REVIEW PAPERS

Appropriate Measures for Retention Forestry

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Abstract

In this review I attempt to reveal the significance of life history and fractal organisation theory for retention forestry. The retention approach has emerged from the recognition that even intense natural disturbances leave biological legacies and spatial heterogeneity in the new forest which contrasts with the simple and homogeneous environment that is often the outcome of traditional harvesting practices. The review presents some insight into the understanding of a complex, self-organising dynamical system that supports organismal units being its branches and leaves in a tree, or a wide variety of flora and fauna in a forest. It seems that the formation of a scale-invariant structure of life cycle events may fit in the general terms of homeostasis, lifespan and fitness, so it could be argued that habitat quality and integrity of forest communities should be evaluated based on the assessment of organism-specific effects and responses in ecosystem functioning. Moreover, biological legacies defined as biologically created patterns that persist from the pre-disturbance ecosystem and influence recovery processes in the post-disturbance ecosystem should include organically derived measures of ecosystem integrity, such as habitat quality.
Keywords: life history, fractal organisation, retention forestry.

Introduction

Natural ecosystems are generally better able to absorb and recover from disturbance: the lower their exposure to humans the greater their area and continuity. An intact forest landscape is an unbroken expanse of natural ecosystems within the zone of continual forest extent, showing no signs of significant human activity, large and old enough that all native biodiversity, including viable populations of wide-ranging species, could be maintained (see Rose 1999, IFL 2015). “In the future, more emphasis should be given to the preservation of the last primeval forests in Europe and to the development of an appropriate instrument that integrates natural dynamics and its habitat features at the forest-landscape mosaic outside strictly protected forests” (Bollmann and Braunisch 2013). Retention forestry can achieve these aims through providing a certain continuity of forest composition, structure, and functioning (Gustafsson et al. 2012), so there is a need to develop new retention concepts. In this review I attempt to reveal the significance of life history and fractal organisation theory for retention forestry, which is “applicable to all forest biomes, complements conservation in reserves, and represents bottom-up conservation through forest manager involvement” (Gustafsson et al. 2012).

“Integration of key structural characteristics and old-growth attributes at the tree and stand level provides a general basis for biodiversity conservation in European forests” (Krumm et al. 2013). “Research in the past 20 years has shown that old-growth forests can serve as valuable references for the assessment of habitat quality and integrity of forest communities.” Large quantities of deadwood and a high density of old and hollow trees (so called “habitat trees”) are characteristic elements of intact forests (see Harmon et al. 1986). Nevertheless, for both deadwood and retained live trees long-term studies of their conservation efficiency and importance on the landscape scale are still lacking. For this reason, my review paper is focused on retention forestry in the context of ecosystem functioning. Generally, the purpose is to analyse intuitively a segment of a published body of knowledge through juxtaposition of related topics. In essence, the material used comprises literature on the various aspects of continuity of forest composition, structure, and functioning. An appropriate context for the reviewing is provided in the next chapter.

Perspective on the issue

Although the stability of a forest ecosystem depends to a large extent on the characteristics of the dominant species (such as lifespan, growth rate, or regeneration strategy), less abundant species also contribute to the long-term preservation of ecosystem functioning because of biotic cross-scale interactions (see Millennium Ecosystem Assessment 2005). Biotic cross-scale interactions with important consequences for forest ecosystem services include pollination; links between plants and soil communities, including mycorrhizal fungi and nitrogen-fixing microorganisms; links between plants and herbivores and seed dispersers. There are also interactions involving organisms that modify habitat conditions; and indirect interactions involving more than two species. For example, Simard (2009) has made the major discovery that trees really do communicate and interact with each other by means of mycorrhizal networks. The largest trees in forests that act as central hubs for vast below ground mycorrhizal networks support young trees or seedlings by infecting them with fungi and ferrying them the nutrients they need to grow. "Hub trees for mycorrhizal networks are ''foundational'' because they even out resource availability and create favourable local conditions for tree establishment, which is fundamental to structuring of the whole forest community" (Simard 2009). Unfortunately, the future looks challenging for the largest trees, and human-caused climate change along with selective felling seems to be a major factor (see McIntyre et al. 2015, for example).

