Ecological Modelling 278 (2014) 29–51

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Ecosystems emerging: 6. Differentiation

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ARTICLE INFO

Article history:
Received 6 June 2013
Received in revised form 6 January 2014
Accepted 7 January 2014
Available online 25 February 2014

Keywords:
Diversification
Differentiation
Eco-exergy
Ecological networks
Extreme environments
Utricularia–periphyton microecosystems

ABSTRACT

An unlimited variety of within- and across-scale constraints generated by self-organizing processes in ecosystems presents problems for life to solve. Solutions reached at all levels of the ecological hierarchy spawn further constraints in an endless spiral of ecosystem growth and development. Diversification, exposed to natural selection, produces differentiated function within organized wholes. This paper reviews such differentiation over the span of organizational levels from atoms and biochemical molecules to cells and their genetics, from organs and organisms to species and their phylogenetics, from populations and communities to their compositions as ecosystems, and thence to the cosmos itself. On Earth, life occurs in non-extreme and extreme environments, enabled by a biphasic *adaptive radiation* that drills into and fills available niche space. The first phase is *diversification*, which is the generation of variations. The second phase is selective *differentiation* that sculpts meaningful function from an endless stream of diversified, niche-filling possibilities. The paper asks, from the apparent universality of this diversification/differentiation pair, whether or not there is a force in Nature that drives the phenomenon. Diversification arises more in atomism and differentiation in holism, in a part/whole resolution between particulate and aggregate spheres of existence. Examples from Okefenokee Swamp and extreme environments exemplify the two-phase process—deep sea, intertidal zones, carnivorous plants in nitrogen-poor conditions, insects in winter, and creatures of deep caves and, perhaps, subglacial lakes. Diversification (Darwin's generation of variants) and differentiation (via natural selection, and other agencies) of Nature's living forms is a prerequisite for *Adaptation* (our next installment) and the ultimate expression of (our final chapter) systemic *Coherence*. Liberation through in-system interaction, bonding, and coupling—all antithetical to degrees of freedom—is the paradoxical result.

Prologue

> Ruby pointed to the red splashes of color on the green hillside of the ridge: sumac and dogwood already turning color in advance of other trees. Why would they do that near a month ahead? she said.
> —Chance? Ada said
> Ruby made a little sound like spitting a fleck of dirt or a gnat from the tip of her tongue. Her view was that people like to lay off anything they can't fathom as random. She saw it another way: Both sumac and dogwood were full of ripe berries at that time of year. The thing a person has to ask was, What else is happening that might bear on the subject? One thing was, birds moving. They were passing over all day long and all night too. You didn't have to look up to know that. Enough to make you dizzy at the numbers of them. Then think about standing on a high place like the jump-off rock and looking down at the trees as the birds see them. Then wonder at how green and alike the trees look. One very much resembling another, whether it offers a meal or not. That's all roving birds see. They don't know these woods. They don't know where a particular food tree might live. Ruby's conclusion was, dogwood and sumac maybe turn red to say *eat* to hungry stranger birds.
> Ada said, You seem to suppose that a dogwood might have a plan in this.
> —Well, maybe they do, Ruby said.
> She asked whether Ada had ever looked close up at the particular mess of various birds. Their droppings.
> —Hardly, Ada said.
> —Don't act so proud about it, Ruby said. In her view that's where the answer to this issue might lie. Every little dogwood can't grow up right where it falls under the big dogwood. Being rooted, they use the birds to move themselves around to more likely ground. Birds eat berries, and the seeds come through whole and unmarred, ready to grow where dropped, already dressed with manure. It was Ruby's opinion that if a person puzzled this out over time, she might also find a lesson somewhere in it, for much of creation worked by such method and to such ends.

. . .

> Ada stood still and let her eyes go unfocused, and as she did she became aware of the busy movements of myriad tiny creatures vibrating all through the massed flowers, down the stems and clear to the ground.

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0304-3800/$ – see front matter © 2014 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.ecolmodel.2014.01.001

> Insects flying, crawling, climbing, eating. Their accumulation of energy was a kind of luminous quiver of life that filled Ada's undirected vision right to the edges.
>
> Charles Frazier (1997), *Cold Mountain*
> Grove Press, New York

1. Introduction: why differentiation?

In the previous installment, *Constraints*, in this series on *Ecosystems Emerging* (Patten et al., 2011), we took these to be problems imposed on organisms in their natural selection scramble to endure or not, and contribute or not, to life in ecosystems. The ecosystems antedate them in having both composed, and been composed by, their ancestors. We showed diverse kinds of constraints—epistemic and ontic, explicit and implicit, obvious and subtle—generated by combinatorics no less than astronomical, that cause biota and biotic processes to vary enormously in space and time, at all scales of the ecological hierarchy, from biomolecules to the ecosphere. There is a growing conception in science that the biosphere, and its systems within this Petabyte Age of "big data" that we now inhabit (Anderson, 2008) are all "Too Big to Know" (Weinberger, 2011)—too complex for the human mind to ever begin to really comprehend or understand. Living organisms, as the model-making machines we previously discussed (Patten et al., 2011, figure 1), seems an apt way to engage a Nature that is beyond realistic knowing. The conceptions of CAHSystems (Complex Adaptive Hierarchical Systems; Patten et al., 2002a,b) seem here to stay as the powerful new tools of science begin to reconstruct a new, if halting (and in some aspects haunting), sense of ecological reality—and the ecosystems that compose it. The result of all the implied constraint-breaking activity is an enormous differentiation of form and function at *all* levels of the ecological hierarchy, wherever in the universe life or life-like processes exist. The constraints can be considered to be continuously changing challenges ecosystems have to meet to grow and develop (see *Growth*, Jørgensen et al., 2000). Nature has developed many different available solutions to meet these challenges. By our hypothesis, solutions that offer most growth and development (antientropic movement) on *all* levels of the ecological hierarchy will be favored in selection by ambient conditions. Differentiation reconciles diverse parts, so generated, to the whole.

