims and measures that enable nature to be autonomous. This autonomy is effected by setting aside a variety of sites of varying degrees of connectivity and isolation so that natural systems have diverse ecological resources to follow their own recovery. This is why I refer to my approach as a “geographical environmental ethics.”

I have also argued that attention to geography serves as an appropriate starting point for ecocentrism. The importance of geographical context in promoting resilience has been confirmed by spatial resilience theory (Allen et al. 2016). Some critics of global tipping points have adopted this more site-specific approach. For example, Boettiger and Hastings (2015) argue that global tipping points probably do not exist and suggest that it is better to deal with real systems than with generic warning signs. Even those like Rocha, Peterson, and Biggs (2015) who do worry about a global tipping point, posit local and regional approaches to avoid cascading regime shifts. The cross-scale interconnectedness of natural systems (i.e., panarchies) makes it difficult to say definitively whether the terrestrial biosphere possesses tipping points. But as Lenton and Williams (2013) conclude, it is possible to recognize that the biosphere is in trouble without necessarily thinking on a global scale. Trends observed within global systems are alarming, and whether catastrophe is abrupt or smooth does not deter from the fact that something needs to be done.

Someone might object to my criticism of tipping point explanations on the grounds that ignoring potential tipping points, especially global ones, puts life at risk, human and non-human alike. Lenton et al. (2019), for example, regard the possibility of a global tipping point as a risk not worth taking. I agree. But the target of my criticism is not the possibility of a global tipping point but the mentality it can instill in management practices. Tipping point explanations look to identify thresholds that, if not surpassed, do not bring natural systems out of fixed states. Even if environmentalists who rely on such explanations seek outcomes that benefit nature, this does not change the fact that this approach is arrogant and problematically anthropocentric for suggesting that humanity can and should dominate nature. Tipping point explanations are certainly helpful for orienting practices and policies and making predictions. But a geographical perspective that prioritizes adaptation and evolution across space as well as time, versus one concerned with constraining emergent processes to ensure continued exploitation of natural resources, succeeds in respecting nature's autonomy.

Conclusion: The Primacy of Openness

The aim of this dissertation has been to show how the principle of openness functions within the larger causal histories that complex systems theory studies. In chapter one, I problematized how many complex systems theorists approach investigations of emergence. Typically, these investigations take the form of network analyses and topological depictions of internal system dynamics. Although I do not dispute the existence of such causal dynamics or the usefulness of explanations that utilize concepts rooted in the principle of emergence, I do find it problematic how other parts of the causal narrative are seemingly minimized or overlooked in the process. Complex systems theory is often portrayed as "the science of emergence" (Waldrop 1992; Kauffman 1995; Holland 1998; Morowitz 2002; Bedau 2008; Jensen 2023), to a certain extent, rightly given its commitment to antireductionism. However, conducting investigations informed by the principle of emergence alone seems unnecessarily restrictive and, in many cases, misleading. Complex systems theory is fundamentally a pluralist science, in the sense of Mitchell (2009), which means that it should resist dogmatism in its approach to scientific investigation. My dissertation has been an attempt to defend this pluralism by underlining the primacy of openness in causal, epistemological, and ethical dimensions of ecosystems. In the paragraphs that follow, I reiterate how exactly openness has primacy.

Most complex systems owe their origin to open-system dynamics, i.e., a relatively constant exchange between a set of loosely interconnected processes and the environment. Over time, open-system dynamics give way to stronger cybernetic feedbacks that strengthen the interconnectedness of the constitutive elements. For von Bertalanffy (1968), one of the chief tasks of complex systems theory, then called "general system theory," is to investigate this ontogenetic progression from an open steady state to a closed homeostatic state. He proposed that different sets of regulations operate with different strengths at different stages of a system's development. Primary regulations mediate open-system dynamics so as to effect equifinality, whereas secondary regulations identify feedback structures that maximize efficiency and control. Although the secondary regulations exert greater constraint on the parts constituting a system, thus portending greater emergence, von Bertalanffy (1968) argued that primary regulations play an important role in directing the contingent trajectory of the emergent properties and behaviors observed in fully developed systems. I find von Bertalanffy's argument persuasive, which is why I introduced it in the second chapter to frame the discussions to follow.

