Chapter 6
Indicators for Monitoring Climate Change-Induced Effects on Habitats – A Wetlands Perspective

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6.1 Introduction

Climate change is expected to become a major threat to biodiversity by influencing the quality of landscapes and habitats. Thus monitoring techniques need to be adapted to provide information on climate change induced impacts in habitat conditions in the long run in order to be able to adapt management strategies in respective protected areas. Climate change may affect many ecosystem functions; consequently, specific indicators of symptoms of ecosystem degradation shall address various ecosystem properties and effects due to different pressures

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including climate change. Climate change-driven impacts overlap and interfere with other environmental pressures of various origins, and their effects may be observed as multifaceted changes in ecosystems. For the purpose of management decisions, the extent of these changes shall be evaluated using ecological indicators as measures providing insight into the state of the environment by quantifying habitat conditions.

An ecological indicator is a numerical value derived from measurements of selected ecosystem/habitat properties, used for detecting and describing environmental changes over space and time (Duelli and Obrist 2003; Maxim 2012; Bauler 2012; Heink and Kowarik 2010a; Dziock et al. 2006). Indicators are usually designed to reflect the achievement of specific goals. Moldan et al. (2012) specify two approaches of goal setting:

- Perspective oriented – established in the course of political debates; policy relevant indicators can be used to assess the effectiveness of legal regulations adopted in order to reach definite goals, such as to limit CO_2 emission to the atmosphere;
- Long and short term – adopted at regional or local level and defining the needs to measure and monitor ecosystem conditions and trends including the impacts of climate change; in the latter case, the environmental properties which are particularly sensitive to pressures of climate change would be of best indicatory value.

There are several systems of indicator typology (Maxim and Spangenberg 2006). The EEA classification of indicators distinguishes four simple groups including descriptive, performance, efficiency and welfare indicators within the system of the "DPSIR" or "drivers, pressures, state, impact, response" indicators (EEA 2007). Drivers and pressures embrace indicators of anthropogenic pressures on the environment, such as land pollution or relief changes while the state and impact indicators measure the resulting environmental effects, including habitat sensitivity to stresses. Climate change-relevant indicators for habitat monitoring belong, according to EEA, to the subsets of descriptive impact and state indicators. In contrast, the Millennium Ecosystem Assessment (MEA) proposes that drivers can be both anthropogenic and natural factors that directly or indirectly cause a change in an ecosystem, thus climate change indicators can be assigned to the driver class also (Maxim and Spangenberg 2006).

In this chapter we focus on long and short term ecological indicators which can be used for tracking and monitoring climate induced changes in habitat quality, especially in wetland habitats. Consequently, they can be used for adaptation of conservation planning. The assessment of habitat changes with the use of indicators requires the values measured (metrics) to be validated (Bockstaller and Girardin 2003). Not many ecological indicators have so far been empirically tested to determine if they meet the criteria by which they were purportedly chosen.

The validation of indicator reliability may be made using reference standards, normative values and limit numbers as well as by referring to iterative measurements performed in selected habitat compartments. Under the HABIT-CHANGE project, some indicators of habitat sensitivity to climate change were experimentally validated in wetlands (in the Biebrza National Park). An attempt was made to determine which impact indicators are most sensitive and valid for monitoring climate change effects in wetland areas and how these indicators may be applied in monitoring (short and long term) for management purposes (Ostrowska 2010; Heink and Kowarik 2010b; Ostrowska and Sienkiewicz 2011). It was found that changes in peat soils, including, in particular, changes in the contents of carbon and nitrogen and their water soluble forms as well as in soil solution concentrations, are correlated with the dynamics of precipitation and temperature over several decades.

6.2 Criteria to Select Indicators for Monitoring Climate Change Effects on Habitats

Climate change leads to a variety of effects in habitats including changes in water and nutrient circulation, soil quality and community structure and functions. This diversity of effects results in a diversity of assessment situations and requires many procedures and indicators whose performance can be directly associated with climate change over time. Over the last several years a variety of ecological indicators have been developed to document the status and changes in environmental quality. Ecological indicators include both site-specific, field-derived metrics and landscape-level properties (Tiner 2004; Stratmann et al. 2011). An extensive literature review made under the HABIT-CHANGE project yielded comprehensive lists of selected applicable indicators addressing climate change-induced effects in various habitats, based on hydrological, soil, botanical, plant sociological, zoological and climatologic metrics (Förster et al. 2010; Vohland et al. 2011; Stratmann et al. 2011).