"Trees are not a single habitat but dozens of habitats inhabited by thousands of different species" (Rose 2005). "Many of our rarest species are associated with ancient trees and only occur where there has been a continuous cover of old trees back through time on the site." Thus, "To maintain viable populations of all naturally occurring forest species in Europe, legacies of habitat structures and ecosystem functions in both natural forests and cultural landscapes need to be considered" (Angelstam et al. 2013). Developing management methods for maintenance of viable populations and important ecosystem processes requires an understanding of how the quality, size, juxtaposition and functional connectivity of the different forest vegetation elements affect species and ecosystem processes at the landscape scale (Angelstam and Kuuluvainen 2004). A critical requirement of many species is the maintenance of a relatively stable patch dynamics within the landscape (Angelstam et al. 2004). The patches or phases as Watt (1947) sometimes terms them, consist of aggregates of individuals and of species, and change dynamically often cycling in a progression of states (e.g. pioneer → building → mature → degenerate) (Stone and Ezrati 1996). The thing that persists unchanged is the process and manifestation in the sequence of phases. Patches of habitat have a definite shape and spatial configuration, and can be described compositionally by internal variables such as number of forest strata, number of trees, number of tree species, height of trees, or other similar measurements (Forman 1995). In the issue, we can think of forests as mosaics, containing a variety of patches in different phases of restoration. Each patch is dynamically related to other patches or phases. It should be noted, however, that reducing a continuous ecological surface to a patch mosaic, even if based on the best information available, eliminates information as a result of imprecision in boundary placement and class divisions, or because ecological variation is important across several scale ranges (McGarigal and Cushman 2005). Moreover, landscape analysis and delineation of habitat patches should take into account organism-specific behavioural and perceptual responses to landscape structure because different organisms perceive and respond to landscape features over different ranges of spatial scales (Girvetz and Greco 2007). "The commonly used methods for delineating habitat based on rules of contiguity do not account for organism-specific responses to landscape patch structure and have undesirable properties, such as being dependent on the scale of base map used for analysis." This calls for an integrated approach and clearly addresses scaling questions since the different levels of detail must be compatible to ensure a consistent modelling output.

"Scale" as the spatial, temporal, quantitative, or analytical dimensions, is used to measure and study any phenomenon, and "levels" as the units of analysis are located at different positions on a scale (Gibson et al. 2000). However, there is no scale for observing all phenomena. "Depending on the research objects, there are many different interpretations of the term 'scale'" (Sun and Southworth 2013). "For example, from a wildlife perspective, each organism scales the environment differently, and thus there is no absolute size for a landscape." Nevertheless, "scale" is a main concept in landscape ecology that focuses on the influence on the organisation of, and interaction among, functionally integrated multispecies ecosystems: associations, communities, and the like. Three distinctive but interrelated issues of scale have frequently been discussed in the literature: characteristic scales, scale effects and scaling (Wu and Li 2006). According to Wu and Li (2006), "Effective scale detection requires that the scale of analysis be commensurate with the intrinsic scale of the phenomenon under study. Because the latter is unknown *a priori*, multiple observation sets at different scales usually are necessary." Moreover, one of the major issues in ecology is the ability to take into account the multiplicity of scales of study so that each of the phenomena studied at their specific levels can be integrated during a phase called "scale transfer" (CIRAD 2014). Some successful methods have been developed to tackle the scale variation problem, where the scale independence property of fractals seems interesting for describing this phase in ecology. "The essence of fractals is the recognition that, for many phenomena, the amount of resolvable detail is a function of scale" (Turner et al. 2001). It is the scale of self-similarity called fractal dimension. "As a standardized value, fractal dimension can be used to describe the geometry and morphology of the target objects, and importantly, to do comparisons both over time and space, as well as to be useful in developing more global models and comparisons" (Sun and Southworth 2013).