One shortcoming of von Bertalanffy's conceptual distinction between primary and secondary regulations is that it remains unclear how exactly primary regulations regulate. Being a biologist, von Bertalanffy (1968) took metabolic processes as a model of primary regulations. Metabolic processes lack a clear equivalent in ecology, however, due to the spatial scales involved. So, what features of ecosystems function as primary regulations, and how? In chapter two, I answer these questions by discussing the equilibrium theory of island biogeography (ETIB) posited by MacArthur and Wilson (1963; 1967). The ETIB is an open-system model that predicts an equilibrium number of species based on two parameters: area and degree of isolation. Both parameters refer to topographical variations, which, I argue, function as primary regulations by influencing the rate of incoming and outgoing species. The ETIB generated relatively accurate predictions when applied in the way intended (i.e., to guilds rather than whole communities). However, many subsequent refinements of the ETIB sought to remedy its inability to account for the development of strong ecological interactions (e.g., predation, symbiosis, parasitism, etc.) over time which affect the number of species present on an island (Sauer 1969; Wilson 1969; MacArthur 1972; Simberloff 1974; Diamond 1975; Lack 1976). Some have viewed this inability as a reason to reject the ETIB, but I argued that it is in fact evidence for the ontogenetic narrative described by von Bertalanffy. Instead of dismissing the ETIB, it can be utilized as a way to study the causal origins of systems and the effects of topographical variation (as primary regulation) on the contingent development of the complex interactions between species that characterize an ecosystem's internal dynamics (which function as secondary regulations). It is rather unreasonable to expect a single model to properly account for both causal principles. Employing the ETIB makes sense during early stages when open-system dynamics are strongest. During later stages, a different model will be more apt. In any event, if one asks why a particular island ecosystem exhibits the sorts of properties and behaviors it does, the topographical parameters studied by the ETIB seem like the appropriate place to start.

Chapter three continued the general discussion begun in chapter two that emphasizes the causal narrative describing an ecosystem's ontogenesis from open-system dynamics to self-organizing feedbacks by investigating the topic of resilience as it is discussed in more contemporary ecology. Conceptions of resilience form a theory of adaptive change that explains an ecosystem's persistence in a qualitatively distinct state despite encountering disturbances and exhibiting regular turnover in species (Holling, Gunderson, and Ludwig 2002). Analogous to my arguments the first chapter, the literature on ecological resilience often emphasizes emergent feedback as the principal causal mechanism effecting this persistence with little consideration given to other sorts of causal factors (Peterson, Allen, Holling 1998; Gunderson 2000; Peterson 2008; Scheffer 2009). However, recent developments in the spatialization of resilience theory have begun to emphasize how much such understandings of resilience turn out to be misleading. For example, the movements of mobile links across non-nested ecosystems, which require spatial contextualization to explain, play an important role in preventing localized regime changes (Lundberg and Moberg 2003; Folke et al. 2004; Allen et al. 2016; Cumming, Morrison, and Hughes 2017; Scheffer and van Nes 2018; Kéfi et al. 2019; Rietkerk et al. 2021).

Most notably, the ecological resilience literature provides an invaluable heuristic for explaining the shifting causal dynamics that an ecosystem exhibits: the adaptive cycle model. The adaptive cycle model defines four continuous stages through which ecosystems self-organize: exploitation, conservation, release, and reorganization. Open-system dynamics predominate throughout the cycle except during the progression from the exploitation to the conservation phase. Granted, this transition is often the longest of the four phase transitions and also the one in which ecological complexity is maximal. Nonetheless, the centrality of open-system dynamics in most of the complete cycle makes it effectively function as an important precursor to complex self-organization – without denying the importance of emergent feedbacks. The adaptive cycle model explains the ontogenetic trajectory of an ecosystem in a way that successfully combines the principles of openness and emergence, with openness marking nascency and emergence maturity.

The final chapter uses the adaptive cycle model to develop an ethics of ecological management that gives primacy to the principle of openness in making decisions about ecological interventions or management. In recent decades, ecological complexity theorists have stressed the existence of tipping points that, if surpassed, may lead to the collapse of natural systems humans depend upon. Some predictions posit global-scale tipping events with planetary impacts. As such, avoiding tipping points has become a primary way of justifying environmental practices and policies. Moreover, a widespread prescription for averting tipping point catastrophes has been manipulating the dynamics that control an ecosystem's internal feedbacks in response to changing environmental conditions, an approach rooted in the principle of emergence. I demonstrate how such an approach reflects what Katz (1992; 2012) condemns as the "domination over nature" mindset. In this mindset, humanity, instead of working to address unsustainable practices of overexploitation, relies on technological quick fixes that leverage emergentist ideals to shape ecosystems for the sake of human interests. I agree with Katz's condemnation of this anthropocentrism that hubristically envisions near total control over natural systems, or at least more control than is currently possible. As an alternative for addressing mounting environmental problems, adaptive cycle models provide guidance for ecological management that is more attuned to an ecocentrism that values nature's autonomy. When mechanisms responsible for open-system dynamics are prioritized in management practices, ecosystems are able to determine their own developmental path and ensure that adaptive cycles begin anew after disturbances. I argued that such an approach to environmental management is the appropriate philosophical framework to utilize in a world filled with complexity and with calls for geoengineering earth systems.

Thus, granting the principle of openness primacy in ecology has significant consequences when considering complex ecological matters related to causality, epistemology, and ethics. Given its place within the general ontogenetic history, openness seems like the correct principle to contextualize explanations. Focusing too intently on the principle of openness at the expense of emergence can lead to deficient explanations and irresponsible practices. Complex systems like ecosystems are highly contingent and historically constructed, which makes a universal program of investigative practices nearly impossible to implement. However, complex systems theory does offer a robust conceptual framework, chiefly guided by the principles of emergence and openness, that helps to navigate the complexities as they are discovered.

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