In: Ministry for Ecology and Natural Resources of Ukraine & Carpathian Biosphere Reserve (eds.) 2013. Primeval and ancient beech forests of Europe: problems of protection and sustainable use. Proceedings of the International Conference, Rakhiv, September 16-22, 2013. 66-76.

"Forest econics:" mimicking processes and patterns in old growth forest to promote sustainable forestry under global change

Hobson, P.R. [1,2]**, Ibisch, P.L.** [1,3]

[1] Centre for Econics and Ecosystem Management
[2] Writtle College, Chelmsford CM1 3RR, Essex, UK (peter.hobson@writtle.ac.uk)
[3] Faculty of Forest and Environment, Eberswalde University for Sustainable Development, Alfred-Moeller-Str. 1, 16225 Eberswalde, Germany

Keywords: old growth; ecosystem function; vegetation function traits; thermodynamics; forest econics

Abstract
Thermodynamic theory has been applied to ecological studies to help understand and describe the complexities of ecosystem function and resilience. Ecosystems are efficient when they exhibit optimum conditions in three principal functional characteristics; biomass; information; and networks. The synergistic properties of complex structures, higher biomass storages and greater functional diversity enhance energy dissipation and storage, which provides the system with resilience. Old growth forests are rich in these functional traits and express optimum thermodynamic tendencies in the form of cooler surface temperatures and greater attenuation of temperature. Forests subjected to human-induced disturbance undergo structural and compositional simplification and this reduces the ability of the system to degrade energy. The results of a study used in this paper indicated that old-growth and mature semi-natural forests ordinate towards competitor-stress communities in contrast to secondary forests or managed stands that were more dominated by ruderal species and with fewer competitor and stress-tolerant plants. Older stands also appeared to have higher biomass in the form of living and dead wood. Surface temperatures in old-growth and semi-natural forest stands were significantly more attenuated than in managed forest. The indications are for greater efficiency of energy dissipation in complex forest ecosystems. These findings have important applications to the management of forests undergoing environmental change. Forestry practices that attempt to promote higher thermodynamic function by mimicking ecological processes of natural forests are more likely to conserve eco-exergy and so enhance resilience in forests facing the impacts of climate change. The principles of forest econics are presented in the wider context of close-to-nature forestry.

Introduction
A long history of land use change and exploitation of forests has dramatically altered the landscape of Europe as well as shaped cultural values of wilderness. The transformation of space and perception that began in earnest soon after the Mesolithic period and has continued unabated to the present day has created the cultural landscape of Europe, and engineered a baseline shift in social values of biodiversity (Vera 2009). Evidence for the extent and nature of European forests leading up to the Neolithic period are unclear (Birks 2005), as there are two competing hypotheses: the "high-forest" hypothesis (Iversen 1973, Bradshaw 2003); and the "wood-pasture" hypothesis (Vera 2000). The outcome of this debate is of significance to conservationists because, if Vera was correct, then traditional perceptions of closed-canopy forests would not be appropriate indicators of old growth. A more recent and thorough analysis of both pollen records and insect fossils (Bradshaw et al. 1994, 2003) would suggest large herbivores played a part in maintaining open areas but were not necessarily influential in the structuring of forests. The implication would be that forests existed as large tracts across the landscape with intermittent breaks some which were larger and more permanent than others.

If Russia is included, approximately 47% of present-day Europe is under tree cover (MCPFE 2003), of which 1 – 3% might be classified as old growth (Gilg 2004). The largest continuous tracts of natural and near natural forest are to be found in Finland, Sweden and the remote mountainous areas of

Central and Eastern Europe (Diaci 1998) although the exact extent and quality of the Eastern Europe forests is still being investigated (Veen *et al.* 2010).

The complexity of forest ecosystems, particularly old growth, cannot be adequately represented or classified using simple terms or any one defining criterion. Science is unable to capture the changes over time in the natural order of ecosystems or the levels of spatial and functional complexity that operate to self-referential processes, which generate new emergent properties in order to provide the system with resilience to uncertain changes in the environment. However clumsy, most definitions of old growth forest employ several criteria (Kimmins 2003; Gilg 2004), which can be categorised broadly as structure and composition; natural processes or dynamics; and biogeochemical processes that help describe interactions between species and also between biota and the physical environment (Wirth *et al.* 2009).

