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CLIMATE SIGNAL IN THE RING WIDTH, DENSITY AND CARBON STABLE ISOTOPES IN PINE (*PINUS SILVESTRIS* L.) IN CENTRAL CAUCASUS

ABSTRACT

Variability of width, maximum density and stable isotopes ($\delta^{13}C$) in tree-rings of Scots pine (*Pinus sylvestris L.*) were studied in Northern Caucasus. Statistically sufficient agreements between ring width chronologies allow to construct composite chronology for the Elbrus area. Absence or low correlation between indices of the ring width and maximum density chronology point out different climatic signal. The influence of temperature and precipitation on these tree-ring parameters was also analyzed. The ring width of pine at the upper tree limit in the Baksan valley correlates positively with the June and July precipitation ($r = 0.3; 0.3; 0.4$, $p < 0.05$). No correlation with temperature parameters was found. The maximum density reflects the warm period temperature (April-October). The similarity in interannual variations of $\delta^{13}C$ in annual rings between the individual samples means that their display a coherent common signal. This signal can be largely interpreted as the June and July precipitation.

KEY WORDS: Scots pine, stable isotopes ($\delta^{13}C$), tree-ring width, tree-ring maximum density, Northern Caucasus

INTRODUCTION

The longest continuous time series of meteorological observations in Caucasus slightly exceed a century. Those located at the high elevation are only half century long or even shorter. In order to better predict the decadal and interannual climatic variations in this region it is important to extend the time series in the past. In the areas, where the growth of annual rings in trees closely associates with some of the climatic parameters, this problem can be at least partly solved basing on the dendrochronological approach.

Tree-ring formation consists of three stages: cell division, cell enlargement and cell-wall thickening [Thomas, 1991]. Wood properties are determined over time by various factors during tracheid development. Earlywood formation depends mainly on growth reserves from the preceding growing season, while latewood formation depends on photosynthetic production and net CO_2 assimilation during the current growing season. Thus, all the seasonal and annual temperatures and precipitation may influence tree-ring development (cambial cell division, radial growth and lignification).

In this paper we report the results of the study of climatic signal in pine tree rings in Caucasus. As soon as different parameters of the annual rings often reflect different climatic forcings we analyzed the total wing width, early and late wood ring width, maximum density and stable isotopes ($\delta^{13}C$) in pine (*Pinus silvestris L.*) in Central Caucasus at the vicinity of the upper tree limit and report here our first results.

STUDY AREA AND STATE-OF-THE-ART

The Caucasus Mountains are located on the south of the East European Plain between the Black Sea in the west and Caspian Sea in the East. The tree-ring sites analyzed in this study are situated in the western and central part of the Greater Caucasus in Baksan and Teberda valleys at the elevation of 2200–2500 m asl.

In general, climate of the region is defined by the complex topography and prevailed westerly wind. In winter atmospheric circulation over the Greater Caucasus is dominated by extensions of the Icelandic depression from the west and the Siberian high from the east. In summer extensions of the Azores high prevail. Annual precipitation declines from over 2000 mm in the western Caucasus to less than 200 mm in the east. The western and central sectors of northern slope of the Greater Caucasus, where the study area is located, are in particular characterized by a strong convective activity in summer. Precipitation maxima occur in July–September in response to convective activity triggered by a combination of strong insolation and depressions developing on the Polar front and enhanced by the orographic uplift [Shahgedanova, 2002].

The pine (*Pinus silvestris L*.) forests are broadly distributed in the region. The upper tree limit of pine rises up to 3000 m asl. Some pine trees at in the vicinity of the upper timberline exceed the age of 400–500 years. The attempts to reconstruct climatic changes in Caucasus using the width of annual rings have been undertaken repeatedly since the 1960s (see review by Solomina [1999]). So far none of these was successful, because the ring width here is influenced by many simultaneously acting factors and the correlation between individual meteorological parameters and tree-ring width indices was found to be weak or statistically insignificant. For example Turmanina [1979] found out that the ring width of the pines growing on the southern slope of the Baksan River valley increases during the humid and warm summers and decreases during the summers with the low temperatures.

MATERIALS AND METHODS. CHRONOLOGIES.

To construct and analyze the ring width chronologies we used the standard procedures of measuring, cross-dating and indexation routinely used in tree-ring analysis [Stokes, 1968]. Two cores per tree were collected. They were sanded by progressively finer paper to obtain more contrast between ring boundaries. Then we used LINTAB ver. 3.0 system with a resolution of 0.01 mm [Rinn, 1996] and TSAP software to measure ring width and graphical presentations of the results. Some sites are located quite close to each other and represent the same climate conditions. Thus to enhance the sample depth of ring-width chronologies we have combined sites CHS and CHE into one called CHS and KHAT and KHTP into one entitled KHTP (Table 1).

To develop maximum density chronology (MaxD) we used 46 cores of pine from two sites (KHAT and KHTP) located at the upper tree limit (2300–2400 m a.s.l.) in the valley of the Teberda River. For densitometry analyses the resins must be extracted first. The samples were treated by Soxhlet apparatus with solution of ethanol and toluene during 6 hours, then 2 hours of pure ethanol [Schweingruber, 1988]. To make wood surface flat and delete any curvature appeared due to dryness the microtome was used. After that cores were scanned by flat-bed scanner with high resolution of 1000 dpi. Scanned images were processed using commercially available software LignoVision (Rinntech) to obtain brightness profile of the reflected light images as a substitution of the regular densitometry. This routine was done in the Laboratory of Tree-Ring Research (Tucson, Arizona) in 2009. In this paper we use the term "maximum density" although X-ray densitometry wasn't applied. This approach was advocated earlier [e.g. McCarroll, Pettigrew, and Luckman, 2002].

