Searching for spatial patterns in the northern environments – Modern physical geography at the University of Oulu

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Abstract: In physical geography, the focus of research is on the natural processes of the Earth which provide the physical settings for human activities. Technical innovations like geographical information system (GIS) and remote sensing combined with statistical analysis have become effective approaches to study complex spatial patterns at various scales. Many of modern physical geography studies concentrate on exploring the human–environment relationship and assessing possible future changes caused by the global change. Geographical approach has proven to be crucial in understanding for example climate change and the degradation of ecosystems and biodiversity, particularly in northern environments. Changing environmental conditions and increasing human impact on our environment have set the scientist in front of a new challenge to solve conflicts between conservation and use of natural resources. These challenges have provided new research possibilities for physical geography. In this paper, we highlight the current study ensembles of the physical geography research group working at the University of Oulu, and address some opportunities and challenges physical geography is facing in the future. Basically, a geographical approach is crucial in studying changing northern environments so that the comprehensive and holistic point of view is not forgotten. Physical geographers with a working knowledge of modern GIS methods and spatio-temporal modelling tools can significantly contribute to the study of cutting-edge environmental issues.

Introduction

Modern physical geography (PG), relies intensely on empirical data and quantitative analysis first developed in the middle of 20th century. Contemporary PG studies various physical components and natural processes of the Earth across temporal and spatial scales (Arbogast 2007). These components and processes provide the physical setting for human activities, for which human-environment relationship is one of the key research agendas in PG (Strahler & Strahler 2005). At the moment, physical geographers are at the center of global change and ecosystem service research (e.g. Thuiller *et al.* 2000; Haines-Young *et al.* 2012).

Technical innovations have significantly changed the nature of the discipline since the origin of modern PG. The focus of research has shifted to gradients at relatively large-scales thanks to improved computer capacity combined with geographical information system (GIS), remote sensing (RS) and spatial statistical analysis (Figures 1 and 2). Thus, physical geographers can investigate the functioning of regional environment systems, possibilities to utilize natural resources and environmental tolerance to anthropogenic, human activity related, stress. In addition, developments in geographical theories have supported PG research substantially. In particular, spatial scale issues have been emphasised in PG during the recent years. For example, environmental variables representing a biotic community structure or an abiotic feature are typically hierarchical, as large-scale processes and constraints interact with biotic and abiotic factors across scales (Field *et al.* 2009; McGill 2010). Thus, environmental mechanisms operating at regional scales may, for example, exceed local-scale patterns in the distribution of species and abiotic features (Hjort *et al.* 2010; Sormunen *et al.* 2011; Varanka & Luoto 2012; Alahuhta & Heino 2013).

Northern environments are important study realms for PG. Firstly, information on natural phenomena is well documented in many high-latitude regions. This

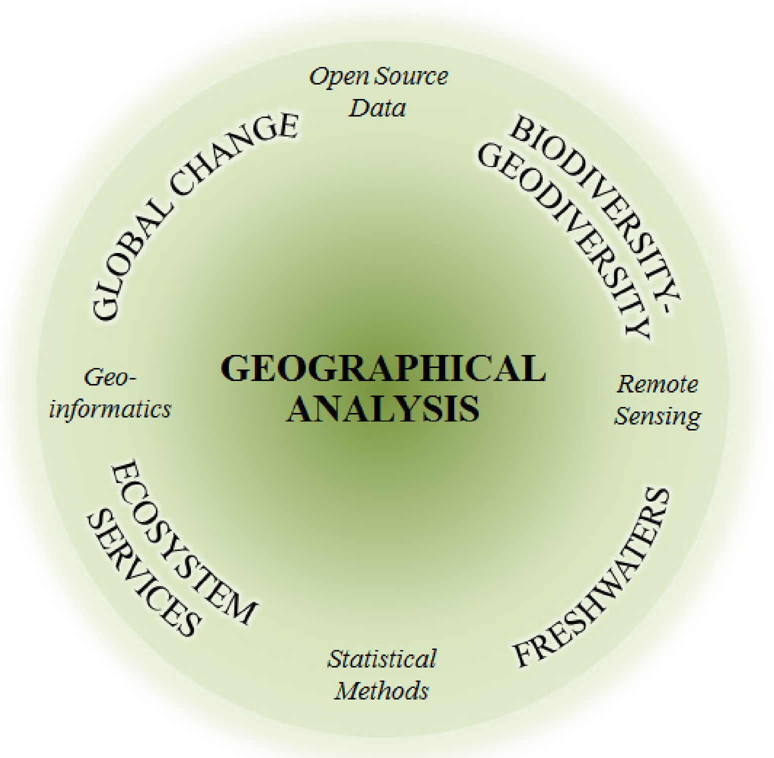

Figure 1. Geographical analysis is in the core of each study topic of the physical geography research group working at the University of Oulu. Used methodology is given in italics.