More recently, the laws of physics, specifically thermodynamics, have been applied to explain ecosystems and to get round some of the problems inherent in working with ecological concepts. The law of conservation of energy shapes and drives ecosystems and is at the heart of evolution. Simply translated, biological diversity is the product of the second law of thermodynamics and it can be explained by introducing three key ecological attributes of functional ecosystems: **biomass**; **networks** (describes the composition and complexity of an ecosystem); and **information** (the function and role of components of an ecosystem, processes and trophic structures) (Jørgensen 2006; 2007; Norris *et al.* 2011; Freudenberger *et al.* 2012). The need to efficiently dissipate incoming energy and build up eco-exergy that allows for physiological processes and reproduction would be a major driver of ecological and biological evolution. Functional biodiverse systems optimally balance between hydric, material and energetic efficiency and resilience needed in the face of unpredictable events and environmental change. The relative ease of recording and translating the above-mentioned three key ecological attributes into environmental proxy measures is of particular value to managers who till now have worked with more predictive indicators derived from linear experimental science.

The historical and more recent commercial exploitation of forests across Europe has altered the structure and composition enough to change the vegetation function and surface energy balance. A decline in biodiversity that amounts to losses in biomass, ecological information and networks, has caused the simplification of ecosystem processes and a reduction in functional processes and resilience (Daily *et al.* 1997; Foley *et al.* 2005; Wagendorp *et al*. 2006). Local climatic feedback processes have been disrupted creating more extreme temperature conditions (e.g. Rebetez *et al.* 2007; Teuling *et al.* 2010; Royer *et al.* 2011; Smith 2011). There exists clear scientific evidence for the effects of human-induced modifications to forest ecosystems on local and regional climates (Robinson *et al*. 2009; Medvigy *et al*. 2010; Teuling *et al*. 2010; Zisenis 2010).

Temperate old-growth forests function at optimum ecological capacity and are naturally rich in ecosystem functional indicators (e.g. Nilson *et al.* 2002; Brumelis *et al.* 2011). Typically, old growth forests contain between 500 – 1000 m^3/ha of living biomass and an additional 50 – 150 m^3/ha of dead wood (Gilg 2004). The building of energy-dissipative structures and exergy capital within an ecosystem is the means a forest has of maximizing the buffer capacity, and is the basis of resilience and adaptation to environmental change (Bendoricchio & Jørgensen 1997; Fath *et al.* 2004; Achten *et al.* 2008). The relationship between the three key ecological attributes and local surface temperatures (see Kay *et al*. 2001; Lin *et al*. 2011: Norris *et al*. 2011), is a useful parameter in evaluating ecosystem functioning and health (Aerts *et al.* 2004). For instance, in forests human disturbance can result in the increase in surface temperatures and a corresponding reduction in the capacity for thermodynamic regulation (Aerts *et al.* 2004; Wagendorp *et al*. 2006). Drawing on this science, and supporting experimental evidence the authors present the case for adopting ecosystem function traits as appropriate indicators of forest sustainability. True close-to-nature forest management should not be defined by selected representations of desirable structures and features of natural forest. Instead, is should include the mimicking of key processes and functions observed in free-willed old growth, more in line with principles of “econics”. In brief, Econics describes the systematic learning from ecosystems for sustainable development. Among the key processes to be taken into account is the accumulation of eco-exergy related to the dissipation of incoming energy.

Evidence in the field

Recent studies carried out in near-natural / old growth and managed forests in the UK, Germany and Ukraine to investigate the relationship between ecosystem function and surface temperature conditions (see Norris *et al.* 2011), suggest there is a significant increase in temperature fluctuation where forests have been disturbed by humans (Figure 1). The evidence points to the overriding importance of biomass in the system (Figure 2) although it is not clear whether the relationship is directly related or if it involves more complex processes to do with water. Small-scale analysis of dead wood across the study sites would indicate that water capture and retention is important in regulating surface temperature in forests. For instance, older, more decayed logs appear to moderate surface temperatures more effectively than similar sized fresh dead wood (Figure 3).