The indicators vary from simple ones indicating changes in climate such as temperature, water balance, snow cover and water deficit, to indices of land cover derived from remote sensing at landscape and regional scales to the site specific indicators of climate change effects which have been developed based on field study and measurements. Remote sensing detection tools for natural resource managers in the context of climate change are discussed in Chap. 7. Here we focus on site-specific indicators that rely on environmental properties which are most sensitive to climate change and are helpful in qualifying and simplifying the complex phenomena of habitat changes. These changes are typically due to multiple stresses; therefore the effect of an individual stressor such as climate change cannot be easily separated from that of other pressures. The difficulty in selecting such purpose-oriented indicators arises from the dynamics of natural processes and of local environmental conditions (Dahl 2012).

The practical criteria for selecting appropriate indicators should be related to such qualities as their capacity to inform about complex changes in habitats and landscapes, to supply reliable information on the status and trends and, at the same time, to allow for quantification of the intensity of changes. As indicators have double function: to supply information and to support management decisions, they also need validation against their utility to the end-users. Management decisions in protected areas concern mainly the maintenance of favourable status of specific habitats and species by controlling pressures which change environmental quality. Thus, indicators should allow for monitoring the efficiency of measures applied to mitigate pressures on habitats. Therefore, we concentrate on indicators that, being relatively simple, reflect collective response of target habitats, and respond in an integrative way to environmental stresses (relevant and efficient), providing an overall ecosystem performance which can further be used as reference for predicting habitat sensitivity to climate changes. It is important to note that notwithstanding the fact that the extant typologies divide ecological indicators referring to such criteria as assessment methods and spatial scales at which they are applied (global, landscape, local, site), the indicators on various levels are complementary in evaluation and prediction of habitat changes and should be considered jointly in order to provide effective help to the managers in protected areas (EEA 2012).

6.3 Indicators for Monitoring Climate Change at Landscape and Habitat Levels Focusing on Wetlands in Biebrza National Park

The Biebrza National Park (BNP) embraces about 60,000 hectares of wetlands on peat soils in the Biebrza Valley. The distribution of local wetland habitats reflects both site hydrology and management intensity showing typical zonation of the river valley (Oświt 1991). In the BNP there prevails mainly extensive agricultural management, but socio-economic changes over the last three decades resulted in partial depopulation of the countryside and abandonment of traditional agricultural practices. This initiated forest succession and led to disappearance of semi-natural landscapes and habitats of many species as is the case with abandoned meadows in BNP. The indicators of effects of these driving forces include changes in land use pattern, landscape patchiness and richness of landscape elements which may be traced with indices based on analysis of land coverage. It is generally acknowledged that climate-induced alterations in landscapes may best be evaluated by structural analysis including the assessment of land use pattern, complexity, shifts in ecosystem boundaries and their fragmentation (Watts and Handley 2010). The indicators at landscape level suggested and partially tested in the BNP are given in Table 6.1.

As mentioned above, schemes of land cover-based indicators rely on visual scales using various data sources including remote sensing, aerial and landscape photographs (EEA 2006; Ode et al. 2010b). Visual scales allow for the determination of such features of landscape visual structure as land use pattern, complexity, disturbance and naturalness. Complexity refers to the diversity and richness of landscape elements and features and the interspersion of patterns in the landscape using e.g. LDI and EMS indices (Ode et al. 2010b). The quality of data obtained in visual analysis varies depending on image resolution, period when it was taken and accurateness of its interpretation. In the Biebrza National Park, the assessment of richness of landscape elements (complexity), i.e. the presence of patches of forest and shrubs,

Table 6.1 Landscape level indicators of habitat change in support of land management at BNP (Stratmann et al. 2010)

