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Biebrza wetland research: required science for sustainable management

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Biebrza wetland research: required science for sustainable management

Abstract
A synthesis of research fields is required for a sustainable future of our planet. One of the ingredients suggested for seemingly conflicting scientific traditions is to 'embrace the science

of place'. Place-centered studies provide the best means we have for going beyond pattern to process and for identifying the actual mechanisms at work. Here we provide a case study in which we integrate a number of natural scientific disciplines. This interdisciplinary approach aims at sustainable management of natural resources such as water and biodiversity. We will demonstrate that the insights obtained go beyond the particular wetland we studied and have implications for preservation and restoration of wetlands elsewhere.
The Biebrza River (NE-Poland) is an almost natural lowland river with a mean annual discharge of about 30 m3/s. In 1921 and 1925 two strict nature reserves were established in the valley wetlands, originally to protect elk population and mires. In 1993 these became part of the Biebrza National Park, covering more than 59,000 ha, protecting the wetlands in the upper, middle and lower Biebrza basins.
Biebrza is quite undisturbed, making it for Europe a unique reference area for lowland valley mires and river floodplains. Nevertheless, it is changing and sustainable management needs proper scientific input. Regular field campaigns have determined ecological, surface and groundwater conditions and given insight in: plant-water relationships; effects of nutrient availability on floristic diversity; river ecosystem functioning; groundwater discharge to wetlands supporting habitat connectivity within natural fens; spatial and temporal heterogeneity of groundwater-surface water exchange processes; bush encroachment; and effects of changing land management. Analyses are supported by a suite of rainfall-runoff, hydraulic and groundwater models.
It is shown that due to interdisciplinary research Biebrza is a showcase for the analysis of spatial patterns of plant communities and occurrence of plant species, hydrological features such as groundwater discharge, river flooding and concomitant chemical water types and nutrient availabilities. Embracing Biebrza research is of great value for three reasons: gain fundamental knowledge on the functioning of these types of ecosystems; realize effective preservation strategies for the Biebrza wetlands; and design restoration measures for deteriorated ecosystems elsewhere.

Introduction

The environmental physicist Harte (2002) published a paper titled ‘Toward a synthesis of the Newtonian and Darwinian worldviews’. In this paper he argues that physicists and ecologists have a different intellectual tradition. Physicists (and we classify hydrologists in this paper as physicians), are determined from their education and the historical development of their field of science by a Newtonian approach. However, ecologists and ecology as a science is filled with ideas stemming from a Darwinian approach. Table 1 simplifies the Darwinian and Newtonian worldviews in opposing concepts (Harte, 2002). It is then argued that if one could come to a synthesis of these opposing worldviews this might offer opportunities in making progress towards attacking big research issues of the earth system science as: How will climate warming alter life? How important is biodiversity? What is needed for a sustainable future?

Table 1: Comparison of Newtonian and Darwinian worldviews (after Harte, 2002).

However, several difficulties can be expected in trying to solve these issues. For example is due to human activities the past not a reliable indicator for predicting the effects of actions. Further make mechanisms as feedback, non-linearity, thresholds and irreversibility complex and hard to predict functioning systems. Finally, there is an impossibility of performing largescale experiments, which could give insight to the problem, since the Newtonian approach demands inaccessible or impossible detailed data on initial conditions.

Harte (2002) suggests consequently three possible confronting ‘solutions’:
1. Give up the goal of prediction, start doing scenario building, pattern identification and historical analysis.
2. Force a complete Newtonian framework, i.e. build detailed predictive models and measure all necessary model parameters.
3. Stop improving knowledge: we know enough, so go straight to implementation of policies.

As usual there is not a simple one sentence solution and therefore only the following ingredients of synthesis, contributing to the solution, can be suggested (Harte, 2002). Firstly, aim initially for simple falsifiable models, which are mechanistic with lumped system variables. Secondly, search for patterns and laws e.g. spatial scaling and finally, embrace the science of a place, i.e. try to understand very specific environments, then it is possible to go from pattern to process and then to generalizations. In this paper we use the Biebrza wetlands as a specific example of a place centred study for wetland processes. We describe site characteristics, hydrodynamic, ecohydraulic, groundwater and ecohydrological features of these wetlands.