The cross-dating procedure was validated by using COFECHA software [Holmes, 1983] and core segments with low correlation values were excluded from the analysis. Each

Table 1. List of samples in Caucasus

Sites	Location	N	E	H	Number of samples (trees)	Date of collection	Age for two or more series
KV	B. Azau, at the MSU station (moraine 14th century)	43 15 951	42 28 847	2200	8 (4)	2002 August, September	1653–2002
GAR	Forefield of Garabashi glacier	43 15 965	42 29 201	2340	13 (7)	2003 June	1697–2002
CHS	Southern slope of Cheget mt.	43 15 977	42 29 199	2470	8 (4)	2003 June	1765–2002
CHE	Eastern slope of Cheget mt.	43 14 478	42 30 773	2535	7 (4)	2003 June	1860–2002
BAZ	Forefield of B. Azau glacier, terminal moraine	43 26 660	42 46 272	2420	18 (11)	2004 September	1684–2004
KHAT	Valley of Malaya Khatipara river (right valley side)	43 25 815	41 42 513	2285	24 (12)	3 June 2006	1779–2005
KHTP	Valley of Malaya Khatipara river (left valley side)	43 26 835	41 42 339	2394	22 (11)	2 June 2006	1709–2005
SOF	Valley of Psysh river (moraine)	43 27 060	41 16 592	2022	14 (7)	16 August 2007	1720–2006
KYZ	Valley of Kyzgych river (upper tree-limit)	43 25 680	41 18 212	2392	13 (7)	17 August 2007	1578–2006

tree-ring series contain biological trends associated with tree-age. To remove the trend and preserve variations related to climate we standardized tree-ring series to dimensionless indices using the program ARSTAN [Cook, 1985]. Tree-ring series were standardized by fitting either a negative exponential curve or line with negative slope or horizontal line to each series and ring-width indices generated by division. Resulting site chronologies were developed by averaging the indices from the each tree-ring series by using a bi-weight robust mean [Cook, 1990]. The composite chronology was developed by the indices averaging.

Our ring width pine chronologies cover at the moment the period AD 1550–2009 and o ne ring width density chronology at the Khatipara site in Teberda valley covers AD 1800–2005 (Figs. 1–2, Table 1). For the stable isotopes ($\delta^{13}C$) analyses we extracted wood from three disks of pine trees killed by the avalanche on 29 December 2001 in the vicinity of the Research Station of the Moscow State University (LAV site, samples 11, 23 and 26) (Fig. 3). The site is located in Baksan valley at the edge of the Garabashi debris flow cone. The wood that we extracted from 50 annual rings (1960–1999) contains both early and late wood portions, although due to the larger early wood rings this one dominates in the samples. We also measured separately the early and late wood ring width for the samples processed for the $\delta^{13}C$ analyses.

Whole wood (i.e., earlywood and latewood) from each single tree-ring was ground using a Retsch mill (Mixer Mills, MM 200, Haan, Germany). The resulting powder was weighed (approximately 1.5 mg) in tin capsules. Tree ring isotopic ratio was determined by combustion of the samples in an elemental analyzer (Carlo Erba, model NA 1500, Milan, Italy) coupled to an isotopic ratio mass spectrometer (ISOPRIME, Isoprime Limited, Cheadle, UK). Analysis precision was greater than ±0.03‰. The results were expressed as $\delta^{13}C$ in ‰ relative to the international standard VPDB [Brugnoli and Farquhar, 2000] according to $\delta^{13}C = (R_{sample}/R_{standard} - 1) \times 1000]$, where R_{sample} and $R_{standard}$ represent the $^{13}C/^{12}C$