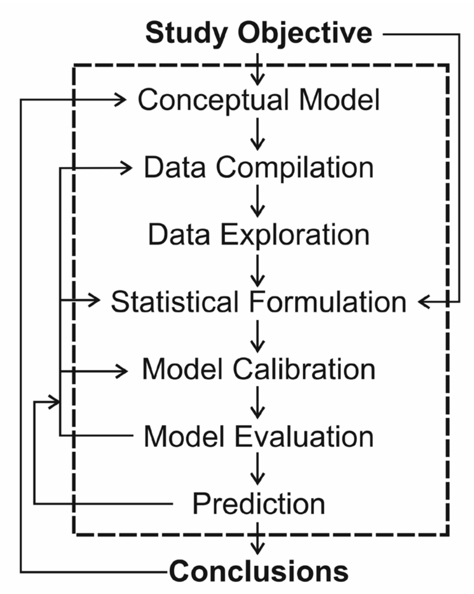

Figure 2. A conceptual model how statistically-based spatial modelling is performed (Hjort & Luoto 2013).

offers good possibilities to use northern environments as natural laboratories to address burning research topics (Figure 3). For example, many geographical patterns, such as latitudinal and altitudinal gradients, are evident in the high-latitudes. Secondly, northern environments provide valuable ecosystem services and natural resources to people living in and outside these areas. Thirdly, many of the northern ecosystems are vulnerable to changing conditions, for which it is important to understand the functioning of marginal ecosystems in the face of global change.

In this paper, we shortly review the current study ensembles of physical geography research group working at the University of Oulu, and highlight some opportunities and challenges PG is facing in the future.

Current research ensembles

Geodiversity–biodiversity relationships in northern environments

The loss of biodiversity is a key environmental issue at the moment (e.g. Hooper *et al.* 2012). Mapping and measuring biodiversity is a challenging task, especially in extensive remote areas. Thus, robust and efficient methods for cost-effective measuring and targeting of biodiversity conservation are urgently needed. In recent years, the concept of geodiversity has been put forward as a new promising approach to explore biodiversity at different spatial scales (Anderson & Ferree 2010; Beier & Brost 2010). Geodiversity refers to the variability of the Earth's surface materials, forms, and physical processes at different scales (Gray 2013). In general, there is a lack of studies where geodiversity has been systematically inventoried across environments and scales. Importantly, the potential of geodiversity as a surrogate of biodiversity has not been assessed using comprehensive biological and geodiversity data sets. To address this gap in the literature, our studies focus on: (1) quantifying spatial patterns of geodiversity in different regions and at various scales (e.g. Figure 4; Hjort & Luoto 2010), (2) determining the key factors that control the variability of geodiversity (e.g. Hjort & Luoto 2012) and (3) exploring the relationship between geodiversity and biodiversity (Hjort *et al.* 2012).