No.	Indicator	Interpretation of measure
1	Diversity of land cover categories	% share of open habitats per area unit, % share of shrub and forest habitats per area unit
2	Presence of water	% share of water bodies per area unit
3	Richness of landscape components/ elements	Number of various elements
4	Landscape diversity index (LDI)	Evaluation of diversity of land cover types in a given area, based on land-use maps, remote sensing and calculation of land-use classes within a defined area
5	Effective mesh size (EMS)	The effective mesh size measures landscape fragmentation due to linear elements such as technical infrastructure; the indicator measures landscape fragmentation in ha, ranging from 0 ha (totally fragmented) to the area size of the largest patch investigated for the region (the procedure is described by Moser et al. 2007)
6	Land cover diversity based on data from remote sensing and interpretation of imagery	NDVI (Normalised Difference Vegetation Index) – the index calculated from light reflectances measured in the visible and near infrared channels as the normalised difference between the near infrared and red reflectance values; NDVI is related to the fraction of photosynthetically active radiation absorbed by chlorophyll; NDVI has been correlated with a variety of vegetation parameters such as abundance, productivity and biomass LAI (Leaf Area Index) – a dimensionless variable defined as the maximal projected leaf area per unit ground surface area. LAI is used in remote sensing to quantify many biological and physical processes such as primary productivity, plant respiration, transpiration, photosynthesis and nutrient cycles VM (Vegetation Moisture) – the vegetation water content is defined as water volume per leaf or ground area of the amount of water per dry vegetation mass and is applied to assess e.g. water deficit or drought stress in vegetation
7	Edge density/spatial configuration/variation of element shape	Expressed as ratio: length per area unit; e.g. m/ha
8	Habitat fragmentation/patchiness	Number of patches per area unit; e.g. 1 = one large open area; 2 = split open area; 3 = patchy open area
9	Area visually affected by disturbance	% of area classified as visually disturbed per area unit
10	Agricultural intensity index	Agricultural intensity index measures the proportion of intensively used agricultural area in the total agricultural area; constitutes a common indicator to measure intensification of agriculture
11	Changes in ranges of plant communities	Observation of changes based on field measurements and mapping/ study of archival data
12	Wind and water erosion/physical degradation of land cover/denudation	Number of sand dunes, erosion gullies, etc. features per area unit; change in soil and water coloration according to Munsell scale

may best be done using aerial photographs taken in October, while the assessment of meadow cover diversity with those taken in July (Tomaszewska 1988). This author found that complexity of landscape attributes in the Biebrza Valley has considerably increased over the preceding three decades due to encroachment of shrubby and woodland vegetation onto the open landscape. This was also corroborated by Piórkowski and Rycharski (1999). The accurateness of image interpretation is largely dependent upon the indices which result from the comparison of image readouts and data obtained in the course of in-situ survey or ground truthing (Tomaszewska 1988). The evaluation of changes in the land cover diversity of Biebrza Valley may also be interpreted from aerial photographs with the use of such indices as NDVI – Normalised Difference Vegetation Index, LAI (Leaf Area Index) and VM (Vegetation Moisture). In the latter case, the images need to be taken at the peak of vegetation season (Tomaszewska 1988). Other important indicators rely on erosion phenomena – transportation of soil material and physical deformation of soil surface as well as on biodiversity in terms of changes in the flora and fauna species richness. The latter attributes depend largely on climate changes both in the long term and as short term disturbances. Temporal resolution for evaluations of changes at landscape level based on remote sensing imagery was defined for several year (3–5) intervals (Tomaszewska 1988). The changes in wetland landscapes in BNP are conditioned to a great extent by the changes in the local hydrological systems – water cycle, inflow and outflow (Kucharski 2010; Schmidt et al. 2000).

According to Jones-Walters (2008), biodiversity may be used as an indicator for assessing changes at landscape scale (contribution of individual ecosystems – assessment of landscape patchiness) and for the estimation of changes in individual ecosystems, especially to evaluate their fragmentation. Changes in the behaviour and distribution of birds as a group and individual species provide metrics for indicators of climate change at national, regional and global levels. The same is valid for amphibian species and populations which are extremely sensitive to changes in climatic and site parameters. Being comparatively easy to monitor with standard methods, they may be applied as indicators at various spatial scales, e.g. metrics built on species composition and population size at biotope or habitat level, and those built on data of species assemblages (composition, species richness, diversity) at the protected area level.