Fractal-based models have been applied in analysing foraging behaviour of animals, animal movements, ecotone and interfaces, environmental transects, dispersal of organisms and disease, size-frequency distributions, landscapes, disturbance, habitat complexity and fragmentation, plant and fungal structures. For instance, a number of successful investigations have proposed that animals adopt fractal motions when searching for food, as the amount of space covered by fractal trajectories is bigger than for random trajectories, and a mid-range fractal dimension value appears to be optimal for covering terrain efficiently (Fairbanks and Taylor 2011). Kenkel and Irwin (1994) have hypothesized that the dispersal of diaspores and pathogens has fractal properties. They found that species producing diaspores adapted for long-distance dispersal (e.g. 'weeds') have a low fractal dimension. These species advance through the landscape in large leaps, continually establishing new colonies or epicentres (a 'guerilla' strategy). Conversely, species lacking adaptations for long-distance dispersal move through the landscape more conservatively (a 'phalanx' strategy), with only occasional 'forays' to establish new epicentres. These species have a higher fractal dimension, resulting in less patchy, more continuous spatial distributions. Krummel et al. (1987) have examined the fractal dimension of forest patches ('islands') using the perimeter-area method and found that smaller forest patches had lower mean D than larger ones. Zeide and Gresham (1991) have estimated the fractal dimension of the crown surface of loblolly pine (*Pinus taeda*) trees in North Carolina, and found evidence that D varies with site quality and thinning intensity. Osawa (1995) has determined that trees with higher crown fractal dimensions have less negative self-thinning exponents; it was hypothesized that species-specific changes in foliage packing over time account for this relationship. Bolton and Boddy (1993) have found that fractal dimension varies between fungal species, and tends to be greater when nutrient availability is higher.

Three major applications of concepts derived from fractal geometry to biological problems are identified by Fielding (1992): modelling of structures; investigation of theoretical problems; and the measurement of complexity. In forestry modelling, many recent spatially-explicit studies use fractal landscape-scale models as the arena for ecological processes in order to obtain a more realistic understanding of species distributions and diversity extinction thresholds, dispersal, competition and foraging (Halley et al. 2004). For instance, Palmer (1992) has modified the 'competition gradient' model of Czárán (1989) to include fractal habitat complexity. He found that species coexistence increased as landscape fractal dimension increased. What to the investigation of theoretical problems, Frontier (1987), for example, has discussed the ecological significance of contact zones (ecotonal boundaries) between ecosystems, and outlined how fractal organisation theory can be used to examine boundary phenomena. Finally, according to Yurth (1997), the records of the evolution of all natural, open, complex, self-organising systems are manifested as a function of fractal geometry. "Natural disturbances from fire and flood, wind and storm damage, to large falling trees are fractal disturbances to which diverse species become adapted in disseminating seed in an ever more complex arrangement of species diversity" (Fielder and King 2014).

General implications

Forestry in the broadest sense involves the science, art, and business of managing forests for human benefit (Seymour and Hunter 1999). "The earliest forms of forestry could be characterized as custodial (focusing on protecting the forest from overexploitation and fire), usually followed by sustained yield timber production (focusing on assuring a continuous supply of timber)."Recently, we have entered an era of ecological forestry, which depends on each of its three principles for management to fully succeed. These principles include (1) retention of biological legacies at harvest; (2) intermediate treatments that enhance stand heterogeneity; and (3) allowances for appropriate recovery periods between regeneration harvests (Franklin et al. 2007). Biological legacies are defined as the organisms, organic matter (including structures), and biologically created patterns that persist from the pre-disturbance ecosystem and influence recovery processes in the post-disturbance ecosystem (Franklin et al. 2000; Table 1). "The retention approach has emerged from the recognition that even intense natural disturbances leave biological legacies and spatial heterogeneity in the new forest, which contrasts with the simple and homogeneous environment that is often the outcome of traditional harvesting practices, particularly clear-cutting" (Gustafsson et al. 2012). The following five Montreal Process criteria for the conservation and sustainable management of temperate and boreal forests could serve as some guidance to the retention forestry: conservation of biological diversity, maintenance of productive capacity of forest ecosystems, maintenance of forest ecosystem health and vitality, conservation and maintenance of soil and water resources, and maintenance of forest contribution to global carbon cycles (Table 2). However, the core criterion of resilience is lacking among them. The definition of resilience (ecological r.) is given, for example, in the Third Edition of the Technical Notes on Implementation of the Montréal Process Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests (The Montréal Process 2009). It is the capacity of a community or ecosystem to maintain or regain the desired condition of diversity, integrity, and ecological processes following disturbance.