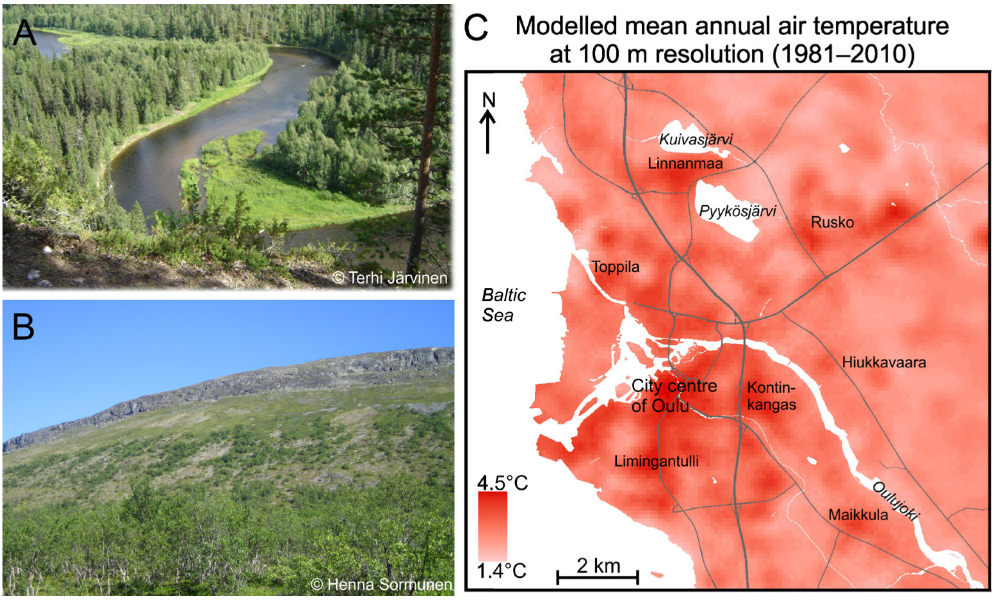

Figure 3. Northern environments offer countless study possibilities for physical geography ranging e.g. from aquatic ecosystems (A) to tree-line ecotone (B) and urban environments (C). The urban temperature map (C) for the city centre of Oulu and adjacent areas was produced using a statistically-based spatial modelling approach (Hjort et al. 2011).

Spatial variation of ecosystem services, biodiversity and human health

There has been an elevated interest, especially since the release of the Millennium Ecosystem Assessment (MA 2005), in what is referred to as the 'ecosystem service' concept, meaning the benefits that humans derive from ecosystems (Seppelt *et al.* 2011). Especially after the MA and The Economics of Ecosystems and Biodiversity study (TEEB 2010), the awareness of the negative impacts of the biodiversity loss have on human well-being have increased. In addition, many studies have shown that biodiversity and ecosystem services have intrinsic link to each other, with biodiversity playing a key role at all the levels of ecosystem services (MA 2005; Egoh *et al.* 2009; Mace *et al.* 2012; Alahuhta *et al.* 2013b). Despite recent findings, there is still a need to estimate the spatial connection between the areas which produce ecosystem services and supports physical structure that makes up biodiversity (Naidoo *et al.* 2008; Burkhard *et al.* 2012). For example, attention needs to be paid to the fact that biotic nature is only a part of the structural composition of environment with abiotic components forming an equally fundamental component of ecosystems. Unfortunately, ecosystem disservices (e.g. Dunn 2010) and position of human settlements in relation to ecosystem services have received relatively little attention among the research discipline.

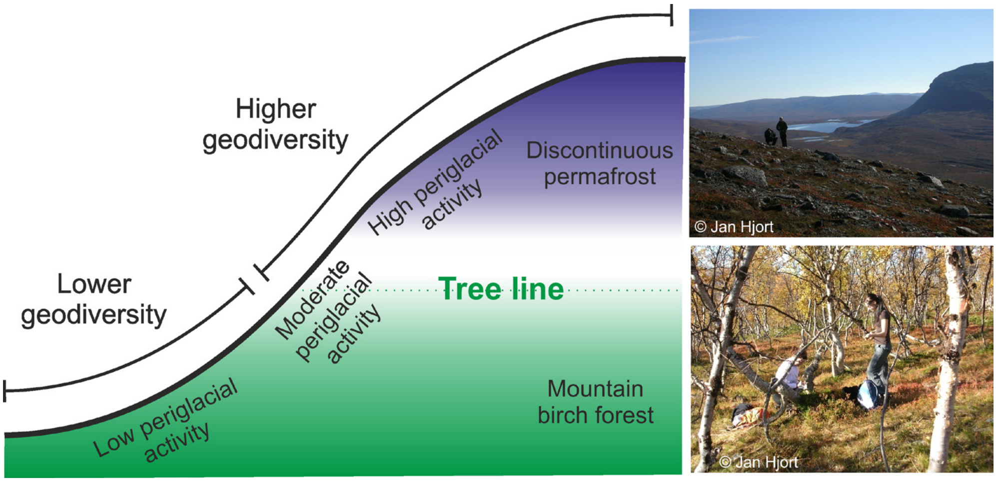

Figure 4. An example of the relationship between geodiversity and periglacial process activity in northernmost Finland (Hjort & Luoto 2008, 2010).

To date few studies have evaluated the spatial concordance among biodiversity, geodiversity and ecosystem (dis-) services, especially in the northern environments.