Study area

Biebrza (Fig. 1) is an almost natural lowland river of intermediate size (mean annual discharge c. 30 m3/s) running through a valley of about 1000 km2 in N.E. Poland (22°30' - 23°60'E and 53°30' -53°75'N). The valley contains non-drained floodplains, marshes and fens and surrounded by a post-glacial landscape with ice-pushed hills, moraines and outwash plains (Okruszko 1990). One of the principal aims of the Biebrza National Park (BNP) established in September 1991 is preservation and restoration of the unique nature values of the Biebrza Wetlands. The Park, the largest of its kind in Poland, protects the Biebrza River Valley with 60 000 ha of wetlands.

Figure 1 Location of Biebrza catchment and wetlands, in green the boundaries of the Biebrza National Park.

According to its geomorphologic description the Biebrza River Valley is an extensive depression formed during the last glaciation, filled with several thick deposits of fluvioglacial sands. Basing on features of its morphology, the Biebrza Valley has been distinguished into three basins: Upper Basin, stretching from the springs of the Biebrza to its confluence with the Netta River; Middle Basin, extending from the Biebrza-Netta Rivers confluence to its junction with the Rudzki Channel; Lower Basin, covering the southern part of the valley as far as the alluvial cone of the Narew River.

The natural and primary character of the Biebrza valley is reflected in a very regular pattern of plant communities, which run the length and breadth of the valley. However, this is not the case anymore in the Middle Basin which is affected by agricultural drainage. The characteristic zonation in the Upper and Lower Basin is as follows: floodplain along the river (absent in the Upper Basin), rich fens in the occasionally flooded belt further away from the river, transitional fen outside the reach of river floods and closer to the valley edge and finally rich fen along the valley edges. These vegetation gradients are smooth.

Anthropogenic changes introduced 150 years ago have disturbed the development of many wetland ecosystems mainly in the area of the Middle Basin. Channels were built in order to drain the area for the agriculture (Rudzki and Woznawiejski channels) or for navigation (Augustowski channel). Some small scale drainage works (ditches) were also introduced in the Upper Basin. The accumulation phase (characterized by a positive balance of organic matter) has been replaced by the compensation phase (characterized by an equilibrium between biomass production and decomposition) or worse by the recession phase (in which processes of mineralization of organic matter prevail over more favorable processes). In the recession phase hydrogenic sites dried out and peat structure deteriorated, which was accompanied by adverse changes of their ecological functioning. Substantial decrease of soil moisture retention and permeability leads to the development of plant species better adapted to water deficits.

The channels continued to serve their purpose while the area was under extensive agriculture, as long as harvesting hay from small, frequently remote meadow plots was still economically feasible. At present, this is no longer true for most of the area and farmers have been abandoning some of their plots.

Reduced soil moisture and changes in land use have resulted in the development of a patchwork of sites having a widely dissimilar value for nature. Less valuable areas, eg., as birch land with nettles are observed in the neighborhood of more valuable sites such as low sedge-moss ecosystems. The two principal permanent and widespread threats identified in the Middle Basin are expansion of scrub vegetation onto the no longer farmed open meadowland and fire hazard in overdried areas. Improvement is made difficult by a complicated ownership situation (the area being a mosaic of private plots and State property) and vague administrative competence (Biebrza National Park, State Forest, local commune self-governments).

Hydrodynamic modelling of Biebrza

Swiatek et al. (2008) developed a hydrodynamic model to investigate the most important flood characteristics for plant communities' development: flooding area, average depth of flooding and flooding frequency. Obtained results show that the variation of the flood extent is strongly related to the vegetation structure of the floodplain. It was proven that biota can have a significant controlling effect on flooding processes. As it was expected secondary succession, by introducing high vegetation on the floodplain area, modified significantly flood characteristic e.g. flood extend, flood depth and flooding frequency.

In the scenario of secondary succession birch forest and willow shrubs occurred over large areas of wetland. The flood extent and water depth increased significantly, which means that the area of plant communities dependent from rich surface water from the river like Phragmition and Magnocaricion will increase at the cost of more valuable plant communities (like sedge-moss meadows). Long lasting inundation also does not support the development of woody vegetation except the alluvial forests. Using the hydrodynamic model it was impossible to predict how much changes in flooding characteristic will affect the vegetation, changing in the next turn it's structure and location. Swiatek et al. (2008) state that secondary succession probably does not form a climax vegetation on the floodplain.

