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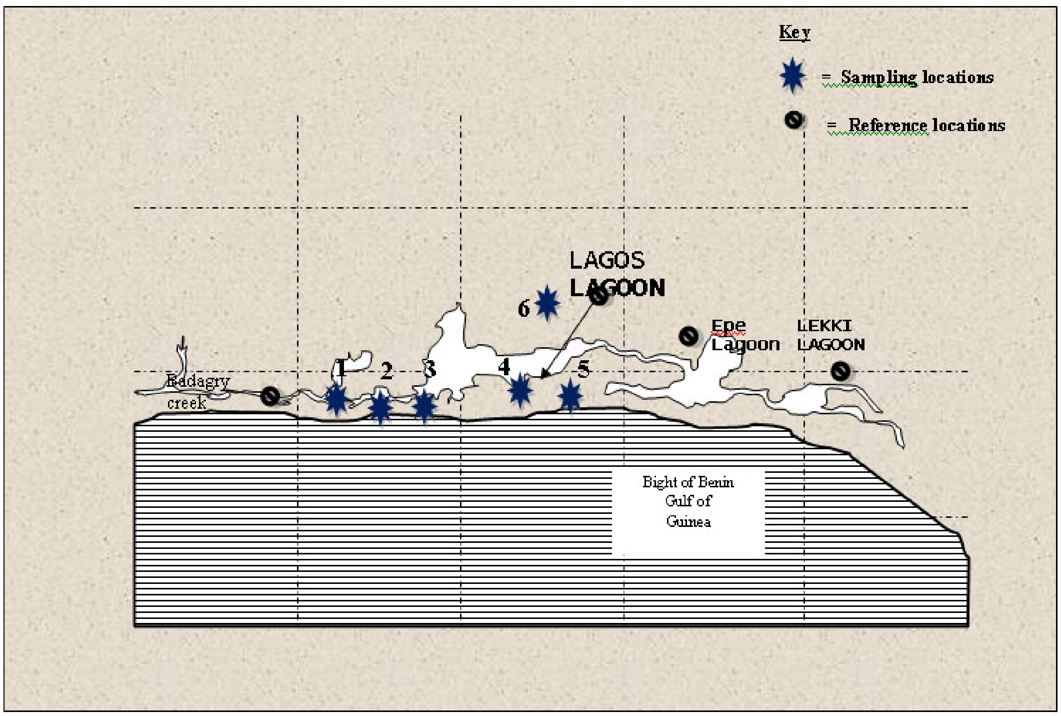

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A CLIMATE PROFILE INDICATOR BASED COMPARATIVE ANALYSIS OF CLIMATE CHANGE SCENARIOS WITH REGARD TO MAIZE (ZEA MAYS L.) CULTURES

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Abstract. Using ecological data compiled from scientific literature on pest, pathogen and weed species characteristic in maize cultures in Hungary, we defined monthly climate profile indicators and applied them to complete a comparative analysis of the historical and modelled climate change scenario meteorological data of the city of Debrecen. Our results call attention to a drastic decline of the competitive ability of maize as compared to several C_4 and especially C_3 plants. According to the stricter scenarios, the frequency of potential pest and pathogen damage emergency situations will grow significantly by the end of the century.
Keywords: *climate changes, agriculture, seasonality, new method*

Introduction

Climate change of our planet has by now become an unquestionable fact accepted by all scientists. The general concepts regarding this change roughly coincide, though this is not true when taking smaller details – that might be of extreme importance for agricultural research – into account [16]. Recent research results let us conclude that climate change might have a significant effect on the yield of wheat, barley, rye, potato and maize, and the borderlines of their area of cultivation might shift 100-150 kilometres to the north [10]. The possible mass occurrence of new aggressive pest, pathogen and weed species in our country might also create a problem for plant protection [17].

Maize is one of our most important fodder-plants and Hungary has close on the largest total cultivating area in Europe. Maize is used in many ways, thus being of outstanding economic importance. In Hungary the conditions of maize cultivation are – except for the dry years – quite favourable in most cultural regions and complex cultivating technologies are available. It also might gain a significant role in the line of new environment-friendly alternative sources of energy. For these reasons, it is important to examine the influence of meteorological factors on maize ecosystems and this examination should include as many climate change scenarios and as long a time series as possible.

Materials and Methods

We may study the impact of climate change on maize ecosystems and the consequent changes of the risk of potential plant protection emergency situations using various alternative research methods, each characterised by different limitations. **Modelling by species** is an unsuitable method, as only the modelling of maize – though it is quite well known and some maize-simulation model types already exist – is a great enough challenge for scientists. **A statistical analysis of the past data** of pests would equally not provide true results, as the 50s, 60s and 70s were characterised by an excessive use of chemicals, while protection later on was rather based on prognostics.

In the course of our research we compiled from Hungarian scientific literature the pest, pathogen and segetal weed species potentially occurring in Hungarian maize ecosystems and also surveyed their ecological needs. Using these we created monthly **climate profile indicators** to be able to make a comparative analysis of the relative frequencies of potential plant protection emergency situations. We introduced the concept of climate profile indicator based on our methodological research. In our study we completed a comparative analysis of the historical and modelled scenario meteorological data of Debrecen, based on monthly climate profile indicators.

Data concerning pest, pathogen and weed species of maize ecosystems were collected from as many Hungarian sources as possible [1, 3, 5, 7, 8, 11, 12, 13, 14, 18, 19, 20, 21,25, 26]. The abovementioned works are characterised by different structures, some of them list pest species, micro organisms or weeds by taxonomic order, others group them by host plants. But they all have one thing in common: they all provide more or less detailed descriptions of the biological and ecological needs of the given harmful creatures.

These descriptions of the climatic needs of harmful creatures have rarely yielded exact numbers, instead they report on the warm or cold, wet or dry circumstances favourable for their occurrence or reproduction in the given month or season. While converting these descriptions into numerical data, we took the many years' mean meteorological data of the base period of the description as a reference. We tried to primarily rely upon data from Hungarian scientific literature, but in some of the cases, for the refinement of data we also took statements of the international literature into consideration. Unfortunately, data concerning the climatic needs taken from international scientific literature are not always applicable for the area of the Carpathian-basin, due to their different ecological and biogeographical characteristics.

The monthly mean temperature and precipitation values concerning the present climate of Debrecen were taken from the monitoring network database of the Hungarian Meteorological Service (OMSZ). A series of data were at our disposal complete from 1952 to 1992.

The change of climate is studied by scientists using climate models. International simulation experiments using these models result in **climate scenarios**. A scenario is a consistent and realistic description of a possible future state of the world. It is not a prediction, but rather an alternative picture of future climate. Scenarios are the final results of 3D numerical General Circulation Models (GCM). They are usually created as a solution of Navier-Stokes partial differential equation systems defined for the cells of a vertically 10-20 times multilayered 250-600 km grid, considering the laws of energy and mass conservation. The solution of these complicated and robust systems of differential equations is only possible with the help of high capacity computers, so only larger institutes are capable of running these models.

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Although the starting parameters are the same, it is interesting that the different runs of the models produce different results [2]. Because of this, we examined in our study runs of the United Kingdom Met Office Hadley Centre and also those of the American Geophysical Fluid Dynamics Laboratory. The scenario called BASE is the run of the Hadley Centre simulated with current conditions, forming the base for further scenarios. We also used data series of the recently created new model runs, representing the latest results of Central European climate modelling. Thus, to analyse the climate of Debrecen, we used UKHI (1990) and UKLO (1987) balanced, UKTR (1992) transient, as well as HCA2 and HCB2 scenarios of the HadCH3 (1998) climate change model created by the **United Kingdom Met Office** (UKMO) **Hadley Centre** (England), MPA2 scenario by the **Max Planck Institute für Meteorologie** (MPI-M, Germany), and GFDL2534 (1991) (=GF2), GFDL5564 (1991) (=GF5) and Base scenarios of the **Geophysical Fluid Dynamics Laboratory** (GFDL, USA).

For the definition and evaluation of monthly climate profile indicators we used **KKT,** a software and database created by [22]. The software works with special data handling functions, thus being perfectly suitable for the handling of a great mass of data.

We introduced the concept of climate profile indicator based on our methodological research. By climate profile indicator we mean the seasonal pattern of the climatic needs of a certain species. Climate profile indicators may be of different temporal resolutions. During this work, we only applied monthly climate profile indicators, assigning monthly precipitation and temperature need values to the 12 months of the year.

Based on literature data we used KKT to generate 55 monthly climate profile indicators and named them after their serial number. Each monthly climate profile saved in the computer can be considered as an individual indicator that could be used to classify both real historical and official climate scenario meteorological data.

The climate profile is consisted of 3 – minimum, mean and maximum – temperature – and one precipitation data. For every month we defined the lower and higher limit of the 4 meteorological parameters mentioned above, meaning 96 data, 8 parameters for each 12 months.

After the selection of the appropriate meteorological database uploaded in the software, we may apply further limitations concerning the annual (year to year) and seasonal (month to month) period of investigation. The historical meteorological data set of Debrecen has been incomplete since 1993, so we restricted the evaluation of monthly profiles for the period between 1951 and 1992. *(Fig. 1.)*

Having selected the preferred profile from the previously defined indicators, we could start with the evaluation of climate profile indicators. **Our question was in how many years do the defined climate profiles come true regarding historical meteorological data of the 1951-1992 period and 31 years of applied scenario data.** With the help of the software for each parameter we received a result, namely, an answer to the question whether the defined monthly conditions did or did not come true in the given year. *(Fig. 2.)*

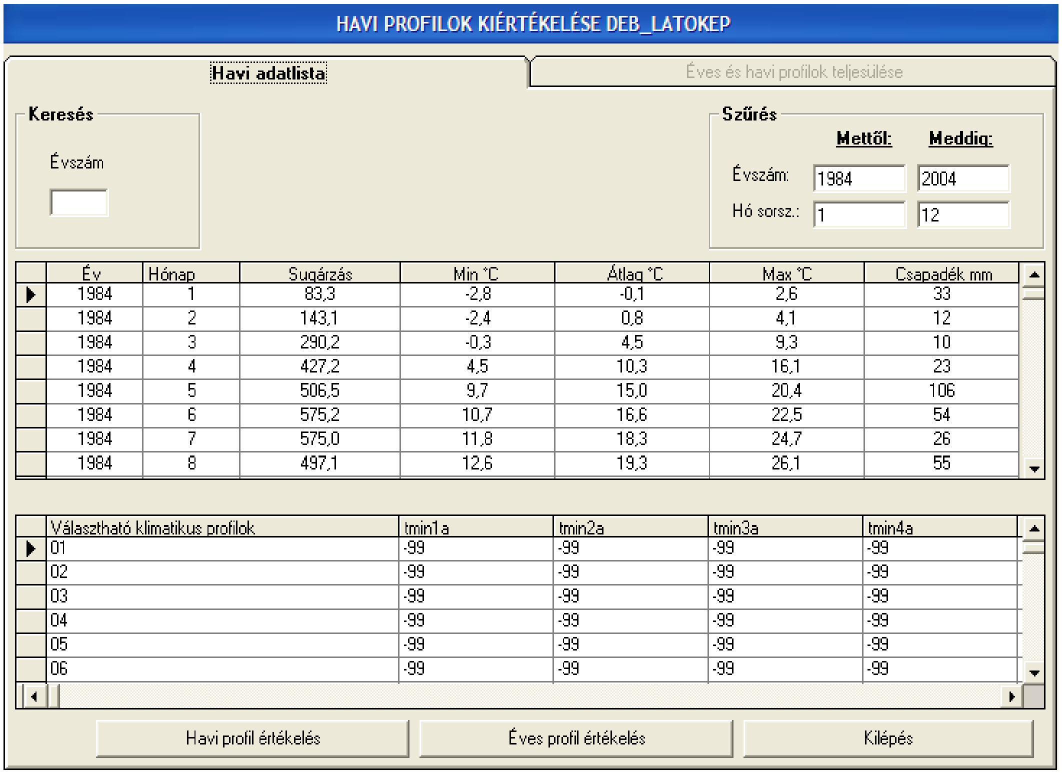

Figure 1. *Monthy data list of DEB_LATOKEP used for the evaluation of monthly climate profile indicators*

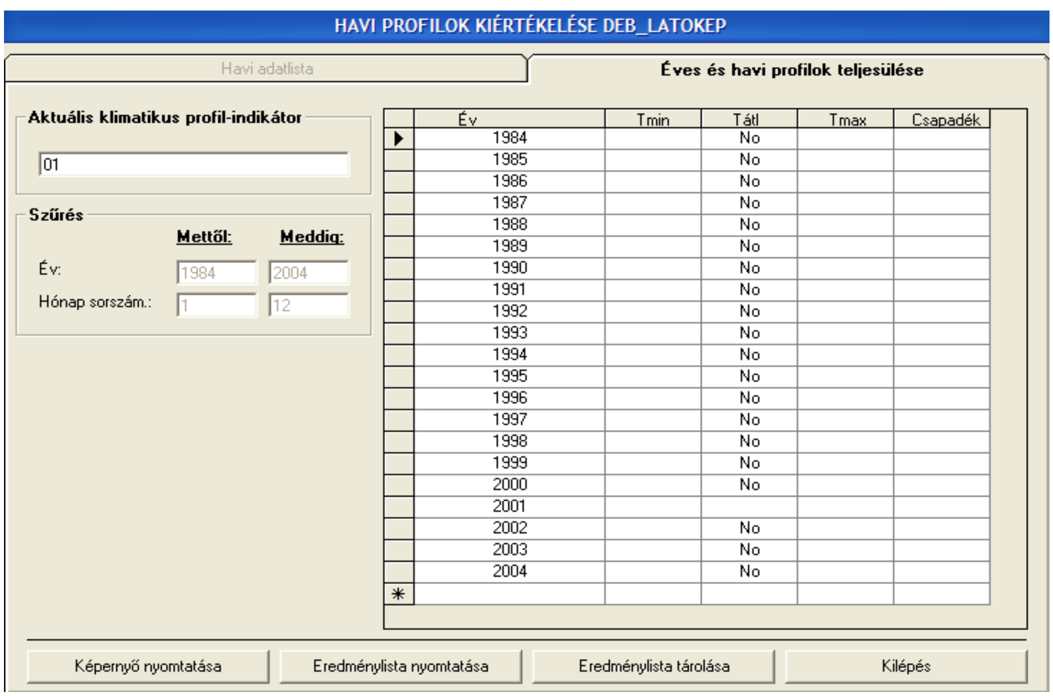

Figure 2. *The database of the annual evaluation of monthly climate profile indicators*

Table 1. *Relative frequencies of monthly climate profile indicators concerning historical and modelled scenario data of Debrecen*

	Látókép	Base	GF2	GF5	UKHI	UKLO	UKTR	HCA2	HCB2	MPA2
1	5	3	19	68	100	100	26	94	71	84
2	0	0	6	32	97	100	0	94	71	84
3	0	0	0	6	3	26	3	6	13	19
4	0	0	3	13	48	16	3	26	16	13
5	0	0	0	6	3	0	0	6	3	3
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	3	3	3
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	3	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
17	5	3	3	3	3	6	6	3	3	6
18	0	0	0	3	0	3	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	14	0	6	0	0	0	0	3	10	3
21	0	0	6	32	97	100	94	94	84	90
22	0	3	3	19	42	10	6	29	19	13
23	10	10	10	0	0	0	6	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	84	97	0	13	0	6
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	71	90	84	84	71	87	87	45	58	87
30	5	3	3	0	0	0	3	0	0	0
31	0	0	0	0	0	0	0	0	0	0
32	0	0	0	3	55	16	3	81	77	45
33	0	0	0	0	6	10	3	16	23	10
34	5	16	23	39	65	29	32	55	45	32
35	0	0	0	3	35	3	0	48	39	26
36	0	0	0	3	35	0	0	29	32	16
37	0	0	0	0	16	29	0	13	0	0
38	0	0	0	0	0	0	0	0	0	0
39	0	0	6	3	42	13	13	65	65	35
40	0	0	0	0	0	0	0	0	0	0
41	14	10	45	58	97	100	32	100	100	100
42	10	3	26	45	97	100	26	100	100	100
43	5	13	61	74	97	100	71	97	94	100
44	5	6	45	90	94	100	61	100	94	97
45	0	0	0	0	16	29	0	13	0	0
46	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	6	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0
51	24	13	48	68	100	100	45	100	100	100
52	10	3	32	23	71	35	32	97	97	68
53	0	0	0	3	0	3	0	0	0	0
54	5	13	3	16	0	13	3	0	0	3
55	0	3	3	6	0	13	3	3	13	13

After the yearly evaluation of the monthly climate profile indicators with the KKT software we summarized the results in an Excel table. At first, we recorded in a table the number of fulfilments of all monthly climate profile indicators in the examined years, for all scenarios. Afterwards, we calculated the relative frequencies of these indicators. The obtained table of results *(Table 1.)* we compared with multivariate pattern analytic methods, both from the aspect of objects and variables, using the statistical software package Past (PAST – PAlaeontological STatistics, ver. 1.79, [9]. We analysed the columns (objects, i.e. climatic data series) and rows (variables, i.e. indicators) of the table by hierarchical cluster analysis – a method of classification – and by non-metric multi dimensional scaling (NMDS) – a method of ordination. We verified the results by graphically projecting the classifications and ordinations onto each other, then, based on verified cluster orders, we applied a two-way clustering for the re-arrangement of tables.

Results and Discussion

Definition of Monthly Climate Profile Indicators

As a result of synthesizing literature data, we created a classified numerical database, introducing 55 monthly climate profile indicators *(Table 5.).* including information on 91 species. Besides maize, the species under examination included 23 zoological pests *(Table 2.),* 12 pathogenic micro-organisms *(Table 3.)* and 55 weed species *(Table 4.)* typically occurring in maize cultures. The tables list the species in taxonomic order.

Table 5. lists the 55 monthly climate profile indicators, the red numbers showing temperature and the blue ones precipitation values. Relation marks indicate if the given indicators demand of temperature or precipitation is higher or lower. The values were established as follows: if we found in literature that e.g. a warm and dry spring was favourable for a given creature, then we recorded the mean temperature and precipitation values with the appropriate relation marks for all the spring months. The profiles of weed species were created after their growth form, this way the 55 species were divided into groups, containing different numbers of weeds.

Table 2. *Most important zoological pests of maize in Hungary and their indicators (ISN: serial number of climate profile indicators)*

SCIENTIFIC NAME	ISN	HUNGARIAN NAME
Ditylenchus dipsaci	18	Szár-fonálféreg
Melanogryllus desertus	35	Fekete tücsök
Gryllotalpa gryllotalpa	35	Lótücsök
Dociostaurus maroccanus	32	Marokkói sáska
Tetraneura ulmi	34	Kukorica-gyökértetű
Rhopalosiphum maidis	5	Zöld kukorica -levéltetű
Rhopalosiphum padi	5	Zselnicemeggy-levéltetű
Schizaphis graminum	5	Zöld gabona-levéltetű
Aphis fabae	6	Fekete répa-levéltetű
Myzus persicae	5	Zöld őszibarack-levéltetű
Zabrus tenebrioides	54	Gabonafutrinka
Opatrum sabulosum	20	Sároshátú gyászbogár
Amphimallon solstitalis	41	Közönséges júniusi cserebogár
Melolontha melolontha	22	Májusi cserebogár
Melolontha hippocastani	22	Erdei cserebogár
Anoxia pilosa	22	Pusztai cserebogár
Polyphilla fullo	54	Kalló cserebogár
Diabrotica virgifera virgifera	39	Amerikai kukoricabogár
Psalidium maxillosum	3	Fekete barkó
Tanymecus dilaticollis	17	Kukoricabarkó
Ostrinia nubilalis	33	Kukoricamoly
Autographa gamma	36	Gamma-bagolylepke
Heliothis maritima	36	Somkóró-bagolylepke
Helicoverpa armigera	36	Gyapottok-bagolylepke
Mamestra brassicae	36	Káposzta-bagolylepke
Scotia segetum	36	Vetési-bagolylepke
Oscinella frit	23	Fritlégy

Table 3. *The most important pathogenic micro-organisms of maize in Hungary and their indicators (ISN: serial number of climate profile indicators)*

SCIENTIFIC NAME	ISN	HUNGARIAN NAME
Maize dwarf mosaic potyvirus	5	Kukorica csíkos mozaik
Sclerophora macrospora	30	Kukoricaperonoszpóra
Ustilago maydis	47	Golyvásüszög
Sorosporium holci-sorghi	51	Rostosüszög
Puccinia sorghi	4	Kukoricarozsda
Phyllosticta maydis/Mycosphaerella maydis	40	Sárga levélfoltosság
Rhizoctonia bataticola	52	Kukorica szürke szárkorhadása
Kabatiella zeae	53	Kabatiellás szemfoltosság
Nigrospora oryzae/Khuskia oryzae	55	Nigrospórás szárazkorhadás
Fusarium graminearum	24	Kukorica fuzáriózása
Helminthosporium turcicum	48	Kukorica helmintospóriumos levélfoltossága

Table 4. *The most important segetal weeds occurring in maize cultures in Hungary and their indicators (ISN: serial number of climate profile indicators)*

SCIENTIFIC NAME	ISN	HUNGARIAN NAME
Equisetum arvense	19	Mezei zsurló
Portulaca oleracea	28	Kövér porcsin
Atriplex patula	46	Terebélyes laboda
Atriplex tatarica	13	Tatár laboda
Chenopodium album	15	Fehér libaparéj
Chenopodium hybridum	15	Pokolvar libaparéj
Chenopodium polyspermum	15	Hegyes levelű libatop
Amaranthus albus	14	Fehér disznóparéj
Amaranthus blitoides	46	Henye disznóparéj
Amaranthus clorostachys	25	Karcsú disznóparéj
Amaranthus retroflexus	25	Szőrös disznóparéj
Bilderdykia convolvulus	11	Ugari szulákpohánka
Polygonum lapathifolium	15	Lapulevelű keserűfű
Polygonum persicaria	15	Baracklevelű keserűfű
Cannabis sativa	2	Kender
Lathyrus tuberosus	21	Mogyorós lednek
Mercurialis annua	43	Egynyári szélfű
Capsella bursa-pastoris	10	Pásztortáska
Diplotaxis muralis	46	Fali kányazsázsa
Raphanus raphanistrum	8	Repcsényretek
Sinapis arvensis	9	Vadrepce
Reseda lutea	42	Vadrezeda
Abutilon theophrasti	45	Selyemmályva
Hibiscus trionum	28	Varjúmák
Anagallis arvensis	15	Mezei tikszem
Convolvulus arvensis	31	Apró szulák
Datura stramonium	43	Csattanó maszlag
Heliotropium europaeum	49	Parlagi kunkor
Symphytum officinale	19	Fekete nadálytő
Plantago major	19	Nagy útifű
Ajuga chamaepitys	11	Kalinca ínfű
Stachys annua	15	Tarlóvirág
Ambrosia elatior	13	Parlagfű
Cirsium arvense	50	Mezei aszat
Galinsoga parviflora	11	Kicsiny gombvirág
Matricaria inodora	16	Ebszékfű
Xanthium italicum	12	Olasz szerbtövis
Sonchus arvensis	44	Mezei csorbóka
Sonchus asper	44	Szúrós csorbóka
Elymus repens	1	Tarackbúza
Phragmites communis	19	Nád
Cynodon dactylon	7	Csillagpázsit
Eragrostis spp.	37	Tőtippan fajok
Digitaria sanguinalis	38	Pirok ujjasmuhar
Echinochloa crus-galli	37	Közönséges kakaslábfű
Panicum miliaceum	1	Termesztett köles
Setaria glauca	27	Fakó muhar
Setaria media	46	Tyúkhúr
Setaria verticillata	45	Ragadós muhar
Setaria viridis	26	Zöld muhar
Sorghum halapense	1	Fenyércirok

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Table 5. *Monthly climate profile indicators (Budapest, 2008) (red: temperature data, blue: amount of precipitation)*

	March	April	May	June	July	August	September	October	November
1	6<	11<	16<						
2	6<	11<	16<	19<	21<	20<			
3	6<	11<	16<						
4	6<	11<	16<						
5	6< <31	11<	16<	19<					
6	6<	11<	16<	19<	21<	20<	16< 42<		
7	6<	11<	16<	19<	21<	20<	16< <42		
8	8-14	8-14	8-14						
9	8-14	8-14	8-14	8-14	8-14	8-14	8-14 42<		
10	10<	10<	10<	10<	10<	10<	10< 42<		
11	18<	18<	18<	18<	18<	18<	18<		
12	18<	18<	18<	18<	18<	18<	18<	18<	
13	18<	18<	18<	18<	18<	18<	18<	18<	18<
14	18<	18<	18<	18<	18<	18<	18< 42<		
15	18<	18<	18<	18<	18<	18<	18< 42<		
16	18<	18<	18<	18<	18<	18<	18<	18<	18<
17			16<						
18						58<			
19						58<	42<		
20						<58	<42		
21		11<	16<	19<	21<	20<	16<		
22		11<	16<	19<					
23		<11	<16						
24		<11	<16			58<	42<		
25		18<	18<	18<	18<	18<	18<		
26		18<	18<	18<	18<	18<	18< 42<	18<	
27		18<	18<	18<	18<	18<	18< 42<	18<	
28		18<	18<	18<	18<	18<	18< 42<		
29			5<	10<	10< 5<	10< 5<	8<	5<	
30			<16	<19					
31			16< 59<	19<	21<	20<	16< 42<		
32			16<	19<	21<	20<			
33			16< 59<	19<	21<	20<	16< <42		
34			16<				16< <42		
35			16<	19<	21<	20<	16< <42		
36			16<	19<	21<	20<	16< <42	11<	
37			18<	18<	18<	18<	18<	18<	
38			25<			58<	42<		
39				19<	21<	20<	16< <42		
40						58<	42<		
41				19<	21<				
42				19<	21<	20<			
43				18<	18<	18<	16<	11<	
44				18<	18<	18<	18<		
45				18<	18<	18<	18<	18<	
46				18<	18<	18<	18<	18<	18<
47				19<	21<	20<			
48				19<	21<	20<	16< 42<	11<	
49				19<	21<	20<	16< 42<		
50						58	42 <		
51					21<	20<			
52					21<	20<			
53					21<	20<	16< 42<		
54						58<			
55							16< 42<	11<	

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A Comparative Analysis of the Historical and Modelled Meteorological Data of Debrecen

We used the statistical software package PAST for the analysis of the relative frequency table *(Table 1.)* regarding the monthly climate profile indicators for the historical and modelled scenario data of Debrecen.
The dendrogram *(Fig. 3 a)* shows the classification of the monthly climate profile indicators. We can see that the indicators (1, 2, 21, 29, 41, 42, 43, 44, 51) preferring warm springs or/and summers without any precipitation demands (e.g. *Datura stramonium, Sonchus species, Sorosporium holci-sorghi, Reseda lutea, Elymus repens, Lathyrus tuberosus, Zea mays*) belong to one big group which is closely related to the indicators (32, 34, 39, 52) demanding hot dry summers (e.g..: *Dociostaurus maroccanus, Tetraneura ulmi, Diabrotica virgifera virgifera, Rhizoctonia bataticola*). Indicators (4, 22, 25, 35, 36) demanding warm and dry spring or/and summer (e.g.: *Helicoverpa armigera, Gryllotalpa gryllotalpa, Melolontha species, Puccinia sorghi, Amaranthus species*) are linked to the group of indicators demanding warmth and various amounts of precipitation in the spring and summer (e.g. *Nigrospora oryzae, Kabatiella zeae, Ustilago maydis, Abutilon theophrasti, Ostrinia nubilalis, Tanymecus dilaticollis, Ditylenchus dipsaci*). The lower part of figure *(Fig. 3 b)* shows the position of indicators after the dimension reduction by NMDS, the elements of the groups are exactly the same as those of the groups produced by cluster analysis in higher dimensions of space.

After the results of the monthly climate profile indicator based evaluation of the model runs for the scenarios of Debrecen and the classification and ordination of data we found that data may be divided into two larger groups *(Fig. 4 a).* The first group includes the historical data of Debrecen (Látókép), the Base scenario fitted on past data and the scenarios GF2, GF5 and UKTR calculating with a moderate change of climate. The second group is formed by balanced models (UKHI, UKLO) and the scenarios originating from the PRUDENCE project (HCA2, HCB2, MPA2), both calculating with a significant change of climate. Inside the two larger groups well identifiable sub-groups can be recognized. In the first group the data series Látókép and Base are much similar, being closer to each other than to any other scenarios. This fact supports the reliability of the models applied. Inside the group scenarios calculating with a more significant climate change, regional data series of the PRUDENCE project (HCA2, HCB2, MPA2) are separated from the older balanced models (UKHI, UKLO). Ordination *(Fig. 4 b)* also shows us the model runs calculating with more and more serious changes of climate getting further and further away from the data of the historical base period. The picture may be considered as a proof for the applied monthly climate profile indicators being suitable for the efficient evaluation of information lying inside model runs.