Climate change and the degradation of ecosystems are among the biggest global health threat of the 21st century (e.g. MA 2005; McMichael *et al.* 2006). Global climate change and the associated changes in emissions of air pollution, concentrations of allergenic pollen, ecosystems and land use impact both outdoor and indoor exposures which have adverse effects on human health. Physical geography research group is contributing to a research program that applies multidisciplinary research methodologies (including expertise in public health, medical sciences, environmental and ecosystem service research, GIS and computing science) to respond to health impacts related to global climate change. In addition to addressing adverse health effects, our research program focuses on ecosystem services and functions that promote public health and human well-being. There is an urgent need for a more systematic inventory of current and likely population health impacts of ecosystem change. Our research into ecosystem services, biodiversity, and human health in northern environments addresses this shortcoming.

The overall purpose of the ecosystem services ensemble is to 1) study how biodiversity, geodiversity and ecosystem services co-vary geographically in Finland across spatial scales, 2) explore the geographical relationships between human settlements and ecosystem services, and 3) develop methodologies to (i) map health-related ecosystem services and (ii) predict the distribution of allergenic pollen and concentrations of air pollutants in urbanized areas across scales.

Large-scale patterns of northern freshwater biota and water quality

The number of biogeographical studies from freshwater ecosystems has increased from the early 2000s onwards (Heino 2001; Ulmack 2001), and the investigations conducted at large-scales have become firmly established in freshwater ecology. Understanding the large-scale gradients in northern freshwaters is highly important due to changing environmental conditions, which alter the biotic and abiotic features of freshwaters (Heino *et al.* 2009). Changing environmental conditions are also directly related to species traits, which can provide a better generality in understanding and predicting the assembly of ecological communities and ecosystem functions than approaches based on species identity alone (McGill *et al.* 2006). In addition, the freshwaters offer a relatively fixed environment to study different large-scale biogeographical patterns, such as a latitudinal gradient, which are mostly explored in terrestrial ecosystems (Field *et al.* 2009). But, there is a clear bias in the studied freshwater biological groups at large-scales, as most of the studies have focused on fish and macroinvertebrates (Ulmack 2001). Investigations on the less well-known groups can yield contradicting results, influencing on the generality of the studied phenomenon (Alahuhta & Heino 2013).

Water quality is the outcome of countless landscape factors in the catchment. Land use, soil deposits, bedrock, topography, geomorphological processes and climate participate in different catchment processes, and thus, affect water quality (e.g. Ye *et al.* 2009; Varanka & Luoto 2012). GIS-based methods combined with statistical analysis and modelling are effective approaches in water system studies (e.g. Zhou *et al.* 2012). These methods enable investigation of the multi-scale relationship between environment and water quality and forecasting possible changes in the future. Environmental characteristics provide an essential baseline for cost-efficient estimation and prediction of water quality attributes of boreal water systems in space and time.

The main objectives of the freshwater and water quality research ensemble are to study 1) large-scale patterns of freshwater biota and water quality at various spatial scales, 2) biogeographical and macroecological theories using freshwater assemblages such as aquatic plants as a model group, and 3) spatial patterns in freshwater bioassessment.

Global change across temporal and spatial scales: biogeographical and geomorphological perspectives

Human-induced climate change, habitat fragmentation and loss as well as land use changes are global threats that are changing the atmosphere, climate, hydrology, biodiversity and even earth surface processes and ultimately landscapes (Hooper *et al.* 2012). High-latitudes are experiencing rapid and significant change associated with climate warming. This places global change research at the centre of the international scientific agenda. A key aim of the global change research is to improve understanding and forecast the nature of change in the biogeographical and geomorphological systems, particularly at high latitudes (Christiansen *et al.* 2010; Virtanen *et al.* 2010; Alahuhta *et al.* 2011b; Sormunen *et al.* 2011).

Possible changes in the structure and position of treeline ecotone and changes in species occurrence and patterns of biodiversity in space and time can be studied using species distribution modelling. When predicting changes in treeline ecotone we cannot simply use the changing temperature patterns alone, but we need to consider the complex interactions between biotic and abiotic factors. When we include local abiotic and biotic information into bioclimatic models the assessments of climate change impacts on subarctic vegetation and biodiversity alters significantly (Sormunen *et al.* 2011; Wisz *et al.* 2013). Hence, we need to build more complex and ecologically realistic models. The new approach is linking functional traits with multi-species distribution models. The functional traits define how the species interact with the environment and with other species. Plants with similar functional traits respond to the environmental change in similar ways (Gitay *et al.* 1999; Rozman *et al.* 2013). The novel modelling techniques and higher quality of data will significantly advance species distributions modelling. This will improve the understanding of sensitivity of subarctic tree-line to climate change.