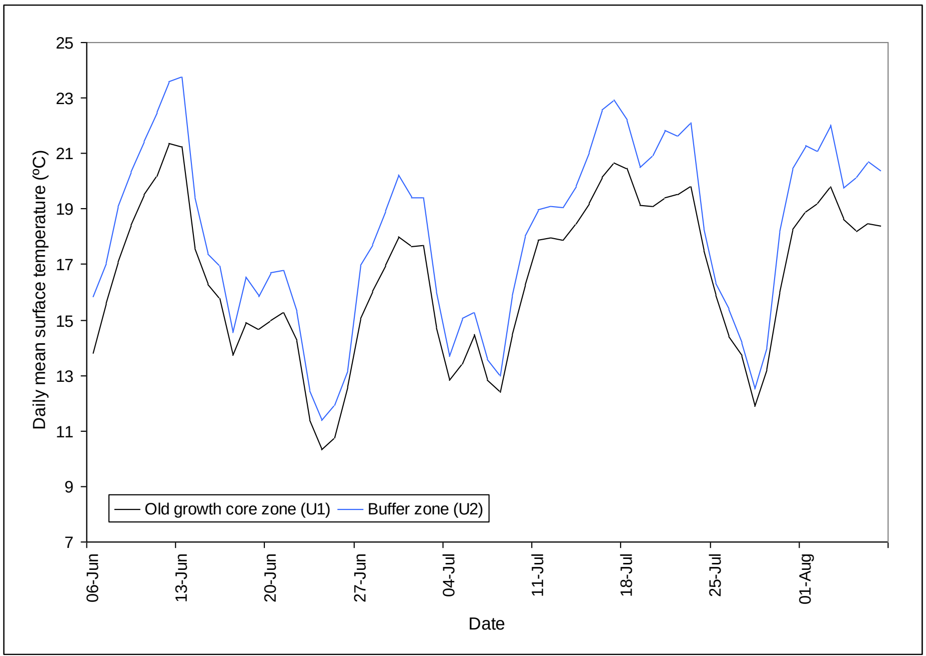
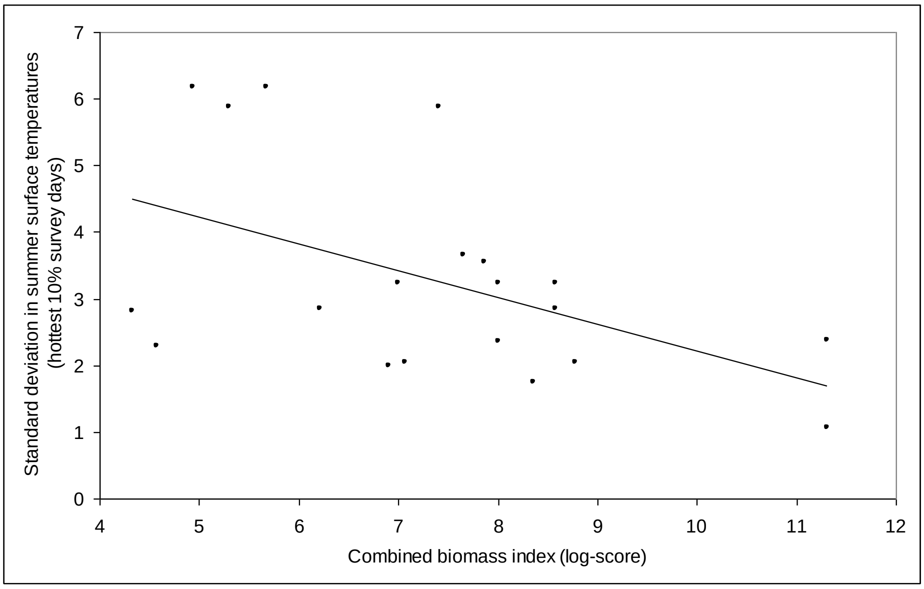


Figure 1 Daily mean surface temperature (^{0}C) in two contrasting forest stands in the Carpathian Biosphere Reserve, Ukraine; Old growth forest in the core zone, and used forest in the buffer zone.

.