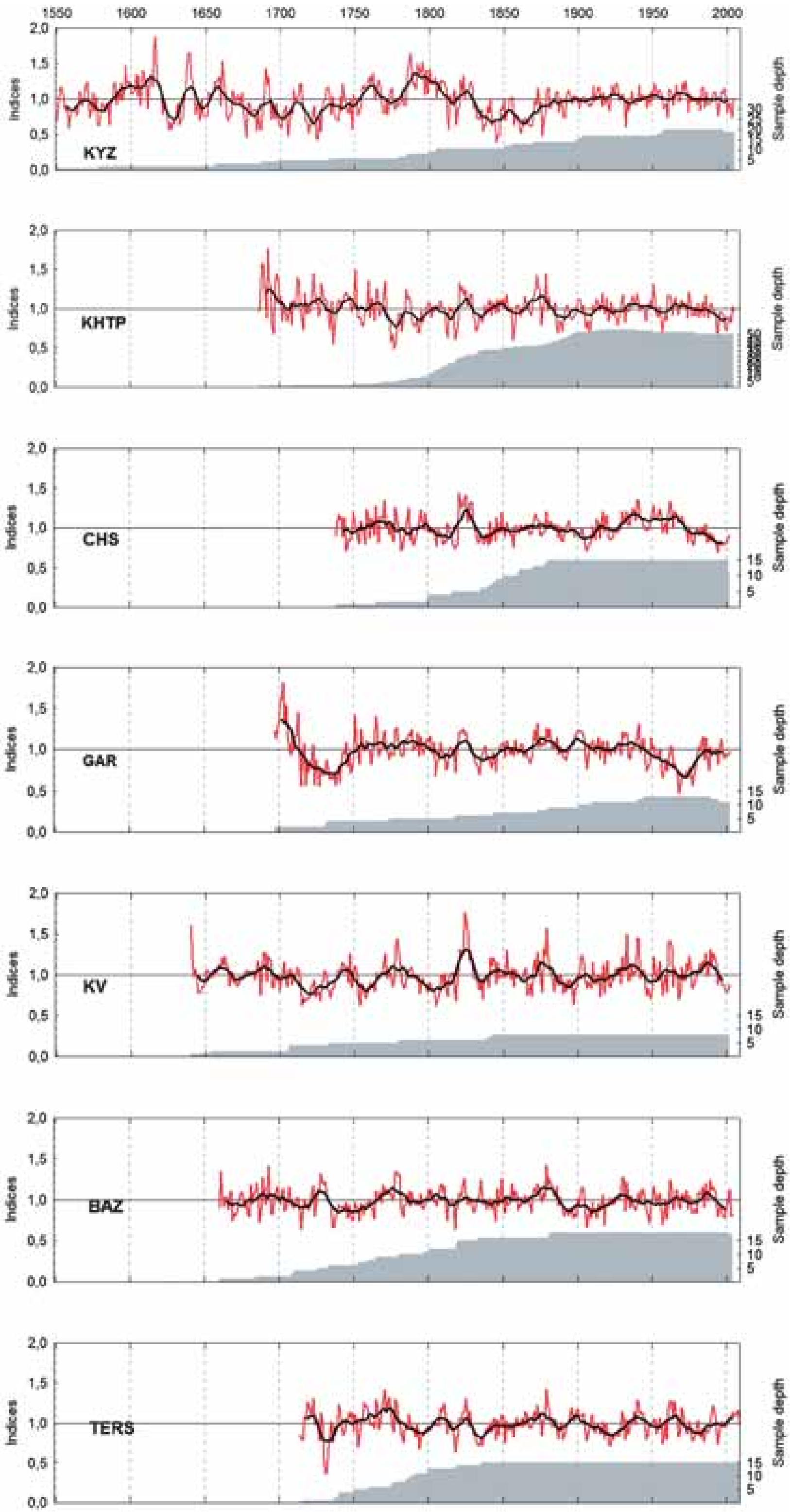


Fig. 1. Pine ring width chronologies in Caucasus (Baksan, Teberda and Kyzgich valleys). Gray fields – samples depth

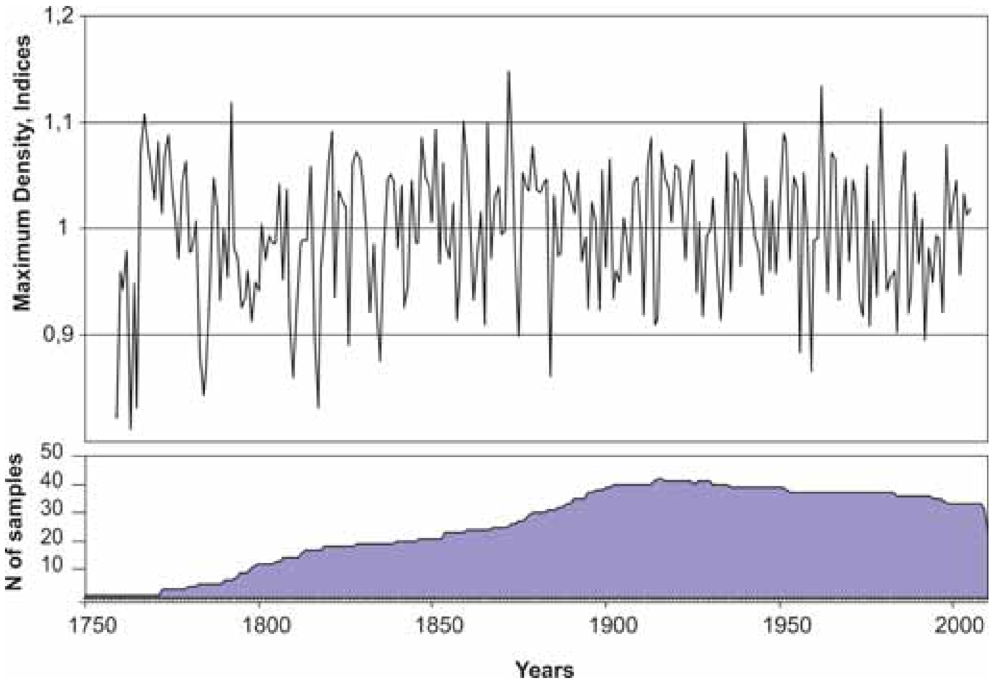


Fig. 2. Maximum density pine chronology in Teberda valley

Fig. 3. Pine trees killed and damaged by the avalanche in 2001 sampled for the analyses of stable isotopes

Table 2. Correlation coefficients of the 7 standard chronologies.
Marked values significant at $p < 0.05$

Chronology	KYZ	KHTP	CHS	GAR	KV	BAZ	TERS	MaxD
KYZ	1.00	0.41	0.33	0.23	0.25	0.32	0.39	–0.02
KHTP		1.00	0.64	0.42	0.58	0.53	0.63	0.23
CHS			1.00	0.36	0.57	0.41	0.53	0.30
GAR				1.00	0.50	0.45	0.48	0.11
KV					1.00	0.57	0.55	0.10
BAZ						1.00	0.53	–0.03
TERS							1.00	0.12
MaxD								1.00

molar ratios of the sample and the standard, respectively. An internal standard consisting of a C3 sucrose with a $\delta^{13}C = -25.08‰$ was analyzed periodically every ten samples to check the accuracy of analysis.

In order to explain the climatic forcing for different annual ring parameters (width, density and stable isotopes) we correlated these time series with the monthly temperature and precipitation measured at the nearest meteorological stations (Terskol, Severny Klukhor, Teberda).

The individual ring width samples as well as local chronologies cross-date and intercorrelate very well (Table 2). This correlation allowed the construction of the composite chronology for the Elbrus area. Most of ring width chronologies do not correlate with the maximum density, which is a sign of different climatic signal embedded in the two tree ring parameters.

RESULTS

Ring width and density

Table 3 shows the correlation of the pine ring width of the composite Elbrus chronology and maximum density chronology with monthly temperature and precipitation. The coefficients

