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Urban green mosaic and sustainable water processes

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ABSTRACT

Water is the main energy processor agent creating the landscape hierarchical non-random structure of communicating interfaces. In natural landscapes maximum vegetation growth and thick raw humus layers leads to a closure of water and matter cycles and energy dissipation to local sites. In urban regions structural randomisation, combined with a large input of unstructured energy causes high fluctuations in temperature and wetness, associated with large irreversible erosion losses. Sustainable redevelopment of the urban environment must emphasise the spatiotemporal distribution of communicating green interfaces. This article puts forward a holistic concept for urban water cycle management adapted to first principles. The symmetry between entropy decreasing water processes and urban morphology is evaluated based on heuristic pattern recognition and dynamic modelling, using high resolution spatial (Remote Sensing) and temporal measuring. A modular concept for urban water process restructuring is suggested, and implementation in societal planning and decision making is outlined.

INTRODUCTION

Ecological development leads to a closure of matter (notably water) cycles to local sites. For instance paleolimnological investigations show a clear sequence of decreased sedimentation since the last glaciation (e.g. Digerfeldt, 1972). After an initial phase of successive closure, irreversible losses (measured as conductivity) decreased to a stable level of about 10-40 µS/cm (Fig. 1). With the agricultural revolution, and further accelerated by the industrial ditto, irreversible losses have increased to 200 - 1000 µS/cm, as also indicated from studies in many environments (e.g. Larsson *et al.*, 1985; Peierls *et al.*, 1991; Baker, 1992).

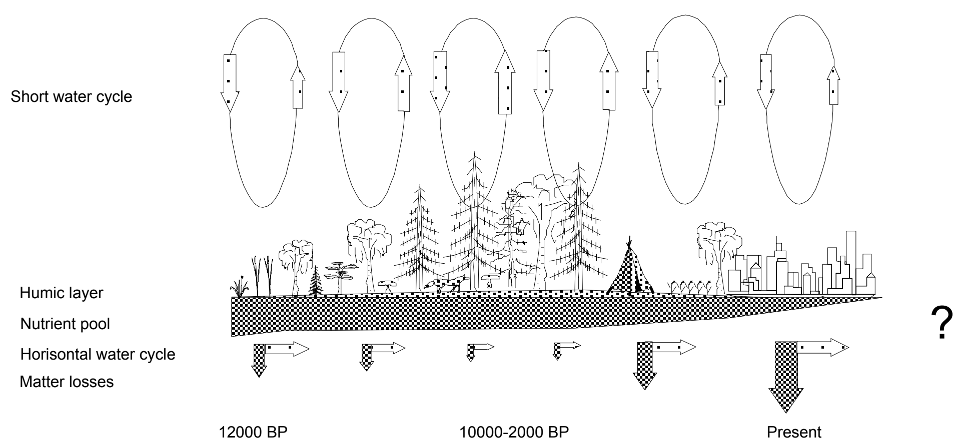

Fig. 1 Postglacial ecological development (after Ripl and Gumbricht, 1995).

The leaking system turns into a transient state of erosions, large scale eutrophication, acidification, and climate changes. Traditionally these problems have been modelled and managed using simplified linear cause-effect concepts assuming continuos response strengths.

However, the importance of non-linear dynamics of complex systems and of discontinuous properties now pervades the basic sciences underlying environmental problems (e.g. May, 1975; Prigogine and Stengers, 1984; Davis and Gribbin, 1991). A new set of tools for integrated management of life supporting systems towards sustainable development in the spirit of the Brundtland commission (WCED, 1987) and Agenda 21 is thus called for (Wiman, 1991; Svedin and Hägerhäll, 1992). In a transient world short of space, phase related spatial and temporal configuration of different activities and ecosystems must be emphasised (Picket and White, 1985; Forman, 1990; Holland *et al*, 1991; Hillbricht-Ilkowska, 1995; Ripl, 1995). For urban environments this means restitution and management of mosaic green structures at different scales (cf. Ripl, 1993).

This article puts forward a holistic concept for urban water cycle management adapted to first principles. The symmetry between entropy decreasing water processes and landscape pattern is evaluated based on high resolution spatial and temporal measuring. A modular concept for sustainable urban water process restructuring is outlined.

HIERARCHICAL INTERFACES OF WATER PROCESSES

Energy from the sun furnished in daily pulses with annual modulation is the major driving force of earth surface processes. Through these energy pulses life evolved as a dissipative structure far from thermodynamic equilibrium (Prigogine and Stengers, 1984). Evolutionary resource competition has led to a closure of energy dissipation and matter to local sites (the maximum energy principle - Odum and Odum, 1981), decreasing the flow of energy and matter from land to sea. This led Ripl (1995) and Ripl and Gumbricht (1995) to suggest sustainable development objectively defined as increases in thermodynamic efficiency: productivity(P)-irreversible losses(L)/(P), where P and L are measured in terms of charge (proton) turnover and flow per time and space unit respectively.

The energy dissipation in the thermodynamic open landscape is very different on vegetated and non-vegetated land and wet and dry land respectively (Peschke *et al*., 1991; Avissar, 1993). With sufficient moisture conditions energy flow density is effectively decreased by the evapotranspiration-condensation cycle. Abundant vegetation and thick humic layers increases the active water pool participating in this vertically closed cycle, and the surface of evapotranspiration (and the production of condensation nuclei for liquid water formation). In a natural watershed the hydrograph will be controlled by the vegetation (Gumbricht, 1996). Vegetation act as a cooling cell of the atmosphere, capable of attracting energy, water and matter fluxes from adjacent sites with less vegetation at patch to landscape scales (e.g. Shukla *et al*., 1990: Taniguchi, 1991; Gay and Bernhofer, 1991; Kedciora, 1989). Other studies have concluded that patchiness of forested areas will influence (i.e. increase) large scale precipitation pattern (Veen, 1991; Avissar and Chen, 1993).

The large energy damping and energy potential redistribution in the evapotranspiration-condensation cycle is caused by the leap in enthalpy between liquid and gaseous water - a unique physical energy processor property of water (Fig. 2). Water redistribution and landscape relief create spatiotemporally shifting water potential in the landscape inducing both overland and subsurface flow. Along its flow path water interacts with its environment, having a strong chemical processor property through dissolution-crystallisation. This property is dependent on the dipole character and its resulting dissociation, reinforced by kinetic energy. Thus larger potential differences causes more chemical interactions at the liquid-solid

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interfaces. Finally water also has a biological processor property, water being cleaved in photosynthesis and reassembled in respiration. The conclusion must be that water, in natural environments, is the major agent controlling energy dissipation and partitioning at the earth's surface (Ripl, 1995; Ripl and Gumbricht, 1995), producing its non-random structure in time and space.