Why do we say "differentiation" instead of, for example, "diversification?" In general, differentiation and diversification are both processes that make things more varied. They are two sides of evolutionary *adaptive radiation*. Darwin wrote about the generation of variants (species) and their subsequent natural selection. This kind of core concept of diversification contrasts with differentiation. It implies little about the selecting context—the environment, or ecosystem. Diversification devoid of the organization that is to receive it does not call attention to the functions or purposes to be served. This is one of the unintended legacies (witness the finches story) of original Darwinism to evolutionary biology, which is slowly evolving itself in directions to overcome it. Differentiation puts the context to diversification. It implies generation of variants, yes, but then their integration into the whole. The variants are diversified parts that fit the whole and contribute to making it a system; they are *differentiated* in terms of the whole, and fit in with respect to it. Moreover, we consider differentiation to apply to *all* levels of the ecological hierarchy that join together and achieve integration of system properties. The unknowable complexities of "too-big-to-know" existence are composed into this CAHSystems framework. Differentiation, rather than diversification, is the title for this paper because the ecosystem is a holistically organized unity as well as an individualistic collection of components seemingly unrelated to one another. In this frame of reference even organisms are ecosystems, particularly as perhaps thousands of inquilant species may inhabit and be functionally significant within any one of them. The inquilants not only differ genetically and functionally, but remnants of their genomes are often carried as junk genes within the primary genetic material, and they occupy specific bodily niches and perform specific bodily functions in respect to the whole.

By the term *differentiation* we want to emphasize, then, the "designed" or "co-designed" interplay (next paper: *Adaptation*) between the environment and the ecosystem, and the ecosystem and its organisms. The enormous variability of the environment in presenting its opportunities and constraints to ecosystem components as input forcing functions requires that the ecosystemic collectives meet this variability with an equally complex differentiation (Ashby, 1956—Law of Requisite Variety; previous paper, Patten et al., 2011: *Constraints*) to be able to grow, develop, and serve function sustaining the whole. By mechanical analogy, ecosystems and their environments may be likened to gear wheels working together for a long time that have become closely adjusted and fitted to each other. The teeth of the environmental gear wheel are the variability of opportunities and constraints; the teeth of the ecosystem gear wheel are the within- and across-scale differentiated properties of all the represented hierarchical levels. The gears perform smooth function as a result of the evolutionary self-designing processes operating over very long time, and the number of teeth (differentiated components and relationships) in the ecosystem gear wheel is astronomical. Due to the said interplay, the three growth forms of our earlier paper (Jørgensen et al., 2000—*Growth*) can continue and long-term ecosystem integrity, sustainability, and assured evolution (at the component level, coevolution) are realized.

This paper will selectively (and, we are sorry to say, perforce superficially) review examples of differentiation across the scales of ecological organization. Constraints are important in this, so Section 2 briefly reprises this theme from our previous paper (Patten et al., 2011). Then, Sections 3–14 examine how differentiation operates at twelve different scales of time, space, and organization. Atoms and inorganic molecules are pre-organismal (Section 3). Organic molecules (Section 4), genomes (Section 5), cells (Section 6), and organs and organ systems (Section 7) are sub-organismal. Treatment of organisms themselves (Section 8) is followed by three supra-organismal categories, substantially the domains of modern ecology—populations (Section 9), communities (Section 10), and ecosystems (Section 11). Phylogenetic differentiation (Section 12) extends the observations from these previous sections to life on very long time scales. Then, the main ideas are generalized to all living systems (Section 13), and the cosmos considered (Section 14). Section 15 focuses on extreme environments, where interactions between constraints and differentiation are particularly clear. Section 16 describes how selection provides solutions that offer most growth and development at all levels of the ecological hierarchy, and how differentiation is the outcome. Section 17 examines the possibility that differentiation is one of Nature's basic directional forces. Finally, Section 18 asks and answers our usual question: What would the world be like without differentiation?

2. The wide spectrum of constraints (redux)

All known life on Earth resides in the thin layer of ecosphere that envelops the globe. This region extends from sea level down about ten kilometers into the ocean depths and up approximately the same distance into the atmosphere. Its thinness is such that if an apple were enlarged to the size of the Earth the ecosphere would be thinner than the peel. Yet a vast and complex biodiversity arose and continues to operate within this thin-layer domain.