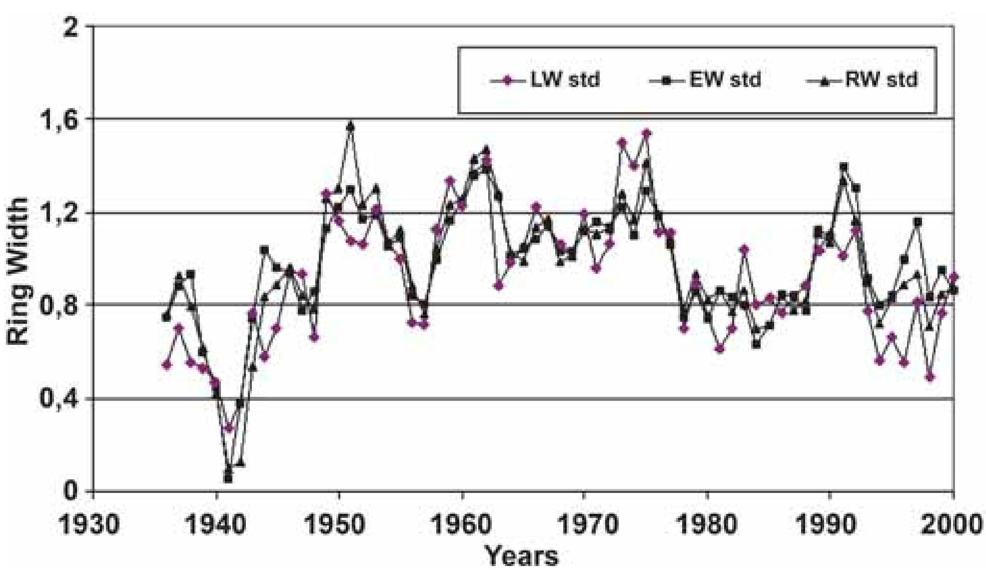


Fig. 4. Early (EW), late (LW) and total (RW) ring width measurements averaged for three samples used for the stable isotope analyses

Table 3. Correlation coefficients of the ring-width regional chronology (denominator) and tree-ring maximum density chronology (numerator) with mean monthly temperature and precipitation recorded at the Severnyi Klukhor, Teberda and Terskol meteorological stations. Marked values significant at p < 0.05

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	год
Mean monthly temperatures													
Severny Kluhor	0,1/0,1	0,2/–0,1	0,3/0,1	0,4/0,0	0,3/–0,2	0,3/–0,1	0,4/0,2	0,7/–0,0	0,5/–0,1	–0,1/–0,1	0,4/0,0	0,1/–0,0	0,7/0,0
Teberda	0,0/0,1	0,2/–0,2	0,3/0,2	0,4/0,0	0,2/–0,2	0,3/–0,0	0,3/0,2	0,6/–0,0	0,4/–0,1	–0,1/–0,1	0,3/0,1	0,2/0,0	0,6/0,0
Terskol	0,1/0,1	0,2/–0,1	0,3/0,2	0,3/0,1	0,2/–0,2	0,2/–0,1	0,3/0,2	0,5/0,0	0,5/–0,1	–0,1/–0,1	0,4/0,1	0,2/0,0	0,6/0,0
Precipitation													
Severny Kluhor	–0,1/0,1	0,2/0,1	0,1/0,0	0,1/0,2	0,0/0,1	0,0/0,3	–0,1/0,2	–0,2/–0,1	–0,1/–0,1	–0,1/0,1	–0,1/0,0	0,2/0,2	0,0/0,3
Teberda	–0,1/0,1	0,1/–0,1	0,1/–0,0	0,1/0,2	0,2/0,2	–0,1/0,2	–0,2/0,3	–0,4/–0,2	–0,1/–0,1	–0,1/0,1	0,0/0,1	0,3/0,2	–0,1/0,2
Terskol	–0,1/0,0	0,0/–0,0	0,1/–0,1	0,1/0,0	0,1/0,3	–0,1/0,2	–0,1/0,4	–0,4/–0,1	–0,1/–0,2	0,0/0,1	–0,1/0,0	0,3/0,3	–0,1/0,2

of correlation for the ring width (below the lines) show no statistical significance with climatic parameters except for the cases: positive correlation can be seen with precipitation in June at the Severnyi Klukhor meteorological station (r = 0.3, $p < 0.05$), in July (r = 0.3, $p < 0.05$) at the Teberda met station and in July (r = 0.4, $p < 0.05$) at the Terskol station. The numbers above the lines in the table 3 display a systematic positive significant correlation of the maximum density with the spring-summer temperatures measured at different meteorological stations. Due to this significant and sustainable correlation the April–October temperature values at the Severnyi Klukhor meteorological station and the maximum density we were able to reconstruct this parameter for the last 200 years [Dolgova, Solomina, 2010].

Stable isotopes

The total ring widths of three samples used for the isotope analyses cross-date well against each other and versus the composite Elbrus chronology. It means that the three selected samples represent adequately the whole regional data set. The measurements of the early and late wood ring width of these three samples show that the early and late wood ring width are very closely correlated. They also agree quite well with the total ring width (Fig. 4).

The correlation of monthly mean temperature and precipitation of Terskol meteorological station located in the vicinity of the sampling site with the early, late and total wood ring width show that all three parameters responded similarly to the climate changes. This result is not surprising taking into consideration the similarity of the ring width curves. Namely they showed a significant negative correlation with September temperature, a negative correlation with the precipitation in April and a positive one with the precipitation in July (Fig. 5). The composite pine chronology in this region positively correlates with June precipitation, i.e. our smaller data set generally shows a similar reaction to climate. Fig. 6 shows a very good agreement between the $\delta^{13}C$ variations in the three analyzed samples both in terms of high frequency variations and the long-term negative trend observed since 1980s (the last one except for the sample LAV 23) (see also Table 4).

The mean $\delta^{13}C$ LAV chronology correlates positively (although weakly) with the summer temperature sensitive maximum density, and the late ring width chronologies (Table 4).