.

Figure 2 Combined biomass scores (log-transformed values for live and dead wood characteristics extrapolated to the hectare against standard deviation in temperature for 10% hottest survey days

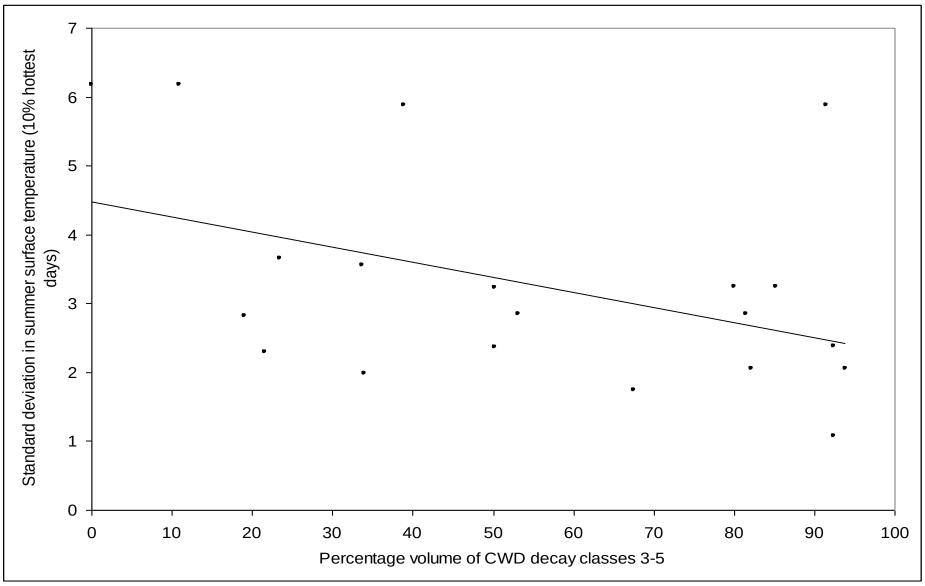


Figure 3 Percentage volume of coarse woody debris in more decayed classes 3-5, against standard deviation in temperature for 10% hottest survey days.

There are apparent differences between used and old growth forest in vegetation functional traits (Figure 4), and some indication of a relationship between the two ecosystem function indicators, information and networks, and surface temperature (Figure 5). However, it is unclear whether the trend between function traits and temperature is operating independently of biomass. It is more likely that local temperature conditions are under the control of complex processes involving the diversity of energy dissipative structures influencing both carbon and water storage.

The similar microclimatic conditions observed at both stand and log scale would suggest the influences of vegetation structure and function on temperature produce fractal patterns across scales. A related study on global ecosystems and vegetation functional traits appears to support this idea (Freudenberger et al. 2012). It is possible that cross-scale patterns reflect levels of connectedness (networks) in ecosystems, which has implications for forested landscapes that are fragmented.