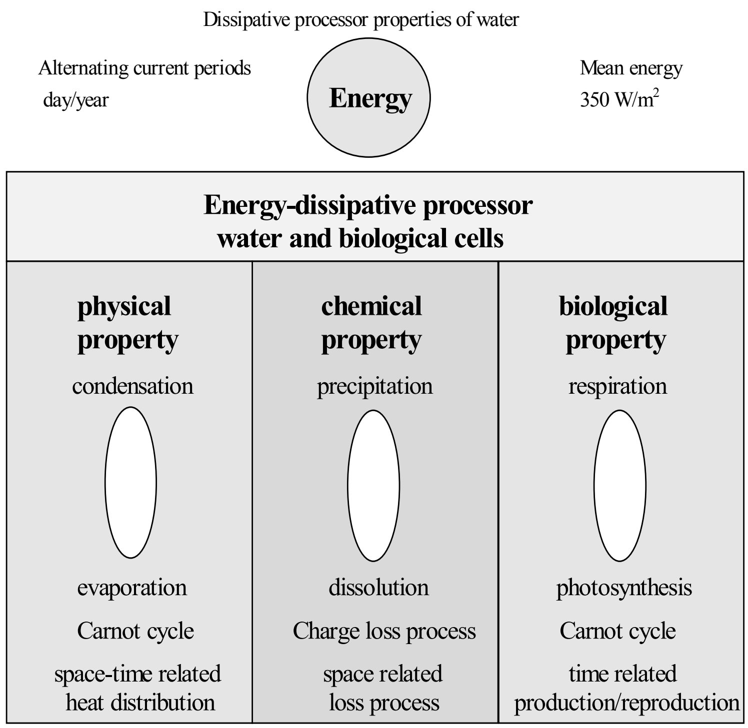

Fig. 2 The processor properties of water (after Ripl and Gumbricht, 1995).

Dissipative water processes and resulting structural interfaces are organised as a nested hierarchy (cf. Allen and Starr, 1982; O'Neill *et al*., 1986). The smallest autonomous unit being able to control energy dissipation is the coenotic unit, equivalent to biofilm in aquatic and stand in terrestrial environments respectively (Fig. 3). Other natural scales (or quanta), suggested e.g. by Holling (1992) of the continuos hierarchy include patch and landscape (Fig. 3). With a few key species and related processes these quanta represent both spatial architectures and temporal frequencies attracting and entraining other species, processes and patterns. The quanta communicate via different (water carried) signals up and down the scales. At any scale the receiving signal stream is interpreted via its interface (equivalent to a filter), and either processed in connected parallel structures (Fig 4), or randomised due to asymmetries (overconnection) or lack of interfaces (underconnection). System efficiency and stability is dependent on coherence in communication, and closely connected to vegetation and accumulated capital of organic matter in the forest floor (e.g. Bormann and Likens, 1979; Gorham *et al*., 1979; Vitousek, 1985; Holling, 1992).

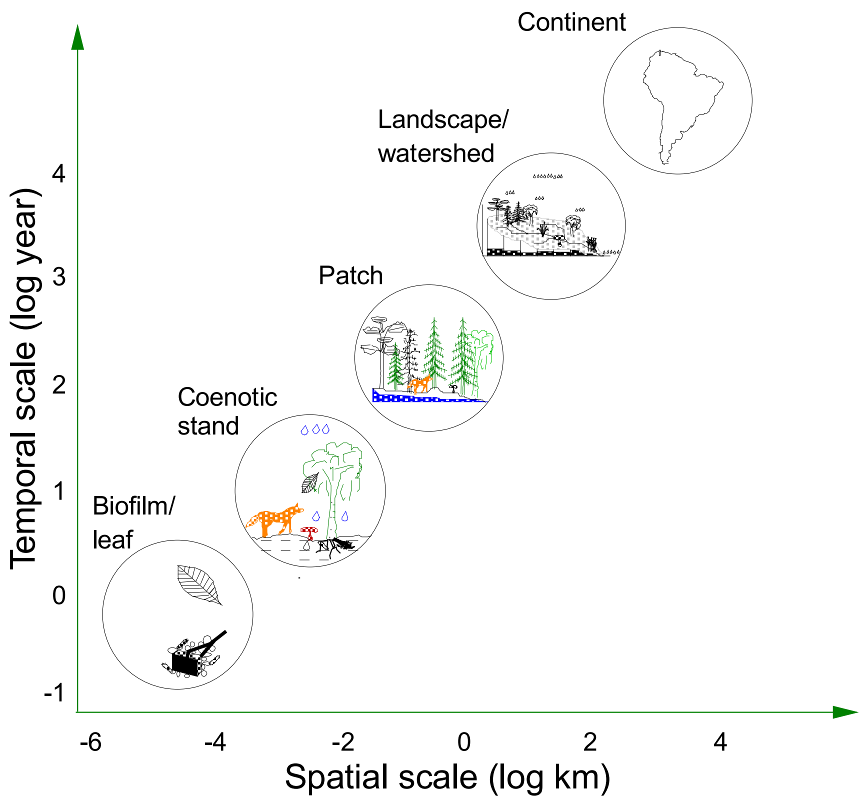

Fig. 3 Hierarchical organisation of natural frequencies and quanta of energy dissipation

At a landscape scale the most important components for communication are patches of different vegetation and their dynamic transition zones - ecotones (e.g. Wiens, *et al*.; 1986; Pringle *et al*., 1988; Naiman and Decamps, 1990). The latter include wetlands and riparian forests in lower slope positions with unique regulatory properties; their influence on evapotranspiration and nutrient capturing largely exceeds their areal extents (e.g. Howard-Williams, 1985; Richardson *et al*., 1992; Hillbricht-Ilkowska, 1995). A holistic portraying of system processes must thus consider component order and juxtaposition, as well as scale (cf. Dyck and Baumert, 1991; Avissar, 1993). Due to emergent properties arithmetic averaging of system component behaviour become meaningless, and need be substituted for a phase related analysis recognising the scale of observation.

EFFECTS OF URBANISATION

Within a century the urban environment has turned from a cultural and social marketplace accessible by foot or horse within a day, to a parasitic manufacturing centre heavily dependent on structured energy and matter import from its (global) surrounding (e.g. Turner *et al*., 1991) (Table 1). Considerable areas have been drained or sealed, and unstructured energy is continuously supplied through *inter alia* the transport system its vehicles and maintenance, the heating and cooling systems with pumping and random release of thermal energy, the water supply system with its centralised water production, overexploitation of ground water and disposal of waste water (Fig. 4). Thus the balance sheet for irreversible losses from urbanised areas shows ever-increasing trends (up to 10 000 µS/m). The natural waterways have been straightened and canalised further decreasing the stabilising properties of the natural landscape towards exogenous forces at different scales (e.g. Vorosmarty *et al*., 1986; Pinay *et al*., 1990; Thorne, 1991).

Table 1. Energy flow density in different systems (after Odum, 1993)

System	Annual energy flow density (MJ/m2)
Autogenic natural	5-50 (10)
Allogenic supplied natural	50-200 (100)
Human rural	50-200 (100)
Human urban	500-15,000 (10,000)

With removal of vegetation the landscape system becomes more open and severely underconnected. Energy pulses will not be partitioned into structuring processes, but translated to oscillations of temperature and wetness, increasing in amplitude with gap size (Canham and Marks, 1985; Runkle, 1985). The induced wetting and drying cycles increase detritus pool break down, weathering and erosion (e.g. Pinay and Decamps, 1988). A preferential outflow of soluble nutrients and minerals will leave a bulk of poisonous (e.g. insoluble heavy metals) and inert (e.g. quartz) matter as soil. Increase in oscillation in small scale also effect larger scales and can even trigger other stability domains, *inter alia* in temperature or precipitation pattern, leading to local to regional climate changes (e.g. Shukla *et al*., 1990).