A significant positive correlation is found for the $\delta^{13}C$ chronology and November temperature (Fig. 7). The same parameter correlates significantly with the total ring width of the regional chronology and the maximum density chronology and seems to be very important for the pine growth in these conditions. The warm November may extend the growing season and therefore stimulate more successful growth of woody plants at high elevation stands. The most prominent signal detected for the $\delta^{13}C$

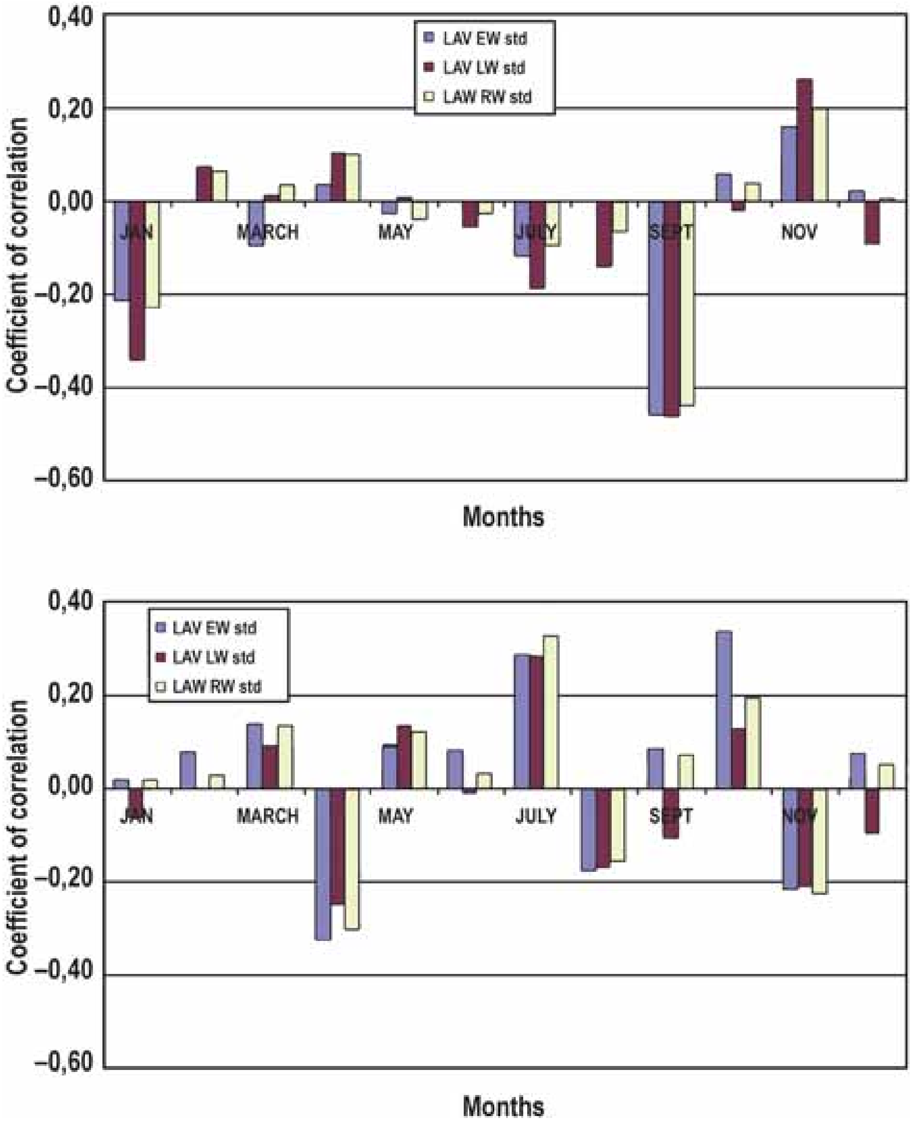


Fig. 5. Temperature (A) and precipitation (B) signals in the ring width of three pine samples for early, late and total ring width of pine used for the isotope analyses

Table 4. Correlation of ring width, maximum density and δ13C chronologies. Marked values significant at $p < 0.01$

	MaxD	δ13C mean	LW std	EW std	RW std
MaxD	1,00				
δ13C mean	0,35	1,00			
LW std	0,08	0,30	1,00		
EW std	0,11	0,14	0,71	1,00	
RW std	0,17	0,19	0,84	0,94	1,00

chronology is the negative correlation with June and July precipitation. It is well known that the pine growth in Central Caucasus is partly limited by moisture availability [Turmanina, 1979] (see Fig. 5B). The correlation of different chronologies (width, density, isotope composition) with the same parameters (e.g. November temperature, July precipitation) may be explained by a common signal. However our analysis shows that the three types of the chronologies that we used are significantly different: they are forced by different climatic parameters and reflect different seasonality.

DISCUSSION

The climatic signal in the ring width and maximum density was discussed many times in special dendrochronological literature [e.g. Fritts, 1976, Schweingruber, 1988, Gagen, D. McCarroll, 2004]. Here we concentrate on some examples of the detection of the climatic signal in the $^{13}C/^{12}C$ series of pine in different ecological conditions.

In general the stable carbon isotope chronologies have been established from tree rings to detect the fluctuations in $^{13}C/^{12}C$ ratios of atmospheric CO_2 or as a means for reconstructing past climates [Stuiver 1978; Leavitt and Long 1988, Carroll and