The other finding proofs that extensive use of floodplain, introduction of cattle grazing and/or sedge mowing once a year does not change significantly the hydraulic characteristics of the floodplain. It means that flooding properties of the floodplain remain almost the same.

The third conclusion from Swiatek et al. (2008) is that the hydrodynamic model is an appropriate tool for assessment of different agricultural practices and management scenarios with regard to flood extent and flood water depth in the valley. It is also an appropriate tool to estimate floodplain vegetation influence on flow conditions. It may be used as a tool to estimate new water surface level for restored rivers, especially for flood conditions, as well as to ensure suitable conditions for habitat diversity in projects of environmental flood management.

Ecohydraulics in the Biebrza

The Biebrza region provides a unique location to gather field data on ecohydraulic processes. The abundant presence of a highly diverse instream plant community makes this river a reference for many of the deteriorated streams in Western Europe. Furthermore, it allows us to test theory of plant influence on flow patterns in the field and to link the obtained data to models and lab-experiments.

Instream patches of Nuphar lutea, Potamogeton natans, Potamogeton perfoliatus, Potamogeton crispus, Myriophyllum spicatum and Sparganium emersum were selected for detailed measurements on vertical flow pattern related to vertical distribution of biomass and patch density within and around the patch. For all species measurements were performed under full and half density biomass conditions and linked to zero measurements, where all biomass was removed (Fig. 2). Vertical flow profiles were measured using an electromagnetic sensor on a longitudinal transect along a patch consisting of 5 points (1 point before, 3 in and 1 after the vegetation patch). The vertical distribution of plant biomass in the patch was measured using a 1*1 m vertically standing metal grid with 0.1*0.1 grid cells (Fig. 3). For each vertical 0.1 grid line all biomass was registered, weighted and number of stems and leaves per gridline counted.

Figure 2 Flow velocity profile data from a Nuphar lutea location without floating leaves (only submerged). All three lines are measured at the same location. The yellow line represents the no-plants situation, the blue and pink represent different densities. The difference in flow profile for different densities is limited, but differences with the noplants situation are strong.

Figure 3 Vertical biomass distribution of a patch of Potamogeton perfoliatus, recorded using a metal grid

Groundwater in the Biebrza

A steady state groundwater model has been developed for the Upper Biebrza Basin (Batelaan and Kuntohadi, 2002). Purpose of the groundwater model is to explore the groundwater feeding and system of the wetlands. Important aspects of this system analysis are the determination of the location and the quantification of the groundwater discharge to the river valley. The groundwater model has been set up by using MODFLOW as interfaced by GMS in combination with recharge simulation with the WetSpass model (Batelaan and De Smedt, 2007) integrated in a GIS. From the model it is shown that the simulated phreatic water table and areas of groundwater discharge show good agreement with respectively measured heads and occurrence of peat (Fig. 4). This shows the strong reliance for the wetland vegetation on regional groundwater flow from the morainic plateau to the valleys.

Figure 4: Left: Simulated groundwater discharge to the land surface, rivers, peat area, etc. per model cell of 200 by 200m. Right: Observed locations of peat occurrence in the Upper Biebrza catchment.

Van Loon et al. (submitted) performed a stationary groundwater transport modeling study to quantify the impact of shallow subsurface flow mechanisms on the presence of exfiltrated groundwater across a near-natural fen situated in the Biebrza Upper Basin. The results indicated that throughflow dispersed exfiltrated groundwater and locally infiltrated precipitation in various concentrations across the surface of the fen. This so-called throughflow mechanism provided an explanation for the major patterns in the shallow groundwater composition and in the plant alliances typical of fens and bogs. The results showed that throughflow (1) enabled a spatially continuous supply of exfiltrated groundwater across fens, and (2) facilitated abiotic conditions suitable for fen plants outside the zones that are directly supplied by exfiltrated groundwater. Even though throughflow was composed of a mixture of exfiltrated groundwater and locally infiltrated precipitation, it is the dominant hydrological mechanism driving suitable conditions for fen plants across the river valley. For this reason, the study of Van Loon et al. provides evidence that habitat connectivity within natural fens is facilitated by throughflow originating from elongated exfiltration areas adjacent to regional groundwater recharge areas. Knowledge of such hydrological mechanisms that underlie stable plant communities within natural fens is essential to improve current fen restoration and conservation strategies.