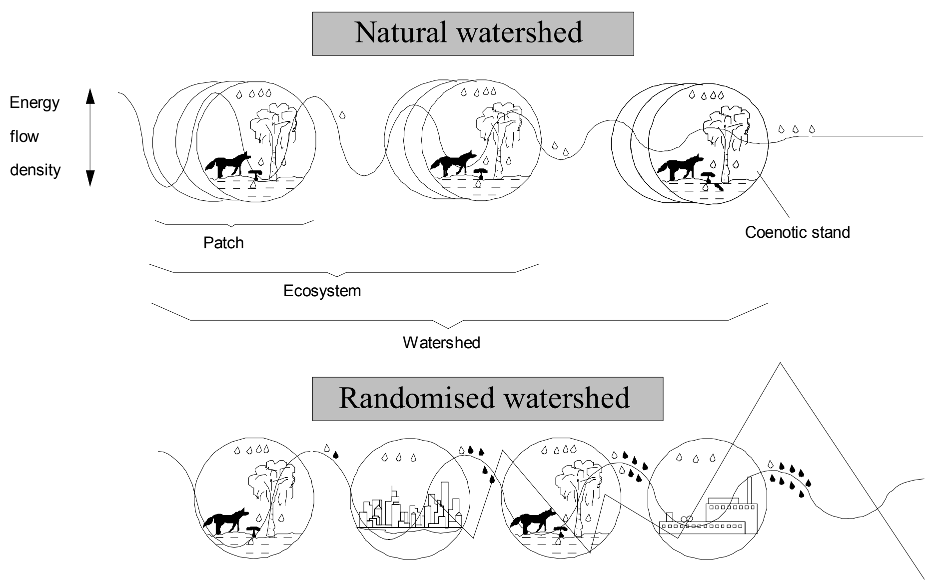

Fig. 4 Schematic hierarchical energy pulse dissipation in a) natural watershed with a maximum of parallel dissipative structures in space resulting in low sequential changes with stable spatial and temporal patterns and high efficiency, and b) watershed with randomised spatial and temporal patterns resulting in a transient state of low efficiency.

METHODS

The study takes on a holistic approach emphasising the relation between pattern and processes, seeking the least number of logically defined and experimentally corroborated explanatory parameters. In practical terms this means using heuristic methods and simple statistics. Remote sensing (RS) and geographical information systems (GIS) are used for spatial process and pattern recognition (Gumbricht *et al*, 1995, 1996a, 1996b; McCarthy, 1996, in prep.), and high

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time resolved samplers for temporal process recognition. The water cycle is evaluated with a dynamic hydrological model emphasising vegetation and elevation tightly coupled to GIS and RS (Gumbricht, 1996). Elevation segments are filled by precipitation and water content is partitioned to evapotranspiration and runoff based on elevation, vegetation and soil conditions. The model uses GIS and RS for automatic physical parameterisation, and is calibrated using 3 to 5 empirical soil parameters.

By logical encoding into synoptic indices it is emphasised that the generic symmetry between processes and patterns in different environments and scales should be possible to falsify (*sensu* Popper, 1979). The methodological approach is summarised in figure 5.

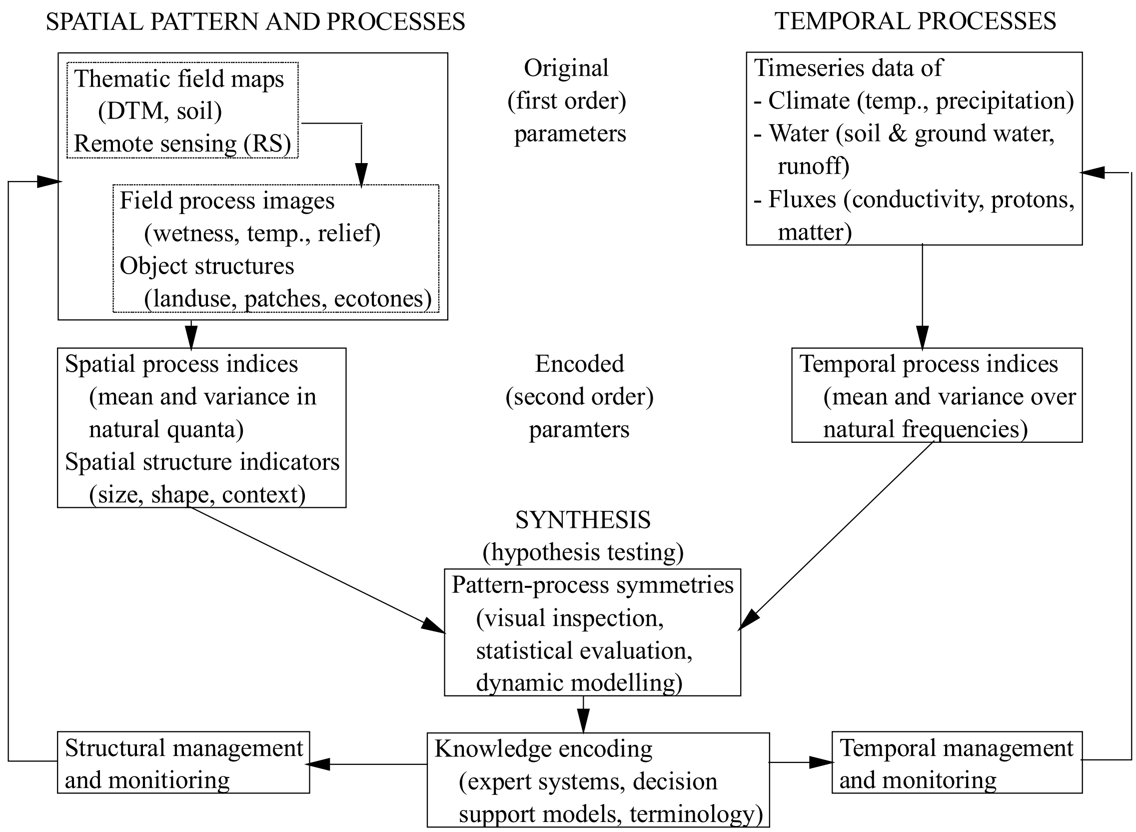

Fig. 5 Summary of methodological approach.

Three different sites were used to illustrate different scales of urban water processes, Kristianstad (city and its setting), Olofström (district) and Uppsala (blocks) (Fig. 6). Kristianstad and Olofström are covered by a system corrected Landsat TM scene (resolution 30 m) obtained July 12th 1994. For Kristianstad the image was resampled to a resolution of 50 meters, for Olofström to 25 m, both fitted to the Swedish map co-ordinate system. The RMS of position error was 10.77 m. Based on the TM-scene field data of vegetation density and vigour (i.e. normalised difference vegetation index - NDVI), wetness and temperature were produced at the respective resolutions (McCarthy, in prep.). Land cover object classes were taken from a commercial classification from the Swedish Space Corporation (based on Landsat TM data).