Changes in air, soil and water temperature, in precipitation, humidity and radiation affect animal and plant life cycles, in particular wetland plant communities and amphibian populations are highly dependent on climate changes. Observations of amphibian behaviour (migration time/e.g. earlier or later, reproduction time), reproduction success (number and size of clutches, developmental time/metamorphose rates, sex ratio) and habitat quality (spawning water temperature, presence of winter habitats for hibernation) provide bases for indicating changes at habitat level (Table 6.2).

Plant cover, phenology and species composition provide for one of the best indicators for monitoring climate-induced changes in habitats on condition that the observations are repeated over a long time period since e.g. “community structure” and “species composition” show net assignment to fluctuations in abiotic parameters such as light, temperature and water availability. Soil organic matter (SOM) is

Table 6.2 Habitat level indicators of climate change induced habitat changes

No.	Indicator	Interpretation of measure
1	Changes in local water balance (inflow/outflow)	Depicts local hydrological conditions; water balance deficit expressed as difference between precipitation and runoff; defines the degree of plant community vulnerability versus water shortage
2	Soil water – maximum water holding capacity (MWHC), field water capacity (FWC)	Evaluates soil porosity and general water storage capacity
3	Water availability to plants (WAP)	Provides information on the water accessibility to plants
4	River discharge	Provides information on the rate of water loss from wetlands
5	Depth of groundwater table	Provides information on water availability/water deficit for plant communities
6	Nitrogen load in water	Provides information on local water pollution and on the rate of peat soil mineralisation
7	Soil nitrogen, including changes in: $N\text{-}NO_3/N\text{-}NH_4$ rate; $N\text{-}NO_3$ content, with limit ranges of 5–10 mg/dm^3 of soil which denotes low level mineralisation, and >40 mg/dm^3 of soil denoting high intensity of peat mineralisation	Provides information on the rate of peat soil mineralisation, peat decay and moorsh formation
8	Mineral element content in soils	Provides information on peat soil mineralisation, peat decay and moorsh formation
9	Quantitative and qualitative changes of Soil Organic Matter (SOM mineralisation) including changes in: Soil Organic Carbon and Dissolved Organic Carbon; Soil Organic Nitrogen and Dissolved Organic Nitrogen; C/N rate; CO_2 diffusion from soil	Carbon storage and balance in soils provide information on the rate of soil organic matter decomposition and mineralisation
10	Biodiversity: species richness in communities listed in Annex 1 of the Habitat Directive: Total No. of species at a site Shannon-Wiener diversity index (H′); Evenness H′; Species richness versus boreal/glacial relics plant richness; No. of boreal plants in herbaceous layer; % of boreal/glacial relics plants, including: *Betula humilis, Calamagrostis stricta, Carex chordorrhiza, Carex secalina, Empetrum nigrum, Pedicularis sceptrum-carolinum, Pinguicula vulgaris, Polemonium caeruleum, Salix lapponum and Saxifraga hirculus*; Ratio: (No. of boreal/total No. of plants) × 100	Indices based on species richness provide insight into the degree of community transformation and general decline in native species diversity and losses of valuable elements targeted by the Habitat Directive

(continued)

Table 6.2 (continued)

No.	Indicator	Interpretation of measure
11	Changes in ranges of mesotrophic tree and shrub species (e.g. *Corylus avellana* in alder woods)	Provide information on community function and structure in wetland forests
12	Non-native species richness No. of non-native species (excluding ambiguous genera); % of non-native species; No. of non-native species/total No. of plants (excluding ambiguous genera) × 100; % cover of non-native species; % cover of non-native species/No. of plots; % of dominant plants that are non-native; No. of non-native plants with cover >5 %/total No. of plants with cover >5 %	Indices provide information on change and transformation in wetland plant communities structure and functions and on the increase in community hemeroby
13	Numbers of moisture loving diurnal butterflies including: Umbrella species of Lepidoptera found in peatlands: *Vacciniina optilete, Boloria aquilonaris*; and on meadows: *Lycaena dispar, Maculinea alcon, M. teleius, M. nausithous, Melitaea diamina, Euphydryas aurina* and *Heteropterus morpheus*; No. of moisture loving butterflies per transect; No. of warm loving and xerophilic diurnal butterflies per transect or observation plot	Indices provide information on the loss of umbrella species typical of wetlands, changes in species composition of biocoenoses of diurnal butterflies and change in species composition
14	Number, abundance and occurrence frequency of selected species of fauna such as birds and herpetofauna (amphibians), including: changes in population numbers; changes in survival rate of adults (birds, amphibians); timing of reproduction period (end of hibernation); migrations; arrival time; calling (males); rates of reproduction; changes in hatching time, clutch numbers, larvae survival	Indices provide information on changes in valuable fauna conenoses due to site desiccation and habitat loss, and inform on the loss of species targeted by the Habitat Directive