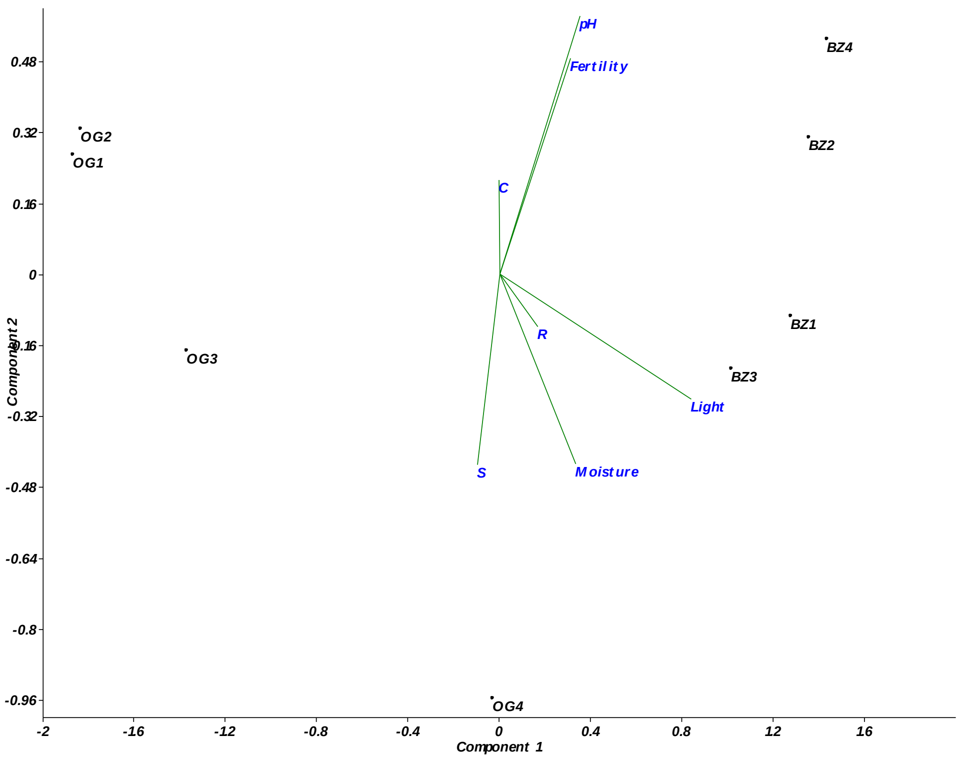
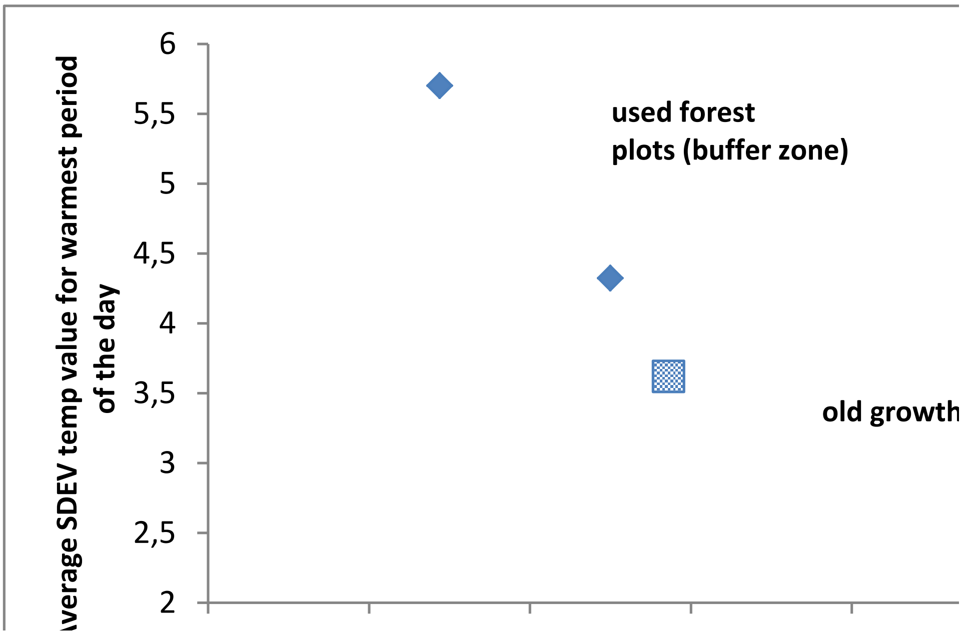


Figure 4 Principal Component Analysis for old growth and used forest plots in the Carpathian Biosphere Reserve, Ukraine. The data used are vegetation function traits. OG is old growth; BZ is managed stands in the buffer zone; C is competitor plant trait; S is stress tolerant plant trait; and R is ruderal plant trait, based on plant ordination analysis (Grime *et al.* 2007).



Forest econics: Establishing an ecologically grounded baseline for the sustainable management of forests

Continued debates about the character and definition of old-growth forests are likely to distract conservation efforts away from more pressing issues of safeguarding forests that are functionally efficient and intact. The primeval forests of Europe we yearn for have been lost in the evolutionary history of Europe. However, there remain a very small number of sites that appear to be naturally intact, "free-willed" forests exhibiting all the characteristics we would consider to be 'old growth'. Our focus should be on protecting these last vestiges of free-willed forest as baselines and reference points for the rest of Europe's forested landscape.