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In Uppsala three separately homogenous areas having individual outlet point in the stormwater drainage system were selected for study. In each outlet point an automatic logger recording water level, conductivity and temperature with 15 minutes interval was installed during the autumn of 1995 (Espeby *et al*., 1996, in prep.). In Uppsala a more fine grained classification was desired, and thus a SPOT XS scene (obtained July 10th 1994, resolution 20 m) was used for feature definition. A hierarchical definition of the urban environment was developed (table 2), and implemented in an expert system classifier using ”and ... if ... then ...” rules for multisource data and spatial relations (Gumbricht et al., 1995).

Table 2 A suggested hierarchical classification of urban landscape components and agglomerates emphasising energy flow density regimes.

	Degree of exploitation					
Scale	**low**		**intermediate**		**high**	
Building (10^1-10^2 m)	tree		lawn	roof	infrastructure	
Block (10^2-10^3 m)	park	field	bungalow	block of flats	road	industry
District (10^3-10^4 m)	living district		suburb	office district	industrial district	
City (10^4-10^5 m)	rural city				megacity	

All GIS operations were done in IDRISI, and both the hydrological model (PHASE) and the expert image interpreter (GUIDE) are closely coupled to the IDRISI software (Gumbricht and McCarthy, 1996). Field data encoding into mean and standard deviation was done in IDRISI and EXCEL, object encoding was done in FRAGSTATS (McGarigal and Marks, 1993).

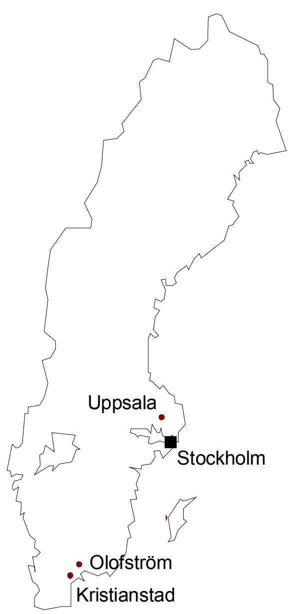

Fig. 6 Map showing the three study sites, Kristianstad, Olofström and Uppsala.

RESULTS

Kristianstad

Figure 7 shows Kristianstad and its rural environment displayed as a) object classes, b) vegetation density, c) temperature distribution, and d) wetness index. Statistical patterns of b) to d) given as mean and standard deviation covering the same area as in figure 7 is shown in figure 8. Some of the objects in figure 7 have been divided in finer categories in the latter.

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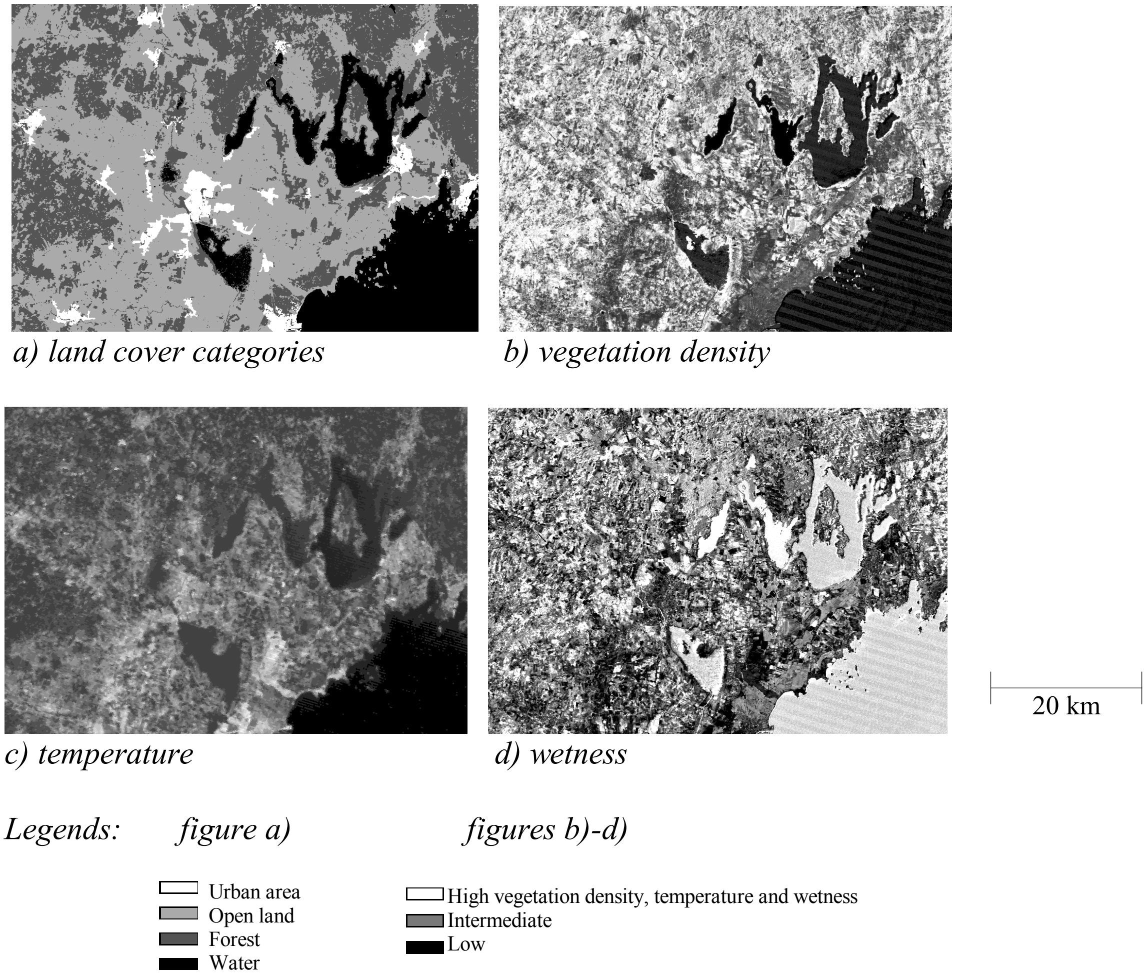

Fig. 7 Landscape pattern of Kristianstad and its surrounding.