related to several other soil properties (Ostrowska et al. 2006). LAI and VM show correlation with soil moisture content, while NDVI is correlated with vegetation productivity, biomass and the intensity of vegetation cover development (Adegoke and Carleton 2002; Dąbrowska-Zielińska et al. 2003, 2009; Sienkiewicz and Ostrowska 2010).

6.4 Integrative Indicators

Ecological indicators may be broadly divided into two categories, i.e. simple which reflect the status of an indicated habitat attribute, and integrative indicators that summarise the ecological response of habitats to stress (Girardin et al. 1999). The latter category also includes those indicators that reflect the status of the habitat property which is significantly correlated with various other habitat attributes. Indicators built on metrics provided by measurements and observations of species and populations are regarded as integrative indicators of chronic changes in ecosystems. Integrative indicators represent summary responses reflecting ecosystem stress (ecosystem sensitivity) due to climate change and other pressures and, at the same time, may be simple and easy to apply. The summary response of habitats to climatic stress can be assessed, among others, by quantifying changes in community biodiversity and in soil properties and as well as in water, carbon and nutrient cycles. To this end, integrative indicators derived from metrics build on community biodiversity and soil properties are of special significance.

Soil properties can be used for constructing a variety of climate change sensitive indicators, and particularly the properties of peat soils built of organic matter (Ostrowska et al. 2006). Progressing climate warming is detrimental to hydrological regime of peat soils and results in disturbance of production and accumulation of organic matter and its decomposition, shifting the balance towards the latter process. The loss of organic matter is accompanied by the release of CO_2 and leaching of mineral elements, especially of nitrogen to groundwater. All the properties of peat soils are predefined by the content and quality of soil organic matter (SOM) and SOM decomposition is a highly sensitive indicator of temperature changes (Ostrowska et al. 2006). SOM mineralisation and CO_2 emission show a high assignment to climate change at habitat level. Therefore, carbon content of soil may be applied as basic metric of long-term processes of SOM decomposition as changes in this content will reflect, in an integrative way, the changes in peat soil quality. Accelerated SOM mineralisation results also in an increased migration of nitrogen to the soil environment. Likewise, a change in the content of soil nitrogen, and particularly of its mineral form, constitutes an integrative basic indicator of the above process. The indicator evaluates the rate of SOM mineralisation at a given moment of time; therefore it may be applied as a short term indicator (Ostrowska and Sienkiewicz 2011).

Wetland habitat sensitivity to climate change may be estimated using integrative indicators based on changes in plant communities. Accelerated SOM mineralisation causes a “quasi eutrophication” of soils due to an increase in plant nutrient availability. The increase in the pool of available nutrients leads to the expansion of species which have a high nutrient demand and are not typical of respective wetland communities (invasive species).

6.5 Validation of Climate Change-Related Indicators – The Case Study of Biebrza National Park

An attempt was made to validate integrative indicators derived from vegetation study and soil metrics which may be used to predict habitat sensitivity to climate change and applied for short and long term monitoring in wetland areas. Wetland habitats in the BNP were developed as a result of an interplay of correlations between river flooding, depth of groundwater table, climate pressure and vegetation development within the three topographically distinct basins, i.e. northern (upper), central and southern (lower) along the 60 km stretch of the Biebrza River (Oświt 1991). The Park area is located in three climatic zones which conform more or less to the three basins of the river (Liszewska 2011). The three zones vary significantly in climatic conditions, and especially, in temperature and precipitation distribution. The northern basin is cooler and moister than the southern one, while the central basin has transitional climatic conditions. For these three climatic zones changes in basic climatic parameters (precipitation, temperatures) were determined for the period of the last 50 years (1951–2000) and climate forecast until the year 2100 was made. Soil properties and plant communities were also studied within the above zones along the established transects. The results obtained along with the literature data concerning sensitivity of soil and vegetation parameters to climate change were used as a basis for selecting characteristics which are most sensitive to climate change driven pressures and for determining variability scales for every property within the area examined. In this way, indicators most sensitive to climate change, could be established and validated with respect to their suitability for management support.