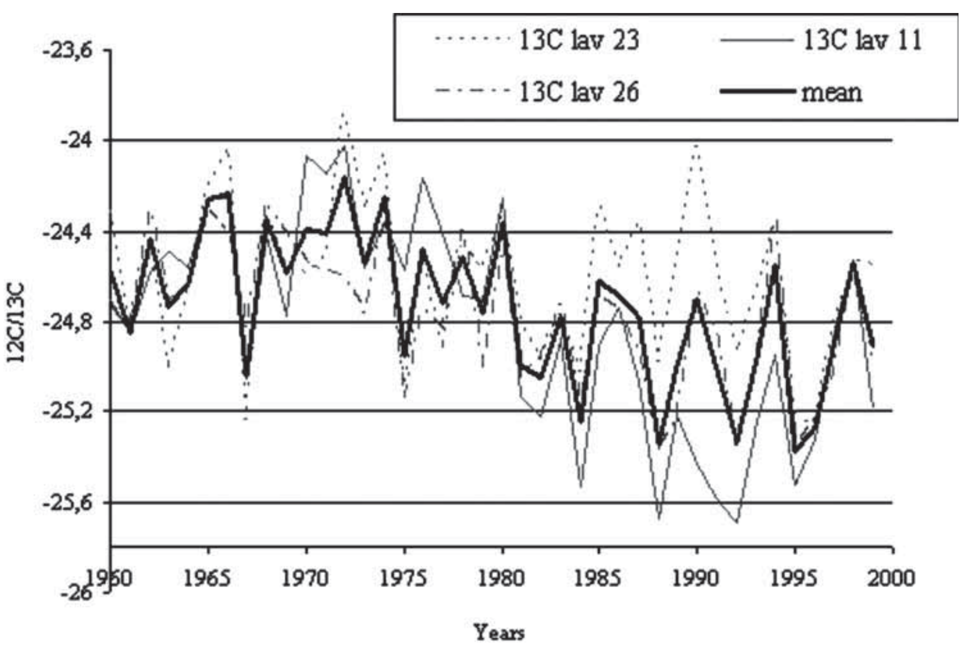
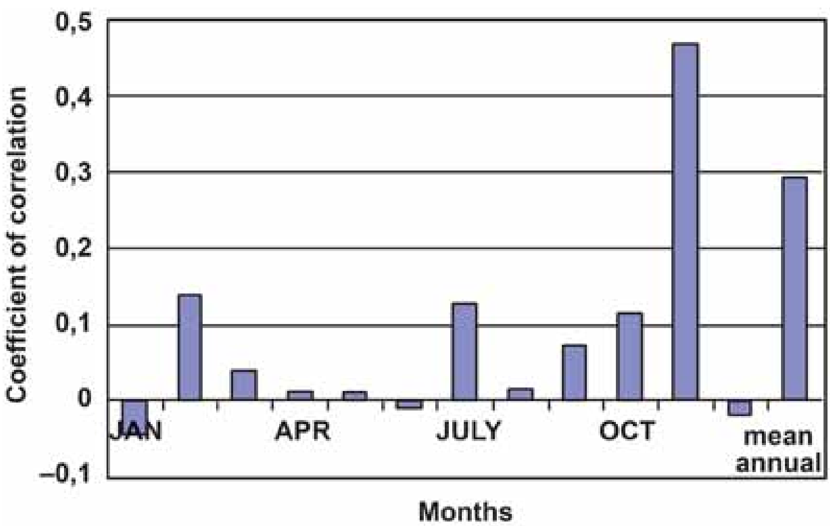


Fig. 6. Variation in $\delta^{13}C$ in three samples of pine (site LAV) in Baksan valley and their averaged values

Loader, 2004]. Stable carbon isotopes record the balance between stomatal conductance and photosynthetic rate, dominated at dry sites by relative humidity and soil water status and at moist sites by summer irradiance and temperature [Carrol and Loader, 2004; Brugnoli and Farquhar, 2000]. In our case the carbon isotope composition in pine tree rings clearly depends on moisture stress and soil water availability. Low precipitation during the period of June-July likely induces stomatal closure and a decrease in the ratio of chloroplastic to atmospheric CO_2 concentrations which, in turn, causes an increase in $\delta^{13}C$.

Lewitt [1993] found a moisture stress signal in the $\delta^{13}C$ pine (*Pinus edulis*) in North America. Liu et al. [1996] identified correlation with the May-June precipitation for the *Pinus tabilaeformis* in Northern China. In Northern Finland the signal in the Scots pine (*P. silvestris*) was very site specific [Mc Caroll and Pawelck, 2001], while Waterhouse et al.



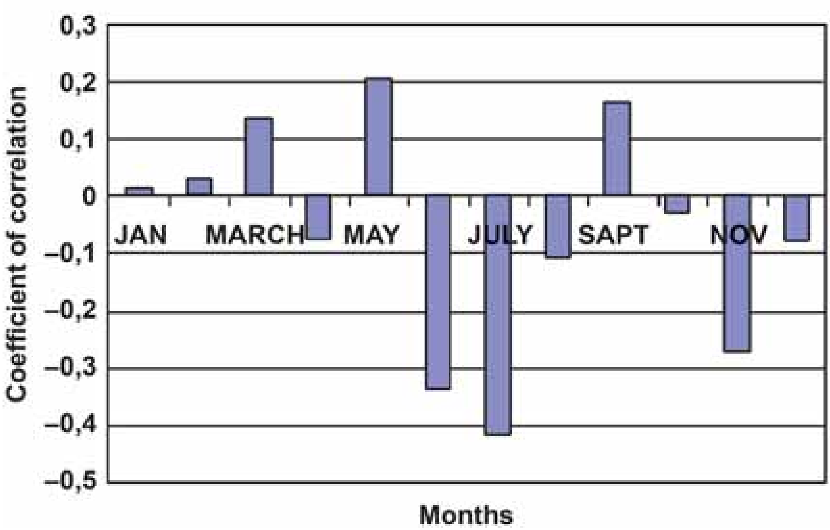


Fig. 7. Response function and correlation coefficients between the $\delta^{13}C$ chronology and monthly temperature (A) and precipitation (B) at Terskol meteorological station

[2004] found a correlation of 3-year smoothed $\delta^{13}C$ pine (*P. silvestris*) chronology with the flow of Ob river reflecting the moisture stress. Feng and Epstein [1995] discovered that the high frequency $\delta^{13}C$ variability in pine, juniper and oak in North America correlates with the precipitation while the long term changes are coherent with the atmospheric CO_2 ^{13}C composition and its decrease due to the effect of ^{13}C dilution by fossil fuel combustion.

Our findings generally agree with those studies reporting the dependence of the $\delta^{13}C$ fluctuations in pine annual rings upon the drought stress and precipitation of the warm period. The closest results, i.e. the negative correlation between $\delta^{13}C$ of pine chronology and the summer precipitation was previously reported for the French Alps [Gagen, McCarroll, 2004] – a region which is quite similar by its climatic and environmental conditions to the Central and Western Caucasus.

Our research demonstrated that the high elevation pine vegetation in the Central Caucasus is a very promising climatic proxy. Different parameters of the pine rings can be used as predictors for the reconstruction of various climatic variables: the maximum density correlates with the warm period thermal conditions while the $\delta^{13}C$ largely reflects the moisture stress.

CONCLUSIONS

1. The ring width of pine at the upper tree limit in the Baksan valley correlates positively with the June-July precipitation. No correlation with temperature parameters except for the month of November is found.

2. The maximum density proved to be more clearly related to climatic parameters, namely it reflects the warm period temperature (April–October). The correlation is high enough to be used for the modeling and reconstruction of this parameter.