Ecology in the Biebrza

Plants require several nutrients of which nitrogen (N) and phosphorus (P) are amongst the most important nutrients. According to Liebig's Law of the Minimum, the growth of a plant will be restricted by the nutrient which is most limiting. Koerselman and Meuleman (1996) proposed the vegetation N/P-ratios as an efficient tool to predict possible limitation of the above-ground production by either N or P. Furthermore, Wassen et al. (2005) found that more endangered plant species are found in P-limited systems.

To gain a better understanding of the possible threats to plant diversity in the Upper Biebrza basin we collected the above ground biomass of several plant species along a hydrological gradient (Fig. 5) and determined their internal N and P concentrations with a H_2SO_4/H_2O_2 digestion after drying for 48h.

Along the hydrological gradient the vegetation composition changes from species rich small sedge communities to a less species rich Phragmition/Magnocaricion near the river Biebrza. Not only the vegetation composition but also the internal N and P concentrations change along this transect (Fig. 6). The plots situated near the river (plots 10-12) are not or only slightly N-limited. However, there is a shift in internal N/P-ratios with increasing distance from the river. The vegetation gets more P-limited with increasing distance from the river.

These differences can partly be explained by differences in plant available nutrients. Nutrient availability on its turn is largely determined by groundwater quantity and quality. Closer to the river there are more fluctuations in the groundwater table and hence a greater mineralization potential resulting in increased nutrient availability. Further away, continuous seepage leads to a rather constant, very shallow watertable, which limits mineralization opportunities. Apart from the groundwater quantity, differences in quality also influence the nutrient availability.

Further away from the river, Ca-enriched groundwater gains importance compared to surface or rain water. Higher Ca-concentrations result in a lowered P availability due to the formation of insoluble Ca-P-precipitates.

Figure 5 Hydrological transect with location of piezometers and vegetation plots

Figure 6 Nutrient concentrations of individual plants along transect. Ratios above 16 are indicative of P-limitation, ratios below 14 are indicative of N-limitation (Koerselman & Meuleman 1996). Open squares: plot 1-9; filled squares: plot 10-12

Wassen and Olde Venterink (2006) used the quite undisturbed Biebrza wetlands as a reference to compare with wetlands elsewhere which were dominated by human interference. Their aim was to evaluate the importance of historical increases of N- and P-fluxes on wetlands by comparing N- and P-budgets in western European sites with comparable sites in the Biebrza valley where atmospheric N-deposition and other nutrient fluxes were expected to be near to natural background levels. The studied wetland sites had a negative nutrient balance, which means that nutrients are depleted but only if mown annually, except for the western European fens which had an equilibrium N-balance and the Polish fen which had an equilibrium P-balance. For the N-budget it appeared that atmospheric deposition added significantly to the budget of western European fens and N-mineralization added significantly to fen and floodplain budgets, except for the Polish fens. Mineralization dominated the Nbudget of the western European floodplains. Hay-making was the most important output pathway, particularly if practiced annually. In the Polish fens this was less due to low atmospheric deposition and lower N-mineralization rates. The latter was associated with less drying out of the studied Polish ecosystems in summer (Wassen and Olde Venterink 2006).