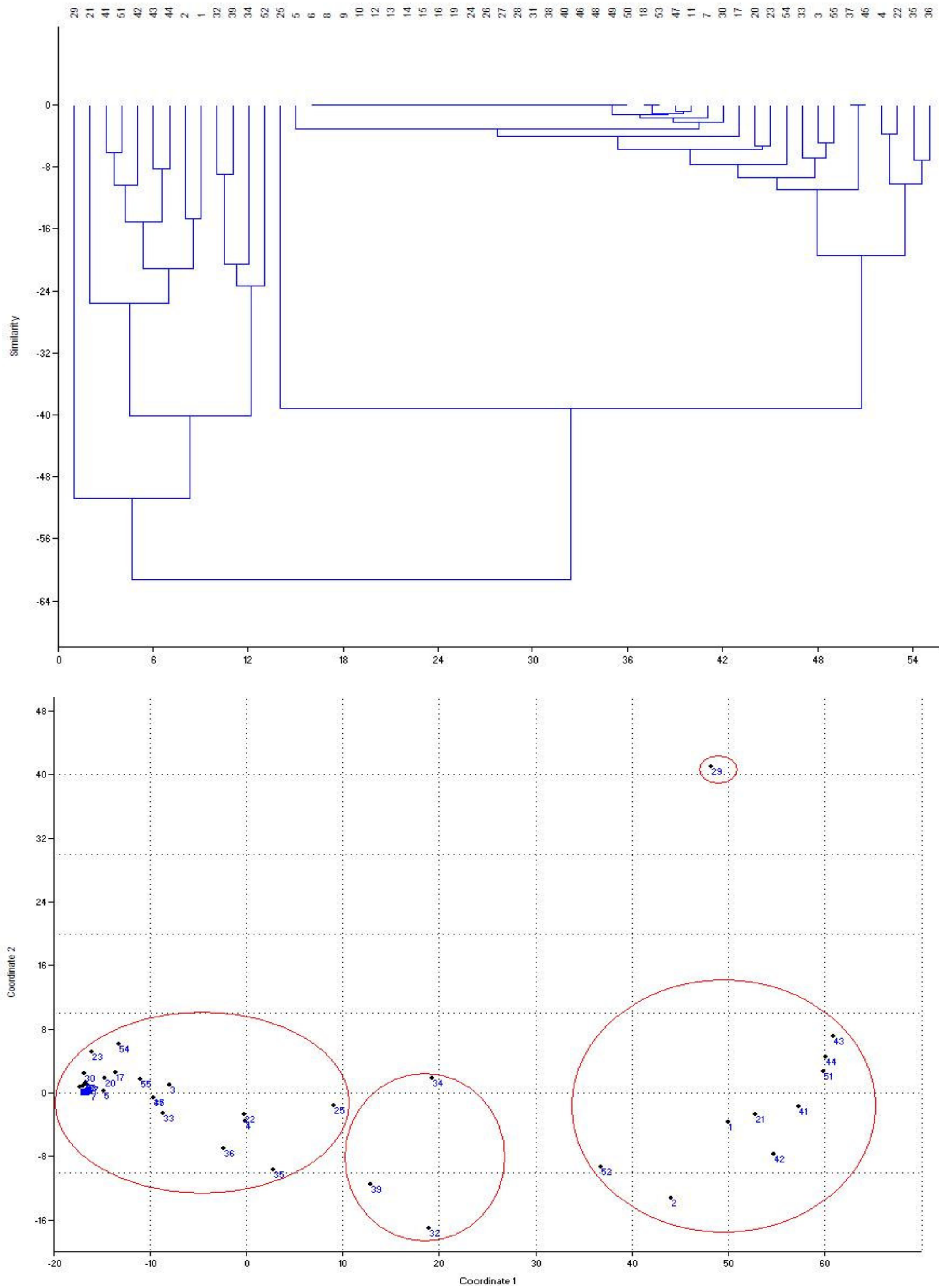

Figure 3. a, *Classification of monthly climate profile indicators based on historical and modelled scenario meteorological data of Debrecen, by cluster analysis* ***b,*** *Ordination of monthly climate profile indicators including the projection of groups created by cluster analysis, based on historical and modelled scenario meteorological data of Debrecen, by NMDS*

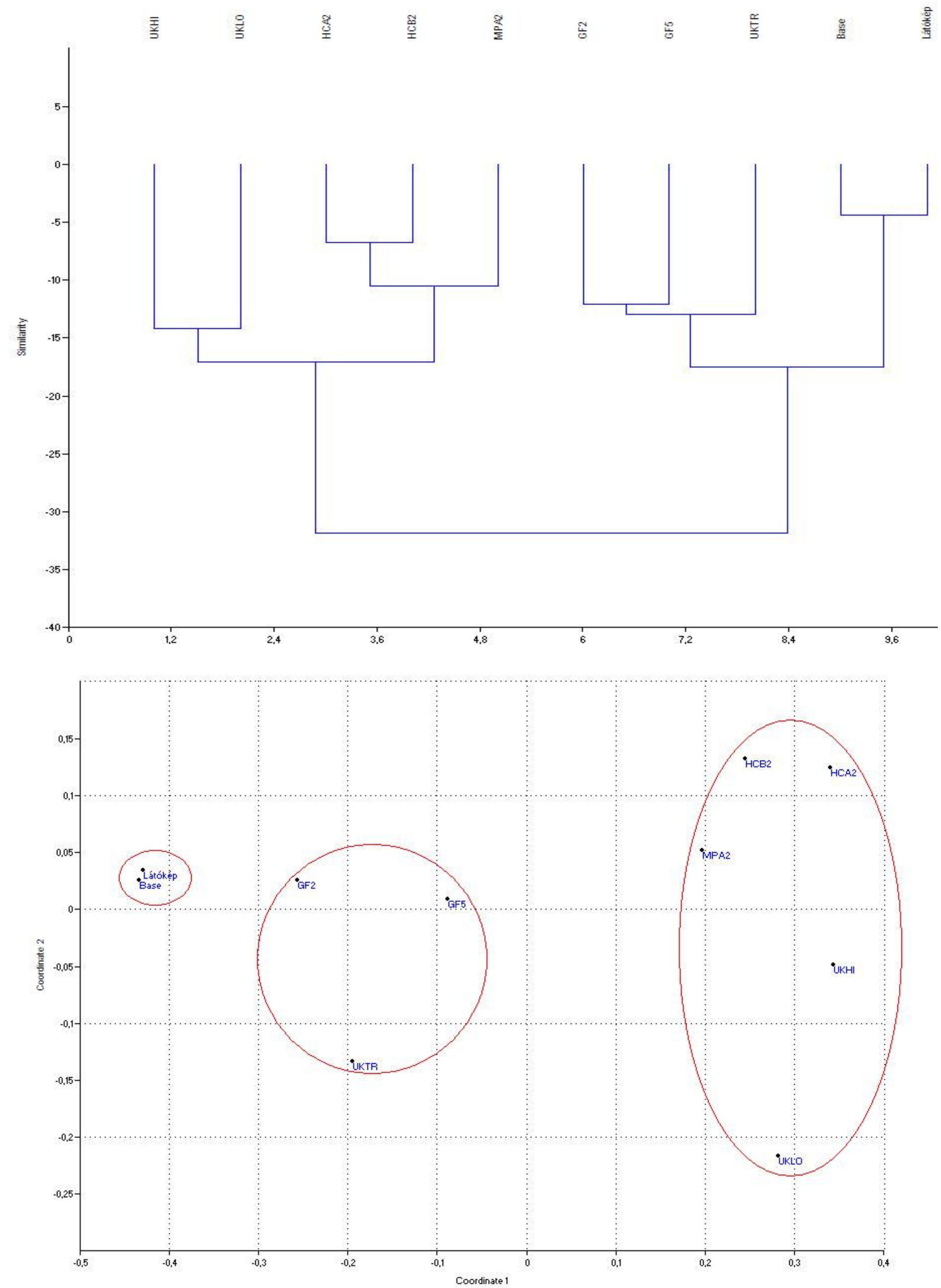

***Figure 4. a,** Classification of monthly climate profile indicators based on historical and modelled scenario meteorological data of Debrecen, by hierarchic cluster analysis **b,** Ordination of monthly climate profile indicators including the projection of groups created by classification, based on historical and modelled scenario meteorological data of Debrecen, by NMDS*

Fig. 5 and *Table 6*. shows a two-way cluster analysis of the monthly climate profile indicators and the meteorological data of scenarios for Debrecen. Rows were created by a classification of monthly climate profile indicators, as columns by one of the data of the Debrecen scenarios. Indicators containing only 0 values and thus no information were excluded from the analysis. We found Base scenario being much similar to the historical meteorological data of Látókép. This proves, that Base scenario simulated using present conditions may form a suitable basis for the other scenarios.

The relative frequency of all indicators falls between 0-24% for Base and Látókép data. In the case of GF2, GF5 and UKTR scenarios, indicators with warm spring and/or summer temperature and no precipitation demands (e.g. *Datura stramonium, Sonchus fajok, Sorosporium holci-sorghi, Reseda lutea, Elymus repens, Lathyrus tuberosus)* had a relative frequency of 19-94%. Indicators needing warm and dry summers (e.g. *Dociostaurus maroccanus, Tetraneura ulmi, Diabrotica virgifera virgifera, Rhizoctonia bataticola*) came up with a relative frequency of 0-39% at these scenarios, and those needing warm and dry spring and/or summer (e.g. *Helicoverpa armigera, Gryllotalpa gryllotalpa, Amaranthus species, Melolontha species, Puccinia sorghi*) with a relative frequency of 0-19%.

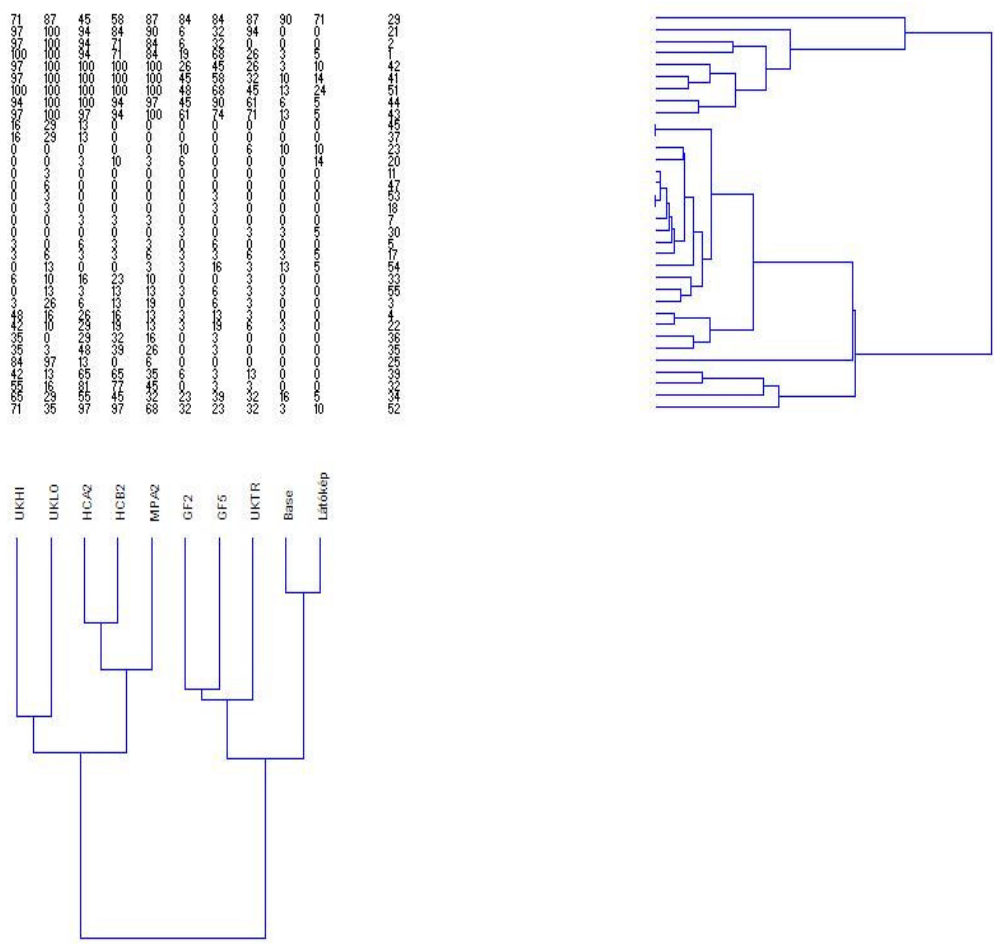

Figure 5. *Two-way cluster classification of monthly climate profile indicators and the historical and modelled scenario meteorological data of Debrecen*

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Table 6. *The result of two-way classification of monthly climate profile indicators and the historical and scenario meteorological data of Debrecen, including the monthly climate profile indicators*

	UKHI	UKLO	HCA2	HCB2	MPA2	GF2	GF5	UKTR	Base	Latókép	március	április	május	június	július	augusztus	szeptember	október
29	71	87	45	58	87	84	84	87	90	71			5<	10<	10< 5<	10< 5<	8< <100	5< <100
21	97	100	94	84	90	6	32	94	0	0		11<	16<	19<	21<	20<	16<	
2	97	100	94	71	84	6	32	0	0	0	6<	11<	16<	19<	21<	20<		
1	100	100	94	71	84	19	68	26	3	5	6<	11<	16<					
42	97	100	100	100	100	26	45	26	3	10				19<	21<	20<		
41	97	100	100	100	100	45	58	32	10	14				19<	21<			
51	100	100	100	100	100	48	68	45	13	24					21<	20<		
44	94	100	100	94	97	45	90	61	6	5				18<	18<	18<	18<	
43	97	100	97	94	100	61	74	71	13	5				18<	18<	18<	16<	11<
45	16	29	13	0	0	0	0	0	0	0				18<	18<	18<	18<	18<
37	16	29	13	0	0	0	0	0	0	0			18<	18<	18<	18<	18<	18<
23	0	0	0	0	0	10	0	6	10	10		<11 44<	<16 59<					
20	0	0	3	10	3	6	0	0	0	14	<31	<44	<59	<72	<60	<58	<42	
11	0	3	0	0	0	0	0	0	0	0	18<	18<	18<	18<	18<	18<	18<	
47	0	6	0	0	0	0	0	0	0	0				19< 72<	21< 60<	20< 58<		
53	0	3	0	0	0	0	3	0	0	0					21< 60<	20< 58<	16< 42<	
18	0	3	0	0	0	0	3	0	0	0	31<	44<	59<	72<	60<	58<		
7	0	0	3	3	3	0	0	0	0	0	6< <31	11< <44	16< <59	19< <72	21< <60	20< <58	16< <42	
30	0	0	0	0	0	3	0	3	3	5			<16 59<	<19 72<				
5	3	0	6	3	3	0	6	0	0	0	6< <31	11< <44	16< <59	19< <72				
17	3	6	3	3	6	3	3	6	3	5	<31	<44	16< 59<					
54	0	13	0	0	3	3	16	3	13	5					60<	58<		
33	6	10	16	23	10	0	0	3	0	0			16< 59<	19< <72	21< <60	20< <58	16< <42	
55	0	13	3	13	13	3	6	3	3	0							16< 42<	11< 43<
3	3	26	6	13	19	0	6	3	0	0	6< 31<	11< 44<	16< 59<					
4	48	16	26	16	13	3	13	3	0	0	6< 31<	11< <44	16< <59					
22	42	10	29	19	13	3	19	6	3	0		11< <44	16< <59	19< <72				
36	35	0	29	32	16	0	3	0	0	0			16< <59	19< <72	21< <60	20< <58	16< <42	11< <43
35	35	3	48	39	26	0	3	0	0	0			16< <59	19< <72	21< <60	20< <58	16< <42	
25	84	97	13	0	6	0	0	0	0	0		18<	18<	18<	18<	18<	18<	
39	42	13	65	65	35	6	3	13	0	0				19< <72	21< <60	20< <58	16< <42	
32	55	16	81	77	45	0	3	3	0	0			16<	19< <72	21< <60	20< <58		
34	65	29	55	45	32	23	39	32	16	5			16< <59				16< <42	
52	71	35	97	97	68	32	23	32	3	10					21< <60	20< <58		

In the case of scenarios UKHI, UKLO, HCA2, HCB2, MPA2, indicators with warm spring and/or summer but no precipitation demands (pl.: *Datura stramonium, Sonchus species, Sorosporium holci-sorghi, Reseda lutea, Elymus repens, Lathyrus tuberosus*) occured with a relative frequency of 32-100%. Indicators needing warm and dry spring and/or summer (e.g. *Helicoverpa armigera, Melanogryllus desertus, Amaranthus species, Melolontha species, Puccinia sorghi*) showed a relative frequency of 13-48%. Maize (*Zea mays*) indicated a relative frequency of 45-90% for historical and modelled scenarios.

Based on literature, C_3 plants are much more sensitive to a higher CO2 concentration than C_4 plants (Fuhrer, 2003). According to our own studies, the monthly climate profile indicator of C_4 maize was the only one indicating a significant decline of its high present relative frequency with climate change, although the interpretation of decline is more difficult than that of growth, as here we can not consider the possibility of the phenological acclimatization of maize or the adaptation effect of breeding. Still, the results indicate the rise of the risk of abiotic damages (direct climatic effect) of maize. On the other hand, in the case of more C_3 and C_4 weed species, the relative frequency of the years suitable for their monthly climate profile indicators is significantly rising, from the current low value to even 90-100%. As literature information, the result also calls our attention to the drastic decline of the competitive abilities of maize, as compared to numerous C_4 and especially C_3 plants. Of C_3 plants the weed species *Elymus repens, Abutilon theophrasti, Datura stamonium* (represented by indicators 1, 43, 45) should be mentioned, along with C_4 *Sorghum halapense, Amaranthus retroflexus, Echinochloa crus-galli* (1, 25, 37). Of these species *Elymus repens, Datura stramonium, Sorghum halapense, Amaranthus retroflexus, Echinochloa crus-galli* have already been considered as the most important weeds of maize cultures in the past [3].

Being one of the most important pests of maize, the development of the larvae of the European Corn Borer (*Ostrinia nubilalis*) depends on heat units, growing faster in higher temperature [24]. According to our study the frequency of potential damage emergency situations of *Ostrinia nubilalis* will be significant by the end of the century, primarily regarding scenarios calculating with a stronger change of climate (UKLO, UKHI, HCA2, HCB2, MPA2). Occurring in Hungary in 1995, the successful European acclimatization of *Diabrotica virgifera virgifera* is due to the dry and arid climatic conditions of Central Europe [15]. Based on scenario data, the risk of potential damages caused by this species will be considerably high. Scarce-Bordered Straw (*Helicoverpa armigera,* indicator 36) has been a regular - and in dry years serious - agricultural pest in Hungary since 1993 [23]. According to the scenarios counting with a stronger change, the risk of potential damage of this species will also grow significantly.

In view of pathogen micro-organisms, autumnal, winter and spring low temperatures may be considered as limiting factors, as in the summer, precipitation is the most important [4, 6]. According to our study, the risk of potential damage emergency situation of *Maize dwarf mosaic potyvirus*, *Puccinia sorghi*, *Sorosporium holci-sorghi*, *Rhizoctonia bataticola* and *Nigrospora oryzae* (indicators 4, 5, 51, 52, 55) will grow significantly. In case of *Sorosporium holci-sorghi* this growth might reach 100% by the end of the century.

We must emphasize that though our indicators represent the best information sources available, the interpretation of the results requires certain awareness, considering the unsatisfactory literature data and the way of turning them into numerical data. We also have to keep in mind that our study calculated only with temperature and precipitation data, leaving CO2 concentration – obviously changing with climate change – and radiation out of consideration. Our presumption that the behaviour of pathogen, pest and weed species will be constant regarding climate is also a simplification, not counting with the physiological, phonological, biochemical and onto-genetic acclimatization, or adaptation at the population genetic level. As a consequence, in the comparative analysis of historical and scenario climates using profile indicators only the rise of relative frequencies is of professional importance. Namely, in this case, the rise means the rise of the frequency of potential damage situations even if we do not consider the adaptive ability of the plant. On the other hand, the stagnancy or decrease of this value does not mean that the risk of emergency in question may not grow.

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CORAL REEF ANTHROPOGENIC IMPACT BIO-INDICATORS IN THE NORTHERN PART OF THE PERSIAN GULF

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Abstract. Potential and efficiency of coral reef bio-indicators proposed by Reef Check for coral reef monitoring in the Persian Gulf were studied as anthropogenic impact bio-indicators. Data were collected from the coral reefs in the northern part of the Persian Gulf in 2007 using Reef Cheek standard methodology and analyzed using Redundancy Analysis and Indicator Species Analysis. Similar data collected in 2002 and 2003 were also incorporated into our data. According to the results short-spine sea urchin (*Echinometra mathaei*) showed consistent positive correlation with commercial fishing and high indicator value for commercial fishing areas and could be pointed out as a weak bio-indicator of over-fishing. Also Arabian butterfly fish (*Chaetodon melapterus*), showed negative correlation with commercial fishing and high significant indicator values for none to low fishing areas in 2003 and 2007 and could be considered as indicator of low fishing pressure in the region. None of Fin fishes proposed as indicators of over-fishing, and also other proposed species showed consistent correlation or consistent significant indicator values for any anthropogenic impacts and are not recognized as anthropogenic impact bio-indicators. It is concluded that a much shorter and more efficient list of bio-indicators could be used for monitoring coral reefs in this region.
Key words: *Reef Check, IndicatorSpecies, Overfishing, Arabian butterfly fish, Short-spine sea urchin.*

Introduction

Coral reef communities in the Persian Gulf exist in a harsh environment with respect to salinities, sea temperatures and extreme low tides [6]. In this region, coral reefs experience long periods (months) of high sea temperature (above 30 °C) in the summer and low (below 16 °C) temperature in the winter [9].

These factors have a serious influence on community structure by restricting the number of species in the area and by causing recurrent mortality among the dominant species [6, 11,]. In last two decades, coral bleaching has occurred throughout the world resulting in mass mortality of corals mainly due to the elevated temperature [28]. This has also been the case in the Persian Gulf [24].

However, to date, the majority of damage to coral reefs around the world including Persian Gulf and Iranian waters has been through direct anthropogenic stress [2, 4, 8, 12, 14, 15, 23, 26]. The major causes of damage are:

Excessive pollution from domestic, industrial and agricultural waste; poor land use practices, which increase the amount of land derived sediments flowing onto coral reefs; and over exploitation, particularly through damaging practices such as dynamite fishing.

Industrial projects could cause such anthropogenic damage to coral reefs mainly through industrial waste pollution, poor land use practice, uncontrolled coastal construction and reclamation.

Reef Check (RC), as the largest and most widespread global organization dedicated to monitoring reefs proposes some fish and invertebrate indicators for coral reef monitoring programe in the Persian Gulf region [13].

These indicators include: barramundi cod (*Cromileptes altivelis*), orange-spotted grouper (*Epinephelus coioides*), other groupers, grey grunt (*Plectorhinchus sordidus*), black-spotted grunt (*Plectorhinchus gaterinus*), spotted grunt (*Plectorhinchus pictus*), dark butterfly fish (*Chaetodon nigropunctatus)*, Arabian butterfly fish (*Chaetodon melapterus),* long-fin butterfly fish (*Heniochus acuminatus*), grunts/Sweetlips, parrot fish, snappers, moray eel (all species), humphead wrasse (*Cheilinus undulates)*, long-spined black sea urchin (*Diadema* spp.) banded coral shrimp (*Stenopus hispidus*), lobster (all edible species), collector sea urchin (*Tripneustes* spp.), black sea urchin (*Echinothrix diadema*), cowries, pencil sea urchin (*Heterocentrotus mammilatus*), short-spine sea urchin (*Echinometra mathaei*), crown-of-thorns starfish (*Acanthaster planci*), edible sea cucumbers (e.g. teatfish *Holothuria nobilis*), Triton (*Charonia tritonis*).

It is very necessary to mention here that there are some serious problems in using bio-indicator-dependent monitoring programs. Firstly when management goals are indistinct and unclear wrong variables may be monitored and therefore inappropriate indicators may be selected, secondly relying on inappropriate bio-indicators fails to reflect changes in environment and leads to poor management, and finally in many cases enough scientific effort is not applied to select bio-indicators and in other words there is a ‘lack of robust procedures for selecting ecological indicators’ [3].

Finally each monitoring problem requires individual treatment and ‘there is no one bio-indicator species that will suit all programmes’ [16]. The complexity and variety of reef ecosystems makes it very difficult to confidently select a single indicator for a large region. Therefore the purpose of this study is to review coral reef fishes and invertebrates indicators proposed for the Persian Gulf region by Reef Check and determine potential and effectiveness of these indicators as anthropogenic impacts in the northern part of the Persian Gulf using Reef Check data or data collected using standard RC methodology [13].

Materials and Methods

Study Area

Data for this study were collected from the coral reefs at Khark, Kharku, Hendorabi, Kish, Farur and Farurgan Islands and Nayband bay in 2007 in the northern part of the Persian Gulf. Similar data collected in 2002 and 2003 in some of the mentioned regions and in Lavan and Larak Islands were also used *(Fig.1).*

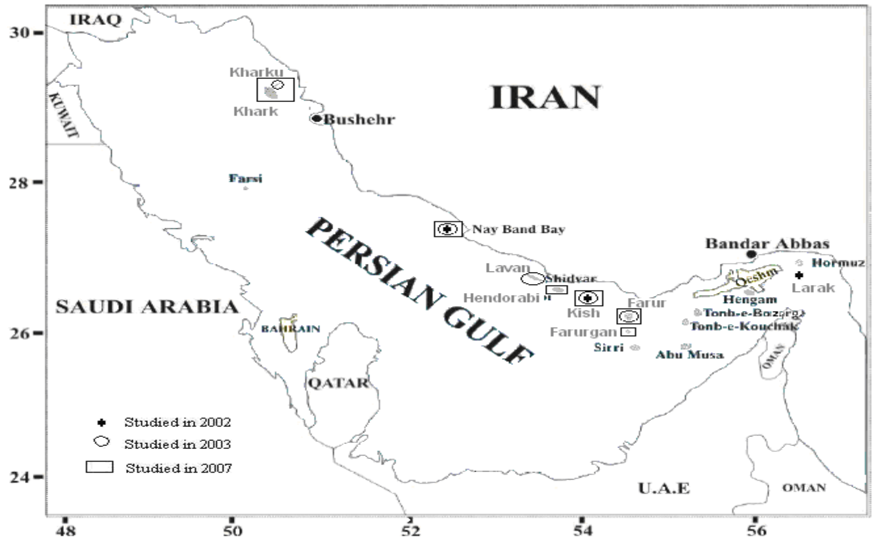

***Figure 1.** Study areas in 2002, 2003 & 2007 in the northern Persian Gulf*

Sampling techniques

Survey sites were chosen using manta tow surveys and reconnaissance dives. They were popular diving areas, the 'best' reefs in the area or the 'worst' reefs in the area and they reflect a wide range of habitats.

At each site a site description sheet was completed with anecdotal, observational, historical, locational and other data. This included impacts at the site, giving values of 0 (none), 1 (low), 2 (medium) or 3 (high) for the following: 'tourist diving', 'sewage pollution', 'industrial pollution', 'commercial fishing' and 'other impacts' *(Table 1).*

***Table 1.** Site description definitions and field guide, clarifying measurements.*

Impact	Low (1)	Medium (2)	High (3)
Aquarium fishing	Less than once per month	More than once per month, but less than once per week	Once a week or more
Tourist diving	1-5 individuals per day	6-20 individuals per day	More than 20 individuals per day
Sewage pollution	Sewage, irregular or rare discharge	Source of discharge > 100 m but < 500m from transect	Source of discharge < 100 m from any point on transect
Industrial pollution	Source > 0.5 km	Source between 0.1 and 0.5 km	Source less than 100 m
Commercial fishing	Less than once per month	Less than once a week and more than once a month	Once a week or less

Then data were collected along 2 depth contours at shallow (3-6 m) and intermediate (6-12 m) depths (if the reef was too shallow, the 6-12 m depth transect was not completed). Along each depth contour a 100 meter transect was placed and along it four 20 meters replicate transects were surveyed. The start and end points of 20 meters transects were five meters apart.

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Along each transect at each depth a belt transect (5m wide centered on each 20 meters transect line) was sampled for commercially important fish favored by fishers and aquarium and invertebrate taxa typically targeted for curios and food [13].