Forests play a large role in climate change through the sequestration or emission of carbon, albedo, evapotranspiration, and temperature – all of which influence forest disturbance regimes, successional dynamics and landscape structures. This has important consequences for how forests ought to be managed by protection, management and restoration to produce renewable resources, maintain biodiversity and forest health, and provide ecosystem services (Angelstam and Kuuluvainen 2004). Management regimes that integrate variable length treatment intervals and variable production of ecosystem services can accommodate the uncertainty associated with disturbance (O'Hara and Ramage 2013). Landscape-scale ecosystem management could retain forest successional dynamics across multio-

Table 1. Categories and examples of biological legacies

Legacy category	Examples	References cited
Organisms	Hub trees Sexually mature and intact live trees Tree reproduction (seedling and sapling banks) Vegetatively reproducing parts (e.g. roots) Seed banks Shrub, herb, bryophyte species Mature and immature animals and microbes	Simard 2009 Franklin et al. 2007 Franklin et al. 2007 Franklin et al. 2007 Franklin et al. 2007 Franklin et al. 2007 Franklin et al. 2007
Organic matter	Fine litter Particulate material	Franklin et al. 2007 Franklin et al. 2007
Organically derived structures	Tree-related habitats Standing dead trees Downed trees and other coarse woody debris Root wads and pits from uprooted trees	Rose 2005 Franklin et al. 2007 Franklin et al. 2007 Franklin et al. 2007
Organically derived patterns	Soil chemical, physical, microbial properties Forest understory composition and distribution	Franklin et al. 2007 Franklin et al. 2007
Organically derived measures of ecosystem integrity	Habitat quality based on the assessment of organism-specific effects and responses in ecosystem functioning, such as homeostasis, lifespan, and fitness	

Table 2. The Montreal Process criteria and indicators, which could serve as some guidance to the retention forestry at temperate and boreal forests (The Montréal Process 2009)

Criterion 1: Conservation of biological diversity

Ecosystem Diversity

1. Extent of area by forest type relative to total forest area.
2. Extent of area by forest type and by age class or successional stage..
3. Extent of area by forest type in protected area categories as defined by IUCNN or other classification systems.
4. Extent of areas by forest type in protected areas defined by age class or successional stage.
5. Fragmentation of forest types.

Species Diversity

6. The number of forest dependent species.
7. The status (rare, threatened, endangered, or extinct) of forest dependent species at risk of not maintaining viable breeding populations, as determined by legislation or scientific assessment.

Genetic Diversity

8. Number of forest dependent species that occupy a small portion of their former range.
9. Population levels of representative species from diverse habitats monitored across their range.

Criterion 2: Maintenance of productive capacity of forest ecosystems

10. Area of forest land and net area of forest land available for timber production.
11. Total growing stock of both merchantable and no merchantable tree species on forest land available for timber production.
12. The area and growing stock of plantations of native and exotic species.
13. Annual removal of wood products compared to the volume determined to be sustainable.
14. Annual removal of non-timber forest products (e.g. fur bearers, berries, mushrooms, game), compared to the level determined to be sustainable.

Criterion 3: Maintenance of forest ecosystem health and vitality

15. Area and percent of forest affected by processes or agents beyond the range of historic variation, e.g. by insects, disease, competition from exotic species, fire, storm, land clearance, permanent flooding, salinization, and domestic animals.
16. Area and percent of forest land subjected to levels of specific air pollutants (e.g. sulphates, nitrates, ozone) or ultra violet B that may cause negative impacts on the forest ecosystem.
17. Area and percent of forest land with diminished biological components indicative of changes in fundamental ecological processes (e.g. soil, nutrient cycling, seed dispersion, pollination) and/or ecological continuity.