Determination of the environmental factors controlling earth surface processes and landform patterns in cold regions is one of the central themes in periglacial geomorphology. Recently, novel statistical techniques and modelling methods have gained more attention in the field of periglacial geomorphology (e.g. Berthling *et al.* 2013; Plater *et al.* 2013). Especially in the context of global change, spatial models are essential tools for assessing the impacts of changing environmental conditions on geodiversity and geomorphological processes (Fronzek *et al.* 2006; Hjort *et al.* 2010, 2014).

In this context, the main objectives of the physical geography research group is to investigate 1) the impacts of climate change on the high-latitude tree-line ecotone and periglacial processes (e.g. permafrost), 2) the spatial and temporal changes in high-latitude biodiversity patterns, and 3) evaluate the accuracy, utility and feasibility of statistically-based spatial models in examining tree-line ecotone and periglacial processes.

Future possibilities and challenges

Sophisticated statistical methods combined with comprehensive data sets have placed PG at the heart of the natural sciences. The number and quality of journals in the field of PG has grown in the 21st century. High quality of the journals, such as Journal of Biogeography, Geomorphology and Progress in Physical Geography, has inspired scientists from other disciplines to publish their results in these journals. Other natural sciences have also adopted methodologies from PG that emphasise the vital role of geographical topics, for example spatial autocorrelation and spatial scale issues. Wider interest in geographical perspectives has pushed physical geographers to publish their work in non-geographical journals (e.g. Marmion *et al.* 2009; Varanka & Luoto

2012; Hjort *et al.* 2012; Alahuhta *et al.* 2013a; Kuusisto-Hjort & Hjort 2013). This has extended the possibilities for geographers to reach a broader audience and strengthen the role of PG within the natural sciences.

Every phenomenon around us has a geographical dimension, which can be analysed and mapped using geographical analysis. For example, distribution of pollen from allergy-induced plant can be modelled and linked to presence of asthmatic people. Increased conflicts between man and environment provide new research possibilities for PG outside its traditional agenda (e.g. Hanski *et al.* 2012). One of the most interesting new designs is accessibility measures used in geoinformatics and how they can be utilized e.g. to model dispersal of species.

Modern PG strongly relies on comprehensive data sets based spatially-oriented statistical methods that have both quantitative and qualitative dimensions. An important trend is to make different data freely available for scientific purposes. This allows physical geographers to build large data sets that not only have an improved quality, but facilitate cutting-edge analyses of rapidly changing northern environments (e.g. Christiansen *et al.* 2010; Alahuhta *et al.* 2011a). In the face of global change, decision makers need accurate and reliable estimations on northern physical environments, their transformation, and what should be done to delay or prevent any undesirable changes (Serreze *et al.* 2000; Broström *et al.* 2008; Christiansen *et al.* 2010; Alahuhta *et al.* 2011b).

Statistical modelling has given scientists new tools to study complex spatial patterns in nature (Guisan & Thuiller 2005; Elith & Leathwick 2009; Hjort *et al.* 2014). Physical geographers have moved beyond simple linear models to investigate and predict non-linear spatial patterns in nature, particularly when considering problems of anthropogenic influence on the environment. The development of more accurate and reliable statistical models offers physical geographers many possibilities to understand, importantly, the spatial aspect of human-environmental change. (e.g. Parviainen *et al.* 2008; Marmion *et al.* 2009). Nonetheless, increased emphasis on statistical techniques can produce potential challenges. As the number of different statistical methods increases, we need to caution against lost in technical details and possibly overlook environmental realities and restrictions (Austin 2007; Jiménez-Valverde *et al.* 2008; Araujo & Peterson 2012). That said, the future of PG rests on the shoulders of students, who should not display any unnecessary anxiety regarding quantitative methods such as spatio-temporal statistical modelling. The awareness of GIS methods utilized in PG is already acknowledged among the students. However, it is advisable to underline the need of statistical skills to study PG, because this guarantees the high quality of the research in the future.

A physical geographical approach is crucial for maintaining a comprehensive and holistic point of view of changing northern environments. Physical geographers with the knowledge of modern GIS methods and spatio-temporal modelling tools can significantly contribute not only to the natural sciences and public policy, but also to new multidiscipline research programs and, hopefully, future scientific breakthroughs.

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