Statitical Methods

Detrended correspondence analyses (DCA) were run on the fish and invertebrate data sets using Canoco 4.0 to determine the unimodality of the data. Detrending was done by segments, species were square-root transformed and rare species were down-weighted. Following Chi-squared measure distance and one standard deviation cutoff, Outliers were identified and removed from the data set using PC-ORD 4.17 [21].

Redundancy analyses (RDA) were run using Canoco 4.0 to determine correlations between fish and invertebrate vs. anthropogenic impact variables because all DCA axis 1 gradients were below 2.5 science RDA is useful where gradients are shorter [22]. Once RDA's were performed, collinear anthropogenic variables, those with variance inflation factors (VIF) over 10, were deleted [5], also all data were checked for normality using the Anderson-Darling test in Minitab 13.20, in cases where p values were below 0.05 (Non-normal distribution), data were log transformed using x = Log(x+1).

Indicator species were identified for each habitat type using the method introduced by [10] based on an indicator value index (IndVal) as follows:

$$\text{Specificity measure}: A_{ij} = Nindividuals_{ij} / Nindividuals_{i} \qquad \text{(Eq.1)}$$

In our case $Nindividuals_{ij}$ is the mean number of species *i* across transects of group *j*, and $Nindividuals_{i}$ is the sum of the mean numbers of individuals of species *i* over all groups;

$$\text{Fidelity measure}: \mathrm{B}_{ji} = Nsites_{ji} / Nsites_{j} \qquad \text{(Eq.2)}$$

In our case $Nsites_{ij}$ is the number of transects in cluster (habitat) *j* where species *i* is present, and $Nsites_{j}$ is the total number of transects in that cluster.

The percentage indicator value (IV) for species *i* in cluster (habitat) *j* is then:

$$\mathrm{IndVal}_{ij} = A_{ij} \times B_{ji} \times 100 \qquad \text{(Eq.3)}$$

For maximum A_{ij}, species *i* is only present in cluster *j*. B_{ji} is highest when species *i* is present in all transects of cluster *j*. indicator value is thus highest (100%) when species *i* is present in all transects of only one habitat group. The significance of the indicator values were tested using a random reallocation of transects among transects groups using Monte Carlo randomization test (1000 permutations).

The site hierarchy component of [10] method to select site clusters was not preformed because the transects were already clustered into groups based on different levels of anthropogenic impacts with the following groups: 0 (None), 1(Low), 2 (Medium) and 3 (High).

The calculations of IVs and the associated Monte Carlo (randomization) test were performed using the PC-ORD 4.17 software [21].

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Results

Abundance of indicators and levels of anthropogenic impacts

Levels of anthropogenic impacts in transects and average abundance of indicator fish and invertebrates within belt transects studied in 2002, are respectively presented in *Tables 2 and 3*.

Table 2. *Levels of anthropogenic impacts in 2002 transects*

Anthropogenic impact	Kish 1		Kish 2		Larak	
	3-6 m	6-12 m	3-6 m	6-12 m	3-6 m	6-12 m
Aquarium fishing	1	1	0	0	0	0
Commercial fishing	1	1	0	0	1	0
Sewage	0	0	0	0	0	0
Industrial pollution	0	0	0	0	0	0
Tourist diving	1	0	0	0	0	0

Table 3. *Average indicator fish/invertebrate density (individual/100 m^2) in 2002 transects*

Fish/Invertebrate	Kish 1		Kish 2		Larak	
	3-6 m	6-12 m	3-6 m	6-12 m	3-6 m	6-12 m
Orange-spotted grouper	0.00	0.25	0.00	0.00	0.00	0.00
Other groupers	0.00	0.00	0.25	0.00	0.50	0.25
Hump-head wrasse	1.00	0.00	0.00	0.00	0.00	0.00
Dark butterfly	0.50	1.00	0.00	0.50	14.50	0.00
Arabian butterfly	0.25	0.00	0.00	0.00	0.50	0.00
Long-fin butterfly	0.00	1.00	0.75	0.00	0.00	0.00
Parrot	0.00	0.25	1.75	0.25	2.00	0.00
Moray eel	0.00	0.00	0.00	0.25	0.00	0.00
Short-spine sea urchin	1.50	16.00	5.25	41.75	3.25	0.00
Pencil sea urchin	0.00	3.00	0.00	0.00	0.00	0.00
Sea cucumber	0.00	3.00	0.50	0.00	0.50	0.00
Lobster	0.00	0.00	0.25	0.00	0.00	0.00

Similar data for 2003 are presented in *Tables 4 and 5* and for 2007 in *Tables 6 and 7* respectively.

Table 4. *Levels of anthropogenic impacts in 2003 transects*

Anthropogenic impact	Nayband 1		Kharku		Lavan		Kish 1		Kish 2	Farur		Nayband 2	
	3-6 m	6-12 m	3-6 m	6-12 m	3-6 m	6-12 m	3-6 m	6-12 m	3-6 m	3-6 m	6-12 m	3-6 m	6-12 m
Aquarium fishing	0	0	0	0	0	0	1	1	0	1	1	0	0
Commercial fishing	3	3	2	2	2	2	1	1	2	1	1	3	3
Sewage	0	0	0	0	0	0	0	0	2	0	0	0	0
Industrial pollution	0	0	0	0	0	0	0	0	0	0	0	0	0
Tourist diving	0	0	0	0	0	0	2	0	0	0	0	0	0

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Table 5. *Average indicator fish/invertebrate density (individual/100 m^2) in 2003 transects*

Fish/Invertebrate	Nayband 1		Kharku		Lavan		Kish 1		Kish 2	Farur		Nayband 2	
	3-6 m	6-12 m	3-6 m	6-12 m	3-6 m	6-12 m	3-6 m	6-12 m	3-6 m	3-6 m	6-12 m	3-6 m	6-12 m
Orange-spotted grouper	1.00	2.80	3.00	2.30	4.50	2.80	4.00	1.75	1.50	1.25	5.00	0.00	0.00
Other groupers	0.00	0.50	1.50	0.00	0.50	0.80	1.25	0.75	0.00	0.00	17.00	0.25	0.00
Spotted grunt	0.50	0.00	0.00	0.00	3.50	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00
Arabian butterfly	0.00	0.00	3.00	0.50	0.50	0.00	0.50	1.25	2.00	5.25	5.25	0.00	0.00
Dark butterfly	6.50	10.75	17.00	7.30	5.50	3.00	4.50	11.25	8.50	7.50	10.25	1.00	2.50
Parrot	0.50	3.50	3.50	0.00	0.00	1.50	0.50	5.50	2.00	6.75	9.75	0.00	1.25
Snapper	28.80	1.30	57.50	7.50	13.80	2.30	10.25	4.50	58.25	39.00	10.25	0.00	0.00
Long-fin butterfly	0.00	0.00	0.00	2.80	0.00	0.00	0.00	0.00	0.00	0.00	1.25	0.00	0.00
Grey Grunt	0.00	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.00	0.00
Black-spotted grunt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
Short-spine sea urchin	462.3	0.0	145.5	30.8	96.0	59.3	3.3	5.0	8.0	2.5	1.8	411.8	114.5
Long-spin sea urchin	0.0	123.5	38.0	75.8	2.3	0.5	12.5	8.5	3.0	3.3	1.3	0.0	0.0
Pencil sea urchin	0.0	0.0	13.3	32.0	0.0	0.0	0.5	2.3	0.0	0.0	0.0	0.0	0.0
Cowry shell	1.5	1.3	0.0	0.0	2.0	1.8	0.8	2.3	0.0	1.0	1.5	0.0	0.0
Sea cucumber	0.5	1.8	0.0	0.0	2.8	2.3	0.8	3.0	0.5	0.0	0.5	0.0	2.3
Triton shell	0.0	0.8	7.0	7.3	0.0	0.0	0.0	0.0	0.5	0.8	0.0	0.0	0.0

Table 6. *Levels of anthropogenic impacts in 2007 transects*

Anthropogenic impact	Hendorabi	Nayband1	Nayband2	Kharku		Khark		Kish 1		Kish2	Farur		Farurgan	
	3-6 m	3-6 m	3-6 m	3-6 m	6-12 m	3-6 m	6-12 m	3-6 m	6-12 m	3-6 m	3-6 m	6-12 m	3-6 m	6-12 m
Aquarium fishing	1	0	0	0	0	0	0	2	1	0	1	1	0	0
Commercial fishing	1	3	3	1	1	2	2	0	2	1	1	1	0	0
Sewage	0	0	0	0	0	0	0	0	0	3	0	0	0	0
Industrial pollution	0	0	0	0	0	3	2	0	0	0	0	0	0	0
Tourist diving	0	0	0	0	0	0	0	3	1	0	0	0	0	0

Table 7. *Average indicator fish/invertebrate density (individual/100 m^2) in 2007 transects*

Fish/ Invertebrate	Hendo rabi	Nayband1	Nayband2	Kharku		Khark		Kish 1		Kish2	Farur		Farurgan	
	3-6 m	3-6 m	3-6 m	3-6 m	6-12 m	3-6 m	6-12 m	3-6 m	6-12 m	3-6 m	3-6 m	6-12 m	3-6 m	6-12 m
Orange-spotted grouper	0.5	0.5	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other groupers	1.5	0.8	0.8	0.3	0.3	0.0	0.0	0.5	0.0	0.0	0.0	0.5	0.3	0.3
Spotted grant	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3
Arabian butterfly	0.5	0.0	0.0	0.0	0.3	0.0	0.0	5.5	0.0	0.0	2.5	0.0	0.5	0.5
Dark butterfly	5.5	6.5	5.3	13.0	4.8	5.8	6.0	7.8	0.0	0.0	10.8	0.3	2.3	2.3
Parrot	5.5	0.5	0.3	0.0	0.0	0.0	1.3	0.0	0.0	0.0	1.0	0.0	3.5	3.5
Moray	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Snapper	0.8	25.8	1.8	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Short-spine sea urchin	1.3	0.0	700.8	270.8	155.5	60.8	0.0	0.0	0.0	65.5	0.0	22.8	1.0	0.0
Long-pine sea urchin	0.0	0.0	0.0	13.3	62.5	0.0	58.8	0.0	2.3	13.0	58.8	18.5	0.0	0.0
Pencil sea urchin	0.0	0.0	0.0	0.5	1.5	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Cowry shell	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sea cucumber	0.5	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.3	0.0

Correlation between proposed indicators and anthropogenic variables

Outliers of fish and invertebrate data in 2002, were moray eel and lobester, in 2003, were black-spotted grunt and cowry shells and in 2007 were moray eel and cowry shells.

DCA first axis gradients of fish and invertebrate data in 2002, were 2.174 and 0.782, in 2003 were 1.237 and 1.893 and in 2007 were 1.695 and 1.944 respectively. Therefor redundancy analysis (RDA) was used for all cases.

In redundancy analysis for fish vs. anthropogenic impacts in 2002, dark butterfly fish, Arabian butterfly fish and to some extent hump-head wrass exhibited positive correlation and orange-spotted grouper and long-fin butterfly fish showed negative correlation with commercial fishing. Also hump-hed wrass showed positive correlation and parrot fish and other groupers showed negative correlation with aquarium fishing and tourist diving *(Fig. 2).* For invertebrates vs. anthropogenic impacts short-spine sea urchin, sea cucumbers and pencil sea urchin exhibited positive correlation with commercial fishing and to lower extent with aquarium fishing and negative correlation with tourist diving *(Fig. 3).*

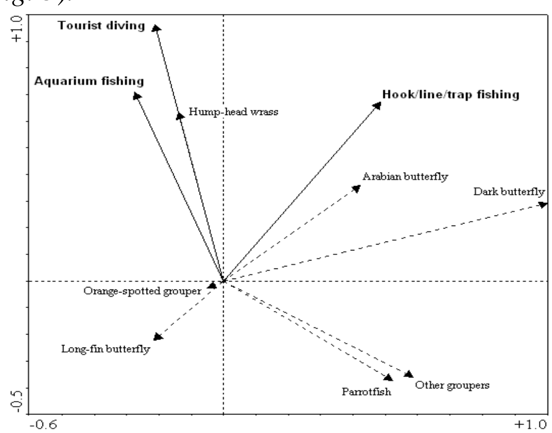

Figure 2. *Redundancy analysis for fish vs. anthropogenic impacts in 2002*

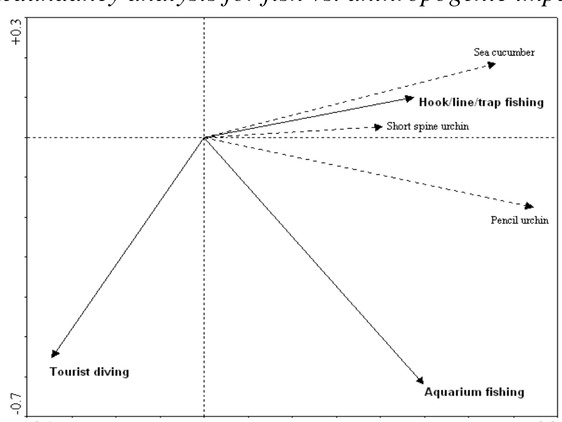

Figure 3. *Redundancy analysis for invertebrate vs. .anthropogenic impacts in 2002*

In redundancy analysis for fish vs. anthropogenic impacts in 2003, grey grut, long-fin butterfly fish, snappers, other groupers, Arabian butterfly fish, dark butterfly fish, orange-spotted grouper and parrot fish showed negative correlation with commercial fishing. In addition orange-spotted grouper, other groupers and spotted grunt showed positive correlation with tourist diving and Arabian butterfly fish, snappers, grey grut, dark butterfly fish, long-fin butterfly fish and parrot fish exhibited positive correlation with aquarium fishing and sewage pollution *(Fig. 4).*

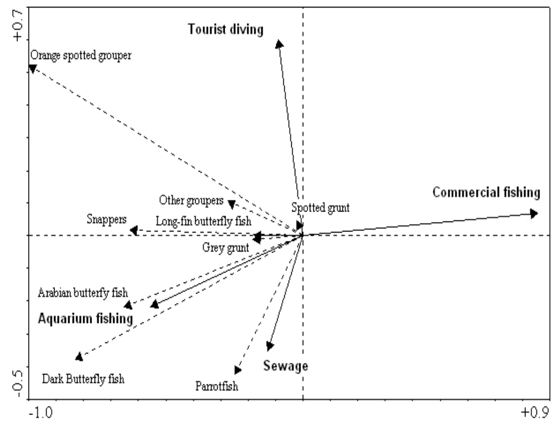

Figure 4. *Redundancy analysis for fish vs.anthropogenic impacts in 2003*

For invertebrates vs. anthropogenic impacts short-spine sea urchin exhibited positive correlation with commercial fishing and negative correlation with aquarium fishing, tourist diving and sewage pollution and sea cucumbers showed positve correlation with sewage pollution *(Fig. 5).* In addition short-spine sea urchin, triton shells, pencil sea urchin and long-spine sea urchin exhibited negative correlation with sewage pollution and long-spine sea urchin exhibited positive correlation with tourist diving.

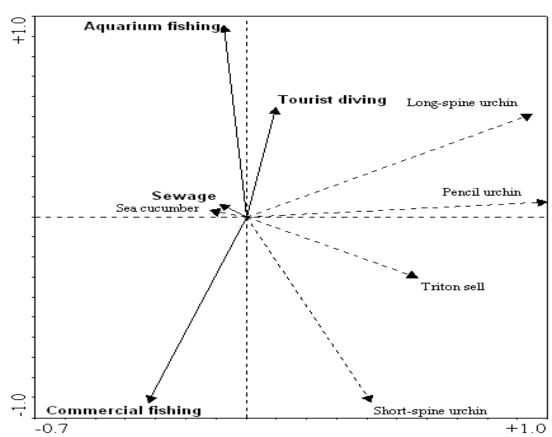

Figure 5. *Redundancy analysis for invertebrate vs .anthropogenic impacts in 2003*

In redundancy analysis for fish vs. anthropogenic impacts in 2007, Arabian butterfly fish, parrot fish and spotted grunt showed negative correlation and snappers, orange-spotted grouper and other groupers showed more or less positive correlation with commercial fishing. Also Arabian butterfly fish, spotted grunt and parrot fish showed positive correlation, and snappers and orange-spotted grouper showed negative correlation with tourist diving, aquarium fishing and industrial pollution. In adition dark butterfly fish, orange-spotted grouper, other groupers, spotted grunt and parrot fish exhibited negative correlation with sewage pollution *(Fig. 6).* For invertebrates vs. anthropogenic impacts short-spine sea urchin and long-spine sea urchin exhibited positive correlation with commercial fishing and sewage pollution and negative correlation with tourist diving and aquarium fishing. Also pencil sea urchin showed negative correlation with industrial pollution and aqurium fishing and sea cucumbers showed positve correlation with tourist diving and negaitive correlation with commercial fishing and sewage pollution *(Fig. 7).*

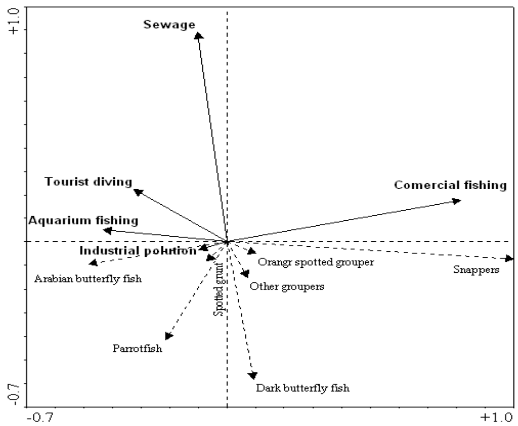

Figure 6. *Redundancy analysis for fish vs .anthropogenic impacts in 2007*

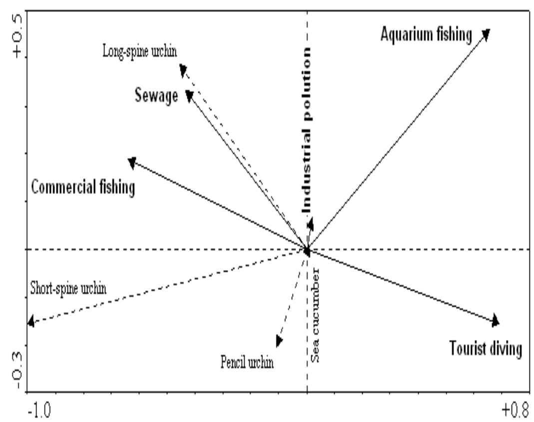

Figure 7. *Redundancy analysis for invertebrate vs .anthropogenic impacts in 2007*

Indicator values of proposed indicators for different habitat groups

Studied transects were clustered into groups based on anthropogenic impact types and levels. Caculated Indicator Values (IV)s for characteritic species/taxa of habitat groups recognized in the survey area in different years are presented in table 8 (Only indicator values > 60% and those with p<0.25 are listed in this table).

Table 8. *Indicator Values for characteritic species/taxa of different anthropogenic impact groups/levels*

Species/Taxa	IV	*P	Habitat(Transect) roup	Year
Dark butterfly	97.0	0.2000	Commercial & aquarium fishing	2002
Arabian butterfly	66.4	0.3980		
Orange-spotted grouper	60.1	0.2370	Mostly Aquarium fishing	2003
Other groupers	69.2	0.1720		
Arabian butterfly	82.1	0.0190		
Parrot fish	80.5	0.0220		
Cowries	65.6	0.0830	Commercial fishing	
Short-spine sea urchin	87.0	0.0530		
Other groupers	64.8	0.2720		
Arabian butterfly	71.81	0.0380	Low Commercial fishing	
Parrot fish	67.5	0.0310		
Spotted grunt	66.7	0.0900	No Commercial fishing	2007
Arabian butterfly	80.0	0.0420		
Snappers	98.5	0.0100	High Commercial fishing	
Short-spine sea urchin	69.0	0.1010	Commercial fishing	

* proportion of Monte Carlo test randomized trials with indicator value equal to or exceeding the observed indicator value. p = (1 + number of runs >= observed)/(1 + number of randomized runs).

Discussion

Looking at anthropogenic impacts, fishes and invertebrates proposed by Reef Check as Bio-indicators of coral reefs in the area are divided into five different groups:

1. Barramundi cod, hump-head wrasse, long-fin butterfly fish, banded coral shrimp, lobsters (all edible species), collector sea urchin, black sea urchin and pencil sea urchin.
2. Sea cucumbers, triton shells, cowries (all species) and lobesters (commomn with the first group).
3. Moray eel (all species) and banded coral shrimp (commomn with the first group).

Members of these three groups are not good indicators of coral reef ecosystems in the region because they are rare or not common, not widely distributed in the region, are nocturnal, hide in holes during the day and can not be counted easily, or they are proposed as indicators of harvest types (such as invertebrate collection for food/for curio) which are not used in the region, also they didn't show any consistent positive or negative correlation with anthropogenic variables such as harvest types, tourist diving, etc. Also they didn't show significant indicator values for different groups of harvesting types and other anthropogenic impact levels.

4. Orange-spotted grouper, other groupers, grey grunt, black-spotted grunt, spotted grunt, other grunts/Sweetlips, snappers, parrot fish, dark butterfly fish and long-spine sea urchin.

Members of this group exhibitted more or less negative correlation with commercial fishing but didn't show consistent significant indicator values for different groups of harvesting types and other anthropogenic impact and are not considered as reliable indicators for anthropogenic impacts in the region.

5. Short-spine sea urchin (*Echinometra mathaei*) and Arabian butterfly fish (*Chaetodon melapterus*).

Members of this group are commom, easy to count and widespread in the region and showed consistent correlation with commercial fishing and consistent high indicator

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values for commercial fishing habitats and could be considered as indicators of fishing status in coral reef ecosystems in the region.

Short-spine sea urchin exhibited positive correlations with commercial fishing in 2002, 2003 and 2007. Furthermore, Indicator Species Analysis showed them to be indicator species for commercial fishing areas, with indicator values of 87.0 ($p = 0.053$), 69.0 ($p = 0.10$) respectively in 2003 and 2007, and therefore short-spine sea urchin could be considered as bio-indicator of fishing pressure in coral reef ecosystems of this region.

Wrasses (Labridae) and emperor (Lethrinidae) also present in the study region are reported as dominant sea urchin predators in kenyan marine protected areas by [17, 18, 19]. Over-fishing and removing of these predator fishes could increase short-spine sea urchin population and high abundance of sea urchins results from reductions in sea urchin predator fishes.

Arabian butterfly fish showed heigh significant indicator values for none to low commercial fishing habitats in 2003 (IV = 82.1, $p<0.05$) and 2007 (IV = 80.0 , $p<0.05$) and this is further illustrated by the RDA's where they have exhibited negative correlation with commerciale fishing in 2003 and 2007. However it appears that Arabian butterfly fish is a good indicator for coral reef habitats with none to low commercial fishing impact.

Although [7, 25] have suggested that corallivore butterfly fish could be used as indicator species for changing conditions of coral reefs and also relationship between temporal variation of butterfly fish population density and the corals was reported by [1, 27], however it dos not seem that commercial fishing and removal of finfish is having direct impact on Arabian butterfly fish population density, becaues it is not target fish in this types of harvest.

Studies indicate that removal of finfish is having the largest impact on reefs, and has a number of tertiary effects on other faunal groups and ecological processes [20].

It is councluded that increased sea urchins (*e.g. Echinometra mathaei*) poulation causes high bioerosion followed by decrease in live coral cover, and finally it is associated with a decrease in corallivore butterfly fish (*e.g. Chaetodon melapterus*) population.

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CLIMATE SIGNALS OF THE NORTH ATLANTIC OSCILLATION DETECTED IN THE CARPATHIAN BASIN

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Abstract. North Atlantic Oscillation (NAO) can be considered as the primary large scale atmospheric driver of the European climate, especially in winter. In the present paper, first, NAO effects on regional circulation represented by the circulation patterns (CP) using the Hess-Brezowsky Grosswetterlagen (HBGWL) and Péczely classification systems are analyzed. Our results for the 1901-2000 period suggest that the zonal/meridional CP classes occur more often during NAO+/NAO– phase in all seasons in case of both classification systems. Furthermore, Cyclonic/Anticyclonic CP types are more/less frequent in NAO– phase, and less/more frequent in NAO+ phase than in case of normal conditions. Then, NAO and CP joint effects on local temperature and precipitation time series are evaluated for the 20th century. In general, NAO– phase is associated with cold and wet winters, whereas NAO+ phase implies warm and dry winters in the Carpathian basin. If considering cyclone or anticyclone dominance over the region, NAO+ is associated with dry and warm winters, and dry summers in case of Anticyclonic CP class, whereas NAO– phase implies wet and cold winters and autumns in the Carpathian basin (either for the Péczely or the HBGWL classification systems). When Cyclonic CP class occurs using the HBGWL classification system (i) winters tend to be drier and warmer than usual, springs tend to be drier and colder than usual in NAO+ phase; (ii) springs and autumns tend to be wetter than usual, winters tend to be colder than usual in NAO– phase. If the Péczely classification system is used then Cyclonic CP class is associated with (i) significantly warmer winters and colder springs during NAO+ phase; (ii) significantly wetter and colder winters, and wetter autumns during NAO– phase.
Keywords: *North Atlantic Oscillation, Hess-Brezowsky Grosswetterlagen, Péczely CP types, temperature, precipitation*

Introduction

Several oscillation phenomena have been recognized [1, 24] in the climate system both in the low- and midlatitudes. In the tropics, El Nino/Southern Oscillation (ENSO) is the leading climatic mode with warm and cold phases [17] both having world-wide ecological, economical and social consequences, especially in strong cases [3]. Let us mention here only some examples of these environmental impacts: fish catches off the coast of Peru, maize harvests in Zimbabwe and the occurrence of malaria in Columbia can all be shown to depend on the ENSO [2]. One of the extratropical large scale oscillations is the North Atlantic Oscillation (NAO) that performs great importance in determining climatic variables of Europe [6, 12], especially in winter. Certainly, climatic conditions affect the European environment and biosphere. The positive NAO phase occurs when the Icelandic low-pressure center is lower than usual while the subtropical high-pressure center near the Azores tends to be higher than usual thus resulting in a strong meridional pressure gradient over the North Atlantic region. This strong gradient is associated with intense westerly flow over the North Atlantic region, and also, a northward shift in the general tracks of midlatitude cyclones [8, 14, 21, 25].

Thus, precipitation tends to increase in Northern Europe, and dry conditions occur in the Mediterranean region [13, 20, 22]. During this positive phase, warmer-than-usual conditions are observed in Northern and Central Europe, which can be explained by the low-level advection over the Atlantic [7]. During the negative NAO phase the meridional pressure gradient is weaker, thus the weakened westerlies across the North Atlantic region result in cold and dry conditions in Northern Europe and wet conditions in the Mediterranean region [8].

In the present study, we are focusing on the teleconnections of NAO, namely, climatic impacts of this large scale phenomenon to the Carpathian basin both on regional and local scales are analyzed. Regional circulation is represented by circulation patterns (CPs): the Hess-Brezowsky Grosswetterlagen (HBGWL) [4, 5] and the Péczely CP types [15, 16]. On local scale temperature and precipitation time series observed in the 20th century are used. After presenting the database in Section 2, the statistical relationship between NAO and CP types is discussed in Section 3. Then, the joint effect of NAO and CP types on the local climate variables of the Carpathian basin is analyzed in Section 4. Finally, the main conclusions are summarized in Section 5.

Data

Monthly NAO index time series

North Atlantic Oscillation can be characterized by the monthly NAO index, which is the difference between the normalized sea level pressure over Gibraltar and that of Southwestern Iceland [9, 23]. The 1901-2000 time series used in the present study is available via Internet (from the data archive of the Climatic Research Unit, University of East Anglia). The large positive and negative index values are separated using the standard deviation of the entire time series (σ= 1.71). Hence NAO+ and NAO– phases are defined when the NAO index is larger than 1.71 (208 months) and smaller than -1.71 (182 months), respectively. In the present analysis normal conditions are defined when the NAO index value is between -1.71 and 1.71.

Daily catalogue of CP types

Two different CP classification systems are used, namely, the Hess-Brezowsky Grosswetterlagen [4, 5], and the Péczely CP types [15, 16]. Both of them are defined to characterize the large scale structure of the air pressure systems over the North Atlantic region and the European continent using daily sea level pressure data. The Hess-Brezowsky CP types (HBGWL) consider the Central European aspects of the European circulation while the Péczely types focuses more on the Carpathian basin particularly.