Criterion 4: Conservation and maintenance of soil and water resources
18. Area and percent of forest land with significant soil erosion.
19. Area and percent of forest land managed primarily for protective functions, e.g. watersheds, flood protection, avalanche protection, riparian zones.
20. Percent of stream kilometres in forested catchments, in which stream flow and timing has significantly deviated from the historic range of variation.
21. Area and percent of forest land with significantly diminished soil organic matter and/or shifts in other soil chemical properties.
22. Area and percent of forest land with significant compaction or other change in soil physical properties resulting from human activities.
23. Percent of water bodies in forest areas (e.g. stream, in kilometres and/or lake, in hectares) with significant variation of biological diversity from the historic range of variability.
24. Percent of water bodies in forest areas (e.g. stream, in kilometres and/or lake, in hectares) with significant variation from the historic range of variability in pH, dissolved oxygen, levels of chemicals (electrical conductivity), sedimentation or temperature change.
25. Area and percent of forest land experiencing an accumulation of persistent toxic substances.

Criterion 5: Maintenance of forest contribution to global carbon cycle
26. Total forest ecosystem biomass and carbon pool, and if appropriate, by forest type, age class, and successional stages
27. Contribution of forest ecosystems to the total global carbon budget, including absorption and release of carbon.
28. Contribution of forest products to the global carbon budget.

wner landscapes by means of various long-rotation, thinning, and partial-cutting techniques, which would also maintain some old-growth attributes in most stands (Gray 2000). There is a limiting condition, nevertheless, i.e. developing management methods for maintenance of viable populations and important ecosystem services requires an understanding the principle of how the quality, size, juxtaposition and functional connectivity of the different forest vegetation elements affect species and ecosystem processes. “The presence of a species is not a guarantee for good habitat conditions; it might be a legacy of the time when its habitat was still available” (Lachat et al. 2013).

The range of environments or communities, over which a species occurs, can be defined only by reference to the organisms that inhabit them and cannot be held in an unchanging state (Whittaker et al. 1973, Franklin et al. 1986, Lewontin 2000, Tagliapietra and Sigovini 2010, Bollmann and Braunisch 2013, Kriebitzsch et al. 2013). “Organisms do not find a niche to inhabit; they dynamically create the relationships with the environment” (Weissman 2007). Locally, through so-called process of niche construction organisms virtually modify abiotic and biotic factors of natural selection and thereby insert feedback loop in evolutionary process (Kazansky 2010). Odling-Smee et al. (2003) define niche construction as follows: “Niche construction occurs when an organism modifies the feature-factor relationship between itself and its environment, either by physically perturbing factors at its current location in space and time, or by relocating to a different space-time address, thereby exposing itself to different factors.” Therefore, a niche refers to the way in which an organism fits into an ecological community or ecosystem; it is an ecological component of habitat which is delimited by functioning of an organism. For instance, Horn (1975) noted that although multilayered (leaf distribution) trees are able to grow faster than monolayered trees in the open environment of early succession the shaded understory limits the growth of the multilayered offspring. This geometric arrangement of leaves is just one feedback mechanism in functional groups of trees that fit under the general term homeostasis (literally, “steady state”). In this light, how do we should measure habitat quality for the relevant management unit, e.g. forest community? Fretwell and Lucas (1970), for example, have combined the concepts of habitat and fitness into the notion that a habitat confers fitness on its occupants (Johnson 2007). Wiens (1989) has considered this contribution to an organism’s fitness the habitat fitness potential, which provides the theoretical basis for habitat quality (Garshelis 2000, Railsback et al. 2003). Therefore, in essence, habitat quality should be evaluated based on the assessment of organism-specific effects and responses in ecosystem functioning, such as homeostasis (related to a state of equilibrium in the body with respect to various functions and to chemical composition of the fluids and tissues), lifespan (pertaining to the period of time an organism survives or is expected to survive or maintains or is expected to maintain a specific function), and fitness (related to the healthfulness of an organism).