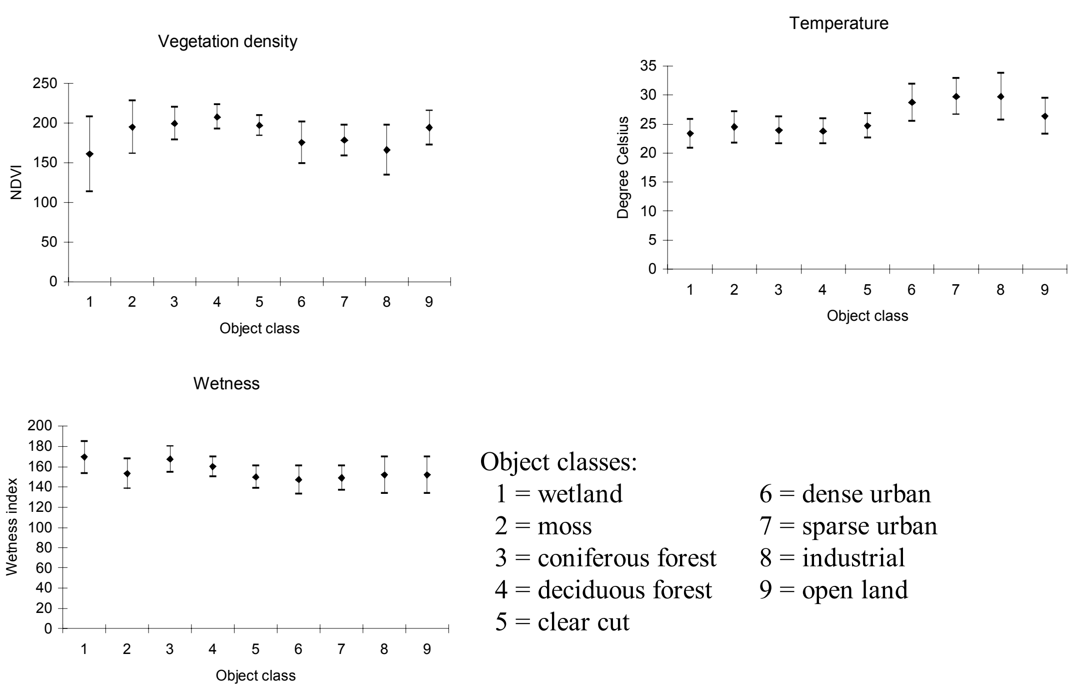

Fig. 8 Mean and standard deviation of vegetation density, temperature and wetness of the area shown in figure 6, divided in 9 object classes.

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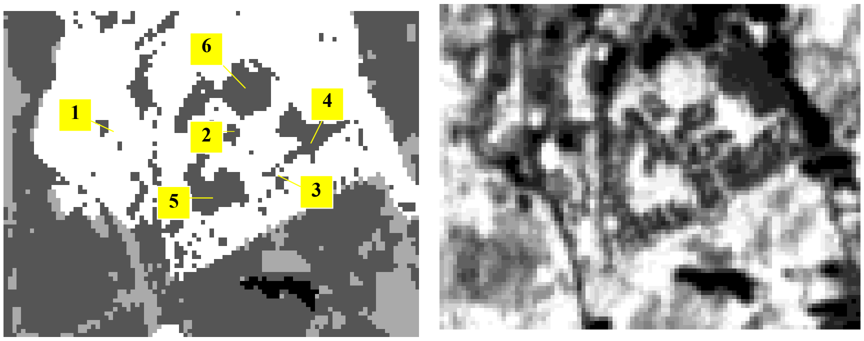
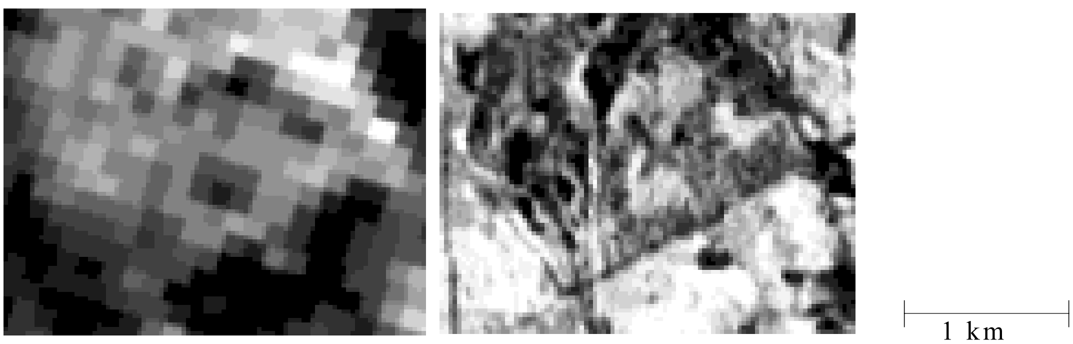
Olofström

Figure 9 shows the town of Olofström as a) object classes, b) vegetation density, c) temperature distribution, and d) wetness index. Six forest patches of different size and shape were analysed statistically regarding wetness and temperature distributions (Fig. 10).



a) land cover categories *b) vegetation density*



c) temperature *d) wetness*

Legends: *figure a)* *figures b)-d)*

figure a):
- Urban area
- Open land
- Forest
- Water

figures b)-d):
- High vegetation density, temperature and wetness
- Intermediate
- Low

Fig. 9 Landscape pattern of Olofström.

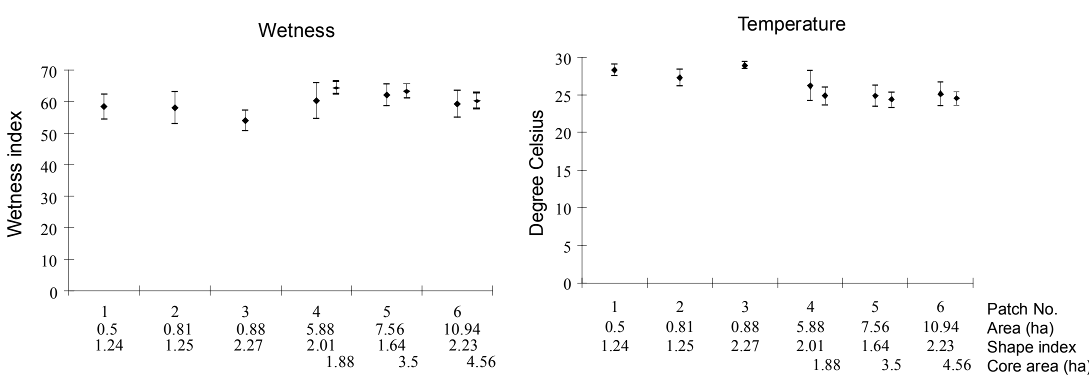


Fig. 10 Mean and standard deviation of temperature and wetness of the patches displayed in fig. 10 a). Core areas have distances more than 50 meters to an edge. Shape is indexed as being one for a perfect circle and increasing with complexity.

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Uppsala

The expert system classifier gave a best accuracy of 65 %, with no improvement in using spatial relations compared to just site specific (i.e. pixelwise) information. Total precipitation over the measured period (10 October- 28 December 1995) was 73.8 mm and average temperature was 0.2 °C. Figure 11 depicts central Uppsala and the three studied urban watersheds, also shown in double scale. Figure 12 illustrates conductivity, shown as mean and standard deviation per week. Figure 13 shows runoff as daily average values. As all areas are flat, and vegetation growth is zero during the winter period, modelled runoff from all three areas give the same generic pattern, illustrated for area 1 in figure 13. Statistical information for the three areas are given in table 3.