The advantages to biodiversity and stand stability of practicing close-to-nature forestry are discussed in detail (Christensen and Emborg, 1996, Bergeron and Harvey, 1997; Schulte and Buongiorno, 1998; Hansen *et al.*,1999; Bradshaw *et al.*, 1994; Fähser, 1995; Mason and Quine, 1995; Nabuurs and Lioubimov, 2000; Bengtsson et al., 2000; Emborg *et al.*, 2000) although general references to nature are misleading as it does not imply ultimate release of forests from human intervention nor does it suggest a mimicking of the old growth conditions prevalent in remnant primeval forest (Gamborg & Larsen 2002). The principles used to guide European practices of close-to-nature forestry are underpinned by the criteria drawn up at the First Expert Level Follow-up Meeting of the Ministerial Conference (1993) in Helsinki for forest sustainability (Gamborg & Larsen 2002). The three fundamental elements proposed by Jørgensen (2007) to describe ecosystem function, namely biomass, information and networks, are coincidentally covered by the criteria, for instance, in the case of the criterion: "*The maintenance of the health and vitality of forest ecosystems*." However, both conceptual and linguistic generalities are likely to encourage subjective and misguided interpretation. For instance, what constitutes a "healthy and vital" ecosystem?

We suggest that managers require more clearly defined and measurable indicators that are based on fundamental laws of physics and corresponding ecological functioning played out and observed in old growth forest. Principles of econics already introduced earlier in this paper can offer an appropriate framework on which to base sound practices in sustainable forestry. The following four objectives are proposed for "forest econics":

- To build and maintain resilience in managed forests
- To ensure forest ecosystems maintain inherent capacity to adapt to uncertain change, in particular, to conditions likely to arise as a result of climate change

- To conserve natural patterns, objects and legacies essential for the full function and evolution of forest ecosystems
- To secure an effective buffer in forest ecosystems by practicing “ecological banking” at all scales.

To practitioners such objectives need translating into action, which can then be measured and incorporated into silvicultural strategies.

The following operational directives could be applied alongside the existing list for sustainable forestry:

- To maximise net biomass retention based on measures taken from appropriate old growth reference sites (retention of super-canopy trees, proportion of post-incremental trees, mounds, large snags and logs, and areas of undisturbed field vegetation, understory and soil).
- To maximise the water-retention capacity of forests through more careful consideration of stand structure, dead wood retention and soil conservation
- To promote connectedness through variable retention of environmental legacies, including native seed banks, vegetation and local geomorphological features
- To safeguard cross-scale processes by planning and managing at landscape scale
- Mimic natural gap dynamics and succession phases using “free-willed” forest as reference sites

Acknowledgements
The authors wish to extend their thanks and gratitude to the various people supporting field research (Germany: Volkmar Ebert from Brandenburg State Forestry Enterprise; Ukraine: staff of Carpathian Biosphere Reserve, especially Fedir Hamor and Vasyl Pokyncherada.

References:

Achten, W.M.J., Mathijs, E. & Muys, B. (2008) Proposing a life cycle land use impact calculation methodology. *Proceedings of the 6th International Conference on Life Cycle Assessment in the Agri-Food sector.* Zurich. November 12-14, 2008.

Aerts, R., Wagendorp, T., November, E., Behailu, M., Deckers, J. & Muys, B. (2004) Ecosystem thermal buffer capacity as an indicator of the restoration status of protected areas in the Northern Ethiopian Highlands. *Restoration Ecology*, 12, 4, 586-596.

Aussenac, G. (2000) Interactions between forest stands and microclimate: Ecophysiological aspects and consequences for silviculture. *Annals of Forest Science,* 57, 287–301.

Bendoricchio, G. & Jørgensen, S.E. (1997) Exergy as goal function of ecosystems dynamic. *Ecological Modelling*, 102, 1, 5-15.

Bengtsson, J., Nilsson, S.G., Franc, A., Menozzi, P. (2000) Biodiversity, disturbances, ecosystem function and management of European forests. For. Ecol. Manage. 132, 39–50..
Bergeron, Y., Harvey, B .(1997) Basing silviculture on natural ecosystem dynamics: an approach applied to the southern boreal Mixed wood forest of Quebec. For. Ecol. Manage. 92, 235–242.