According to the HBGWL classification system CP types are classified into 29 types based on the dominant direction of air mass movements and the presence of cyclones or anticyclones in different European subregions (*Table 1*). The available dataset consists of daily CP codes from 1901 to 2000 and is published monthly in the journal “Die Grosswetterlagen Europas” of the German Meteorological Service. In the present analysis, we use CP classes aggregated using various aspects. (1) According to the main air flow directions (W, SW, NW, N, NE, E, SE, S), eight different groups can be distinguished and two extra classes where the circulation is controlled by Central European pattern. (2) Circulation characteristics can be another factor, thus zonal, half-meridional and meridional CP classes were defined. Zonal CP class includes 4 HB types

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(Wa,Wz, Ws, Ww), meridional CP class consists of 18 different HB types (Na, Nz, HNa, HNz, HB, TRM, NEa, NEz, HFa, HFz, HNFa, HNFz, SEa, SEz, Sa, Sz, TB, TRW), and the other 7 HB types (SWa, SWz, NWa, NWz, HM, BM, TM) compose the half-meridional CP class. (3) Cyclonic and anticyclonic CP types are separated into classes consisting 14 (Wz, SWz, NWz, TM, Nz, HNz, TrM, NEz, HFz, HNFz, SEz, Sz, TB, TrW) and 12 (Wa, SWa, NWa, HM, Na, HNa, HB, NEa, HFa, HNFa, SEa, Sa) types, respectively.

Table 1. *Macrocirculation types defined in the HBGWL system.*

Circulation type	Main flow direction	Macrosynoptic type (notation)
Zonal	West (W)	West anticyclonic (Wa) West cyclonic (Wz) Southern West (Ws) Angleformed West (Ww)
Half-Meridional	Southwest (SW)	Southwest anticyclonic (SWa) Southwest cyclonic (SWz)
	Northwest (NW)	Northwest anticyclonic (NWa) Northwest cyclonic (NWz)
	Central European high (HM)	Central European high (HM) Central European ridge (BM)
	Central European low (TM)	Central European low (TM)
Meridional	North (N)	North anticyclonic (Na) North cyclonic (Nz) North, Iceland high, anticyclonic (HNa) North, Iceland high, cyclonic (HNz) British Islands high (HB) Central European Trough (TRM)
	Northeast (NE)	Northeast anticyclonic (NEa) Northeast cyclonic (NEz)
	East (E)	Fennoscandian high anticyclonic (HFa) Fennoscandian high cyclonic (HFz) Norwegian Sea/Fennoscandian high anticyclonic (HNFa) Norwegian Sea/Fennoscandian high cyclonic (HNFz)
	Southeast (SE)	Southeast anticyclonic (SEa) Southeast cyclonic (SEz)
	South (S)	South anticyclonic (Sa) South cyclonic (Sz) British Islands low (TB) Western European Trough (TRW)

The Péczely classification system was defined by György Péczely, a Hungarian climatologist (1924-1984), on the base of the geographical location of cyclones or anticyclones relative to the Carpathian basin [15, 16]. Altogether 13 types were composed as listed in *Table 2*. In the present analysis individual CP types are grouped according to (1) the main directions: Meridional, northern types (mCc, AB, CMc), Meridional, southern types (mCw, Ae, CMw), Zonal, western types (zC, Aw, As), Zonal, eastern types (An, AF), Central types (A, C), and (2) the cyclonic or anticyclonic dominance consisting 6 (mCc, CMs, mCw, CMw, zC, C) and 7 (AB, Ae, Aw, As, An, AF, A) types, respectively. Daily time series of the Péczely CP types are available for the period 1901-2000 [10, 11, 16].

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Table 2. *Macrocirculation types defined in the Péczely CP system*

Main type	Macrosynoptic type	Notation
Meridional, northern types	Cold front with meridional flow	mCc
	Anticyclone over the British Isles	AB
	Cold front arising from a Mediterranean cyclone	CMc
Meridional, southern types	Warm front arising from a meridional cyclone	mCw
	Anticyclone located east of the Carpathian Basin	Ae
	Warm front arising from a Mediterranean cyclone	CMw
Zonal, western types	Zonal cyclone	zC
	Anticyclone located west of the Carpathian Basin	Aw
	Anticyclone located south of the Carpathian Basin	As
Zonal, eastern types	Anticyclone located north of the Carpathian Basin	An
	Anticyclone located over the Scandinavian Peninsula	AF
Central types	Anticyclone located over the Carpathian Basin	A
	Cyclone located above the Carpathian Basin	C

Local-scale daily observations

Daily temperature and precipitation time series observed in Budapest (47.5°N, 19°E) are used to represent the local climate conditions in the Carpathian basin. Daily minimum, mean, and maximum temperature values and daily precipitation amounts of Budapest for the entire 20th century (1901-2000) are available from the Hungarian Meteorological Service (www.met.hu).

Analysis of CP types during different NAO phases

First, the relationship between NAO and regional circulation patterns is analyzed. For this purpose, annual and monthly frequencies of each CP class is determined for both the HBGWL and the Péczely systems on the basis of CP types' occurrence during the 1901-2000 period. Then, differences of CP class relative frequencies in case of NAO– and NAO+ are calculated relative to the normal conditions (defined by the standard deviation as described in the previous section). Since the positive NAO phase implies strong pressure gradient over the North Atlantic thus resulting in enhanced westerly flow (Hurrell, 1995; Hurrell et al., 2003), therefore, special focus is given to the zonal and meridional patterns. Annual and seasonal frequency differences are summarized in *Table 3* for zonal and meridional CP classes from the HBGWL and Péczely systems. In general, the differences are opposite to each other in case of NAO+ and NAO–, which highlight the remarkable difference of these two phases. The zonal CP class occurs more often during NAO+ phase, and meridional CP class during NAO– phase in all seasons. The frequency difference values are smaller in case of the Péczely classification system than in case of the HBGWL system. This can be explained by the geographical target area of the Péczely system, which focuses more on the Carpathian basin located in a larger distance from the NAO action centers than the target area of the HBGWL. The largest difference values (mostly exceeding 10%) are observed during winter, which is the most relevant season in terms of NAO-associated climatic effects (Hurrell et al., 2003; Osborn, 2006). Furthermore, the occurrence difference between NAO– and NAO+ phases is also large in autumn, whereas it is the smallest in summer.

Table 3. *Difference in seasonal and annual occurrences of zonal and meridional CP classes during NAO negative and positive phases relative to the normal conditions (defined by the standard deviation), 1901-2000. In case of the HBGWL system, zonal CP class consists of the following CP types: Wa,Wz, Ws, Ww, and meridional CP class: Na, Nz, HNa, HNz, HB, TRM, NEa, NEz, HFa, HFz, HNFa, HNFz, SEa, SEz, Sa, Sz, TB, TRW. In case of the Péczely CP classification system, zonal and meridional CP classes contain zC, Aw, As, and mCc, AB, CMc, mCw, Ae, CMw, respectively.*

CP class	Classification system	NAO phase	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)	Annual
Zonal	HBGWL	NAO–	-13%	-10%	-3%	-14%	-11%
		NAO+	16%	15%	13%	11%	14%
	Péczely CP	NAO–	-12%	-6%	-2%	-7%	-7%
		NAO+	11%	10%	8%	9%	9%
Meridional	HBGWL	NAO–	26%	17%	11%	22%	19%
		NAO+	-18%	-21%	-17%	-15%	-18%
	Péczely CP	NAO–	9%	4%	11%	9%	8%
		NAO+	-10%	-7%	-8%	-11%	-7%

Fig. 1 shows the winter mean pressure fields for the zonal and meridional CP classes during NAO– and NAO+ phases, which are characterized by similar structures in case of HBGWL and Péczely classification systems. The composite maps of the NAO+ phase clearly illustrate the strong pressure gradient over the North Atlantic, in case of the zonal patterns the average pressure difference between the Icelandic Low and the Azores High is 38 hPa, and it is 34 hPa in case of the meridional patterns. Much smaller pressure difference can be seen on the NAO– composite maps, not exceeding 20 hPa (even in the zonal CP maps) over the North Atlantic region.

Another aspect is also evaluated, namely, the frequency differences of the cyclonic and anticyclonic CP classes. In the Péczely classification system cyclonic CP types are more frequent in NAO– phase, and more rare in NAO+ phase in each season than in case of normal conditions, the largest differences are found in summer (13% and -10%, respectively) and the smallest in winter (7% and -7%, respectively). Opposite to this, anticyclonic CP types tend to occur more rarely in NAO– phase and more often in NAO+ phase than in normal conditions. Since all CP types are either cyclonic or anticyclonic according to the Péczely classification system, the differences are the same but with opposite signs. In the HBGWL system the largest frequency difference of cyclonic CP types during NAO– phase is also in summer (9%), while during NAO+ phase it can be observed in Spring (-10%). Similarly to this, for the anticyclonic types the largest difference is in summer (-9%) and in spring (7%) in case of NAO– and NAO+ phases, respectively.

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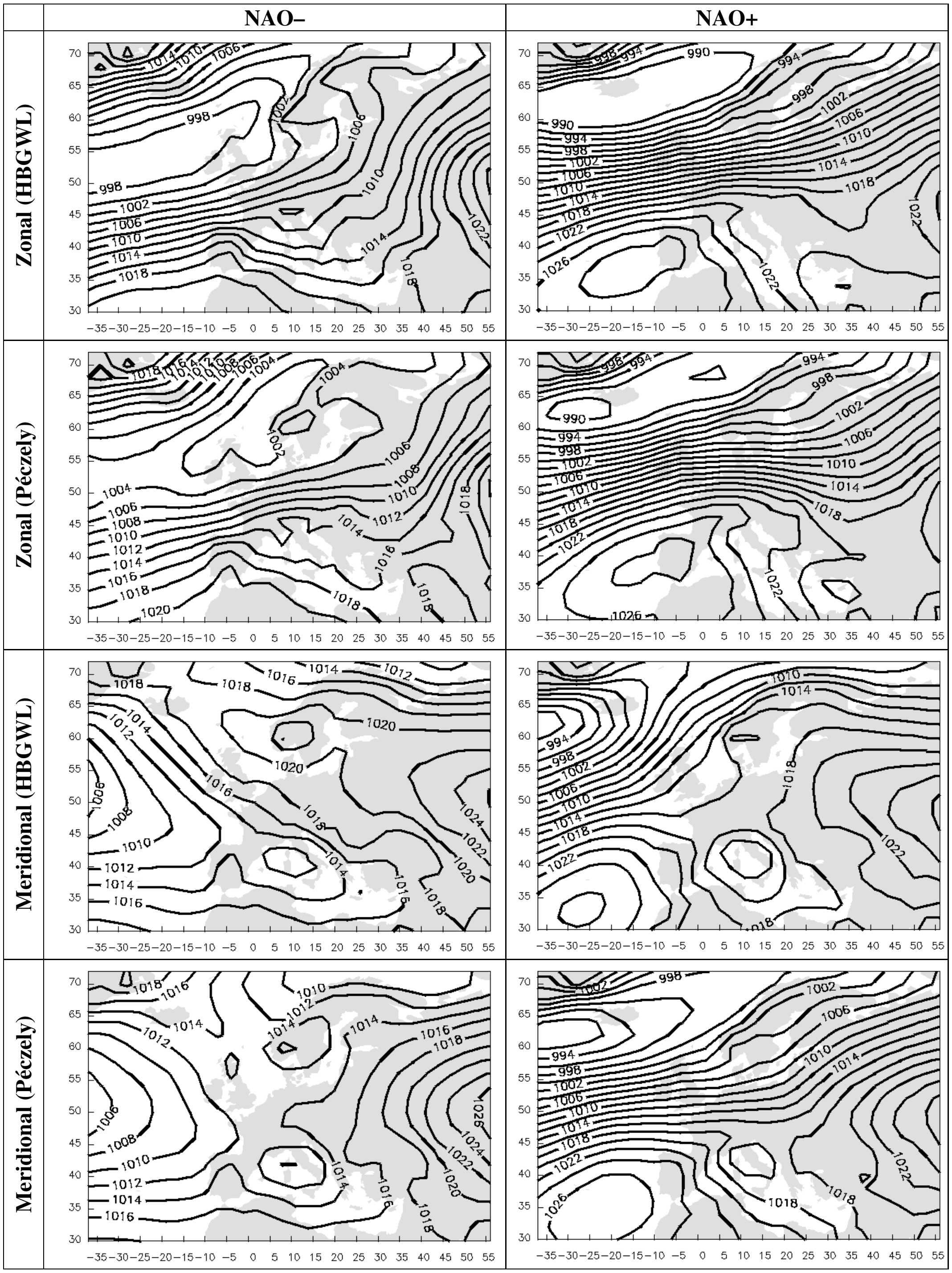

Figure 1. *Winter mean sea level pressure field during NAO negative and positive phases relative to the normal conditions (defined by the standard deviation). In case of the HBGWL system, zonal CP class consists of the following CP types: Wa,Wz, Ws, Ww, and meridional CP class: Na, Nz, HNa, HNz, HB, TRM, NEa, NEz, HFa, HFz, HNFa, HNFz, SEa, SEz, Sa, Sz, TB, TRW. In case of the Péczely CP classification system, zonal and meridional CP classes contain zC, Aw, As, and mCc, AB, CMc, mCw, Ae, CMw, respectively.*

Analysis of local climate conditions

The joint effects of NAO phases and CP types on local climatic conditions are analyzed using temperature and precipitation time series for the 20th century from Budapest. This meteorological station is used in the present paper since it well represents the Carpathian basin in general. The daily minimum, mean, and maximum temperature values as well, as daily precipitation amounts are averaged in case of each CP classes for the HBGWL and the Péczely classification systems. Daily average values are calculated separately for the NAO– and NAO+ phases, and the normal conditions (defined by the standard deviation of NAO index time series as described in 'Data' section).

Temperature

CP-class-wise temperature differences for the NAO– and NAO+ phases relative to the normal conditions are shown in *Table 4* (using the HBGWL system) and *Table 5* (using the Péczely CP system) for daily mean temperature (in the upper large cell), and the minimum and maximum temperature values (in the lower small cells on the left and on the right, respectively). Bold values with grey background indicate significant differences at 0.05 level. In general, the climate of the Carpathian basin is warmer than usual during NAO+ phase, and colder than usual during NAO– phase [18]. According to the temperature difference values shown in *Tables 4* and *5*, most of the significant differences are found in winter, which can be explained by the fact that NAO is the primary large scale atmospheric driver of the European climate mostly in this season [8, 19]. The largest temperature decrease (exceeding 2.5 °C on average!) in the Carpathian basin during NAO– phase is observed in winter when the northern CP classes occur both in case of the Péczely and HBGWL classification systems. The largest winter temperature increase associated with NAO+ phase is observed in case of the Central CP class of the Péczely system (1.8 °C, 1.6 °C, and 1.4 °C for the minimum, mean, and maximum temperature, respectively), and Eastern CP class of the HBGWL system (2.8 °C, 3.0 °C, and 2.9 °C for the minimum, mean, and maximum temperature, respectively).

In spring, the largest significant temperature decrease in NAO– phase is detected when (i) Western CP class occur according to the Péczely system (cooling of all the temperature parameters exceeds 1.4 °C on century-wise average, although only daily minimum and mean temperatures are significant), or (ii) HM type (Central European high) occurs according to the HBGWL system (the temperature is lower by 2.3 °C, 2.9 °C, and 3.5 C than usual on average in case of the daily minimum, mean, and maximum temperature, respectively). The significant temperature changes are also negative for the NAO+ phase in spring, the largest are detected for the Southern (both according to the Péczely and HBGWL system) and Southwestern (only for the HBGWL system) CP classes.

In summer, none of the average temperature differences relative to the normal conditions are significant at 0.05 level. Finally, in autumn significant differences are observed mostly in case of NAO– phase. The largest cooling exceeds 2.2 °C on century-wise average for the daily minimum temperature, 2.5 °C for the mean temperature, and 2.8 °C for the maximum temperature. It is detected when Central CP class occurs according to the Péczely system, or Northwestern CP class according to the HBGWL system.

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Table 4. *HBGWL CP-class-wise average temperature differences (°C) during the NAO negative and positive phases relative to the normal conditions (defined by the standard deviation). Bold values with grey background indicate significant differences at 0.05 level.*

CP classes	Winter (DJF)				Spring (MAM)				Summer (JJA)				Autumn (SON)			
	NAO–		NAO+		NAO–		NAO+		NAO–		NAO+		NAO–		NAO+	
	T_{mean}		T_{mean}		T_{mean}		T_{mean}		T_{mean}		T_{mean}		T_{mean}		T_{mean}	
	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}
W	-0.2		**0.5**		-1.7		**-1.1**		-0.8		0.2		-0.5		-0.3	
	-0.2	-0.1	**0.5**	**0.7**	**-1.4**	-2.1	**-1.1**	-1.1	-0.5	-1.1	0.0	0.3	-0.6	-0.7	-0.4	0.0
SW	0.5		0.2		0.2		**-2.9**		0.1		1.9		-1.7		-2.2	
	0.7	0.2	0.3	0.4	0.5	0.0	**-2.4**	-3.5	0.6	-0.3	1.6	2.2	-1.6	-2.2	**-2.3**	-2.5
NW	**-1.2**		**1.3**		**-2.6**		0.4		-0.2		-0.2		**-2.5**		-2.0	
	-1.2	-1.1	**1.2**	**1.3**	**-2.7**	-2.8	0.5	0.5	-0.2	-0.2	0.1	-0.3	**-2.3**	**-2.8**	**-2.0**	-2.5
HM	**-1.7**		**0.6**		**-2.9**		-0.6		-1.0		0.3		**-1.5**		-0.7	
	-1.6	**-2.0**	**0.6**	0.4	**-2.3**	**-3.5**	-0.8	-0.5	-0.6	-1.4	0.1	0.7	**-1.1**	-1.6	-0.3	-0.9
TM	**-1.7**		0.3		-1.6		-1.4		-0.3		--		2.5		2.9	
	-1.9	-1.5	-0.2	0.8	-1.3	-2.2	-1.1	-2.0	0.0	-0.4	--	--	1.8	3.3	3.4	0.6
N	**-2.6**		**1.4**		-0.4		-0.1		-0.2		0.0		-0.8		-0.4	
	-2.8	**-2.5**	**1.3**	**1.3**	-0.4	-0.4	-0.2	0.2	-0.1	-0.2	0.1	0.2	**-0.9**	-0.8	-0.3	-0.5
NE	0.9		-0.1		-0.5		0.8		0.5		-1.2		1.3		-1.0	
	0.6	0.7	-0.4	0.6	-0.6	-0.7	0.5	1.2	0.9	0.1	-1.3	-1.2	1.3	1.9	-0.9	-1.0
E	-0.4		**3.0**		1.1		0.7		-1.9		0.7		-1.5		0.2	
	-0.8	-0.5	**2.8**	**2.9**	1.0	1.2	0.4	0.8	-1.5	-2.4	0.3	0.4	-1.1	-1.9	-0.2	1.2
SE	-0.5		**1.3**		2.0		-1.2		1.2		--		1.3		2.1	
	-0.6	-0.5	**1.4**	**1.2**	2.1	1.9	-0.9	-1.7	1.1	1.8	--	--	1.2	1.8	1.7	2.0
S	-0.5		-0.7		-0.3		**-2.6**		-0.5		1.4		0.9		0.8	
	-0.4	-0.5	-0.5	-0.7	-0.3	-0.4	**-2.5**	-2.6	-0.2	-0.8	1.2	1.7	1.0	0.9	0.7	0.8
Zonal	-0.2		**0.5**		-1.7		**-1.1**		-0.8		0.2		-0.5		-0.3	
	-0.2	-0.1	**0.5**	**0.7**	**-1.4**	-2.1	**-1.1**	-1.1	-0.5	-1.1	0.0	0.3	-0.6	-0.7	-0.4	0.0
Half-Meridional	**-1.3**		**0.5**		**-1.9**		-0.8		-0.3		0.4		**-1.6**		-1.1	
	-1.2	**-1.4**	**0.5**	**0.5**	**-1.5**	**-2.5**	**-0.8**	-0.9	0.0	-0.5	0.3	0.6	**-1.3**	**-1.8**	**-0.9**	-1.3
Meridional	**-1.7**		**1.2**		-0.1		-0.5		-0.6		0.2		-0.4		0.9	
	-1.9	**-1.7**	**1.2**	**1.2**	0.0	-0.2	-0.6	-0.5	-0.4	-0.8	0.1	0.2	-0.2	-0.4	0.6	1.1
Anticyclonic	**-1.8**		**1.6**		-0.9		-0.2		-0.9		0.3		**-1.4**		-1.1	
	-1.8	**-1.9**	**1.6**	**1.4**	-0.7	-1.1	-0.5	0.2	-0.7	-1.1	0.0	0.7	**-1.1**	**-1.7**	**-1.0**	-1.3
Cyclonic	**-1.9**		**1.3**		-0.4		**-1.2**		-0.4		0.2		**-0.9**		0.9	
	-2.0	**-1.9**	**1.1**	**1.6**	-0.2	-0.7	**-1.1**	**-1.3**	-0.2	-0.7	0.1	0.2	**-0.8**	-1.1	0.6	1.3

If considering cyclone or anticyclone dominance over the region, NAO+ is associated with warm winters and cold springs in case of Cyclonic CP class, whereas NAO– implies cold winters in the Carpathian basin (either for the Péczely or the HBGWL classification systems). When Anticyclonic CP class occurs, winters are significantly warmer than usual (by 1.4-1.6 °C on century-wise average) in NAO+ phase, and both winters and autumns are significantly colder than usual (by 1.8-2.3 °C and 1.0-1.7 °C, respectively) in NAO– phase.

Table 5. *Péczely CP-class-wise average temperature differences (°C) during the NAO negative and positive phases relative to the normal conditions (defined by the standard deviation). Bold values with grey background indicate significant differences at 0.05 level.*

CP classes	Winter (DJF)				Spring (MAM)				Summer (JJA)				Autumn (SON)			
	NAO–		NAO+		NAO–		NAO+		NAO–		NAO+		NAO–		NAO+	
	T_{mean}		T_{mean}		T_{mean}		T_{mean}		T_{mean}		T_{mean}		T_{mean}		T_{mean}	
	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}	T_{min}	T_{max}
North	**-2.8**		**1.3**		0.1		-0.6		0.1		-0.3		-1.1		0.2	
	-3.2	**-2.6**	**1.3**	**1.4**	-0.3	0.0	-0.6	-0.6	0.2	-0.1	0.0	-0.2	**-1.3**	-0.8	-0.1	0.1
South	**-1.4**		0.2		**-1.1**		**-1.1**		-1.1		0.2		-0.1		-0.3	
	-1.5	**-1.4**	0.2	0.3	**-0.8**	-1.4	**-1.1**	-1.2	-0.8	-1.3	0.1	0.1	0.0	-0.2	-0.2	-0.4
West	**-0.8**		**0.8**		**-1.7**		-1.1		-0.4		0.2		**-1.5**		0.3	
	-0.8	-0.7	**0.6**	**1.0**	**-1.4**	-2.0	-0.7	-1.2	-0.2	-0.4	0.3	0.3	**-1.4**	-1.9	0.1	0.8
East	**-1.1**		**1.3**		0.0		-0.4		-0.9		0.3		-0.2		0.5	
	-1.3	**-1.2**	**1.4**	**1.2**	0.3	-0.2	-0.4	-0.4	-0.6	-1.4	-0.1	0.5	0.0	-0.2	0.6	0.6
Central	**-1.8**		**1.6**		0.0		-0.9		-0.8		0.7		**-2.8**		-1.5	
	-1.9	**-1.8**	**1.8**	**1.4**	0.5	-0.3	-1.5	**-0.4**	-0.4	-1.1	0.4	1.2	**-2.2**	**-3.4**	**-1.2**	-2.1
Anticyclonic	**-2.2**		**1.4**		-0.6		-0.5		-0.7		0.3		**-1.2**		-0.2	
	-2.3	**-2.2**	**1.4**	**1.4**	-0.4	-0.8	**-0.6**	-0.4	-0.5	-0.9	0.2	0.5	**-1.0**	**-1.4**	-0.3	-0.2
Cyclonic	**-1.7**		**1.1**		-0.7		**-1.4**		-0.1		-0.5		-0.5		0.2	
	-1.8	**-1.8**	**0.9**	**1.4**	-0.6	-1.0	**-1.2**	**-1.6**	0.0	-0.2	-0.1	-0.5	-0.5	-0.6	0.1	0.1

Precipitation

The NAO– CP joint effect on precipitation of the Carpathian basin is also analyzed. In general, for all seasons, the climate of the Carpathian basin is drier than average during NAO+ phase, and wetter than average during NAO– phase. For this region, similar results are published by [13]. Our results suggest that the NAO+ drying effect is significant in all seasons when either the Central CP class of the Péczely system (the Carpathian basin is drier than average by 37%, 52%, 73%, and 70% on century-wise average in winter, spring, summer, and autumn, respectively), or the Southern CP class of the HBGWL system (the average precipitation decrease is 34%, 44%, 71%, and 15% in winter, spring, summer, and autumn, respectively) occurs. When using the HBGWL classification system, NAO– is associated with significantly wetter than average climate (by 77%, 41%, 76%, and 130% in winter, spring, summer, and autumn, respectively) in case of Half-meridional CP classes. In case of Meridional CP classes, significantly wetter winters and autumns (by 25% and 35% on century-wise average, respectively) are observed during NAO–, and drier summers and autumns (by 36% and 37% on century-wise average, respectively) during NAO+ phase. In case of zonal CP classes, only wetter and drier than average winters associated with NAO– and NAO+ phases, respectively, are significant at 0.05 level.

If considering cyclone or anticyclone dominance over the region, NAO+ is associated with dry winters and summers in case of Anticyclonic CP class, whereas NAO– implies wet winters and autumns in the Carpathian basin (either for the Péczely or the HBGWL classification systems). When Cyclonic CP class occurs (using the HBGWL classification system) both winters and springs are significantly drier than usual (by 19-20% on century-wise average) in NAO+ phase, and springs and autumns are significantly wetter than average (by 22% and 59%, respectively) in NAO– phase. If the Péczely classification system is used then Cyclonic CP class is associated with significantly wetter winters and autumns (by 25% and 22%, respectively) during NAO– phase.

Since the local climatic effect of NAO is most evident in winter [7, 8], this season is selected to illustrate to CP-class-wise average temperature and precipitation differences for the Carpathian basin during NAO– and NAO+ phases relative to the normal conditions (*Fig. 2*). Significant difference values (at 0.05 level) are indicated by an asterisk near the column. In general, NAO– phase is associated with cold and wet winters, whereas NAO+ phase implies warm and dry winters in the Carpathian basin. Both differences for both phases are significant for the Anticyclonic CP classes (using either the Péczely or HBGWL system) as well, as for the Half-meridional CP class of the HBGWL system. In addition, precipitation-wise differences for both NAO phases are significant when Southern CP classes (using the Péczely classification system), and Western or Zonal CP classes (using the HBGWL system) occur.

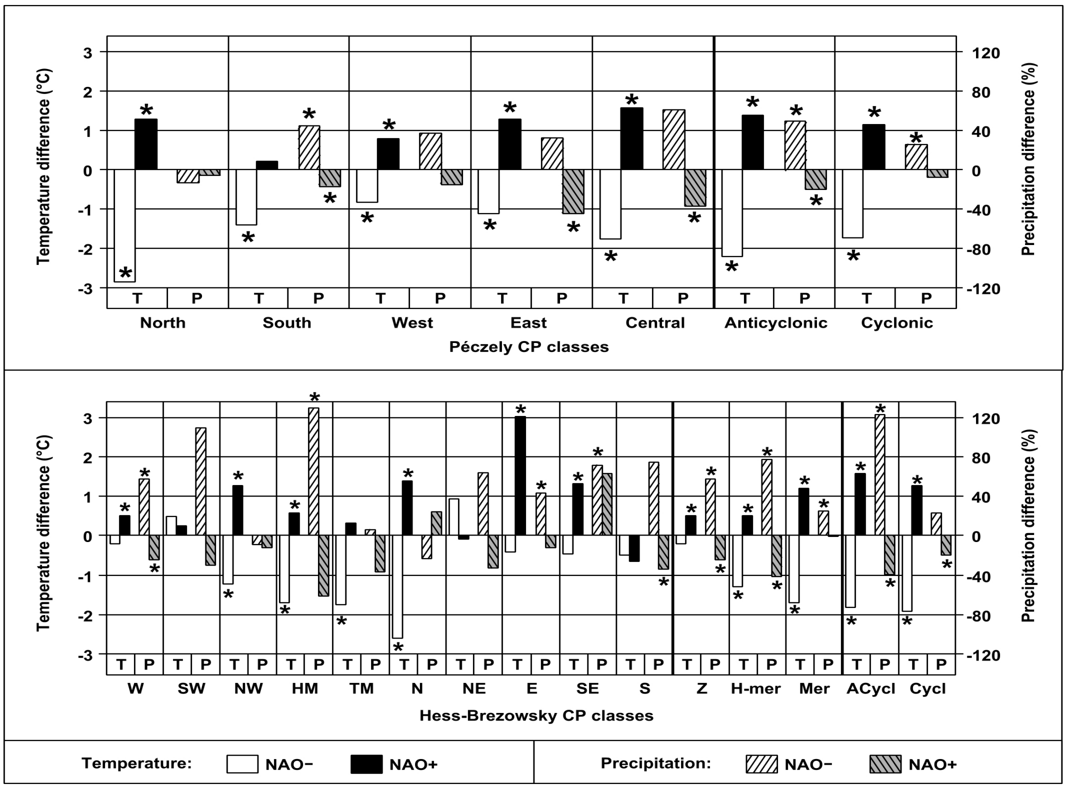

Figure 2. *CP-class-wise average temperature (T; °C) and precipitation (P; %) differences in winter during the NAO negative and positive phases relative to the normal conditions (defined by the standard deviation). Significant differences at 0.05 level are indicated by an asterisk near the column.*

Conclusions

NAO effects on regional circulation represented by the occurrence of HBGWL and Péczely CP classes have been analyzed. Then, NAO and CP joint effects on local temperature and precipitation conditions have been evaluated for the 20th century. NAO+ and NAO– phases applied in our analysis have been defined using the standard deviation of the monthly NAO index time series. Based on the results presented in this paper, the following conclusions can be drawn.