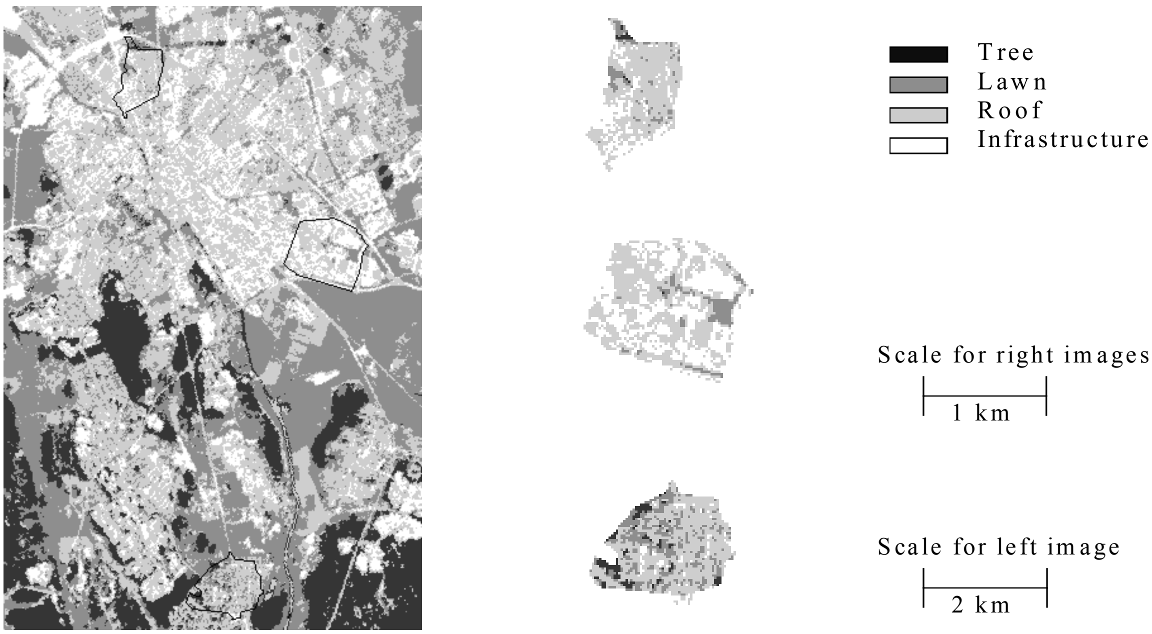

Figure 11. Classification of Uppsala urban components.

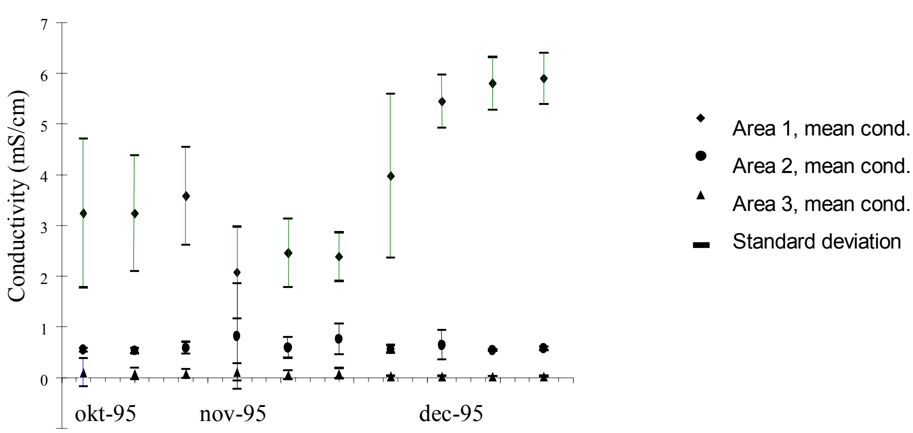

Figure 12 Weekly average and standard deviation of conductivity.

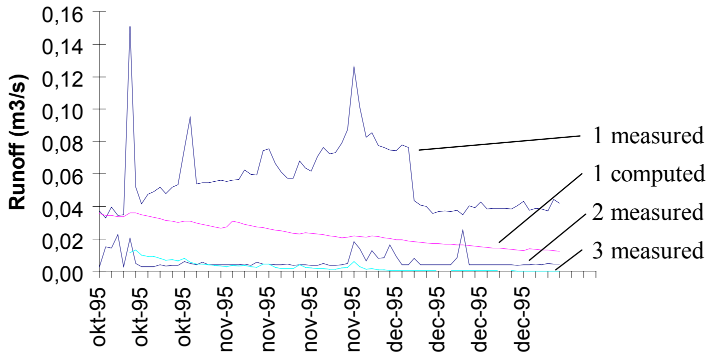

Figure 13. Measured runoff from the three studied areas and calculated runoff for area 1.

Table 3 Encoded pattern and processes parameters for the three Uppsala watersheds

	1 Boländerna	2 Fyrishov	3 Sunnersta
Block type	industry	block of flats	bungalow
Area (ha)	107	55	78
Green/hard made (%)	6/94	10/90	35/65
Runoff (mm)	1678	344	98
Diversity index (Shannon)	0.60	0.43	0.55

DISCUSSION

The destabilisation of the urban environment and its increased vulnerability towards exogenous process is dependent on i) large amount of random energy flow within a limited spatial scale resulting from concentrated cultural and technological activities, and ii) the loss of coherently coupled biological processes and patterns capable of assimilating the high energy flow density. This is clearly illustrated in the presented studies. Compared to cultural and urban systems the forest and other naturally vegetated areas are more cool and wet (Figs 7 to 10). That forest patch size influences the cooling potential is most clearly seen in figure 10. Shape seems to have no clear relation with either wetness or temperature variation (Fig. 10). The period preceding the snapshot images in figures 8 - 11 was extremely dry and hot, thus it is clear that larger forests tend to stabilise both moisture and temperature conditions over both space and time. The larger leakage from more densely exploited areas is illustrated from the Uppsala study (Figs. 12 and 13, table 3). The discrepancy in salt leakage considering temporal scale (Fig. 13) underlines the randomised pattern generated by urbanisation (cf. Fig. 4). From the water transport budgeting and modelling in Uppsala it was evident that anthropogenic derived water determined the hydrograph (Fig. 13, table 3), and the model was not able to forecast flow in the stormwater drainage system based on climate and precipitation data alone.

Recent hypothesis in various scientific fields hold that scale and complexity severely undermines simplified Newtonian cause-effect concepts. This article suggests that Nature's life support functions are highly non-linear, and that water should be regarded the main communication agent and energy distributor in biological systems. The results indicate the urban system to be highly randomised and unable to sustain viable life support functions. Based on these findings and present understanding of natural ecosystem organisation, a modular concept for restructuring of the urban water cycle is suggested (Table 4). The idea of system quanta refers to spatial and structural modules as well as to functional processes sequences. Recognising certain natural frequencies and scales as attractors for typical process and patterns, the modular concept should be done in harmony with those. By intelligent management energy dissipation in nested green structures can be exceeded beyond their natural capacities, *inter alia* by fine tuned water and nutrient application and biomass harvesting (also to avoid overconnectedness and brittleness at a stand scale), perhaps in vertical greenhouses.

Table 4. Modular concept for restoration of the urban water cycle

Scale	Structural module	Functional process	Management	Benefits
Building to block	Facade and roof greening, organic pool increase.	Local closure of matter cycles and energy flow by a short vertical water cycle.	Separation of urea and fecals. Urea and grey water irrigation, compostation.	Water, air and soil quality improvement, temperature and moisture control. Fruit and vegetable production
	Surface desealing	Soil and groundwater stabilisation	Groundwater recharge	Protection of subsurface structures from weathering and erosion.
Block to district	Wetland and forest creation, (vertical) greenhouses.	As above plus biomass production.	Storm water flow, fecal product and compost fertilisation.	Biomass production and harvesting for e.g. biotechnology, medicine, food.
District to city	Agriculture and agroforestry	As above, plus clean water production.	Large scale dense forests and high productive wetlands	Consumption water production.