3. The similarity in the interannual variations of $\delta^{13}C$ in annual rings between the individual samples means that they display a coherent common signal. This signal can be largely interpreted as the June and July precipitation. ■

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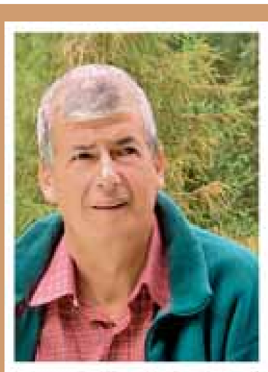

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MIANKALEH TERRITORIES RESPONSE TO CASPIAN CATASTROPHIC FLUCTUATION

ABSTRACT

The main objective of this study is Miankaleh shoreline displacement against Caspian rapid sea level changing and anthropogenic impact. The morphological subunits and shoreline position have been recognized by comparing and processing of aerial photos related to 2 periods of expanded Caspian Sea level fluctuation (1966–2005). Then observational works and surface geology have been done along the eight transects from extremity of western to eastern of mentioned area. Main results show the tendency of flooding vulnerability and shoreline displacement increase at the end of eastern region of Miankaleh near Ashooradeh peninsula where there is an interaction with Caspian rapid sea level changing. In the direction of west, shoreline deformation degree declines gradually.

KEY WORDS: Caspian; beach; fluctuation; Miankaleh

INTRODUCTION

The susceptibility of coastal lowlands, which affected by climatic process, water level changing of oceans and seas and impacts of anthropogenic activities, is very high. So that the ecological and morphodynamic characteristics of these regions become involved in a critical vulnerability due to the function of sea water level rise and down periods. In fact, slight slope of lands behind coast which have negative and reverse direction as compared with coastal berms, provide favorable conditions for marining on the occasion of water level rise and coastal aquifers piezometric level rise. Consequently, marginal wetlands appear. In view of biodiversity in these areas, habitat value and significance for conservation objectives is strongly considerable. Miankaleh wetland has such environmental importance so that according to the defined criteria by international union for conservation of wetlands has presented as a protective area. The connection of this basin and Caspian Sea is established via marginal canals. Usually in the case of water level rise, vast parts of littoral zones could be submerged then territory of Miankaleh wetland will expand. The main question of this study is the impact assessment of natural and anthropogenic factors on morphodynamic deformation in Miankaleh lowland area. Environmental and erosive vulnerability conditions of this area have increased because of Low and reverse slope sandy shore, Caspian rapid sea level changing and hydrodynamic forces from it, furthermore economical efforts expansion (fishery, port, oil and gas, tourism, power plant and construction).

The results of several surveys prove that this coastal significant area of Caspian Sea has permanently been impressed by environmental forces of Caspian Sea level changing throughout the Quaternary geological history [Khoshravan, 1995]. Hence current morphological appearance is depended on hydrodynamic forces and Caspian Sea water fluctuations [Khoshravan, 2000]. With the comparing the shoreline transpositions of Caspian Sea south- eastern coastal parts on the region between Torkaman and Gomishan ports in 40 recent years, we can find out the replacement rate and morphological deformation of Caspian Sea slight slope coasts along with rapid fluctuating periods [Khoshravan, 2002]. Furthermore, it is proven that the wide sandy area evolved from flows parallel with coast in direction of west to the east throughout recent several thousand years [Kosari, 1995]. Survey about native and immigrant bird biodiversity of mentioned wetland in addition to the benthic and fishes, show precious habitat value and excessive bio susceptibility of this area [Kosari, 1995].

Recent accumulation of trading and commercial efforts in ports, water effluents from city and village communities and leading industries, solid waste disposal, toxicant concentrations generated from fertilizers and pesticides, is the main cause of increasing environmental vulnerability rate around Gorgan bay and Miankaleh wetland [Moghadam, 2004]. Therefore, this study aims to assessment of shoreline morphodynamic deformation which effected by rapid sea level changing and human activities in Miankaleh peninsula. To achieve this main goal, we have simulated the structural reaction encounter with the mentioned agents by taking advantages of aerial photos processing and field observations.

STUDIED AREA, MATERIALS AND METHODS

The slight slope and lowland, Miankaleh is located on the south – eastern regions of the southern coasts of Caspian Sea in the lengthwise direction around a canal between Torkaman port and Ashoradeh peninsula where is adjacent to the Amirabad port (Fig. 1). It is situated in the widthwise direction between Gorgan bay and Caspian Sea. This area is expanded as a sandy spit in the direction of western, eastern along with the Caspian Sea shoreline. The length is about 70 kilometers and the width is about 2 kilometers. There is one of the most important Caspian Sea ports (Amirabad port) in the western parts of this region. Also Ashoradeh peninsula, in the end of eastern parts, is considered as a main center for the sturgeons fishing. The aqueous connection of the Gorgan bay and Caspian Sea is feasible via marginal canals such as Ashoradeh and Khozeini canal. The vast regions of Miankaleh area is covered by maritime sandy sediments which appear in the intercalation shape of the microlithic and adhesive wetland sediments. This kind of sediments is seen in central parts of peninsula that contains lots of mussels. Also, the eastern parts of Miankaleh include sedimentary wetland environment and middle part where is concentrating location for the majority of the aquatic organism.

After collecting required data, morphologic features and widespread morphodynamic phenomena conditions of this area were assessed with applying of satellite images during the time between 1965 till 2005. Morphological subunits of the area in the direction of vertical to shoreline between Gorgan bay and Caspian Sea was measured by field works conducted around eight transects where it was chosen in lengthwise direction of Miankaleh. Shorelines position around peninsula was assigned by transferring data to the geological information system (GIS) and putting down them on digitized map. The transpositions of shoreline and submergence of coastal lands were verified by Interpreting and comparing of aerial photos belonged to a 40 years period of times (1965–2005) in a scale of 1:10 000 which contains both water level rise and down conditions. After that, we achieved to identify vulnerable regions towards Caspian rapid sea level fluctuations.