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- The zonal/meridional CP classes occur more often during NAO+/NAO– phase in all seasons in case of both classification systems.
- Cyclonic CP types are more frequent in NAO– phase, and less frequent in NAO+ phase than in case of normal conditions, whereas frequency differences of Anticyclonic CP types are opposite to these.
- The largest frequency difference values between NAO–/NAO+ phases and the normal conditions are observed during winter, which mostly exceed 10%.
- NAO– phase is associated with cold and wet winters, whereas NAO+ phase implies warm and dry winters in the Carpathian basin. This difference is especially manifested when Anticyclonic CP class occur using either the Péczely or HBGWL classification system.
- NAO+ is associated with dry and warm winters, and dry summers in case of Anticyclonic CP class, whereas NAO– phase implies wet and cold winters and autumns in the Carpathian basin (either for the Péczely or the HBGWL classification systems).
- When Cyclonic CP class occurs using the HBGWL classification system winters tend to be drier and warmer than average, and springs tend to be drier and colder than average in NAO+ phase. In addition, springs and autumns tend to be wetter than average, and winters tend to be colder than average in NAO– phase.
- If the Péczely classification system is used then Cyclonic CP class is associated with significantly warmer winters and colder springs during NAO+ phase. Furthermore, significantly wetter and colder winters, and wetter autumns occur during NAO– phase.

Acknowledgements. Research leading to this paper has been supported by the following sources: the Hungarian Academy of Sciences under the program 2006/TKI/246 titled Adaptation to climate change; the Hungarian National Science Research Foundation under grants T-49824, K-78125, K-67626, and K-69164; the Hungarian Ministry of Environment and Water under the National Climate Strategy Development project; the Hungarian National Research Development Program under grants NKFP-3A/082/2004 and NKFP-6/079/2005; the CECILIA project of the European Union Nr. 6 program (contract no. GOCE-037005). Furthermore, support of the Hungarian State Eötvös Fellowship is appreciated.

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THE RELATION BETWEEN THE BIOLOGICAL ACTIVITY AND THE LAND SURFACE TEMPERATURE IN BUDAPEST

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Abstract. The aim of our investigation was to study in detail the relationship between the spatial structure of the urban green surface and land surface temperatures. The research was carried out to support the elaboration of the Environmental Action Programme of Budapest (Hungary) focusing on city planning as well. The ultimate goal was the utilization of the findings to provide planning guidance for the city, on how vegetation could contribute to the mitigation of the negative effects of urban heat island in more effective ways.
Keywords: *Green surface, land surface temperature, satellite image, land use, urban heat island, human comfort, vegetation, remote sensing*

Introduction

Analysing the Landsat5 TM satellite image of Budapest we found strong negative correlation between land surface thermal radiation and biological activity of vegetation. In order to present this correlation for the general public we created cross section diagrams of Budapest, which simultaneously present the land surface temperature and values of a vegetation index (NDVI). In accordance with the city's zoning plan we analyzed the land surface temperature and vegetation characteristics of 14 land use types. The difference between the mean temperature of these land use types exceeded 15 ºC. The land use types of highest land surface temperature values were road and railway junctions, commercial areas (shopping centres), manufacturing sites and high density residential areas. Our suggestion is, that these are the land use types which are chiefly responsible for the creation of the urban heat island.

Utilising the findings of the survey our team made several policy recommendations, which form part of the Budapest Environmental Program 2007.

Review of Literature

The effect of urban heat island on human comfort

The high building density, the lack of surfaces allowing evaporation and increasing human activity change the energy and water balance of the land surface and the atmosphere in urbanised environments. This results in the creation of the phenomenon of urban heat islands (UHI), which are the areas of excess warmth of the urban atmosphere and surfaces compared to their rural surroundings [19]. There is a great number of surveys describing the characteristics and effects of the UHI. Oke's study of 1987 described the changed temperature, moisture and aerodynamic conditions of urbanized areas [16]. There is a difference between atmospheric UHI and land surface UHI. The former has its highest level in the early evening hours, while the latter around the mid day period. [10] The annual characteristics of the UHI vary regionally. For instance while South-East Asian surveys suggest that the annual maximum values of the UHI are in the autumn and winter period [14, 26], a survey of 8 Asian mega cities suggest that in the North Hemisphere the maximum in August, in tropical cities in the dry season [10], while surveys in Hungary demonstrate the maximum values are in June and July [1]. The easier access to satellite images and the improvement of GIS technologies contributed to the increased number of studies. Images of NOAA [6] of Terra and Aqua [1, 10] and of Landsat [19, 23] area also used for UHI related analysis. Because of the effects of UHI the energy demand for cooling of buildings increases [15]. Different land use types have different effects on UHI. Using remote sensing data and GIS analysis, studies try to reveal these effects. (For literature review see [13].) It is suggested that the UHI has a significant effect on the regional climate and also on socio-economic development [3]. In our paper we would like to emphasize that it frequently has a more noticeable local effect, since it can significantly deteriorate the value of human comfort indices of open spaces in urbanized areas.

Human comfort and the mitigation of urban heat island effects

One might think that the thermal environment of the human body is chiefly determined by the air temperature. If the air temperature is too low we are cold, if it is too high we are hot, if neither then we feel comfortable. A study suggests that there are three other factors to be taken in consideration: relative humidity, wind speed and surface radiation [8]. The combination of these four determine the evaporation of the human body, and hence thermal comfort. During the summer period the most significant input in the thermal indices is not the air temperature, but the mean radiant temperature [9]. This suggests that the land surface temperature studied in this research has a very significant effect on the comfort conditions of open spaces.

Research suggests, that there are six main strategies of how the negative effects of UHI can be mitigated [2]: a) modification of urban geometry, b) use of light-coloured surfaces, c) policies and measures to increase energy efficiency, d) management of traffic and better transportation system design, e) use of permeable surfaces, f) use of vegetated surfaces. In our research we study how the presence or the absence of urban greenery in Budapest effects the Land Surface Temperature (LST) and hence the UHI of the city.

Methods

The relation between vegetation and thermal radiation of land surface

It is a well known and documented fact that the land surface temperature and the vegetation are related to each other. Some studies focus on the description of how urbanization process, and the loss of vegetation contribute to rising urban temperatures [13], while others focus on how vegetation can reduce the negative effects of the UHI [21]. Multispectral satellite images make possible the measurement of both the vegetation and the thermal radiation at regional scale. Several indexes are derived from

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satellite images which can be used to describe the urban vegetation, such as the Normalized Difference Water Index (NDWI) [7] or the Normalized difference built-up Index (NDBI) [25]. The most frequently used index to measure vegetation is the Normalised Difference Vegetation Index (NDVI), derived form the red and infrared channels of satellite images [24].

In our research, analysing the Landsat5 TM satellite image, we intended to investigate the relation between NDVI and Thermal Radiation (TR) values in the case of Budapest. The 25-120 m resolution of the image allowed us to analyse urban vegetation and the UHI in greater details than was done so far in Hungary [1]. We used the vegetation index (NDVI) as an index of green surface intensity (vegetation cover) since in our previous studies we have found strong correlation between them [4, 12]. The analysed satellite image was taken on the 1st of August 2005 at 9:30 AM (CET), which was a clear and sunny day. The air temperature at 9:30 was 24,3 ºC, while the daily maximum was 31 ºC at 16:30, hence the radiation values of the image do not present the daily peak values.

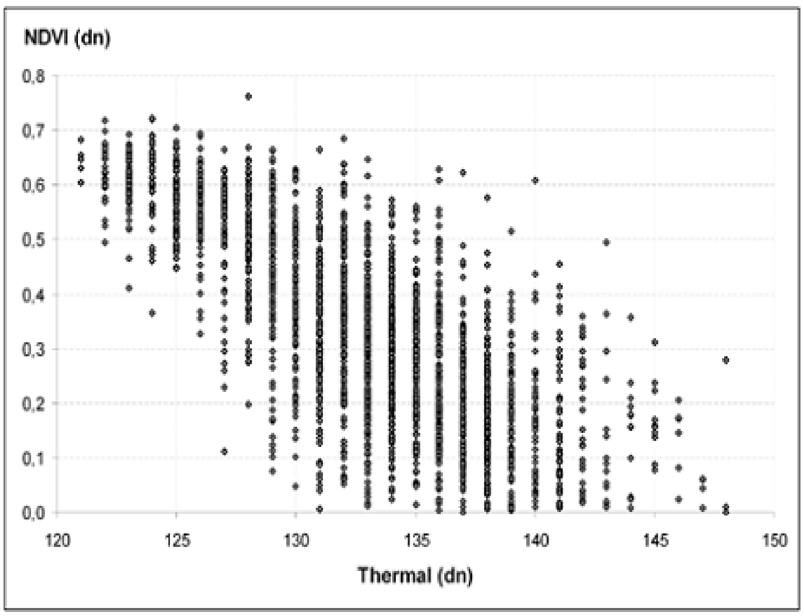

Figure 1. *Relationship between biological activity of vegetation and thermal values of land surface in Budapest. (Represented by positive NDVI values and values of thermal infra band Landsat5 TM satellite image in the 1st of August 2005 9:00 CET)*

The relation between the positive NDVI values and the TR variables were tested by seven different correlation analyses. The value of the square of the correlation coefficient (R^2) in the case of linear regression was 0.588. The value of the R^2 was slightly better in the case of Quadratic (0,603) and Cubic (0,604) correlation. The value of the constant was negative in all cases. These results suggest that there is significant negative correlation between Normalised Differential Vegetation Index and the TR values of the satellite image. *(Fig. 1.)* However the correlation is not strong enough to make it possible to calculate the TR directly from the NDVI value of a designated spot. *(Table 1.)*

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Table 1. *Correlation between vegetation biological activity (NDVI) and land surface thermal radiation (TR) values derived from satellite image (Landsat5 TM)*

Equation	**Model Summary**						**Parameter Estimates**		
	R2	F	df1	df2	Sig.	Const.	b1	b2	b3
Linear*	0,588	2638,38	1848	0,000	140,082	-21,455			0,588
Quadratic**	0,603	1401,51	1847	0,000	138,562	-8,9969	-18,475		0,603
Cubic***	0,604	937,77	1846	0,000	139,033	-16,41	8,6186	-26,727	0,604
Exponential****	0,592	2680,46	1848	0,000	140,224	-0,1624			0,592

Independent variable: NDVI, Dependent variable TR

* Y = b0 + (b1 × A)

** Y = b0 + (b1 × A) + (b2 × A2).

*** Y = b0 + (b1 × A) + (b2 × A2) + (b3 × A3).

**** Y = b0 x (eb1 × A) = ln(b0) + (b1 × A)

Retrieving Land Surface Temperature

It was important to estimate the Land Surface Temperature (LST) from the satellite image in order to facilitate understanding of TR easier and relate to Celsius temperature scale. There are two main methods of retrieving LST using the data basically of the 6^{th}, and additionally the 3^{rd} and 4^{th} band of Landsat TM5 satellite image. One of these is the “Mono Window Algorithm” [18], the other is the “Single Channel Method” [11]. Using the LST software [22] we have calculated the land surface temperature both by using the mono window algorithm developed by Qin et al and the single-channel algorithm developed by Jimenez-Munoz. The publications describe both methods with approximately 2 ºC accuracy. [20]. We generated the LST for our purpose by calculating the average values of the two model outputs. The meteorological data required for the calculations (atmospheric transmittance, effective mean atmospheric temperature, total atmospheric water vapour) were provided by the National Meteorological Institute of Hungary (OMSZ).

Results

Analysing the cross sections of Budapest

Using NDVI values, representing green surface intensity as well, and LST variables we created cross section diagrams of Budapest. It was found that these diagrams make it easier to understand the correlation between vegetation and LST for the general public and also for decision makers. Using the diagram the results of the analysis of the thermal and vegetation biological activity of a given location are more evident, which was the basic for the research team to form policy recommendations.

The diagrams present the Northwest-Southeast and Southwest-Northeast cross sections of Budapest, with well recognisable inverse tendencies of the biological activity of vegetation and LST. The increasing values of biological activity result in the decrease of thermal values and vice versa. This tendency can be recognised for each area where significant differences between NDVI values exist. The only exception being the Danube river where the 0 NDVI values are met with equally low LST values. In this case the cooling effect of the water surface results in low LST values. *(Fig. 2.)*

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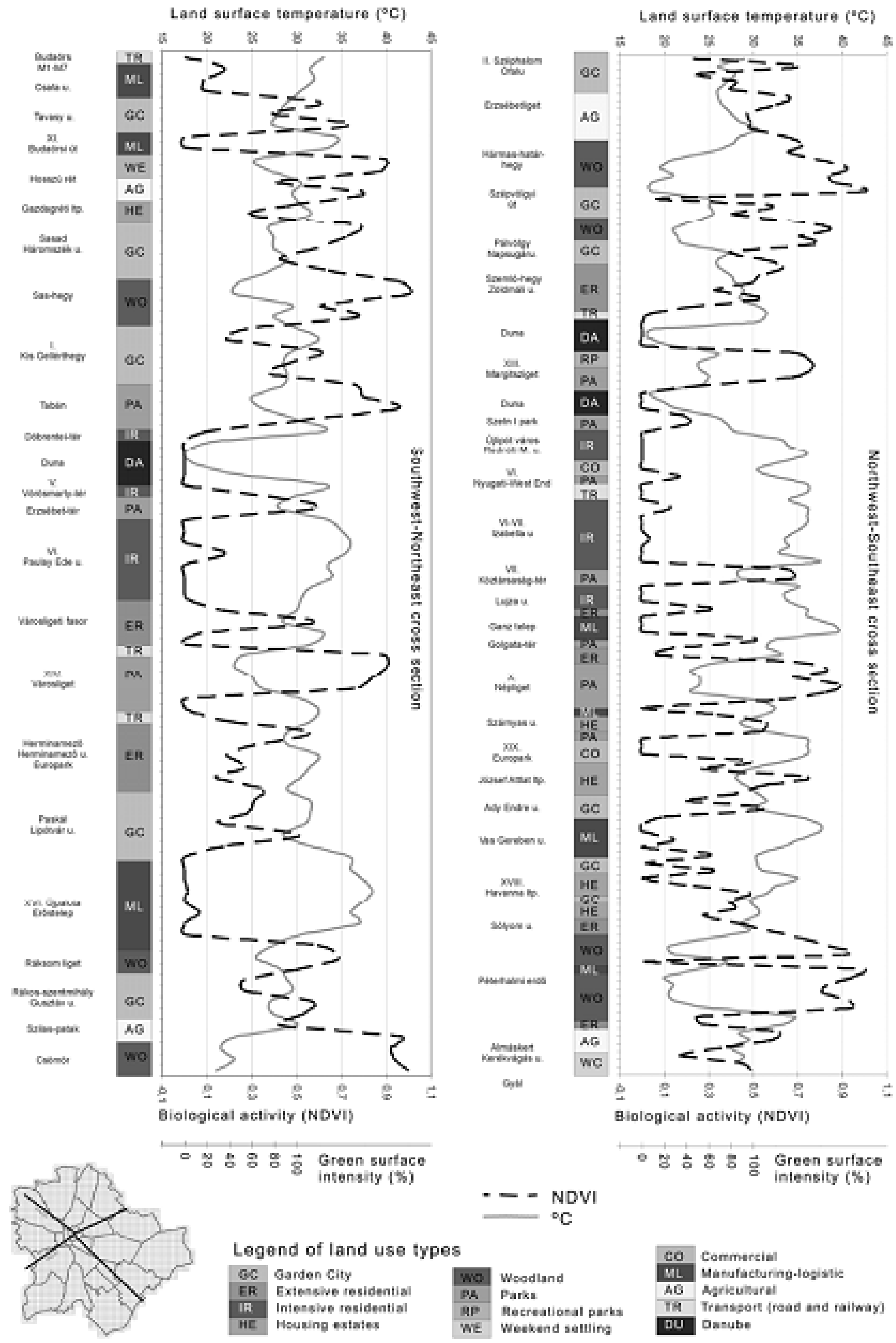

Figure 2. *Diagram of cross sections in Budapest demonstrating green surface intensity (NDVI) and land surface temperature (ºC) connection with regard to land use types as well.*

The maps, based on interpreted satellite images, show that e.g. in the Margit-sziget (Margaret Island), one of the major parks of the city, the intensive vegetation causes low LST values (18,5-24,0 ºC). At the intensive residential area of the East side of the

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river in Újlipótváros one can mainly find low vegetation values and high surface temperatures (NDVI 0, means actually no green surface at all; LST 33,0-36,0 ºC) except of patches of smaller parks, gardens and squares of high green surface intensity (e.g. Szent István park, Honvéd tér, Kossuth tér). The roof garden of the West End shopping centre definitely reduces the LST values by a few degrees Celsius (30,5-32,5 ºC), which is in great contrast with the neighbouring railway area (LST 36,0 ºC). *(Fig. 3.)*

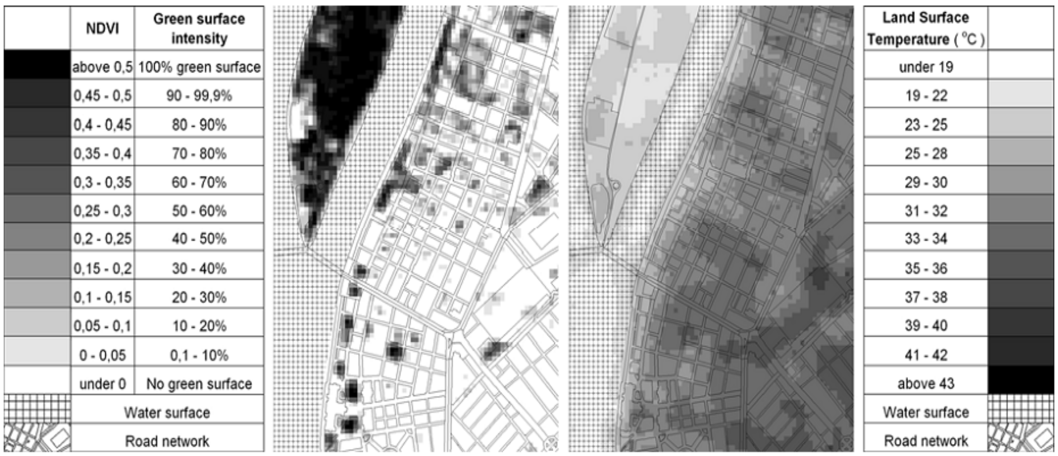

Figure 3. *Map of green surface intensity (based on NDVI) and land surface temperature (ºC). Margaret Island and Újlipótváros.*

It is noticeable that compared to densely built intensive residential areas, the extensive residential area along the Városligeti fasor (City Park alley) with higher green surface intensity (32–100%), results in lower land surface temperatures (28-30 ºC). It is remarkable that the high temperature of the Hungária Ring (32,5-31,5 ºC) is in strong contrast with the adjoining Városliget (City Park) (NDVI 0,3-0,9 mainly 60-100% green surface; LST 23,0-26,0 ºC). *(Fig. 4.)*

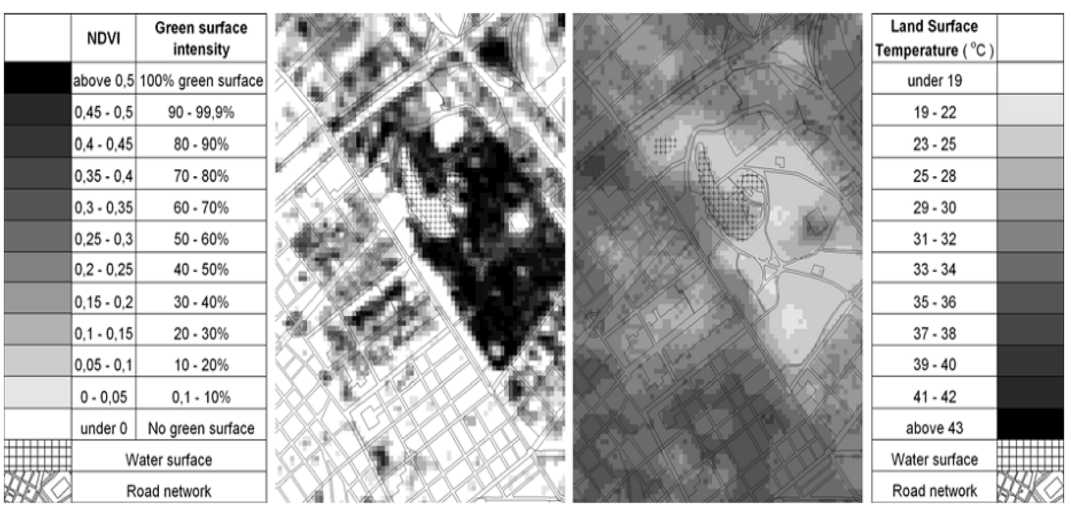

Figure 4. *Map of green surface intensity (based on NDVI) and land surface temperature (ºC). The City Park and the City Park alley in Budapest.*

Analysing land use types

In the next stage of the research we examined how the different urban land use types can be characterised both by vegetation and thermal values. According to the city zoning plan we differentiated 14 land use types, in four groups such as residential, economic, recreation and transport. We examined 95 sample areas covering a total of 3 300 hectares (over 6% of the city area). Calculating the mean value, the standard deviation and the lowest and highest NDVI and the LST values of the pixels we described the characteristics of these land uses *(Table 2.).*

Table 2. *Land use types with vegetation and land surface temperature characteristics*

Land use types	Sample area		NDVI			LST (ºC)		
	sample number	size ha	mean	standard deviation	max. value	mean	standard deviation	max. value
RESIDENTIAL GROUP								
Intensive residential	5	53	0,02	0,05	0,45	33,92	1,47	37,00
Extensive residential	6	120	0,27	0,12	0,61	28,35	2,14	34,50
Garden city	10	288	0,22	0,09	0,55	29,79	1,92	35,50
Housing estates	9	232	0,19	0,11	0,56	30,48	1,53	36,00
ECONOMIC GROUP								
Manufacturing-logistic	6	270	0,05	0,08	0,59	34,87	2,76	43,50
Commercial	4	47	0,03	0,07	0,44	35,30	3,28	44,00
Agricultural	13	596	0,34	0,21	0,70	27,59	5,37	41,50
RECREATION GROUP								
City parks	4	258	0,40	0,16	0,64	25,15	2,65	36,50
Smaller parks	9	51	0,35	0,17	0,65	28,20	3,14	38,00
Cemetery	2	68	0,40	0,13	0,65	26,62	2,39	34,00
Recreational parks	3	29	0,35	0,18	0,63	24,94	2,11	33,00
Woodland	11	1207	0,59	0,10	0,85	20,58	2,45	33,00
TRANSPORT GROUP								
Railway junctions	5	70	0,03	0,08	0,42	35,51	1,42	39,00
Road junctions	8	18	0,01	0,04	0,33	33,53	1,13	30,50
Sum Average	95	3307	0,23	0,11	0,58	29,63	2,41	36,86

Amongst residential land use types the highest mean LST (33,9 ºC) and the lowest NDVI mean value (0,22 which is approximately 44% green surface intensity) can be found in the intensive residential areas, whilst the lowest thermal values and the highest green surface intensity characterize the extensive residential areas (LST 28,3 ºC; NDVI 0,27 means around 54% green surface intensity). We found that the zones of garden city and housing estates have similar thermal and vegetation characteristic in Budapest, and

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that their LST intensity is surprisingly a bit higher than that of the extensive residential areas. *(Fig. 5.)*

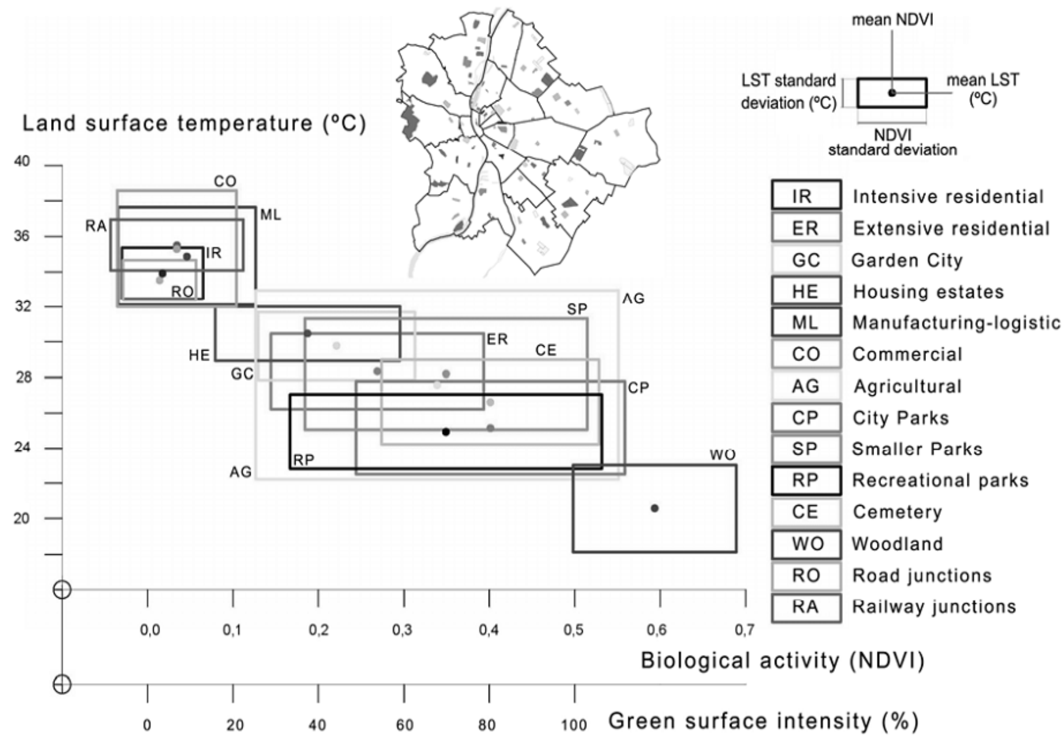

Figure 5. *Diagram of sample area study results (see map of samples in Budapest on the top). The 14 different land use types investigated in Budapest are characterised by the mean and standard deviation values of land surface temperature and biological activity.*

In the economic group of land use types the highest maximal temperatures were found at commercial and manufacturing-logistic areas (43,5-44,0 ºC), which can partly be explained by the low NDVI values (0,07-0,08 14-16% green surface intensity), but the thermal effects of manufacture and the intensive radiation of asphalt surfaces are likely to also be responsible for the high LST values. It is an unexpected finding, that in Budapest the commercial areas have lower mean NDVI value and higher mean LST than the manufacturing-logistic areas. Agricultural areas have higher vegetation and lower thermal values than the types belonging to the previous economic group (LST 27,6 ºC; NDVI 0,34 means 68% green surface intensity). However their most specific character is the high deviation both in vegetation and thermal values, which is not surprising, since the arable land, which mainly covers agricultural type in Budapest, can completely lack vegetation or may also have 100% plant coverage depending on the cultivation. The thermal standard deviation of manufacturing-logistic and commercial areas is also high, which suggest that the thermal characteristic of economic group land use types is not homogenous at all.

Within recreational group the lowest LST mean values (20,6 ºC) and also the lowest standard deviation values (0,10 ºC) were found at woodland which typically have 100% vegetation coverage. The recreational parks (outdoor swimming pools and spas) have very low LST values despite the relatively higher rate of built up areas within them (LST 24,9 ºC, NDVI 0,35 means only 70% green surface intensity), which is probably due to the cooling effect of water surface. Amongst recreation types with the highest LST values (28,2 ºC) are the parks of smaller size. The high standard deviation rate of the thermal values is also noticeable at these areas, which suggests that their thermal condition varies not solely according to their vegetation, but also other factors (e.g. the type and extent of paved surfaces within the park).