To be implemented recognition barriers of (definition of) sustainable development, the close relationship between processes and patterns, perception of hierarchical non-linear systems, and economic value of natures life-support processes need be overcome (cf. Gumbricht, 1993). To harmonise natural processes with societal activities, a resource taxation based on natural time and space limitations (thermodynamic budgeting) could be used to overcome the action barrier of implementation. Experience in water supply regimes indicate that private entrepreneurs under governmental control (e.g. by satellite imagery) and regulation are more efficient than public management (e.g. Falkenmark, 1994). This would open for an entrepreneur market of resource care, and potentially the transformation of society from resource exploitation (ecological r-strategy) to maturity (ecological K-strategy). The transition will be facilitated by recognition of the values preserved and produced by a holistic management.

CONCLUSION

Restitution of the urban environment need consider a holistic and integrative approach based on first principles. It is concluded that water processes and resulting structures are key system components to consider. The hierarchical organisation of processes and patterns strongly suggest a modular concept for restructuring the urban water cycle. Such a solution combine water and waste management, with improved urban ecosystem and air quality. The use of innovative economic and legal incentives could facilitate the transformation to such strategies, *inter alia* by self-organisation through market mechanisms. A new generation of management tools and transparent models emphasising the dynamic relationship between processes and patterns are needed (cf. Moore *et al.*, 1993; Ripl, 1995; Gumbricht and McCarthy, 1996). Initial evaluation of process and pattern symmetries need take a step back, using heuristic principles and deductive logic. Developments in high spatial and temporal resolution sensors can provide the necessary data sets. To be generic and used for hypothesis testing the data need be encoded into logical indices which are both intelligible and represent ontological value related to the spatiotemporal scale (or quanta) under study. A major obstacle is to develop a common terminology for urban environment components and their agglomeration into typomorphological patterns with relevance both for planning and natural processes modelling (Rådberg, 1995). Digital implementation in GIS and RS need consider knowledge relations, *inter alia* between ancillary data and spatial patterns of small scale components. Further improvements in resolution (e.g. radar images, digital aerial photographs, future satellite imagery) and classification methods (e.g. Bayesian statistics, neural networks, statistical discriminations) are needed.

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REFERENCES

Allen, T.F.H. and T.B. Starr, 1982. Hierarchy: perspectives for ecological complexity. University of Chicago Press.

Avissar, R. 1993. Relevance of geographic information systems of landscape characteristics for hydroclimatological models. In Kovar, K. and Nachtnebel, H.P, (Eds), Application of Geographic Information Systems in Hydrology and Water Resources Management, IAHS Publ. No. 211, pp 75-82.

Avissar, R. and F. Chen, 1993. An approach to represent mesoscale (subgrid-scale) fluxes in GCM's demonstrated with simulations of local deforestation in Amazonia. (cited in Avissar, 1993).

Baker, L.A., 1992. Introduction to nonpoint source pollution in the United States and prospects for wetland use. Ecol. Eng., 1:1-26.

Bormann, F.H. and G.E. Likens, 1979. Pattern and process in a forested ecosystem. Springer-Verlag, New York.

Canham, C.D. and P.L. Marks, 1985. The response of woody plants to disturbance: Patterns of establishment and growth. In S.T.A. Picket and P.S. White (Eds), The ecology of natural disturbance and patch dynamics. Academic press, San Diego, California. pp 197-216.

Davis, P. and J. Gribbin, 1991. The matter myth. Penguin books.

Digerfeldt, G., 1972. The post-glacial development of lake Trummen. Regional vegetation history, water level changes and paleolimnology. Folia Limnol. Scand., 16

Dyck, S. and H. Baumert, 1991. A concept for hydrological process studies from local to global scales. In G. Kienitz, P.C.D. Milly, M. Th. van Genuchten, D. Rosbjerg and W.J. Shuttleworth, (Eds), Hydrological interactions between atmosphere, soil and vegetation. IAHS Publ. No. 204, pp 31-42.

Espeby, B. A. Högelin and G. Renman, 1996. Induced leakage of nutrients from urban cachments - a monitoring approach. Manuscript, submitted to Nordic Hydrological Conference 1996.

Falkenmark, M. 1994. Conclusions from the fourth Stockholm water symposium. In proceedings Stockholm symposium, Integrated land and water management - challenges and new opportunities, Stockholm Water Company, pp 23-42.

Forman, R.T.T., 1990. Ecological sustainable landscape: The role of spatial juxtaposition. In I.S: Zonnewald and R.T.T. Forman (Eds), Changing landscapes: An ecological perspective. Springer verlag, New York, pp 261-278.

Gay, L.W. and C. Bernhofer, 1991. Enhancement of evapotranspiration by advection in arid regions. In G. Kienitz, P.C.D. Milly, M. Th. van Genuchten, D. Rosbjerg and W.J. Shuttleworth, (Eds), Hydrological interactions between atmosphere, soil and vegetation. IAHS Publ. No 204, pp 147-156.

Gorham, E., P.M. Vitousek and W. A. Reiners, 1979. The regulation of chemical budgets over the course of terrestrial ecosystem succession. Ann Rev. Ecol. Syst., 10: 53-84.

Gumbricht, T. 1993. Minimum entropy in small farming - Children's ecological village Tatui. In Proceeding Stockholm Water Symposium, Integrated measures to overcome barriers to minimizing harmful fluxes from land to water, Stockholm Water Company, pp 215-222.

Gumbricht, T. 1996. Landscape interfaces and transparency to hydrological functions. In press HydroGIS '96 - Application of geographical information systems in hydrology and water resources management (Vienna 16-19 April).

Gumbricht, T. and J. McCarthy, 1996. Transparent land surface modeling in GIS. In press, Geoinformatics '96, West Palm Beach, Florida 21-24 April.

Gumbricht, T., C. Mahlander and J. McCarthy, 1995. Rule based and contextual classification of landscape patches and boundaries. In J.T. Björke (ed), ScanGIS ´95 Proceedings, Trondheim June 12-14, pp. 245-255

Gumbricht, T., C. Mahlander and J. McCarthy, 1996a. Digital interpretation and management of land cover - a case study of Cyprus. Ecol. Eng. in press.

Gumbricht, T., C. Mahlander and J. McCarthy, 1995. Identification of potential reforestation sites using geographical information system and remote sensing. Ecotechnics 95, 29-31 March 1995, Östersund, Sweden, in press.

Hillbricht-Ilkowska, A., 1995. Managing ecotones for nutrients and water. Ecology International, 22: 73-93

Holland, M.M., P.G. Rissner and R.J. Naiman, 1991. Ecotones - The role of landscape boundaries in the management and restoration of changing environments. Chapman and Hall, New York.

Holling, C.S., 1992. Cross-scale morphology, geometry, and dynamics of ecosystems. Ecol. monographs 62: 447-502.