In the BNP there dominate peat soils mineralised to various degrees. The peat mineralisation degree may be determined using the soil carbon content as a metric. It was found that soil carbon content fluctuates from 50 to 40 % in natural peats in the northern park zone, to less than 20 % in degraded peat soils which occur mainly in the southern climatic zone. In the transitional zone there occur peat soils of various degree of mineralisation where carbon content constitutes 40–30 % in decaying marshy peats and about 30–30 % in marsh soils. Taking into account the results of study in the BNP as well as the literature data on SOM sensitivity to climate change and the threat of CO_2 release to the atmosphere we adopted that it is the carbon accumulation in organic soils that provides for a most sensitive characteristics of the effects of climate change and a good indicator of climate change-induced changes in wetland habitats. To assess the indicatory strength of the soil carbon content, the correlational and functional relationships were statistically determined between this content and the remaining soil attributes such as Soil Organic Carbon (SOC), Soil Organic Nitrogen (SON), SOM, Dissolved Organic Nitrogen (DON), Cation Exchange Capacity (CEC), Bulk Density (BD), Soil Water Content (SWC), Maximal Water Holding Capacity (MWHC) and Field Water Capacity (FWC) (Tables 6.3 and 6.4).

Close relationships were found between all these properties what is evidenced by the high values of correlation coefficients, though the most significant correlation was determined between the soil carbon content and the remaining soil properties. The significance of correlation was corroborated by calculating Pearson's correlation coefficients between each of the soil properties analysed (Table 6.5).

A more detailed description of the relationships between the soil properties was provided on the basis of regression equations. The values of determination coefficients (R^2) > 0.7 were characteristic of the relationships between the contents of

Table 6.3 Mean values and standard deviations (mean ± SD) of the examined variables for four groups of SOC content in soils

	SOC	SON	SOM	DOC	DON	CEC
C content (%) groups	(%)	(%)	(%)	(mg/kg)	(mg/kg)	(mg/kg)
0.1–3	1.24a ± 0.94	0.05a ± 0.04	2.91a ± 3.27	146.1a ± 137.5	4.06a ± 2.51	30.0a ± 13.5
3.1–16	7.96b ± 3.07	0.55b ± 0.24	14.32b ± 5.79	497.8ab ± 383.4	31.04a ± 16.26	225.1a ± 148.3
16.1–35.9	28.61c ± 6.05	1.73c ± 0.63	50.54c ± 16.3	1266.1bc ± 831.7	109.05b ± 63.32	595.2b ± 258.5
36–56	44.65d ± 5.98	2.2d ± 0.61	78.68d ± 9.28	1741.1c ± 1469.6	115.23b ± 56.32	634.7b ± 341.8

All means of SOC, SON and SOM are significantly different between the groups. The lowest mean values of these three variables were observed for group 0.1–3 and the highest for group 36–56. The differences for DON and CEC were significantly different between the groups 0.1–3; 3.1–16 and the two other groups, i.e. 16.1–35.9; 36–56

Table 6.4 Mean values and standard deviations (mean ± SD) of the examined variables for four groups of SOC content in soils

C content (%) groups	BD (g/cm^3)	SWC (%)	MWHC (%)	FWC (%)	SOC (%)	SON (%)
0.1–3	1.39 ± 0.18	18.95 ± 10.31	38.67 ± 6.06	19.72 ± 5.96	1.4 ± 0.92	0.05 ± 0.04
3.1–16	0.81 ± 0.32	57.08 ± 14.51	62.06 ± 12.27	43.73 ± 12.1	8.42 ± 3.36	0.46 ± 0.25
16.1–35.9	0.31 ± 0.11	68.11 ± 21.8	75.22 ± 7.02	55.68 ± 11.76	28.98 ± 5.52	1.55 ± 0.4
36–56	0.14 ± 0.06	47.9 ± 28.84	74.09 ± 11.65	42.9 ± 20.52	48.84 ± 5.17	1.95 ± 0.53