Among the examined sample areas the railway junction areas had the highest mean LST values (35,5 C). The low vegetation at these areas (NDVI 0,08 means 16% green surface intensity) is not capable to reduce the high heat values. The road junctions were the areas of lowest vegetation intensity (NDVI 0,01 means 2% green surface intensity), which reflects that the low vegetation cover of these areas also contributes to the creation of the UHI.

Discussion

Findings

The UHI, prevailing during summer in continental climate, has a significant negative impact on the thermal comfort level of the citizens. Hence its reduction is important to create a better urban environment. As a result of our research we have showed that the manufacturing-logistic, commercial, intensive residential, railway and road junction areas are chiefly responsible for the creation of the UHI. This becomes highly important when results from a previous study about the change of biological activity in Budapest based on more satellite images are taken into account. This former study showed that two of these five land use types (commercial areas, road junctions) were definitely increasing, and green surface was slightly decreasing in the period between 1990 and 2005 [5].

The most important findings of our research:

1. Biological activity and land surface temperature are in strong negative correlation. The vegetation index (surface cover) is on average low in the land use types with the highest LST.
2. The highest land surface temperatures can be found at manufacturing-logistic, commercial, intensive residential land uses and at railway and road junctions. It is suggested that these areas are mainly responsible for the Urban Heat Island.
3. The difference in land surface temperature at 9:30 CET in 1st of August 2005 exceeded 25 ºC.
4. The difference in the average temperature of the examined land use types exceeded 14 ºC.
5. We found that the mean land surface temperature of the city parks was 12 ºC below the mean temperature of intensive residential areas.
6. The low LST values of large parks did not effect the LST values of other land use areas around them. However this does not suggest, that the cooling effect of urban parks does not have effect on the air temperatures of the surrounding areas.
7. In the case of green roofs, surface temperatures were reduced by 3,5 ºC.

Policy recommendations

The conclusion of the research team is that in particular the LST primarily at manufacturing-logistic, commercial, intensive residential land uses and at railway and road junction areas should be reduced order to mitigate the negative effects of UHI, since these are the areas chiefly responsible for creating the UHI. Our recommendation is to reduce the LST at these areas by increasing the areas covered with vegetation within these land uses. These new green areas should be created on ground level but also on roofs as roof gardens or green roofs. The evaporation from vegetation acts like a natural air conditioning system and the foliage of the trees also has a positive shading effect. For these two reasons we suggest that the planting of deciduous trees, with large and highly evaporating foliage during the summer period, is the most effective way of reducing the UHI in Budapest, which is strongest in the summer. Obviously the increase of areas covered by vegetation is not the only way of reducing the UHI. However the aesthetic values of the plants is a very strong argument to support their use in urban environments.

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CLIMATIC EFFECTS ON THE PHENOLOGY OF GEOPHYTES

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Abstract. Nowadays, the scientific and social significance of the research of climatic effects has become outstanding. In order to be able to predict the ecological effects of the global climate change, it is necessary to study monitoring databases of the past and explore connections. For the case study mentioned in the title, historical weather data series from the Hungarian Meteorological Service and Szaniszló Priszter's monitoring data on the phenology of geophytes have been used. These data describe on which days the observed geophytes budded, were blooming and withered. In our research we have found that the classification of the observed years according to phenological events and the classification of those according to the frequency distribution of meteorological parameters show similar patterns, and the one variable group is suitable for explaining the pattern shown by the other one. Furthermore, our important result is that the dates of all three observed phenophases correlate significantly with the average of the daily temperature fluctuation in the given period. The second most often significant parameter is the number of frosty days, this also seem to be determinant for all phenophases. Usual approaches based on the temperature sum and the average temperature don't seem to be really important in this respect. According to the results of the research, it has turned out that the phenology of geophytes can be well modelled with the linear combination of suitable meteorological parameters
Keywords: *climate change, phenophases, meteorology, cluster analysis, correlation, phenological models.*

Introduction

Climate change is one of the most important ecological problems of our times [13]. It is of great significance because it affects the living conditions of the whole global society [10]. Challenges and tasks related to the climate change determine almost all segments of the society and economy fundamentally [4]. Climate policy includes among others several issues of the agriculture and food production, land use, energetics, industry and transport, environmental and nature conservation and public health, but it also has sociological, educational, communication, even safety policy and foreign policy aspects. Changeability of the climate that is the lack of climatic stability in longer periods (and its degree) is determinant for the state and change of state of all earthly ecosystems [7, 8, 11, 16, 17, 20, 29]. The degree of the changeability of the climate (the total variability of the climatic parameters) shows in itself significant heterogeneity both in space (regionally) and time (according to time slots of research). The degree of the changeability and its pattern in space and time are considerably scale dependant attributes at the same time. A further methodological problem is implied by the fact that not only the active component (the changeability of the climate in this case) but also the different, natural and human-influenced ecosystems (as the systems receiving the effects) show fundamental heterogeneity from the point of view of their sensitivity to the effect [12, 26, 27]. Sensitivity can be characterized by the change of state and its dynamics caused by unit effect in this context. Moreover, ecosystems as systems capable of regulation do not endure effects passive but they react to those with adaptation and feedback of different degree and type [6]. In the case of human-influenced ecosystems, this adaptation would require optimising human activity and intervention, which still has significant methodological faultiness nowadays. All these circumstances, the climatic effect and the reactions of the ecosystems as well as human activity play a determinand role in the sustainability of ecosystems and its risks. Among basic ecological phenomena, climate change influences seasonal community dynamics and one of its important factors, the phenology of the species, most strongly [24, 30].

Therefore, in our present study the connection between weather conditions and phenology was examined using Szaniszló Priszter's phenological monitoring data series on geophytes.

In our research we have set three main goals:

1. To explore according to some suitably chosen years whether frequency distributions of the meteorological parameters in the given period play a determinant role in the development of phenological patterns.
2. To survey with the help of correlational analyses, which meteorological parameters have what kind of influence on the phenological behaviour of the individual indicator plants.
3. To examine whether new variables made by linear combinations of meteorological parameters can lead to working out effective phenological models, which could play a role in future climate change research.

Review of Literature

Phenological data collected by research systems all over the world aid with making models and with the help of their statistical analysis the degree of the global warming can be predicted.

In China, it is the CAS network that examines different phenophases [2]. There are both woody and herbaceous plants among the 173 species examined and different phenophases of these plants such as budding or autumn colouring are observed. These data are used to examine their correlation with meteorological parameters. The CAM network collects different meteorological data on 587 stations. Models show to what extent the date of the blooming of the individual plants differs in various regions of China, which is brought into connection with temperature and carbon dioxide concentration.

Japan's network called JMA was founded in 1953 [2]. It has nearly 100 stations, which observe phenophases and collect meteorological data. Phenological models concentrate mainly on the normal phenophase, the effect of the warming of urban regions and the climate change. One of these models shows the relationship between the main blooming and geographical coordinates, while another relationship between temperature and blooming.

In Australia, mainly Eucalyptus species are observed [15] but Araucaria cumminghamii, Corymbia maculata and Pinus species are also examined.

The first phenological network in Europe is linked with the name of Carl von Linné, who made his observations in Sweden [18]. The International Phenological Garden (IPG) is nowadays a unique system in Europe, which was founded by F. Schnelle and E. Volkert in 1957. It observes 7 phenophases of 23 plant species and measures the growing period, the concentration of carbon dioxide and the change of spring temperature. There are networks in several countries of Europe, such as in Albania, Austria, the Czech Republic, Estonia, Germany, Poland, Russia, Slovakia, Slovenia, Spain and Switzerland. There are incomplete systems for example in Portugal and Greece.

Research in the USA mainly began in the 20th century [24]. Between 1851-1859 86 plant species and insects were observed in 33 places. In the 1950s, research of the phenology became important for the agriculture. Beside Syringa and Lonicera species, the observation of Cercis canadensis, Cornus florida and Acer rubrum is significant.

In Canada, first nations and Inuits made a natural calendar, which showed the date of blooming of Thermopsis rhombifolia, the rosaceae and Holodiscus discolor as well as the ripening of Rubus spectabilis [24]. Nowadays blooming of wild flowers, phenology of birds and frogs and freezing of lakes and rivers are observed.

In South-America, blooming of indigenous tropical trees such as coffee and cacao are observed [19]. Research is carried out related to climate change, El Niño and the effects of carbon dioxide emission on plant phenology.

Researchers started to show interest in phenological observations mainly in the 1990s [1]. They have mostly been motivated by the recently risen temperature and changes in the development of plants and animals. The Phenology Study Group was established in Canada in 1993, then the Global Phenological Monitoring (GPM) in 1996. GPM is an important system in the northern hemisphere. A phenophase mostly depends on the temperature, precipitation, soil type, soil humidity and the sunshine. The most significant from these is the effect of the temperature therefore GPM focuses on it.

Criteria of the selection of the species for observation:

- Plants should have phenophases that are easy to observe.
- The start of the phenophases should be sensitive to air temperature.
- Plants should be economically important.
- Plants should have a broad geographic distribution or ecological amplitude.
- Plants should be easy to propagate.
- Blooming should last several months during the growing period.

These criteria are met particularly by fruit trees, bushes in parks and spring flowers. There are special standardized observation programmes when plants are grown in a closed place, watered and eliminating weather effects. In these cases, only temperature effects are examined.

One of the most important phenological models is the plant development model. It goes back to 1735 and is linked with the name of Réaumur [3]. He recorded the dates of phenophases and the mean temperature measured on any day of the phenophase.

Modelling began to develop in the 20th century when computer sciences and examinations related to global climate change were also developing. It was mainly based on the relationship between the rise in temperature and the change of the phenophases. Most models predict the date of budding, blooming and ripening, however, they cannot really prognosticate autumn colouring of the trees yet.

Models have three main types:

- Theoretical: it is based on the cost-benefit ratio in the case of leaves put forth by the plants.
- Statistical: it examines the relationship between climate factors and dates of the phenophases.
- Mechanical: it describes known or assumed cause-and-effect dependences between biological processes and some environmental factors. For example, the spring warming model contains beside mean temperature and heat summation development rates as well. However, this model has a fundamental problem: our knowledge related to biochemical and biophysical processes in dormancy is rather insufficient.

Materials and Methods

We have used historical weather data series from the Hungarian Meteorological Service and Szaniszló Priszter's observations of the phenology of geophytes for the case study. Szaniszló Priszter, the former director of the Botanical Garden of the Eötvös Loránd University has been observing and recording dates of occurrence of three characteristical phenophases of about 200 plant species, mainly geophytes for approximately 40 years in the last decades of the twentieth century [14, 21, 22, 23]. Priszter's data have been substituted for day serial numbers in the individual years. These data describe on which days the observed geophytes budded, were blooming and withered. Our database has been constructed from this mass of data and it contains Latin names of the species and day serial numbers of the occurrence of the three phenological events for each examined year. The Hungarian Meteorological Service has published hundred-year daily data of Budapest for a long time, among which you can find the daily mean temperature, the daily maximum and minimum temperature, tha amount and type of daily precipitation and the daily sunshine duration. In order to complete these, radiation values have also been calculated (according to [28]).

Examining the connection between phenological parameters and weather, we have used three approaches:

- From the meteorological data series, the yearly frequency distribution of the characteristical meteorological parameters has been calculated for the ecologically effective period of each year, then the years have been classified according to these data. The same years have been classified according to the phenological indicators (day serial numbers of the occurrence of phenophases of a given species) as well, then classifications made for the same objects (years) but according to different variables have been compared.
- As a second approach, correlation between the individual phenological indicators and weather parameters has been examined separately. For this purpose, a meteorological parameter vector containing 24 elements has been made for the period in which the phenological change of state of the given plant in the current year has been examined (from 28th August in the previous year and from 27th August in leap year respectively, till the current phenological change). In order that the result of the research is utilizable for further climate change research, daily global radaiation values have also been determined

according to the Szász Gábor algorithm [28]. This method calculates daily global radiation values (W/m^2) from the daily sunshine duration. The following derived meteorological parameters have been calculated:

1. average of daily global radiation (met1),
2. average of daily mean temperature (met2),
3. average of daily maximum temperature (met3),
4. average of daily minimum temperature (met4),
5. precipitation amount (met5),
6. sunshine duration (met6),
7. daily average of sunshine duration (met7),
8. number of days with precipitation (met8),
9. number of days with real precipitation (excluding trace of precipitation) (met9),
10. sum of mean temperature > 10 °C (met10),
11. sum of mean temperature > 9 °C (met11),
12. sum of mean temperature > 8 °C (met12),
13. sum of mean temperature > 7 °C (met13),
14. sum of mean temperature > 6 °C (met14),
15. sum of mean temperature > 5 °C (met15),
16. sum of mean temperature > 4 °C (met16),
17. sum of mean temperature > 3 °C (met17),
18. sum of mean temperature > 2 °C (met18),
19. sum of mean temperature > 1 °C (met19),
20. sum of mean temperature > 0 °C (met20),
21. average of daily temperature fluctuation (maximum-minimum) (met21),
22. relative deviation of precipitation for days with precipitation (met22),
23. number of frost days (met23),
24. sum of nonnegative daily mean temperature after the last frost day till the day of the phenological change (met24).

Using these meteorological indicators, analyses of correlation have been carried out of the phenophases in our geophytes' phenology database for each year of examination. For our work the statistical software package PAST [9] has also been used [5]. We have tried to make an index (G index) so that values on the left side meaning full acceptance have been counted with double weight and values on the right side meaning almost-acceptance have been counted once, and the sum of these has been divided by sixfold of the number of the evaluated plants (93) since three phenological changes of each plant species has been considered (*Table 1*).

- As a third approach, linear combinations have been made of the individual meteorological indicators, then, optimizing their parameters with the help of the Solver adds-on of MS Excel, explanatory models for the phenological indicators have been searched for.

Results

Classification of years according to phenological and meteorological characteristics

In our research, first we wanted to know whether there is a similar aggregation or an outstanding, specific year between general characteristics such as frequency distribution of different meteorological parameters and the date of phenological phenomena in the years 1978–1997. We have used hierarchical cluster analysis with Euclidean and simple average method. Classification according to phenological parameters can be seen in *Figure 1* and classification according to meteorological indicators in *Figure 2*.

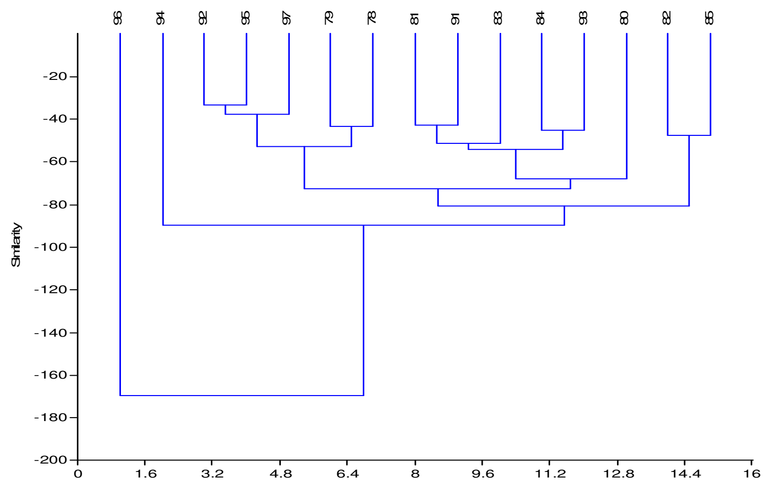

Figure 1. *Classification of the years of examination according to the phenological behaviour of some indicator species. It can be seen that the year 1996 definitely separates from the other years. The years 1982, 1985 and 1994 also have different behaviour than the majority.*

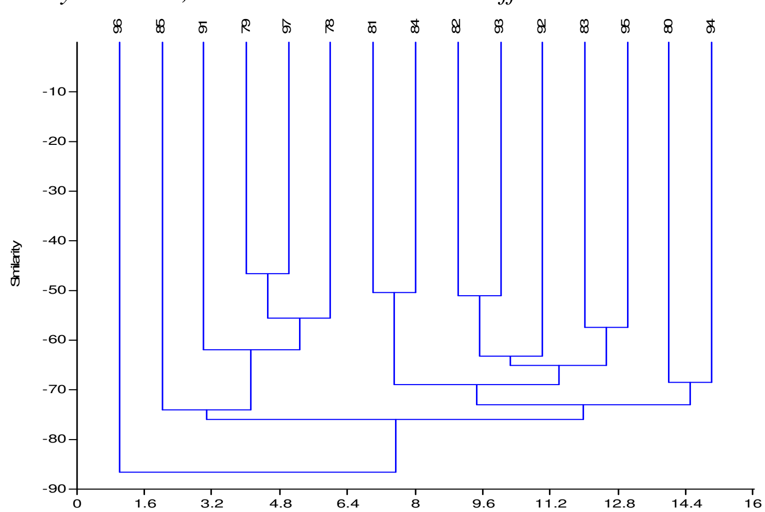

Figure 2. *Classification of the years of examination according to the frequency distribution of meteorological parameters. The year 1996 definitely separates from the others according to this classification, too.*

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A frequency table has been made of the most important meteorological parameters for the years of examination (from 28th August of the previous year to 20th July of the current year), the diagrams of which can be seen below (*Figures 3-7*).

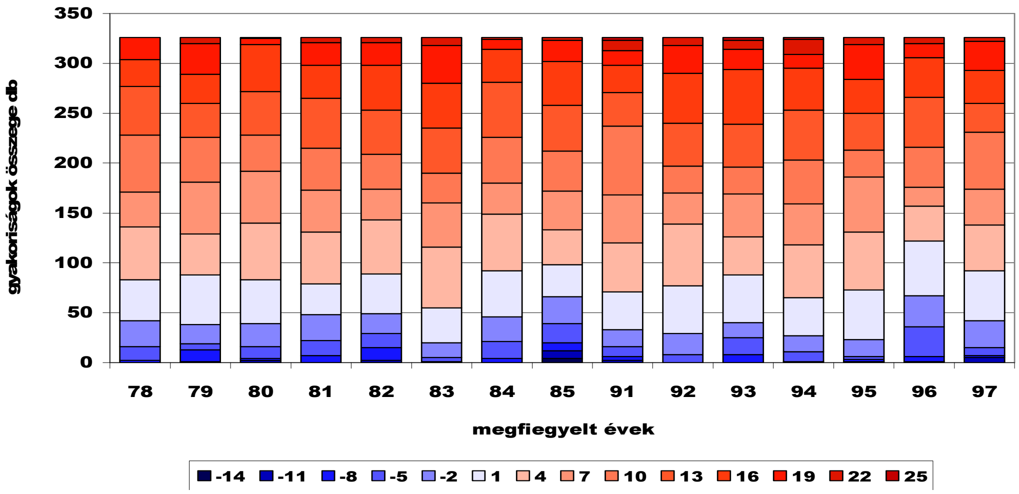

Figure 3. *Distribution of the daily minimum temperature in the years of examination. The number of days with low minimum temperature was definitely higher in 1996 than in other years. The greater proportion of cold days is also characteristic for 1982 and 1985.*

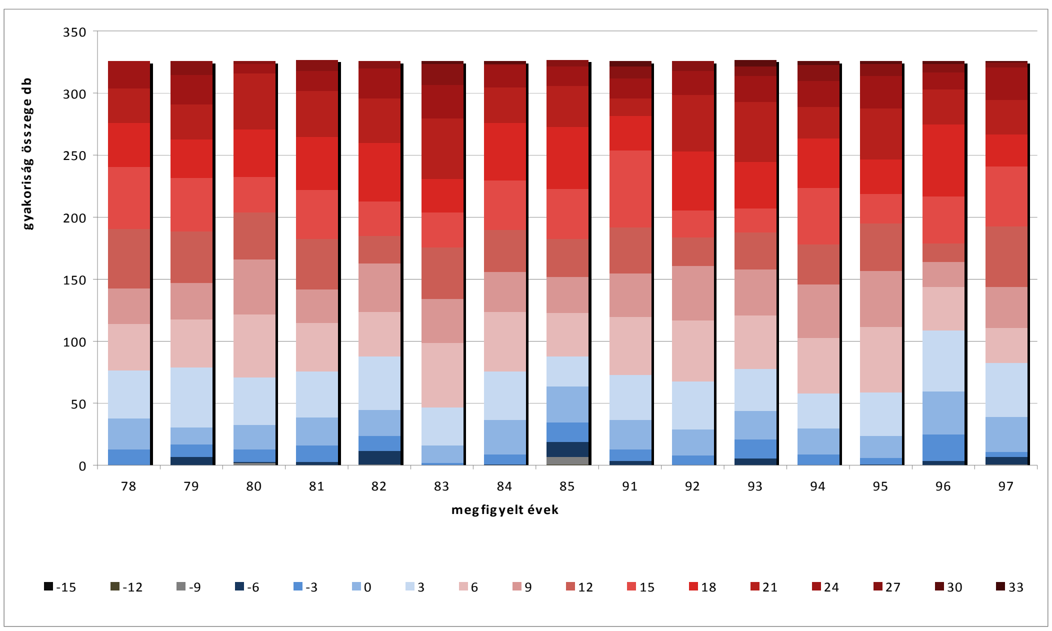

Figure 4. *Frequency of daily average temperature. The number of days with lower average temperature was slightly bigger in 1996 than in other years*

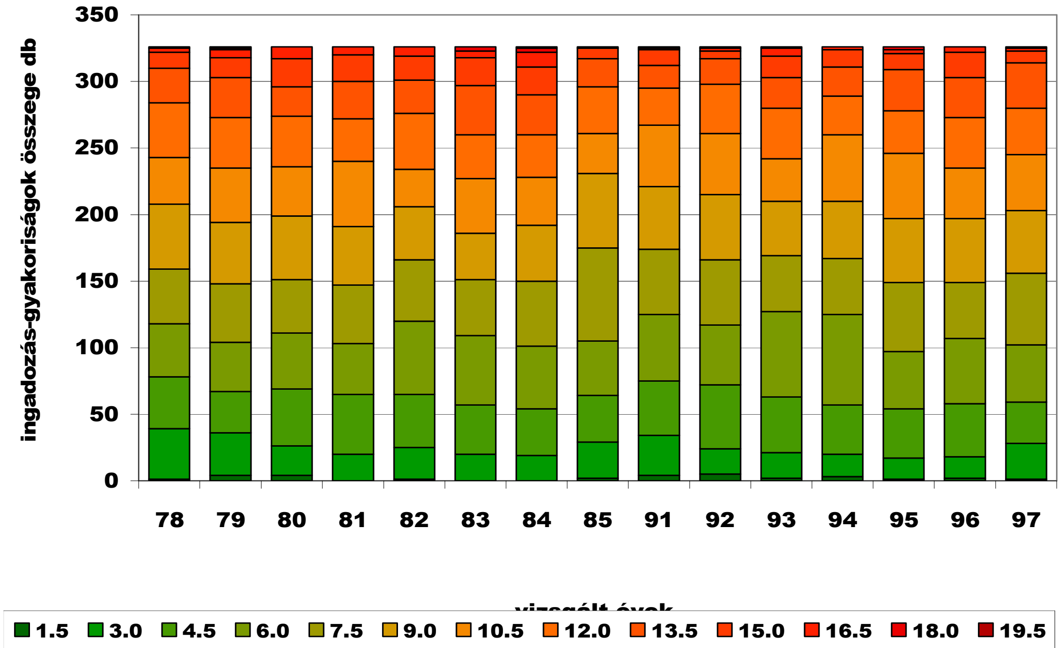

Figure 5. *Distribution of the daily temperature fluctuation in the years of examination. 1996 can be considered as typical from this point of view. 1985 excels in the high frequency of days with lower temperature fluctuation.*

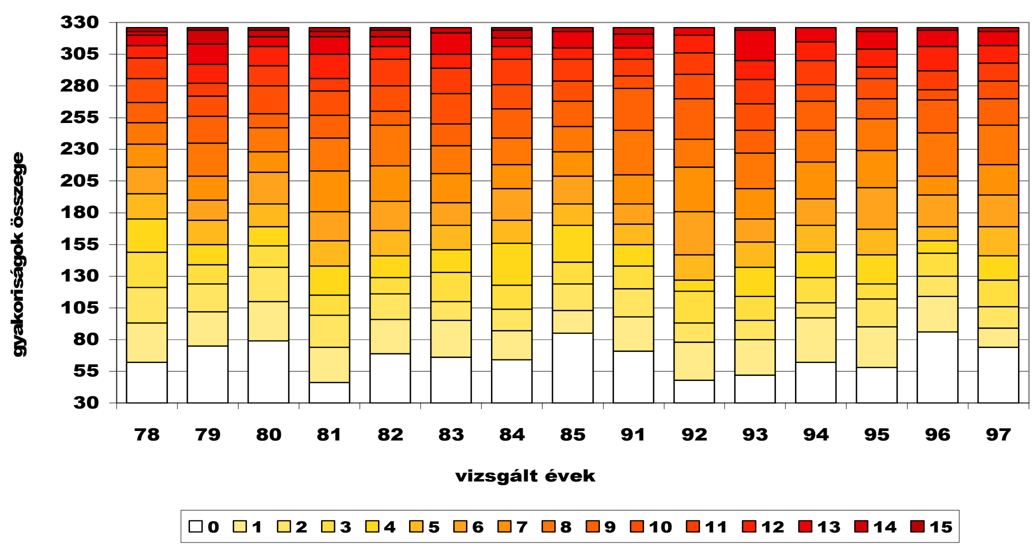

Figure 6. *Distribution of the sunshine duration in the years of examination. 1996 can be considered as ordinary from this point of view, too.*

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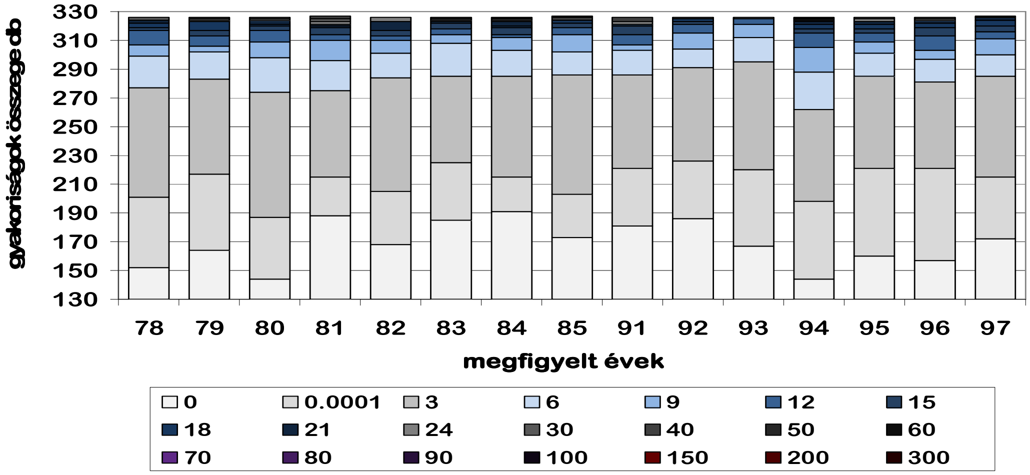

Figure 7. *Trend of the frequency of precipitation in the periods of examination. 1996 is ordinary from this point of view, too. The proportion of days with much precipitation is the biggest in 1994.*

Correlation between phenological indicators and derived meteorological parameters

In the table, rows represent calculated meteorological attributes and cells mean the number of events of the correlation between the three phenophases' date of occurrence and the given meteorological indicator accepted at 95% and 90% significance level as well as the values of G index calculated from these.

Table 1. *Correlation evaluation table. Cells contain the number of events of the correlation between calculated meteorological paramteres (rows) and the three phenophases' date of occurrence (columns) accepted at 95% and 90% significance level as well as vales of G index. The average of daily temperature fluctuation for the given period (met21) has most often correlated significantly with the date of all three phenophases. The second most often significant parameter is the number of frost dyas (met23).*

93	F105	F110	F205	F210	F305	F310	G-index
met01	24	4	28	6	20	6	0.2867
met02	37	12	26	12	13	9	0.3315
met03	37	10	24	9	11	4	0.2993
met04	34	13	30	19	13	14	0.3584
met05	3	2	2	4	3	2	0.0430
met06	31	7	20	14	17	8	0.2957
met07	4	3	2	1	3	3	0.0448
met08	27	10	5	7	4	4	0.1667
met09	11	7	20	12	26	15	0.2652
met10	10	11	5	3	10	5	0.1237
met11	17	5	6	2	14	1	0.1470
met12	20	6	7	3	14	3	0.1685
met13	21	7	8	3	15	5	0.1846
met14	23	5	9	1	14	3	0.1810
met15	23	6	9	1	13	3	0.1792
met16	25	3	9	2	14	3	0.1864
met17	25	3	10	1	15	4	0.1935
met18	24	3	10	1	12	5	0.1810
met19	24	3	10		11	5	0.1756
met20	25	3	8	2	11	5	0.1756
met21	85	3	71	6	69	7	0.8351
met22	2	7	2	6	3	2	0.0520
met23	62	8	53	10	20	15	0.5430
met24	12	10	14	4	12	7	0.1738

Modelling phenological phenomena using linear combinations of meteorological parameters

In the future, strong statistical models will be needed for the comparative evaluation of climate change scenarios, which are able to characterize the behaviour of indicated variables according to indicating variables.