Olde Venterink et al. (2009) carried out an in depth study of nutrient availabilities along a water-table gradient, and by comparing pairs of mown and unmown sites in Biebrza fens and floodplains. This enabled them to explore long-term effects of drainage and annual hayremoval on nutrient availabilities and vegetation response. In undrained fens and floodplains, N-mineralization went slowly (0–30 kg N ha-1 year-1) but it increased strongly with decreasing water table (up to 120 kg N ha-1 year-1). Soil N, P and K pools were small in the all sites but drainage had caused a shift from fen to meadow species and the disappearance of bryophytes. Biomass of vascular plants increased with increasing N mineralization and soil P. Annual hay-removal had induced a shift from P to K limitation in the severely drained fen, and from P to N limitation in the floodplain. They concluded that the low nutrient availabilities and productivity of the undisturbed Biebrza mires illustrates the vulnerability of such mires to eutrophication in Poland and elsewhere. In nutrient-enriched areas, hay removal may prevent productivity increase of the vegetation, but also may alter N:P:K stoichiometry, induce Klimitation at drained sites, and alter vegetation structure and composition. These are crucial factors for plant diversity since the relative availabilities of nutrients strongly determine the balance between competitors, ruderals and stress-tolerators. It seems that in relative nutrientpoor ecosystems such as the Biebrza fens many endangered species survive since they are adapted to low availabilities of especially phosphorus and nitrogen. In eutrophied western European fens these species have gone extinct because the elevated nutrient availabilities enabled competitive species to take over (Wassen et al. 2005).

Conclusions

In this paper we provided an integration of insights from a number of natural scientific disciplines leading to a better understanding of a complex freshwater ecosystem. The interdisciplinary approach was successful in bridging the gap between Newtonian and Darwinian scientific approaches and aimed at sustainable management of natural resources such as water and biodiversity in the wetland studied. We further demonstrated that the insights obtained went beyond the particular wetland and may have implications for preservation and restoration of wetlands elsewhere (see also Wassen et al. 2006). Embracing Biebrza research is of great value for three reasons: gain fundamental knowledge on the functioning of these types of ecosystems; realize effective preservation strategies for the Biebrza wetlands; and design restoration measures for deteriorated ecosystems elsewhere.

References

Batelaan, O. and Kuntohadi, T., 2002, Development and application of a groundwater model for the Upper Biebrza River basin. Annals of Warsaw Agricultural University – SGGW, Land Reclamation no. 33, p. 57-69.

Batelaan, O. and De Smedt, F., 2007, GIS-based recharge estimation by coupling surfacesubsurface
water balances. Journal of Hydrology, 337(3-4), 337-355, doi: 10.1016/j.jhydrol.2007.02.001.
Harte, J., 2002, Toward a synthesis of the Newtonian and Darwinian worldviews. Physics Today, 55(10): 29-34.
Koerselman, W. & Meuleman, A.F.M., 1996, The vegetation N:P ratio: A new tool to detect the nature of nutrient limitation. J. Appl. Ecol., 33, 1441-1450.

Okruszko, H, 1990, Wetlands of the Biebrza valley; their value and future management. Polish Academy of Sciences, Warszawa.

Olde Venterink, H., Kardel, I., Kotowski, W., Peeters, W. and M.J. Wassen, 2009, Long-term effects of drainage and hay-removal on nutrient dynamics and limitation in the Biebrza mires, Poland.
Biogeochemistry 93: 235–252.

Świątek, D., Szporak, S., Chormański, J. and Okruszko, T., 2008, Hydrodynamic model of the Lower Biebrza River flow - A tool for assessing the hydrologic vulnerability of a floodplain to management practices. Ecohydrology & Hydrobiology, 8, 2-4.

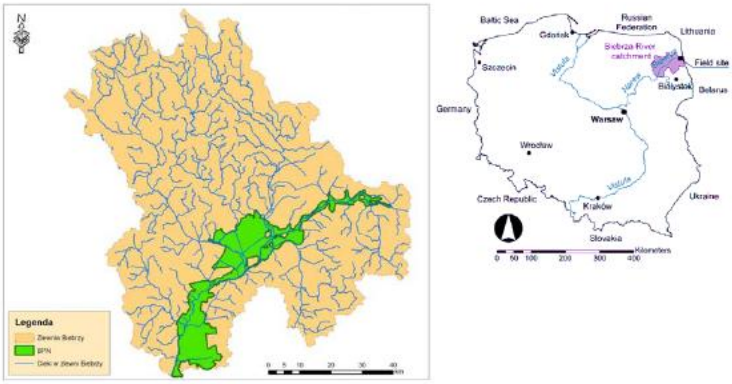
Van Loon et al., Throughflow as a determining factor for habitat connectivity within a nearnatural fen (submitted to J. of Hydrology).