Analyses performed on limited (n = 44) number of observations i.e. the datasets with additional variables

Table 6.5 Data for all groups of soil carbon content

–	SOC	SON	SOM	DOC	DON
SOC	–	0.85	0.98	0.61	0.72
SON	0.85	–	0.90	0.34	0.70
SOM	0.98	0.90	–	0.57	0.72
DOC	0.61	0.34	0.57	–	0.72
DON	0.72	0.70	0.72	0.72	–

Pearson's correlation coefficients between each of the soil properties analysed (n = 100) (all correlations are significant at $P < 0.05$ probability level)

carbon, organic matter and nitrogen. The interrelationships between the remaining soil properties were also significant (determination coefficients (R^2) = 0.4–0.5) (Ostrowska and Sienkiewicz 2011). It was determined that the loss of soil carbon of a range of 1 % results in changes in the remaining soil properties, e.g. the peat soil MWHC is lowered by about 2 %, while the N content and CEC – by more than 1 %. Consequently, it can be assumed that soil carbon content is an integrative indicator of climate change, validated against the remaining soil properties and thus, indirectly, against other habitat properties such as vegetation type, species composition, presence of invasive species etc. Likewise, the changes in the contents of carbon and nitrogen and their water soluble forms as well as those of soil solution concentrations were found to correlate with the dynamics of precipitation and temperature over several last decades (Ostrowska and Sienkiewicz 2011). Therefore, the soil carbon content may be applied as basic metric providing information on long-term changes in peat soils in an integrative way. In addition, accelerated SOM mineralisation results in the increased migration of nitrogen to the soil environment. Change in the content of soil nitrogen, and of its mineral form in particular, constitutes the basic indicator of the above process. This indicator evaluates the rate of SOM mineralisation process at a given moment of time, thus it may be applied as a short term indicator. In addition, the concentration and composition of soil solutions reflect both the rate of SOM mineralisation and the vulnerability of wetland habitat to the invasion of plant species having a high nutrient demand, especially of expansive and alien invasive species (Ostrowska and Sienkiewicz 2011).

Long-term effects of climate change in the vegetation of wetlands can be assessed with the use of indicators derived from the increased presence (numbers and abundances) of species which are not typical of the original natural community and of nitrophytes which are associated with eutrophic habitats and have a higher nutrient demand. In the study made in the BNP this group of species included e.g.: common nettle *Urtica dioica*, herb Robert *Geranium robertianum*, cleavers *Galium aparine*, wood avens *Geum urbanum*, cow parsley *Anthriscus silvestris*, hairy hempnettle *Galeopsis pubescens* and broad-leaved dock *Rumex obtusifolius* as well as touch-me-not balsam *Impatiens noli-tangere* and ground elder *Aegopodium podgararia*. These species were found to enter and replace the typical species composition of the drying riparian alder-ash woods on decaying peat soils in the BNP.

6.6 Suggestions for Using Indicators in Management Practice

Management adaptation to climate change in a protected area must be based on the recognition of the status of target habitats (habitat sensitivity/resilience to stress factors), conservation objectives and the existing conflicts which arise from various anthropogenic and natural pressures. Effective management measures should be built upon recognition of pressures to increase the resilience of target habitats to the ongoing and future climate change. Informed management decisions may be taken after consulting updated maps which provide the information on the vulnerability of protected habitats to changing climatic conditions considering other existing pressures (e.g. land use, drainage). To this end, expert knowledge is needed to provide information in the form of indicators for evaluating habitat sensitivity and potential response of protected habitats to pressures. The indicators shall be regarded as tools for updating the environmental information.

Management adaptation to changing environmental conditions requires a two track approach: first – the evaluation of effectiveness of measures undertaken, and second – the search for the information needed to undertake new actions. Both tasks shall be implemented with the use of indicators. Therefore, the focus was on the construction of indicators which are multidimensional, integrative, strongly assigned to climate change, i.e. evaluate climate change-related effects and impacts within the habitat/ecosystem. At the same time these indicators are relatively easy to apply for habitat monitoring and have a standardised methodology available. They also allow for updating the information contained in the maps.