As a first step of making these models, linear combinations have been made of the individual meteorological indicators, then optimizing their parameters with the help of Solver adds-on of MS Excel, well-fitting models have been searched for, which can be used later as starting hypotheses to develop more complex and reliable models. Now some promising results of our initial attempts are presented (*Figure 8*).

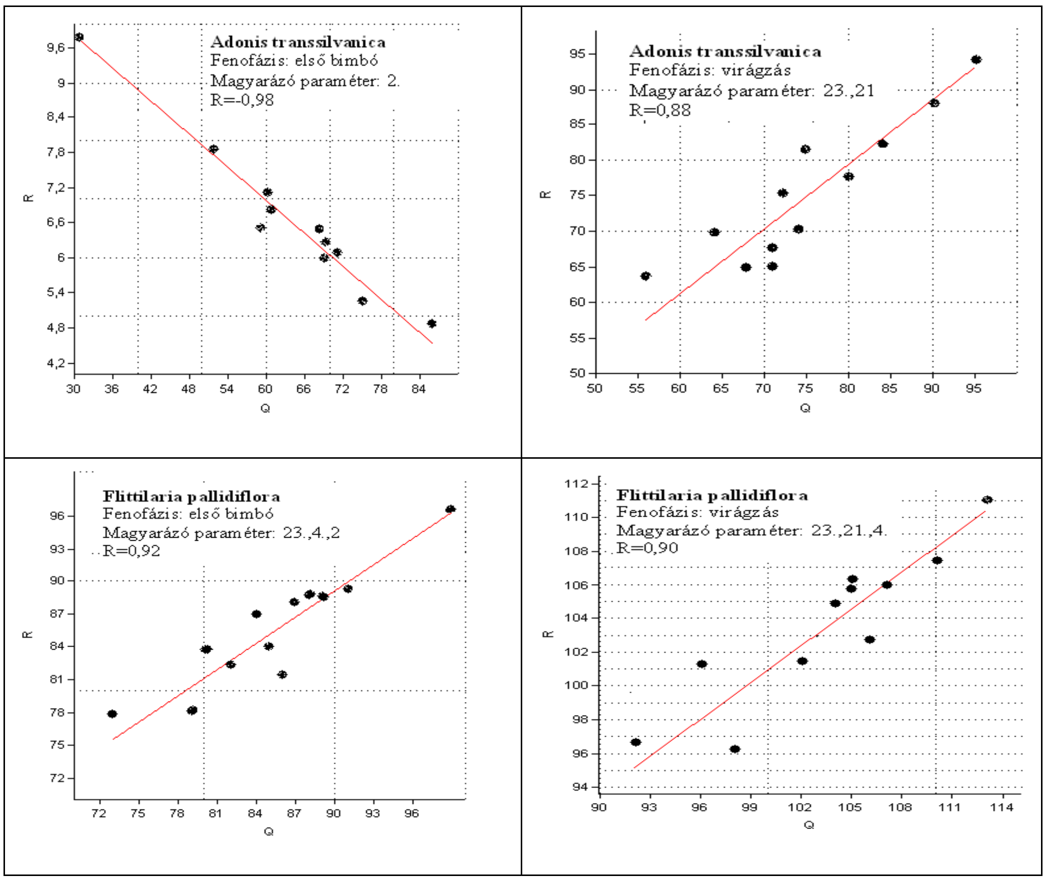

Figure 8. *Correlation between linear combinations calculated from some meteorological parameters and the date of occurrence of the modelled phenophase using the example of two phenophases (first bud and blooming) of two species (Adonis transsilvanica and Fritillaria pallidiflora).Appearance of the first bud of Adonis transsilvanica can be explained by only one meteorological variable, the average of daily mean temperature. However, the beginning of blooming can be well explained by the linear combination made of the number of frost days and the average of daily temperature fluctuation. The phenological behaviour of Fritillaria pallidiflora can be explained by the linear combination of three meteorological variables (number of frost days, average of daily minimum temperature as well as average of daily mean temperature and temperature fluctuation, respectively)*

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Discussion

Classification of years according to phenological and meteorological characteristics

According to classifications on the basis of both phenological parameters and meteorological indicators, it is striking that 1996 definitely separates from the other years (*Figure 1 and 2*). Its explanation becomes clear if the frequency distribution of daily minimum temperature is examined (*Figure 3*). It can be observed that the number of days with lower minimum temperature was definitely higher in 1996 than in other years (just as the number of days with lower mean temperature, but not so striking) (*Figure 4*). As for precipitation amount, daily temperature fluctuation and sunshine duration, 1996 can be rather considered as ordinary, however (*Figure 5, 6 and 7*).

As for phenological behaviour, the years 1982, 1985 as well as 1994 have differnet behaviour than the majority of years. Greater proportion of cold days is characteristic for both 1982 and 1985 but 1985 excels in the frequency of days with smaller temperature fluctuation as well. However, the separation of 1994 is caused by an other factor: the proportion of days with much precipitation is the biggest then (*Figure 7*).

Correlation between phenological indicators and derived meteorological parameters

Examining 93 geophytes, it can be stated that the average of daily temperature fluctuation for the given period (the difference between daily maximum and minimum temperature, met21) has most often correlated significantly with the date of all three phenophases (*Table 1*). It is surprising because models used in phenology usually yield good results using parameters related to heat summation or mean temperature. The second most often significant parameter is the number of frost days (met23), it also seems to be determinant regarding all three phenophases and this is not surprising because these are spring flowers, which can be obviously limited by frost.

However, the other factors differ per phenophase. The appearance of the first buds can be affected by the average of daily maximum temperature (met3) and the average of daily mean temperature (met2) apart from the above, which is easy to understand because this is in connection with spring warming, obviously.

However, the blooming date is rather affected by the average of daily minimum temperature (met4) and global radiation (met1), which can be caused by the fact that the blooming of the developed buds can be limited by low temperature at night or early morning.

The date of withering is often influenced by a factor that almost never affects the previous two phenophases, this is the number of days with real precipitation (met9), which seems to be even more important than the number of frost days (met23) in this case. This is also clear because it is not the thermal but the precipitation conditions which dominate when withering.

It is also extremely interesting to examine which meteorological parameters almost never (that means very rarely) affect the phenology of geophytes. These are the precipitation amount (met5) and the relative deviation of precipitation for days with precipitation (met22). Ineffectiveness of the variables describing precipitation conditions is not surprising because geophytes are able to tolerate lack of precipitation due to their storage organs so they are not exposed to precipitation conditions as much. However, the daily average of sunshine duration (met7) and the sum of mean temperature above 10 °C (met10) do not seem to be effective either, which is surprising

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because sunshine and heat usually are important factors in case of phenological phenomena.

Our results point out that the phenology of geophytes mostly depends on the fluctuation of temperature and limiting factors.

Modelling phenological phenomena using linear combinations of meteorological parameters

It can be seen in the figures (*Figure 8*) that the appearance of the first bud of Adonis transsilvanica can be well explained by only one meteorological variable (that means without using linear combinations), this variable is the average of daily mean temperature, which does not belong to the most significant variables in the case of most of our plants but it has an important role in the case of this species. However, the beginning of blooming can be explained not by this parameter but the linear combination made of the number of frost days and the average of daily temperature fluctuation.

The phenological behaviour of Fritillaria pallidiflora can only be explained by the linear combination of three-three meteorological variables. The number of frost days and the average of daily minimum temperature play a role in both phenophases (appearance of the first bud and blooming) but in the case of the first bud the average of daily mean temperature, in the case of blooming the fluctuation of temperature has to be added moreover.

These results show the usefulness of the method used but also the fact that different factors have an important effect on different phenophases of various plants.

Outlook

The results presented in this paper methodologically enable the comparative evaluation and analysis of the GCM outputs based on climate change scenarios and especially those of their dynamically or statistically downscaled data series related to future climate. Considering this, it seems to be advisable in the future to examine phenological effects of climate change with the help of strategic system models and tactical models based on data, too. Significant progress can be reached by combining statistical and simulation methodology and using theoretical modelling, empirical data collection and monitoring together.

Acknowledgements. Our research has been supported by the research proposal OTKA TS 049875 (Hungarian Scientific Research Fund); the VAHAVA project; the KLIMA-KKT project (National Office for Research and Technology, Ányos Jedlik Programme); the Adaptation to Climate Change Research Group (Hungarian Academy of Sciences, Office for Subsidised Research Units); the Research Assistant Fellowship Support (Corvinus University of Budapest) and the “Bolyai János” Research Fellowship (Hungarian Academy of Sciences, Council of Doctors). We thank Nándor Fodor algorithm developer for his work, which has enabled us to use the Szász Gábor-algorithm of global radiation in MS Excel.

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Electronic information source

Hungarian Meteorological Service: daily meteorological data of Budapest in the 20th century on the home page of the Hungarian Meteorological Service
http://met.hu/pages/climate/bp/Navig/Index2.htm

ASSESSMENT OF SPATIAL AND TEMPORAL FLUCTUATIONS IN WATER QUALITY OF A TROPICAL PERMANENT ESTUARINE SYSTEM - TAPI, WEST COAST INDIA

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Abstract. A study pertaining to seasonal variation in physicochemical properties was carried out at five sites of Tapi estuarine zone for a period of one year i.e. July 2008 to June 2009. It revealed that the estuarine zone was significantly influenced by freshwater input during monsoon and post-monsoon periods. Concentration of all the nutrients and dissolved oxygen (DO) was relatively high during the monsoon, whereas, and salinity were at their minimum level during this period. Phytoplankton production peak in terms of chlorophyll-a (Chl a) was observed in summer and winter during which a typical marine condition prevailed. In present study observed correlated values of salinity, nitrate, phosphate, silicate, values are significantly high in the estuarine zone. Cluster analysis carried out for both monthly and station-wise and average values gives different clusters depending on the affinity and relation between months and sites due to environmental conditions prevailed in the estuary zone. Principal Component Analysis (PCA) was used in the ordination of samples (site, season and physicochemical parameters). The PCA was performed using all variables, Eigenvalues accounts and Scree plot showed that the first three Principal Components are the most significant components which represent more than 75% of the variance in water quality parameters in Tapi estuary, 48.5% by PC1, 14.4% by PC2 and 12.1% by PC3.
Keywords: *Estuary, Dissolved nutrients, Cluster analysis, Principal Component Analysis*

INTRODUCTION

Dissolved nutrients are the raw material for the marine trophic chain and estuaries are the main entry for nutrients coming from continental drainage to the marine environment [3, 16]. The nutrient supply is greater in estuaries that are near densely populated regions, due to the entry of domestic and industrial waste, urban drainage, and agricultural effluents. The increase of nutrient concentrations in estuarine and coastal waters causes several environmental modifications, such as increases in productivity and fishing yields [18, 26, 31]. However, anthropogenic inputs frequently cause excessive eutrophication in the environment, especially where the circulation is restricted, such as in estuaries and coastal regions. Several alterations in chemical characteristics and water quality in such water bodies occur as a result of varying river flows. Such alterations can lead to various ecological consequences like changes in species composition, blooms of phytoplankton and decrease of oxygen concentrations.

Tidal variation and nutrient dynamics is more pronounced in tropical estuaries than in temperate estuaries. Reports on some tropical estuaries include those of [8] on the Kollidan estuary, southeast coast of India, [12] on the Mahi estuary and in Coastal waters of Kalpakam, East coast of India [28]. Physico chemical characteristics of tropical Devi Estuary in the eastern region of India was analysed by [20]. Physicochemical characteristics in relation to pollution and phytoplankton production potential of brackish water were carried out in Sundarbans of India by [30]. This paper aims to assess spatial and temporal fluctuations of water quality of Tapi estuarine system of western India.

STUDY AREA

Gulf of Khambhat on the western India has been profusely endowed with major perennial rivers like Tapi, Narmada, Mahi and many minor rivers. The Tapi River estuary is permanent tropical estuary and one of the major estuaries on the Gulf of Khambhat *(Fig.1).* The estuary is located at geographical position Lat 21°40'N and Long 72° 40'E. Its length from source to mouth is about 720 km and with a catchment area of approximately 1,650,000 km^2. The river originates in Madhya Pradesh state and after its course through Maharashtra, Tapi river ends in Gulf of Khambhat of the Arabian Sea. Along its course the river receives industrial effluents released from urban cities like Surat and many chemical and fertilizers industries in and around Hazira industrial area which forms the major source of pollution in to the estuary. The estuarine region experience high, semi diurnal tides with a range of 5.5 m at spring decreasing to 2.3 m, 25 km upstream and 2.3m at neap going down to 0.4 m at a distance of 25 km in the estuary. Salinity intrusion is largely governed by the tidal phase and is felt up to 30 km upstream during the dry season. Strong tidal current exceeding 1m/s sweep the shallow estuary making it vertically well mixed expect during short period of tidal slacks [23].

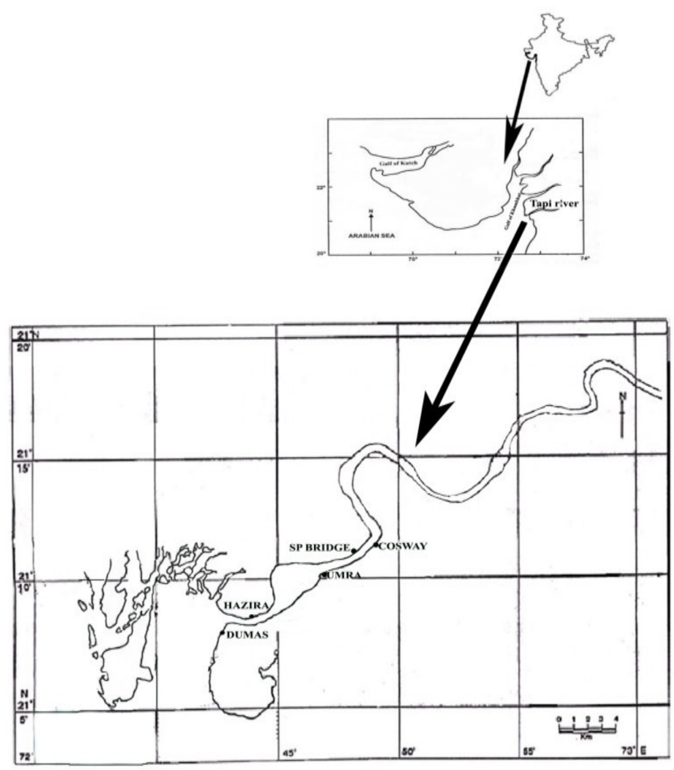

Figure 1. *Study sites along the Tapi estuary region*

Five different study sites were selected on the northern and southern banks of the river. Dumas was the site selected in the mouth of the estuary in the southern bank. Hazira which forms the second study site was about 4 km far from the mouth and located in the northern bank. Third site selected was Umra which is 15-17 km away from the mouth. Fourth site which was selected is SP Bridge which is 22 km away from the mouth. The fifth site, Cosway was 27-29 km away from the mouth of estuary. A small dam built at the upstream of Cosway prevents the sea water in flux to the river and the tidal effect is influenced up to this site only.

MATERIALS AND METHODS

Water samples for physical and chemical parameters determination were collected from the river at monthly interval from July, 2008 to June 2009. The samples were collected during the time of high tide, in polyethylene bottles and brought to the laboratory. In the field its self, pH and DO was analysed. Dissolved oxygen was determined by the alkali-Azide modification of Winkler's technique, alkalinity was determined titrimetricall Nitrate was estimated by the cadmium reduction method. Phosphate and silica were determined by the ascorbic acid and molybdosilicate methods respectively as described by [2]. Sodium and Potassium was estimated using Flame photometer. Chlorophyll-a was estimated by filtering the sample through glass fibre filter papers and it was extracted in 90% acetone, estimated spectrophotometricaly.

RESULTS AND DISCUSSION

Hydrochemistry of Tapi

Descriptive statistics of the data is given in *Table.1.* The average surface water temperature of study sites varied from 23.5°C to 33.5°C *(Fig. 2.a).* The pH of water ranges from 7.2 to 8.5 where the highest recorded at SP Bridge during the dry seasons and lowest in Umra but pH values did not show significant fluctuation during the present study *(Fig. 2.b).* The extensive buffering capacity of the seawater may be the causes of change of pH within a very narrow limit in the present study [25]. As compared with other tropical estuaries tidal influence has a great influence on Tapi estuarine environment [23].

Table 1. *Descriptive statistics of the data along the study sites of Tapi Estuary from July 2008 to June 2009*

	Mean	S.E.M	S.D.	Variance	Coff. Var.	Min	Max	N
Temp (°C)	29.34	0.3761	2.91397	8.49125	0.09931	23.5	33.5	60
pH	7.96666	0.0346	0.26849	0.07209	0.03370	7.2	8.5	60
DO (mgL^{-1})	4.65966	0.191	1.48135	2.19441	0.31791	2.1	8.5	60
Sali (ppt)	10.3443	1.4350	11.1162	123.570	1.07461	0.11	32	60
Alk (mgL^{-1})	124.05	2.9751	23.0455	531.099	0.18577	76	224	60
PO_4 ($\mu molL^{-1}$)	2.73197	0.1797	1.39237	1.93871	0.50966	0.16	4.98	60
SO_4 (mgL^{-1})	1.24409	0.0941	0.72898	0.53142	0.58595	0.385	2.986	60
K (mgL^{-1})	86.1833	5.8459	45.2827	2050.52	0.52542	25	190	60
Na (mgL^{-1})	694.183	61.026	472.712	223456.	0.68096	50	1495	60
NO_3 ($\mu molL^{-1}$)	6.48933	0.2340	1.81277	3.28615	0.27934	3.74	11.6	60
SiO_2 ($\mu molL^{-1}$)	393.8977	11.461	88.7808	7882.04	0.22539	181.45	573.94	60
Chl-*a* (μglL^{-1})	4.0992	0.3624	2.80743	7.88169	0.68487	0.16	10.2	60

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The salinity ranges from 0.11 ppt in fresh water site Cosway during monsoon period to 32 ppt in Dumas in the month of May *(Fig. 2.c).* The dry season experienced the highest salinity range 32 ± 3 ppt. The salinity is greatly influenced by the runoff water, so that the lowest salinity was observed during monsoon season.

The Dissolved oxygen ranges from 2.1 mg L^{-1} during the December in SP Bridge to 8.5 mg L^{-1} in Dumas during September *(Fig. 2.d).* The Dissolved Oxygen was found more on the lower reaches when compared to upper reaches. Dissolved Oxygen shows a negative correlation with temperature (-0.17). In aquatic systems, oxygenation is the result of an imbalance between the process of photosynthesis, degradation of organic matter, re-aeration [10], and physicochemical properties of water [3]. During the present study, salinity was found to be the most important factor that controlled the level of DO in coastal waters as evident from its non-significant correlation with DO *(Table 2).* A positive correlation of all the nutrients, except nitrate and phosphate, with DO was also observed which showed that DO concentration in this coastal water was largely dependent on the freshwater influx. The above observation was further supported by the strong negative correlation of DO with chl-*a*, which showed that contribution of photosynthetic release of DO was negligible [28].

The alkalinity value ranges from 76 mg L^{-1} Cosway during September to 168 mg L^{-1} in Dumas in the month of August *(Fig. 2.e)* with a mean difference 124 ± 23 along the study sites. The sulphate concentration showed a clear variation from 0.385 mg L^{-1} in the fresh water receiving site, Cosway to 2.986 mg L^{-1} Hazira which is in the lower saline region *(Fig. 2.f).* The sulphate concentration shows a significant positive correlation with pH, Salinity, Alkalinity where as it shows a negative correlation with Phosphate, Nitrate and Chlorophyll-a.

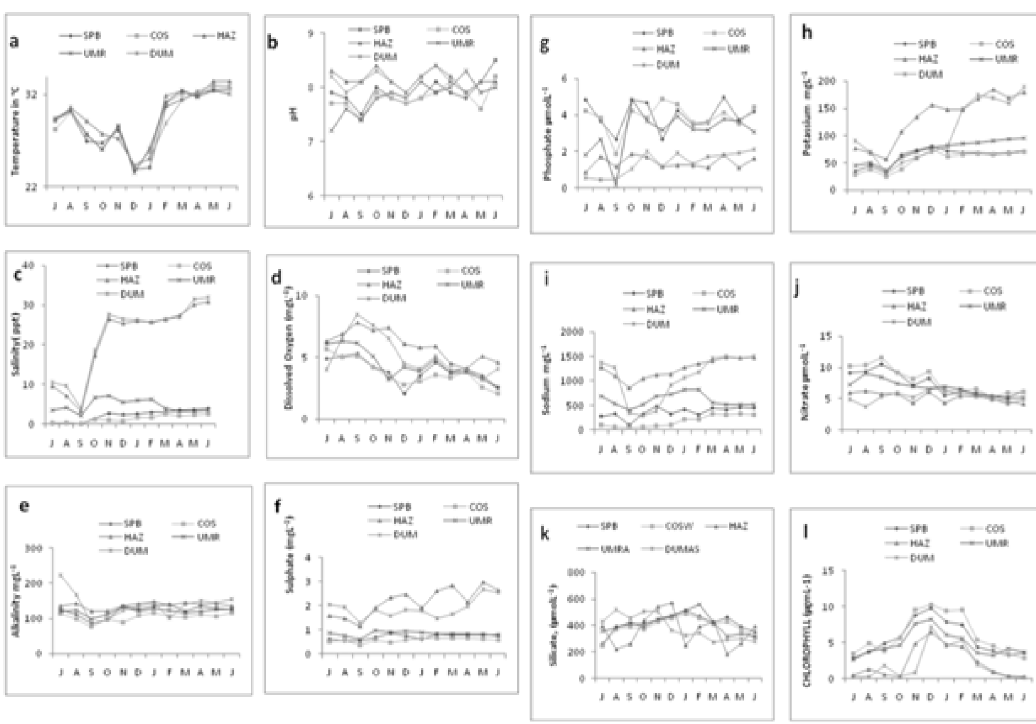

Figure 2. *(a-l) Seasonal Distribution of nutrients along the study sites of Tapi Estuary from July 2008 to June 2009*

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Table 2. *Correlation between different physicochemical parameters along the study sites of Tapi Estuary from July 2008 to June 2009*

	°C	pH	Salinity	DO	Alk.	SO_4	PO_4	K	Na	NO_3	SiO_2	Chl-*a*
°C	1											
pH	0.27	1										
Sal	0.10	0.50	1									
DO	-0.17	0.07	0.21	1								
Alk.	0.16	0.37	0.47	-0.06	1							
SO_4	0.18	0.53	0.92	0.32	0.60	1						
PO_4	-0.03	-0.22	-0.62	-0.59	-0.33	-0.69	1					
K	0.31	0.49	0.83	-0.09	0.52	0.80	-0.39	1				
Na	0.25	0.49	0.82	0.20	0.71	0.88	-0.65	0.84	1			
NO_3	-0.40	-0.55	-0.47	0.029	-0.59	-0.55	0.31	-0.61	-0.64	1		
SiO_2	-0.33	0.02	-0.002	0.35	-0.15	0.05	-0.16	-0.21	-0.21	0.03	1	
Chl-*a*	-0.53	-0.36	-0.42	-0.44	-0.33	-0.52	0.53	-0.30	-0.52	0.31	0.12	1
Alk.-Alkalinity, Sal.-Salinity												

The phosphate value ranged from 0.16 µmol L^{-1} in Umra during September to 4.9 µmol L^{-1} in Umra during October *(Fig. 2.g).* The phosphate concentration was high during the monsoon period which ranges 3.7 ± 1 µmol L^{-1}. It shows a significant negative correlation with sulphate, Dissolved Oxygen and Salinity. The highest amount of phosphate was mostly found in fresh water receiving areas and lower in lower reaches. The upper reaches areas reported the highest phosphate content during monsoon month which might have be received through agricultural runoff and from cities. Moreover, release of phosphate from sediments due to stirring action by strong tidal waves could also be another causative factor. The observed variation might be caused by various processes like adsorption and desorption of phosphate and buffering action of sediments under varying environmental conditions [19].

The concentration of nitrate varied from 4.1 µmol L^{-1} in Hazira during July to 11.6 µmol L^{-1} in Cosway during September *(Fig. 2.j).* Nitrate shows significant negative correlation with pH, Alkalinity, Salinity, Sodium and Potassium. The negative correlation between nitrate and salinity showed that freshwater influx, which is considered to be the main source of this nutrient in coastal waters [5, 29]. It also shows a strong positive correlation with phosphate. Variations in nitrate and its reduced inorganic compounds are predominantly the results of biologically activated reactions. Quick assimilation by phytoplankton and enhancement by surface runoff results in large scale spatio-temporal variation of nitrate in the coastal milieu [7, 24, 32]. During monsoon, the freshwater influx dilutes the coastal water resulting in decrease in salinity and increase in solubility of DO in the present study.

The amount of sodium was in the range 50 µmol L^{-1} to 1495 µmol L^{-1} the highest been observed in Dumas in June and lowest in Cosway during September *(Fig. 2.i).* It shows significant positive correlation salinity, alkalinity and sulphate concentration and negatively correlated with Phosphate (-0.64). Potassium was in the range 25 µmolL^{-1} in Cosway during September to 190 µmol L^{-1} in Dumas in the month of June *(Fig. 2.h).* It shows a significant positive correlation with salinity, phosphate and sulphate. The distribution of Sodium and Potassium is directly influence by the fresh water runoff.

Silicate forms an important parameter of phytoplankton distribution and was in the range 181.5 µmol L^{-1} to 573.9 µmol L^{-1} *(Fig. 1.k).* The highest and lowest silicate value was reported in the Hazira region during April and October, respectively. Silicate shows negative correlation with temperature. The spatio-temporal variation of silicate in coastal water is influenced by several factors, more importantly the proportional physical mixing of seawater with fresh water [22], adsorption of reactive silicate into

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suspended sedimentary particles [13], chemical interaction with clay minerals [3, 9] and biological removal by phytoplankton, especially by diatoms and silicoflagellates [14]. Silicate showed strong negative correlation with salinity and strong positive correlation with DO. [13] explained that the freshwater, which is rich in DO, could be the main source of silicate in this coastal water as entry of silicate into a coastal zone mainly takes place through land drainage rich with weathered silicate material.

In estuarine environment the primary productivity depends upon the phytoplankton, which alone contributes ~ 90% of the total estuarine primary production. Thus, chl-*a*, which constitutes the chief photosynthetic pigment of phytoplankton, is an index that would provide the primary production potential upon which the biodiversity, biomass, and carrying capacity of that system depends upon. The chlorophyll –a, value was observed high in the fresh water zone particularly in the post monsoon season and the value ranges from 0.16 µgm L^{-1} to 10.2 µgm L^{-1} *(Fig. 2.l)*. The lowest been observed in Dumas during the month of June and highest in Cosway during the post monsoon and per summer seasons. Chlorophyll shows a significant negative correlation with temperature, sulphate and sodium. Relatively higher chl-*a* values observed during March to May could be due the phytoplankton productivity in summer. A similar observation has been made from other coastal waters of India [15, 21, 27].

Cluster Analysis

Cluster analysis can be used an important tool for analysing water quality data [1, 28] to understand the relationship among stations and months. Month-wise water quality parameters formed three clusters *(Fig.3)*. This indicated that the coastal water quality over a period of one year exert three clusters in different seasons. The first cluster was formed by the months from July, August, October and November. This showed that during the period of monsoon, the coastal water quality behaved alike. The second cluster was formed by the months from November, January, February and December, which corresponded to the period of winter. The third cluster formed by June, May, April and March is typically different from other periods due to high tidal influence.