Bonan, G.B., Chapin, S.F. and Thompson, S.L. (1995) Boreal forest and tundra ecosystems as components of the climate system. *Climate Change*, 29: 145-167.

Bradshaw, R., Gemmel, P., Björkman, L. (1994) Development of nature-based silvicultural models in southern Sweden: the scientific background. For. Lands Res. 1, 95–110.

Bradshaw, R.H.W., Hannon, G.E., & Lister, A.M. (2003) A long-term perspective on ungulate-vegetation interactions. *Forest Ecology and Management,* 181, 267-280.

Brumelis, G., Jonsson, B.G., Kouki, J., Kuuluvainen, T. & Shorohova, E. (2011) Forest naturalness in northern Europe: perspectives on processes, structures and species diversity. Silva Fennica 45(5): 807–821.

Christensen, M., Emborg, J. (1996) Biodiversity in natural versus managed forests in Denmark. For. Ecol. Manage. 85, 47–51.

Daily, G.C., Alexander, S., Ehrlich, P.R., Goulder,L., Lubchenco, J., Matson, P.A., Mooney, H.A., Postel, S., Schneider, S.H., Tilman, D. & Woodwell, G.M. (1997) Ecosystem services: Benefits supplied to human societies by natural ecosystems*. Issues in Ecology*, 2, 1-18.

Emborg, J., Christensen, M., Heilmann-Clausen, J. (2000) The structural dynamics of Suserup Skov, a near-natural temperate deciduous forest in Denmark. For. Ecol. Manage. 126, 173– 189.

Fähser, L. (1995) Nature-oriented forestry in Luebeck. Int. J. Ecofor. 11 (7), 7–11.

Fath, B.D., Jørgensen, S.E., Patten, B.C. & Straškraba, M. (2004) Ecosystem growth and development. *Biosystems*, 77, 213-228.

Foley, J.A., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Manfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N. & Snyder, P.K. (2005) Global consequences of land use. *Science*, 309 (5734), 570-574.

Freudenberger, L., Hobson, P.R., Schluck, M. and Ibisch, P.L. (2012) A global map of the functionality of terrestrial ecosystems. *Ecological Complexity*, 12, 13-22.

Gamborg, C. and Larsen, J.B (2002) 'Back to nature' – a sustainable future for forestry?. Forest Ecology & Management 179, 559-571.

Gilg, O. (2004) *Old Growth Forests: Characteristics, Conservation and Monitoring*. Cahien Techniques de l'ATEN: 74. ATEN, Montpellier.

Grime, J.P. (1977) Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. *The American Naturalist*, **111**, 1169-1194.

Grime, J.P.**,** Hodgson, J.G., Hunt, R. (2007) Comparative Plant Ecology: a functional approach to common British species. 2nd Edition, Castlepoint Press, Dalbeattie.

Guan B.T., Weng S.H., Kuo S.R., Chang T.Y., Hsu H.W. & Shen C.W. (2006) Analyzing the effects of stand thinning on microclimates with semiparametric smoothing splines. *Canadian Journal Forestry Research*, (36) 1641–1648.

Hansen, A.J., Garman, S.L., Weigand, J.F., Urban, D.L., McComb, W.C., Raphael, M.G. (1999) Alternative silvicultural regimes in the Pacific Northwest: simulations of ecological and economic effects. Ecol. Appl. 5, 535–554.

Hunt, R., Hodgson, J.G., Thompson, K., Bungener, P., Dunnett, N.P. & Askew, A.P. (2004) A new practical tool for deriving a functional signature for herbaceous vegetation. *Applied Vegetation Science*, 7, 163-170.

Jørgensen, S.E. (2006) Application of holistic thermodynamic indicators. *Ecological Indicators*, 6, 24-29.

Jørgensen, S.E. (2007) Application of exergy as thermodynamic indicator in ecology. *Energy*, 32, 5, 673-685.

Jørgensen, S.E., Patten, B.C. & Straškraba, M. (2000) Ecosystems emerging: 4. growth. *Ecological Modelling*, 126, 249-284.