Climate change is indicated by climatic scenarios, covering both a short (a decade) and longer periods based upon climatic parameters (temperature and precipitation) measured at local meteorological stations. The response of wetland habitats is to be seen in the changes of water balance, soil and vegetation properties and in the changes of biodiversity of plant communities.

The change in soil organic matter (SOM) in peat soils is a highly sensitive indicator of climate warming. SOM mineralisation and CO_2 emission are very strongly assigned to climate change. Therefore soil carbon content (SCC) may be applied as basic indicator of SOM stability as changes in its content will integratively reflect changes in peat soil quality. These changes shall be determined in longer periods (a decade) thus SCC may be used as the indicator of long term habitat changes due to climate change. SOM mineralisation results mainly in the release of carbon (CO_2) to the atmosphere and nitrogen to the soil environment. A basic indicator of the above process, in addition to CO_2 content, is the content of soil nitrogen, in particular, of its mineral form. This indicator evaluates the rate of the SOM mineralisation process as it is here and now, so it may be applied as a short term indicator. The concentration and composition of soil solution reflects both the rate of SOM mineralisation and the opportunity for wetland habitat to be invaded by plant species having high nutrient demand, especially by expansive and/or alien invasive species. This is also an integrative indicator of short term changes due to climate change. The following integrated indicators may be applied in habitat monitoring in the BNP and other wetlands:

1. Soil carbon content (SCC) is the best integrated indicator of long term effects of climate change-induced changes in organic soils. SCC shall be determined in the 40 cm-thick soil layer, on the established permanent plots, once a decade.
2. Soil nitrogen content (SNC) provides for the best assessment of climate change-induced changes in the soil environment for determining the short term effects; the effects may be assessed by determining either the SNC or the contents of elements in soils solutions, every 2–3 years.
3. Long-term effects of climate change in the vegetation of wetlands can be assessed with the use of indicators such as the increased presence (numbers and abundance) of nitrophytes which have higher nutrient demand. These indicators may be used for the evaluation of effectiveness of the implemented climate change mitigation and adaptation measures. At the same time, these indicators are relatively easy to apply for habitat monitoring.

6.7 Summary

Climate change effect on ecosystems constitutes a relatively new pressure as regards its intensity and interactions with other anthropogenic and natural pressures. The assessment of impacts relies mostly on the use of indicators based on metrics established by measurements of habitat properties that are particularly sensitive to climate change. Indicators of climate change impacts are required to evaluate and compare the behaviour of ecological systems at reference conditions and those subject to climate and management pressures.

Methods for developing integrative indicators vary between simple ones, as in case of land cover-based indicators, to more elaborate procedures requiring field measurements to develop indicators addressing soil and vegetation properties.

Schemes of land cover-based indicators rely mostly on remote sensing, aerial and landscape photographs (EEA 2006; Ode et al. 2010a). Remote sensing derived indicators allow for the determination of changes at landscape level such as land use pattern, complexity of landscape patterns, landscape disturbances and naturalness. At a habitat level, stress responses of main ecosystem compartments such as plant communities and soils may be measured using indicative parameters, including biomass production and soil carbon stock, biologically bound nitrogen and phosphorus, organic matter production and decomposition, species number and habitat composition, habitat extent and habitat structure, changes in biodiversity, dynamics of selected populations and changes in competitive behaviour of functionally important species.

Monitoring of changes in biodiversity using indicators based on changes in the flora and fauna species richness including amphibian populations reflects summary responses at habitat level. It was found that in wetland ecosystems the indicators built on metrics such as soil organic matter decomposition, soil CO_2 emission, soil carbon content, changes in the content of soil nitrogen and its mineral form, concentration and composition of soil solutions as well as on the presence and numbers of nitrophytes are strongly assigned to climate change. Collectively, the above indicators represent a habitat-level assessment which should serve for the complex bioindication of climate change effects on protected areas.

The complex bioindicatory information resulting from habitat monitoring shall be processed and visualised in the form of maps and models to render it available to the end users the site managers. The maps shall be informative as to the vulnerability of protected area and habitats to changing climatic conditions, considering their basic characteristics and other existing pressures (land use, drainage). The information processed, simplified and constantly updated constitutes an important aid to the management decision makers.

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