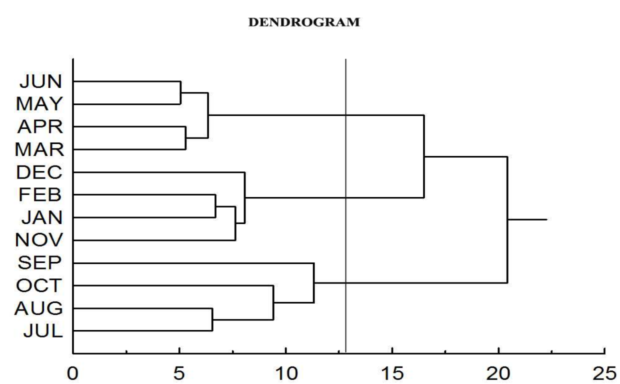

Figure 3. *Month wise cluster diagram*

The station-wise dendrogram showed two clusters *(Fig. 4)*. The first cluster is formed by the fresh water dominant area in the upper reaches at site Dumas, SP Bridge and Umra which receives a continuous fresh water influx from July to February months. The second cluster is formed by the sites Hazira and Dumas which located on the lower reaches nearby to the mouth of the estuary. The similarity of tidal influence and low fresh water influence in the area accounts for the cluster formation. These two cluster formations are justified by the prevalence of different environmental conditions in the study sites.

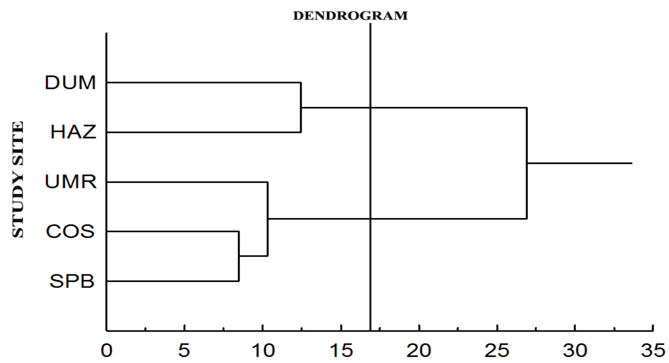

Figure 4. *Site wise cluster diagram*

Principal Component Analysis

The data obtained from the laboratory analysis were used as variables inputs for Principal Components Analysis (PCA), for water samples described by twelve physical, chemical and biological parameters which performed using the SPSS package. Prior to the analysis the data were standardized to produce a normally distribution of all variables, since water quality parameters had different magnitudes and scales of measurements, which if not taken into account would have given more weight to certain variables due to their respective variance [6]. From the standardized covariance or correlation matrix of the data the initial factor solution were extracted by the multivariate principal components extraction, then a number of PC were selected from the initial according to their Eigenvalues and scree diagram.

Table 3. *Explaining Initial values*

Initial Eigenvalues			
Components	**Total**	**% of Variance**	**Cumulative%**
1	5.82	48.5	48.5
2	1.72	14.4	62.9
3	1.45	12.1	74.9
4	0.89	7.5	82.3
5	0.66	5.5	87.9
6	0.55	4.6	92.5
7	0.28	2.3	94.8
8	0.22	1.8	96.7
9	0.19	1.5	98.2
10	0.11	0.09	99.2
11	0.05	0.04	99.6
12	0.04	0.03	100

This method aims to transform the observed variables to a new set of variables of principal components (PC) which are arranged in decreasing order of importance so that to simplify. *Table 3.* represented the determined initial Eigenvalues, its total, % of variance and cumulative %.

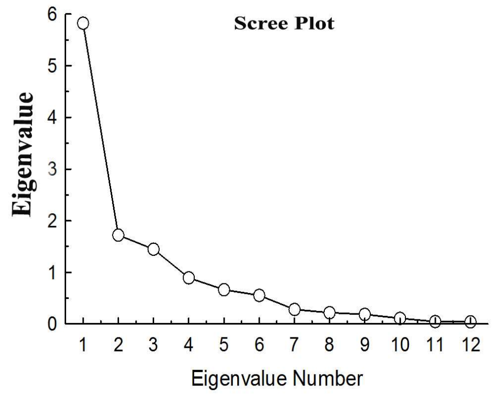

Figure 5. *Scree plot graph for components with its Eigenvalues*

Fig. 5 showed the scree plot of the eigenvalue for each component. Eigenvalues accounts and scree plot showed that the first three PC is the most significant components which represent more than 75% of the variance in water quality; in addition it has eigenvalue of more than one. PC1 accounts for 48.5% of the total variance, which is due to positive load of Salinity (0.364), Sulphate (0.387), Sodium (0.390) and Potassium (0.346) and negative load of Nitrate(-0.314), Phosphate (-0.346) and Chlorophyll-a(-0.269).Whereas PC 2 accounts for 14.4% of the total variance, which is due to positive load of DO (0.633) and Silicate (0.282) and negative load of Temperature (-0.443) and Phosphate (-0.434). While PC 3 accounts for 12.1% of the total variance, which is due to positive load of Silcate (0.502) and Chlorophyll-a (0.546) and negative load of Temperature (-0.436). (*Table 4*).

Table 4. *Principal Component Analysis*

	PC1	**PC2**	**PC3**
Eigen Value	5.822	1.722	1.447
Variability (%)	48.5	14.4	12.1
Cumulative (%)	48.5	62.9	74.9
Factor Loadings			
°C	0.150	-0.443	-0.436
pH	0.261	-0.159	0.058
DO	0.105	0.633	-0.286
Salinity	0.364	0.090	0.155
Alkalinity	0.280	-0.126	0.227
Phosphate	-0.285	-0.434	0.111
Sulphate	0.387	0.132	0.113
Potassium	0.346	-0.192	0.208
Sodium	0.389	0.013	0.085
Nitrate	-0.314	0.164	-0.157
Silicate	-0.119	0.282	0.502
Chl-*a*	-0.268	-0.059	0.545

Components loading (correlation coefficients), which measure the degree of closeness between the variables and the PC, the largest loading either positive or negative, suggests the meaning of the dimensions; positive loading indicates that the contribution of the variables increases with the increasing loading in dimension; and negative loading indicates a decrease.

CONCLUSION

The present study summarizes the seasonal fluctuations in various physico-chemical parameters in the waters of the Tapi estuary as exploratory statistical data output which showed that the physicochemical properties of the estuarine zone were significantly affected by freshwater input during monsoon. The highest concentration for all the nutrients and DO was observed during the monsoon; on the other hand, salinity and chl-*a* were at their minimum level during this period. The distribution of dissolved inorganic nutrients in this tropical coast may be very much influenced by factors like tidal and physical stirring by currents [4] and benthic invertebrates [11, 17] as well as drainage discharged from industries and cities around the estuarine zone. A significant increase in nitrate, phosphate, silicate, and turbidity and conversely, a decrease in DO and chl-*a* concentration were noticed during the present study. Cluster analysis provides a clear variation in water quality, both station wise and month wise. The variability among different components was described by PCA and found that Principal component one; two and three are responsible much of the variation existed in the zone during the study period.

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HEPATIC PATHOLOGIES IN THE BRACKISH WATER CATFISH (*CHRYSICHTHYS NIGRODIGITATUS*) FROM CONTAMINATED LOCATIONS OF THE LAGOS LAGOON COMPLEX

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Abstract. Several toxicological studies into the effects of aquatic pollutants on the liver of teleost fish exist in literature. The focus on the liver in these studies is predicated on its central nature in the scheme of biotransformation and excretion of xenobiotics following exposure in polluted water bodies. As a consequence of the latter primary role of the liver in these processes it is regarded as a predilective site for the sub lethal effects of xenobiotics on the organism usually detectable at histological level. Hepatic histopathology recorded in livers from feral populations of the brackish water catfish *Chrysichthys nigrodigitatus* from locations on the Lagos lagoon complex with significant anthropogenic inputs from denizen populations and industries are presented. Liver sections from sixty specimens from two locations on the Lagos lagoon complex (Badagry lagoon: $6^0$24’N, $2^0$56’E; and Lagos lagoon: $6^0$29’N, $3^0$22’E) were analysed. Observed pathologies included hydropic degeneration (58%), portal / sinusoidal congestion (33%), hepatic necrosis (26%), hemosiderosis (12%) and foci of cellular alterations (FCA’s). No obvious oncologic features were observed; the presence of the hydropic Vacuolation lesion was taken as prelude to the development of neoplasms and discussed as such.
Keywords: *Liver, Pathology, Fish, Toxicology, Water quality*

Introduction

Histopathology provides a sensitive indicator of sublethal stress induced by xenobiotics. Due to the central role of the liver in the biotransformation of several chemical active compounds into the aquatic environment, the teleost liver has been the focus of toxicological studies and has indeed been shown to be very sensitive to pollutant exposure [7, 18, 26, 27]. Hepatic changes resulting as consequences due to exposure to certain chemicals, especially Poly Aromatic Hydrocarbons (PAH's), regarded as characteristic, have being included in the definitions of beneficial use impairment criteria [7]. Relevant aquatic xenobiotic sources in Nigeria in particular, Lagos, the commercial capital with its great (and ever growing) population and industries, include pesticides, plastic wastes, myriad industrial effluents, sawmill and pulp industry runoffs and shipping ballast. The importance of the Lagos lagoon complex to its satellite populations has been described by Olarinmoye [22]. Due to a dearth of

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temporal relevant pathological data relating anthropogenic inputs to fish health, an attempt was initiated in 2005 by the authors to document, and determine the significance of the severity of observed lesions to the different levels of xenobiotic inputs into the Lagos lagoon complex and also to define the baseline health status of the test species which is suggested for use as a biomarker species [21, 22]. The test species, *C. nigrodigitatus,* was selected for use as a local sentinel species for the investigation of the impacts of marine pollutants on fish on the basis of it's ubiquitousness in Nigerian inland waters, and, it's situation in benthic habitat on muddy substrate of river bottoms and channels. Its natural proclivity for the bottom of water bodies brings the fish into intimate contact with the sediments, in which substantial proportions of aquatic pollutants are bound. As part of our efforts to ascertain the deleterious effects of contaminated aquatic habitats on fish health, and to establish beyond conjecture, the latter fact, this study into the hepatic pathology of C. *nigrodigitatus* collected from polluted reaches of the Lagos lagoon complex was carried out.

Materials and methods

Specimen collection

One hundred adult *Chrysichthys nigrodigitatus* were collected, live, from early morning catches at Badagry lagoon ($6^0$24'N, 2^0 56'E), and Lagos lagoon ($6^0$29'N, 3^0 22'E), two locations in the Lagos Lagoon complex, between May and August 2006. Fish were selected using the criteria of size. The external appearance of the fish indicated few abnormalities. No sex selection was made. The fish were sacrificed by a pre-occipital severance of the spinal cord. Each specimen was weighed and the standard length was recorded. The fish were then dissected, necropsies done, and the livers excised. Livers were then examined using hand lens, to detect the presence of gross lesions.

Histology

Liver samples of each specimen were fixed by placing in 10% formalin in phosphate buffer (Electron Microscopy Sciences, Hatfield, PA, USA) for 36 hours. Care was taken to ensure that onset of fixation was immediately post excision. Fixed specimens were dehydrated in graded ethanol (Sigma-Aldrich, St. Louis, MO, USA) and then transferred into xylene (Alfa Aesar GmbH & Co. KG, Karlsruhe Germany) for five minutes preparatory to embedding in paraffin (Sigma-Aldrich, St. Louis, MO, USA). Livers were then embedded in paraffin and histological sectioning subsequently done at 5 µm using a TBS® CUT™ (Cole-Palmer, UK) rotary microtome. Sections were randomly done but care was taken to ensure that a large as possible area of the livers were sectioned. Resulting sections were mounted on glass microscope slides and air dried prior to staining using Hematoxylin and Eosin stain, and cover slipped (Luna 1992). Stained sections were then analysed using light microscopy. Obtained sections were carefully observed under high magnification light microscopy at x350 and x450 magnification, for the presence and quantification of detectable stromal and parenchymal derangements including, but not limited to: 1. Vacuolation, 2. Macrophage aggregation, 3. Biliary duct proliferation, and, 4. Neoplasia. Various regions of each liver sample were sectioned to keep the investigative process as accurate as possible.

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Water analysis

(I) Sampling stations

Sites were selected for inclusion based on the presence of bottom feeding/dwelling, demersal fish, and, sampling locations were established approximately equidistant covering areas deemed representative of the study locations. They were, for Badagry lagoon (6^{0}24'N, 2^{0} 56'E): Akarakumo, Ajido, and the Marina, and for Lagos lagoon (6^{0}29N, 3^{0}22'E): Ikorodu/Ibeshe, Iddo, and the Marina *(Fig. 1).* Each location was sampled every two weeks between May 2 and August 1, 2006.

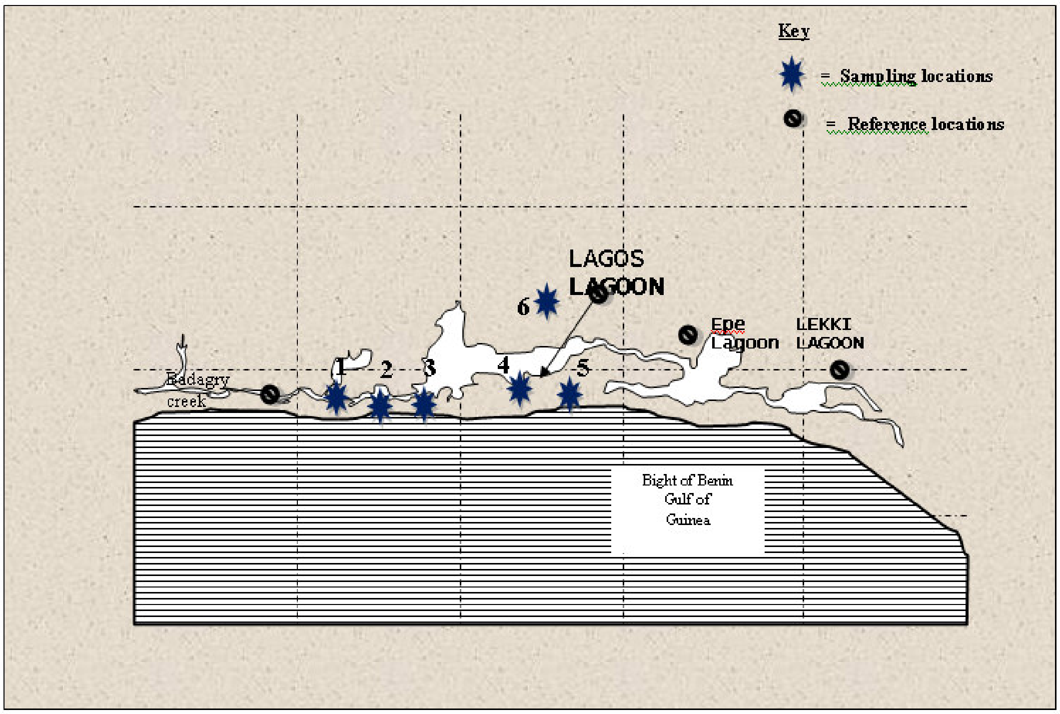

Figure 1. *Map of Lagos lagoon complex showing water sampling locations: 1-Marina, 2-Akarakumo, 3- Ajido, 4-Iddo, 5- Marina, 6-Ikorodu.*

(II) Water sample analysis

Temperature (equilibrated, Mercury in glass thermometer), turbidity, pH, salinity and conductivity measurements were conducted on site using the Horiba U-10 water quality checker. The determination of other parameters commenced in the laboratory within a few hours of collection [2].

(III) Statistics

The water quality results were analysed using the Microsoft Excel 2007 software. Means, standard deviations of water parameter measurements, and heavy metal concentrations were determined and tabulated *(Tables 1 and 2).*

Table 1. *Water quality parameters for Lagos lagoon during period of study*

Water quality of Lagos lagoon									
	Ibeshe/Ikorodu		Marina		Iddo		Total		FEPA Std
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Temperature (c)	30.27	0.64	30.17	0.06	39.8	1.76	33.42	0.82	15
Turbidity	3.63	1.31	8.27	0.46	65	3	25.63	1.59	10
conductivity	160.3	4.51	42.83	0.23	163.3	2.89	122.17	2.54	1500
Salinity	12.23	0.306	2.78	0.015	1.603	0.358	5.54	0.23	0
pH	8.07	0.067	8.19	0.047	8.53	0.1308	8.26	0.08	6.9
Fe(Mg/L)	0.407	0.067	2.01	1.296	0.407	0.067	0.94	0.48	0.001
Cu(Mg/L)	0.11	0.01	2.76	0.452	0.11	0.01	0.99	0.16	0.5
Pb(Mg/L)	≤ 0.1	0	1.26	0.08	≤ 0.1	0	0.42	0.03	0.5
Cd(Mg/L)	≤ 0.1	0	≤ 0.1	0	≤ 0.1	0	0.00	0.00	0.005
Zn(Mg/L)	0.22	0.035	1.75	0.454	0.217	0.035	0.73	0.17	5
Cr(Mg/L)	0.133	0.032	0.51	0.409	0.133	0.032	0.26	0.16	0.001
Ar(Mg/L)	0.1	0	0.14	0.0608	≤ 0.1	0	0.08	0.02	0.1
Mn(Mg/L)	≤ 0.1	0	0.26	0.056	≤ 0.1	0	0.09	0.02	5
Ni(Mg/L)	≤ 0.1	0	0.477	0.232	≤ 0.1	0	0.16	0.08	0.5

Table 2. *Water quality parameters for Badagry lagoon during period of study*

Water quality of Badagry lagoon									
	Akarakumo		Ajido		Marina		Total		FEPA Std
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Temperature (c)	27.28	0.95	24.58	6.92	28.04	1.12	26.63	2.996667	15
Turbidity	13.58	3.49	12	3.26	13.46	3.22	13.01	3.323333	10
conductivity	2366.33	3449.59	42.83	1964.73	3109.9	2260.04	4274.55	2197	3611.347
Salinity	0.94	1.66	0.91	1.67	0.74	1.32	0.86	1.55	0
pH	7.44	0.73	7.45	0.63	7.59	1.09	0.453333	0.816667	6.9
Fe(Mg/L)	0.42	0.2212	0.36	0.1593	0.24	0.9441	0.126833	0.441533	0.001
Cu(Mg/L)	0.25	0.1562	0.25	0.13	0.14	0.737	0.0954	0.341067	0.5
Pb(Mg/L)	≤ 0.1	0	≤ 0.1	0	≤ 0.1	0	0	0	0.5
Cd(Mg/L)	0.13	0.1033	0.15	0.137	0.15	0.137	0.0801	0.125767	0.005
Zn(Mg/L)	1.09	2.042	0.23	0.156	0.31	0.191	0.732667	0.796333	5
Cr(Mg/L)	≤ 0.1	0	≤ 0.1	0	≤ 0.1	0	0	0	0.001
Ar(Mg/L)	0.7	0.044	0.72	0.043	0.078	0.04	0.029	0.042333	0.1
Mn(Mg/L)	0.28	0.222	0.26	0.23	0.15	0.22	0.9	0.124	0.424
Ni(Mg/L)	0.1	0	0.1	0	0.1	0	0	0	0.5

Results

Microscopic examination showed normal liver appearance in forty percent of the test population (n = 40). In the latter group, normal hepatocyte morphology including minimal vacuolation, lipid and glycogen storage, sparse biliary duct numbers, and normal arrangement of hepatic cords were a consistent finding *(Fig. 2).*

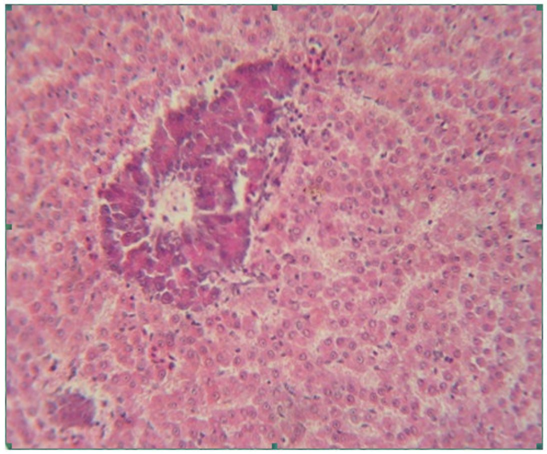

Figure 2. *Normal liver histology of Chrysichthys nigrodigitatus (H & E; x350)*

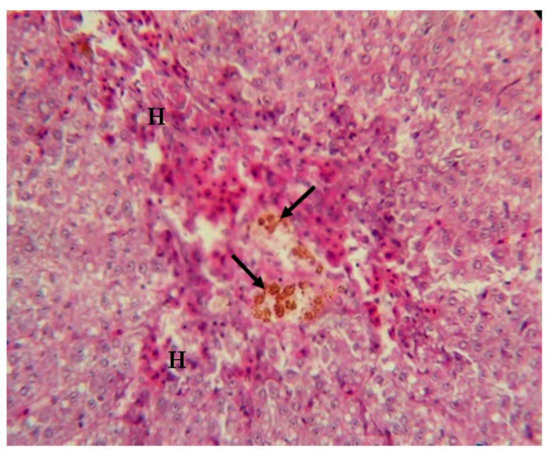

Figure 3. *Portal congestion, vacuolar degeneration of hepatocytes, pancreatic necrosis, heterophilic (H) infiltration and haemosiderin-laden melano-macrophages (arrows) (H & E; x350)*

Mild portal congestion and sinusoidal congestion (33%) ranging from mild to severe were a relatively consistent finding in all pathologic specimens. Vacuolar hepatocellular degeneration and necrosis and pancreatic necrosis (58%) and architectural disruption and dissociation of the Bilroth cords (26%) were a regular finding with the majority of the observed lesions occurring in livers from Lagos lagoon specimens (Hydropic Vacuolation: 31%; Bilroth cord thinning:14%) *(Fig. 3, 4 & 5).* In most of the specimens from the latter location, the observed degeneration was severe and widespread *(Fig. 4)*, in contrast to the mild to moderate vacuolation seen in the Badagry lagoon specimens.

Affected hepatocytes were enlarged with clear staining vacuoles which compressed the cytoplasm and nuclei to the cell margins *(Fig. 3).* In some specimens, the cordlike layout of the hepatocytes was maintained. However, in severe cases, there were severe disruptions in the normal Bilroth cord layout *(Fig. 5).* Coagulative hepatic necrosis, hemosiderosis (12%), and Kupffer cell hyperplasia (11%) as a group of lesions and, individually as unit observations was also observed. An abnormal proliferation of megalocytes *(Fig. 5)*, probably pre-neoplastic or an indication hepatic regeneration, was seen. No neoplastic features were however observed. Tables 1 and 2 set out the water quality determination results.

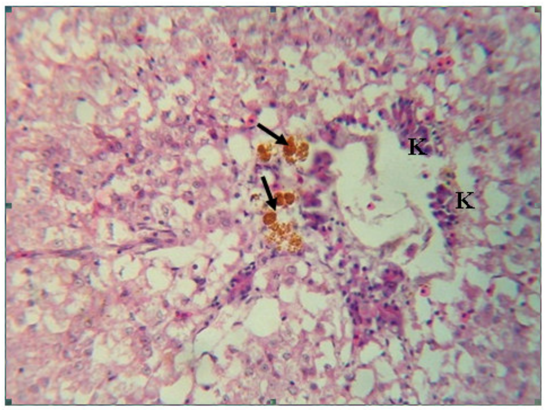

Figure 4. *Severe widespread vacuolar degeneration and necrosis of hepatocytes, pancreatic necrosis and presence of melano-macrophages (arrows) and Kupffer cells (**K**) (H & E; x450)*

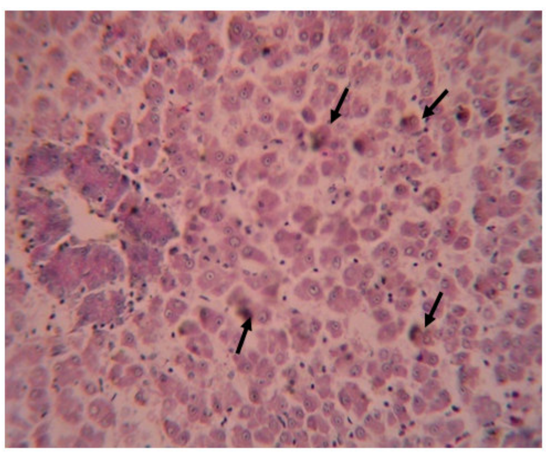

Figure 5. *Hepatocellular and pancreatic necrosis, severe disruption of hepatic cord architecture and presence of megalocytes (arrows) (H & E; x350).*

Discussion

Histopathology is widely accepted as a useful method for the assessment of injury in fish due to the adverse short term and chronic effects of xenobiotic exposure. Several liver lesions have been established as putative tissue biomarkers consistent with the exposure of fish to xenobiotics. These include pigmented macrophage aggregations [24, 10], hepatocyte hydropic vacuolation (*HydVac)* [29], pre-neoplastic foci of cellular alteration [3], and liver neoplasms [6, 26]. These biomarkers have also been conclusively linked with certain factors e.g. macrophage aggregations have been shown to increase with age [7], and stress [10], and, hydropic degeneration with level of exposure to PCB's [29] etc. HydVac was a consistent finding in this investigation and was the most frequently observed and widespread lesion. The preponderance of this lesion in fish from contaminated waters bordering urban locations similar to our test locations has been firmly established and described in detail for, Winter flounder *Pleuronectes americanus* [4, 17, 19], and, white perch *Morone americana* [8], among others. Augspurger *et al.* [4] presented a compilation from various sources documenting the prevalence of HydVac in fish resident in the waters of the northeast United States Atlantic coast, and conclusively established a direct relationship between the pervasiveness and severity of this lesion, hepatic neoplasms and levels of site contamination, noting the absence or low prevalence of HydVac in relatively uncontaminated areas, and the positive relations between the lesion and hepatic neoplasia in highly contaminated areas. Also corroborating this locational correlation, [23] reported that the risk of liver lesion occurrence in Sole *Pleuronectes vetulus*, from non urban, relatively unpolluted locations was lower than for urban and near urban sites on along Puget sound. The latter observations and deductions were consistent with our findings, and conclusively indicative of the relationship between locational pollution indices and lesion prevalence. The prevalence of cases occurring in specimens from the Lagos lagoon could be attributable to the very large influx of all manner of untreated sewage, industrial effluent and other point source pollutants into this water body, the tidal flushing effect of the Atlantic notwithstanding. The converse of the latter situation applies for Badagry, where the satellite population, industrial activity, and, concomitantly, effluent and waste generation and dumping is significantly lower than in Lagos. The water quality information in tables 1 and 2, set out clearly the differences in habitat quality between Lagos lagoon and Badagry. The readings for Lagos consistently exceed, those for Badagry, and, Federal Environmental Protection Agency of Nigeria (FEPA) standards. The stresses of exposure of fish resident in this location seems to adequately explain the preponderance of observed lesions in this location. Certain uncertainties as to whether HydVac is part of a proliferative process or apoptopic in nature have emerged [15, 19]. There is a consensus, however, that vacuolated hepatocytes are frequently found proximal to neoplasms and that tumor prevalence is associated with increasing numbers of vacuolated liver cells and that, the extent of deformity and cell injury is also consistent with hepatotoxicant action [4, 11]. PAH's have been implicated in the development of liver carcinogenesis [5, 14, 30] and a cause and effect relationship between PAH's and liver tumors or preneoplastic lesions in fish has been established by in-vitro studies [16, 28]. Our observations in the present study could be attributable in part to this chemical group, as measurable levels of heavy metals, hydrocarbons, organo-chlorines, PAH's and PCB's have been reported in the Lagos lagoon complex by Ajao *et al.* [1]. In spite of the latter, analytic studies on the lagoon complex ascertaining the true composition and relative concentrations of individual chemicals and chemical groups, in the xenobiotic cocktails present are lacking and have been initiated by this research team as of the present. The absence of frank tumors in the test population should not be taken as given that no such end state lesions of oncogenesis exist in these waters. More realistically, it could be presumed that the levels of xenobiotic contamination in the test waters are significant, and that the exposure of resident feral fish populations could lead to the development of tumors. Such absences could also be a result of limited test specimen numbers, few test locations and migrant proclivities of feral fish populations away from heavily polluted locales. These are some of the experimental limitations to be considered in later screening exercises. Vascular aberrations exhibiting as congestion of sinusoidal vessels was the second most common lesion. Sinusoidal congestion has been reported as pathognomonic of exposure to some toxicants, including insecticides [9]. However the presence of focal and in some cases, widespread areas of hepatic necrosis, as reported in our results would be regarded alongside HydVac, as a more demonstrative indication of contaminant induced hepatoxicity [27]. This study, the third in a series, establishes the significant pollution index of the Lagos lagoon complex and the inducibility of oncogenesis and frank neoplasms in resident finfish, especially benthic species, as a result of exposure to sediment bound xenobiotics. It is planned for the future that analytic studies are carried out on these waters to establish the identities of present pollutants, the relative preponderance of these pollutants, and to establish a definite cause and effect relationship between observed lesions and identified pollutants.

This study has established to some degree the disruptive and pathological potential of polluted Nigerian estuaries on resident aquatic fauna, and corroborates earlier work described by the authors.

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