Wassen, M.J., Olde Venterink, H., Lapshina, E.D. & Tanneberger, F., 2005, Endangered plants persist under phosphorus limitation. Nature, 437, 547-550.

Wassen MJ, Olde Venterink H , 2006, Comparison of nitrogen and phosphorus fluxes in some European fens and floodplains. Appl Veg Sci 9: 213–222.

Wassen, M.J., Okruszko, T., Kardel, I., Chormanski, J., Swiatek, D., Mioduszewski, M., Bleuten, M., Querner, E.P, El Kahloun, M., Batelaan, O. and Meire, P., 2006. Eco-hydrological functioning of the Biebrza Wetlands: Lessons for the conservation and restoration of deteriorated

wetlands. In: R. Bobbink, B. Beltman, J.T.A. Verhoeven and D.F. Whigham (Editors), Ecological Studies: Wetlands: Functioning, biodiversity conservation, and restoration. Springer, pp. 285-310.



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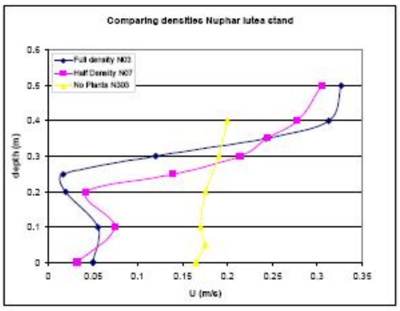

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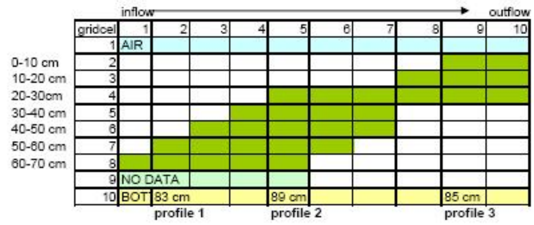

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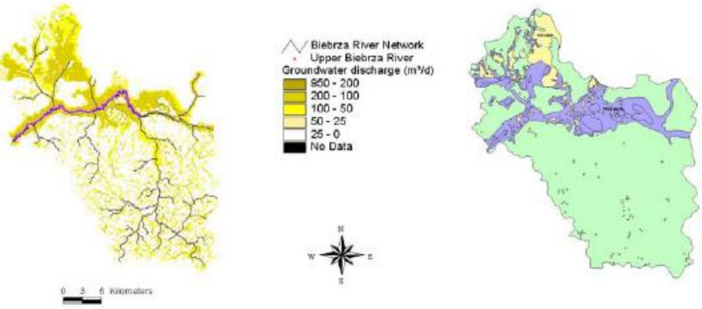

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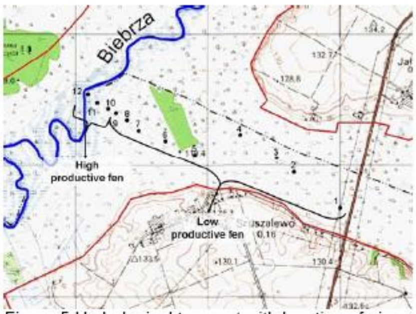

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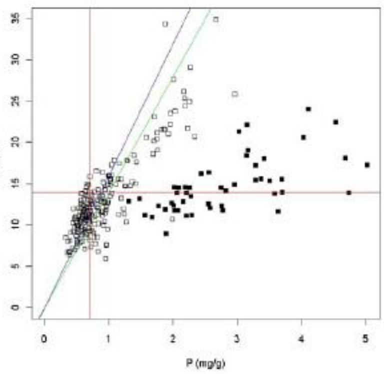

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figure 6

Table 1: Comparison of Newtonian and Darwinian worldviews (after Harte, 2002).

PHYSICS	ECOLOGY
The more you look the simpler it gets	The more you look, the more complex it gets
Primacy of initial conditions	Primacy of complex historical factors
Universal patterns; search for laws	Weak trends; reluctance to seek laws
Predictive	Mostly descriptive, explanatory
Central role for ideal systems	Disdain for caricatures of nature

table 1

Presentation Preference
Additional information