Howard-Williams, C. 1985. Cycling and retention of nitrogen and phosphorus in wetlands. A theoretical and applied perspective. Freshwater Biology, 15: 391-431.

Kedciora, A., J. Olejink and J. Kapuscinski, 1989. Impact of landscape structure on heat and water balance. Ecol. International, 17: 1-17.

Larsson, U., R. Elmgren and F. Wulff, 1985. Eutrophication and the Baltic Sea: Causes and consequences. Ambio, 14:9-14.

May, R. (Ed), 1975. Theoretical ecology - principles and application. 2nd ed. Blackwell, Oxford.

McCarthy, J., 1996. Estimating leaf area from satellite images for parameterising hydroclimatic modeling. Manuscript, submitted to Nordic Hydrological Conference 1996.

McGarigal, K., B.J. Marks, 1993. FRAGSTATS 1.0 - spatial pattern analysis program for quantifying landscape structure (program manual), Forest Science Department, Oregon State University, Corvallis.

Moore, I.D., Turner, A.K., Wilson, J.P., Jenson, S.K. and Band, L.E., 1993. GIS and land-surface-subsurface process modeling. In M.F. Goodchild, B.O. Bradley and L.T. Steyart (Eds), Environmental modeling with GIS, Oxford University Press, pp 196-230.

Naiman, R.J. and H. Decamps, 1990, (Eds). The ecology and management of aquatic-terrestrial ecotones. Parthenon Press Publ.

Odum, H.T. and E.C. Odum, 1981. Energy basis for man and nature, 2nd ed. McGraw Hill, New York.

Odum, E.P. 1993. Ecology and our endangered life-support systems. (2nd ed.) Sinauer, Sunderland.

O'Neill, R.V., D.L. DeAngelis, J.B. Waide, T.F.H. Allen, 1986. A hierarchical concept of ecosystem. Princeton University Press.

Peierls, B.L., N.F. Caraco, M.L. Pace and J.J. Cole, 1991. Human influence on river nitrogen. Nature, 350:386-387.

Peschke, G., J. Scholz and C. Seidler, 1991. Field investigations and temperature fluxes at atmosphere, soil and vegetation interfaces. In G. Kienitz, P.C.D. Milly, M. Th. van Genuchten, D. Rosbjerg and W.J. Shuttleworth, (Eds), Hydrological interactions between atmosphere, soil and vegetation. IAHS Publ. No. 204, pp 433-441.

Picket, S.T.A. and P.S. White, (Eds), 1985. The ecology of natural disturbance and patch dynamics. Academic Press, San Diego, California.

Pinay G.H. and H. Decamps, 1988. The role of riparian woods in regulating nitrogen fluxes between the alluvial aquifer and surface water: a conceptual model. Regulated rivers: Research and management, 2: 507-516.

Pinay, G. H. Decamps, E. Chauvet and E. Fustec, 1990. Functions of ecotones in fluvial systems. In R.J. Naiman and H. D,camps, (Eds), The ecology and management of aquatic-terrestrial ecotones. Parthenon Press Publ., pp 141-169.

Popper, K. 1979. Objective knowledge.(Rev. ed). Oxford University Press.

Prigogine, I. and I. Stengers, 1984. Order out of chaos, Bantam Books, New York.

Pringle, C.M., R.J. Naiman, G. Bretschko, J.R. Karr, M.W. Oswood, J.R. Webster, R.L. Welcomme and M.J. Winterbourn, 1988. Patch dynamic in lotic systems: the stream as a mosaic. Journal of the North American Benthological Society, 7: 503-524.

Richardson, J.L., L.P. Wilding and R.B. Daniels, 1992. Recharge and discharge of ground water in aquic conditions illustrated with flownet analysis. Geoderma, 53: 65-78.

Ripl, W., 1993. Management of water cycle: An approach to Urban Ecology. Water Poll. Res. J. Canada, 2: 221-237.

Ripl, W. 1995. Management of water cycle and energy flow for ecosystem control: the energy-transport-reaction (ETR) model. Ecological Modelling, 78: 61-76.

Ripl, W and Gumbricht, T. (1995) Integrating landscape structure and clean water production. Presented at Stockholm Water Symposium, submitted to *Ambio*.

Runkle, J.R. 1985. Disturbance regimes in temperate forests. In S.T.A. Picket and P.S. White (Eds), The ecology of natural disturbance and patch dynamics. Academic press, San Diego, California. pp 17-33.

Rådberg, J. 1995. Swedish urban typologi - a typomorphological study of Swedish urban environment focusing sustainability and quality. Royal Institue of Technology, Department of Architecture and Town Planning. TRITA-ARK 1995:2, Research report. In Swedish.

Shukla, J., C. Nobre and P. Sellers, 1990. Amazon deforestation and climate change. Science 247: 1322-1325.

Svedin, U. and B. Hägerhäll Aniansson, 1992, (Eds). Society and environment: A Swedish research perspective. Kluwer Academic Publishers, Dordrecht.

Taniguchi, M., 1991. Groundwater, thermal and solute transport between pine forest and pastureland. In G. Kienitz, P.C.D. Milly, M. Th. van Genuchten, D. Rosbjerg and W.J. Shuttleworth, (Eds), Hydrological interactions between atmosphere, soil and vegetation. IAHS Publ. No 204, pp 425-432.

Thorne, C.R., 1991. Analysis of channel instability due to catchment land-use change. In, N.E. Peters and D.E. Walling (Eds), Sediment and stream water quality in a changing environment: Trends and explanation. IAHS, Publ., No. 203, pp 111-122.

Turner, B.L., II, W.C. Clark, R.W. Kates, J.F. Richards, J.T. Mathews and W.B. Mayer, (Eds), 1990. The earth as transformed by human action. Cambridge University Press.

Veen, A.W.L., R.W.A. Hutjes, W. Klaasen, B.Krujit and H.J.M. Lankreijer, 1991. Evaporite conditions across a grass-forest boundary: A comment on the strategy for regionalizing evaporation. In G. Kienitz, P.C.D. Milly, M. Th. van Genuchten, D. Rosbjerg and W.J. Shuttleworth, (Eds), Hydrological interactions between atmosphere, soil and vegetation. IAHS Publ. No 204, pp 43-52.

WCED (World Commission on Environment and Development), 1987. Our Common Future. Oxford University Press.

Wiens, J.A., C.S., Crawford and J.R. Gosz, 1985. Boundary dynamics: a conceptual framework for studying landscape ecosystem. Oikos, 45: 421-427.

Wiman, B.L.B., 1991. Implications of environmental complexity for science and policy. Global Environmental Change, 1: 235-247.

Vitousek, P.M., 1985. Community turnover and ecosystem nutrient dynamics. In S.T.A. Picket and P.S. White (Eds), The ecology of natural disturbance and patch dynamics. Academic press, San Diego, California. pp 325-333.

Vorosmarty, C.J., M.P. Gildea, B. Moore, B.J. Peterson, B. Bergquist and J.M. Melillo, 1986. A global model of nutrient cycling: II. Aquatic processing, retention and distribution of nutrients in large drainage basins. In. D. Correll (Ed), Watershed research perspectives. Smithsonian Institution Press, Washington, DC, pp 32-56.