“The organism is the central unit for integration of both of the major determinants of biological form and function–genes and the environment” (Kültz et al. 2013). An organism’s genes and its environment together determine its phenotype as a life cycle which unfolds dynamically over the whole lifespan of the individual which has its own unique record of life-history exposures and experiences (Bonner 1965, 1974, Kültz et al. 2013). Several aspects of life-history plasticity deserve attention because they influence the direction and the strength of individual–environment interactions, and are, consequently, likely to alter the ecological impact of life-history plasticity (see Miner et al. 2005). However, it is nevertheless true that “Life-history plasticity is conspicuous by its absence in genetically naive life-history theory, which predicts optimal strategies in different environments, and makes the unspoken assumption that natural selection will fix those genotypes yielding the appropriate strategy in the appropriate circumstances” (Caswell 1983). Life-history theory is a theory of biological evolution that seeks to explain aspects of organisms' anatomy and behaviour by reference to the way that their life histories – describing how organisms divide their efforts between reproductive effort, growth, age at reproductive maturity, longevity etc. – have been shaped by natural selection. In fact, all variables relevant to the life history of an organism must be included, and each must be independent of the others (see Hutchinson 1957), which is possible by use of fractal-based models. To sum up, in the context of life-history theory, fractality deserves special attention. After all, the genetic code is based on a fractal self-representation (Weissman 2007).

"Ecosystem perspectives are grounded in thermodynamics and focus on the dynamics of energy and materials through and around organisms" (Angermeier and Karr 1994). Healthy, fully functioning ecosystems provide the basis for sustaining communities, economies, cultures and the quality of human life. A basic research question is how to characterize the relationship between structural features of ecosystems (such as biodiversity or trophic linkages) and measures of functioning (De Leo and Levin 1997). "Ecosystem function" is a general term that includes stocks of materials (e.g. carbon, water, mineral, and nutrients) and rates of processes involving fluxes of energy and matter between trophic levels and the environment. Functional groups are collections of organisms based on morphological, physiological, behavioural, biochemical, environmental responses or on trophic criteria. They perform the same functions and, to some extent, may be substitutable and viewed as a unit (Schulze 1982, Solbrig 1994). Analyses of functional groups typically seek relationships among species in characteristics of ecological importance (e.g. species-by-life history characteristics; McCune and Grace 2002). Several experiments also incorporate a gradient of functional trait diversity into their designs by manipulating the number of *a priori* defined functional groups, in addition to the manipulation of taxonomic diversity (Scherer-Lorenzen et al. 2007). It must be noted, nevertheless, that collections of organisms with similar organism-specific effects on ecosystem functioning may not respond similarly to the changes in the environment. Conversely, collections of organisms responding similarly to such changes often vary in their effects on ecological processes (Hooper et al. 2002, Symstad et al. 2003). Thus, a significant challenge is to understand links among functional response and effect traits which may or may not be correlated with one another (Chapin et al. 1996, Lavorel and Garnier 2002, Hooper et al. 2005). Fortunately, fractal organisation theory could illuminate organism-specific effects and responses in ecosystem functioning. The rules for producing extremely complex, self-organizing dynamical systems, such as forests, can be extremely simple if they are fractallic, as in a fractal system, semi-autonomous agents interact according to certain rules of interaction, evolving to maximise some measure like fitness (see Fryer and Ruis 2004).

Conclusion

As forest and tree are related and a succession is occurring in both, the two will be interwoven in what must be a complex self-replicating pattern of life cycle events. It seems that the formation of a scale-invariant structure of life cycle events (defined as biologically created pattern) may fit under the general terms homeostasis, lifespan and fitness. This is because the lifespan pertains to the period of time an organism or a living system survives or is expected to survive or maintains or is expected to maintain a specific function. Fitness refers to the viability of an organism or to the complexity of a living system. Homeostasis is related to the range of tolerance within which a cell, animal, plant, community etc., can successfully maintain internal conditions with respect to various functions and to composition of the organismal units, regardless of external changes. Therefore, it could be argued that habitat quality and integrity of forest communities should be evaluated based on the assessment of organism-specific effects and responses in ecosystem functioning. Biological legacies defined as biologically created patterns that persist from the pre-disturbance ecosystem and influence recovery processes in the post-disturbance ecosystem should include organically derived measures of ecosystem integrity, such as habitat quality (see Table 1). It is well known that an evaluation of habitat quality is critical to any assessment of ecological integrity and should be performed at each site at the time of the biological sampling. By the way, fractal dimension can be useful here in developing the null or 'neutral' habitat models against which real patterns of environmental heterogeneity may be compared (see With and King 1997, Gardner 1999, Sun and Southworth 2013).

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