Kay, J.J., Allen, T., Fraser, R., Luvall, J. & Ulanowicz, R. (2001) Can we use energy based indicators to characterise and measure the status of ecosystems, human, disturbed and natural? *Proceedings of the International Workshop: Advances in Energy Studies: Exploring supplies, constraints and strategies.* Porto Venere, Italy, 23-27 May 2001, 121-133.

Kimmins, J.P. (2003) Old growth forest. An ancient and stable sylvan equilibrium, or a relatively transitory ecosystem condition that offers people a visual and emotional feast? Answer - it Depends. For. Chron. 79: 429-440.

Lin, H., Cao, M. & Zhang, Y. (2011) Self organization of a tropical seasonal rainforest in southwest China. *Ecological Modelling*, 222, 15.

Mason, W.L., Quine, C.P.(1995) Silvicultural possibilities for increasing structural diversity in British spruce forests: the case of Kielder Forest. For. Ecol. Manage. 79, 13–28.

Medvigy, D., Wofsy, S.C., Munger, J.W. & Moorcroft, P.R. (2010) Responses of terrestrial ecosystems and carbon budgets to current and future environmental variability. *Proceedings of the National Academy of Sciences of the United States of America*, **107**, 8275-8280.

Nabuurs, G.J., Lioubimov, A.V. (2000) Future development of the Leningrad region forests under nature-oriented forest management.For. Ecol. Manage. 130, 235–251.

Norris, C., Hobson, P., & Ibisch, P.L. (2011) Microclimate and vegetation function as indicators of forest thermodynamic efficiency. *Journal of Applied Ecology*, doi: 10.1111/j.1365-2664.2011.02084.x.

Rebetez, M., Dupont, O. & Giroud, M. (2007) An analysis of the July 2006 heatwave extent in Europe compared to the record year of 2003. *Theoretical and Applied Climatology*, 95 (1-2).

Robinson, D.T., Brown, D.G. & Currie, W.S. (2009) Modelling carbon storage in highly fragmented and human dominated landscapes: Linking land cover pattern and ecosystem models. *Ecological Modelling*, 220, 9-10, 1325-1338.

Royer, P.D., Cobb, N.S., Clifford, M.J., Huang, C-Y., Breshears, D.D., Adams, H.D. & Villegas, J.C. (2011) Extreme climatic event-triggered overstorey vegetation loss increases understorey solar input regionally: primary and secondary ecological implications. *Journal of Ecology,* 99 (3), 714-724.

Smith, M.D. (2011) An ecological perspective on extreme climatic events: a synthetic definition and framework to guide future research. *Journal of Ecology*, 99 (3), 656-664.

Teuling, A.J., Seneviratne, S.I., Stöckli, R., Reichstein, M., Moors, E., Ciais, P., Luyssaert, S., van den Hurk, B., Ammann, C., Bernhofer, C., Dellwik, E., Gianelle, D., Gielen, B., Grünwald, T., Klumpp, K., Montagnani, L., Moureaux, C., Sottocornola, M. & Wohlfahrt, G. (2010) Contrasting response of European forest and grassland energy exchange to heatwaves. *Nature Geoscience*, 3, 722-727.

Wagendorp, T., Gulinck, H., Coppin, P. & Muys, B. (2006) Land use impact evaluation in life cycle assessment based on ecosystem thermodynamics. *Energy*, 31, 112-125.

Zisenis, M. (2010) *10 Messages for 2010: Climate change and biodiversity*. European Environment Agency. Copenhagen.

Veen, P., Fanta, J., Raev, I., Biriş, I., Smidt, J., & Maes, B. (2010) Virgin forests in Romania and Bulgaria: results of two national inventory projects and their implications for protection *Biodiversity and Conservation,* 19 1805-1819.

Vera, F.W.M. (2000) *Grazing ecology and forest history*. Wallingford: CABI.

Vera, F.W.M (2009) Large-scale nature development – the Oostvaardersplassen. British Wildlife, 28.

Schulte, B.J., Buongiorno, J. (1998) Effects of uneven-aged silviculture on the stand structures, species composition, and economic returns of loblolly pine stands. For. Ecol. Manage. 111, 83–101.