RESULTS

Miankaleh morphological subunits

The aerial photos processing and field works conducting around eight measurements transects (Fig. 1) specify that Miankaleh territory possess several morphological subunits and sedimentary sub-environments in the direction of west to east (Table 1).

Shorelines transposition

The consequences of processing and comparing the aerial photos of Miankaleh coastal regions in a period of times (1965–2005) which contained Caspian Sea water level rise and down phenomena, show different dislocation of Miankaleh peninsula shorelines in western, central and eastern parts (Fig. 2). The scope of the coastal lands submergence in the situation of water level rise has diverse features in the different regions. Besides the extension of coastal morphodynamic features such as: erosive bays, connecting canals, wetlands and sandy spit expansion happen more in the case of

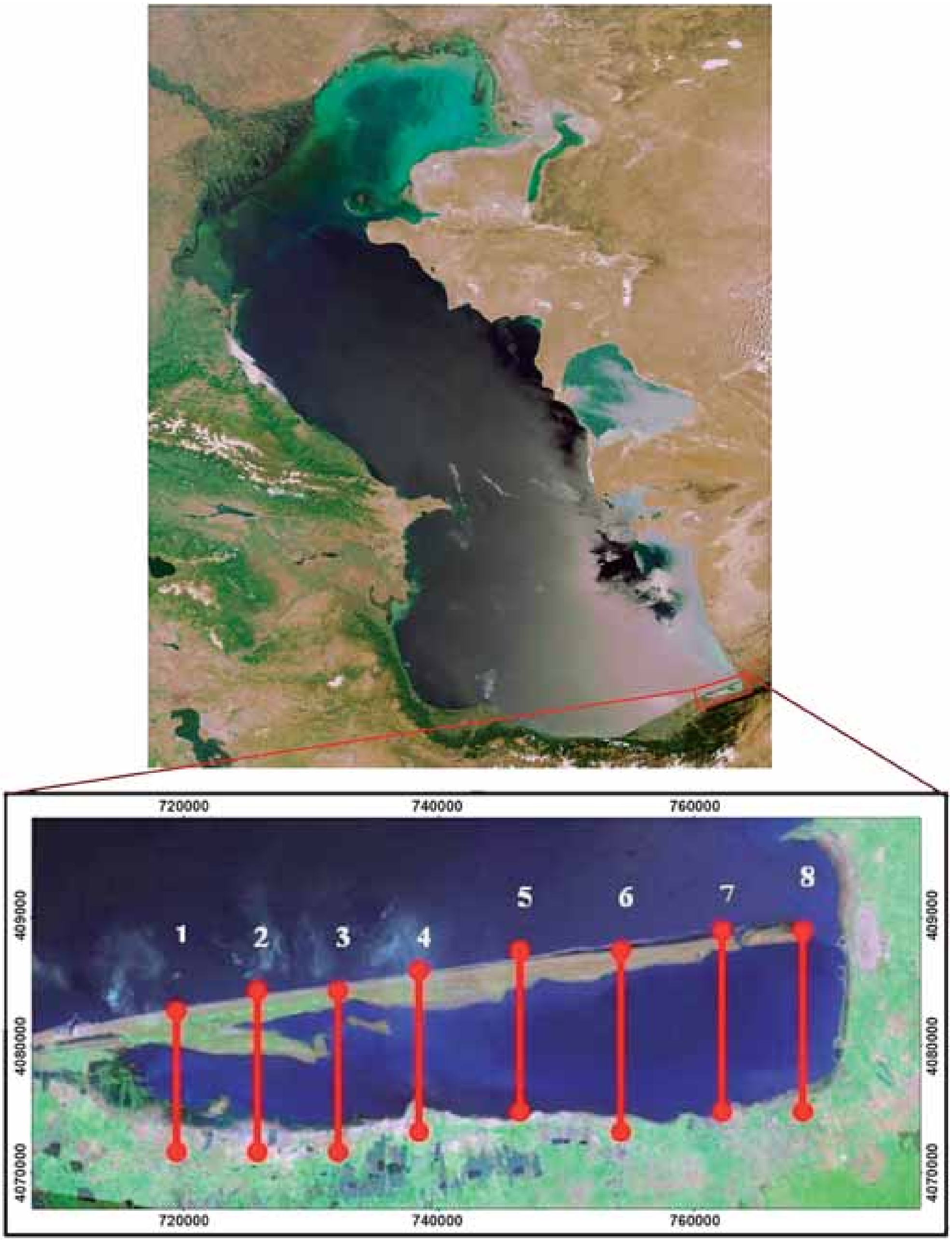

Fig. 1. Studied area location map

Table 1. Sedimentary environments and morphological subunits of Miankaleh territory

Miankaleh Region	Sedimentary sb-environments	Morphodynamic Phenomena
Western Part	Aeolian environments, Primitive Berms, Wetland Fringe, Shoreline, Wetland Band Beam, Gorgan Bay	Erosive terraces, Beach cusps, Sand Dunes, Primitive beach and Fluctuation terraces
Central Part	Shoreline, Wetland, Sand Dunes, marginal canals, Wetland Fringe, Gorgan Bay	Beach cusps, Ripple marks, Scattered Sand Dunes, Strip Pool Pits, Sand Spits
Eastern Part	Marginal lagoon, Primitive Sandy beach , Gorgan Bay	Pool Pits, Lagoon

Fig. 2. Shoreline displacement along the eastern part of Miankaleh

sea water level rise to sea water level down. In the time of Sea transgression period, the growth of vegetable coverage is seen more in berms and sandy dunes.

Anthropogenic impacts on coastal structure deformation

The evaluation of geometric and morphodynamic structures in western parts of Miankaleh, confirms the erosive phenomena enlargement produced by anthropogenic activities like ports construction (Fig. 3). So that shoreline has been retreated to 900 meters in this part of Miankaleh and the growing trend of erosion involves sandy dunes which caused coastal berms eradication. This event has influenced the locations of 20 kilometer radius from west direction to the east.

DISCUSSION

Miankaleh territory morphology condition

The conclusions from field observations and satellite images analysis indicated that morphologic features of Miankaleh peninsula

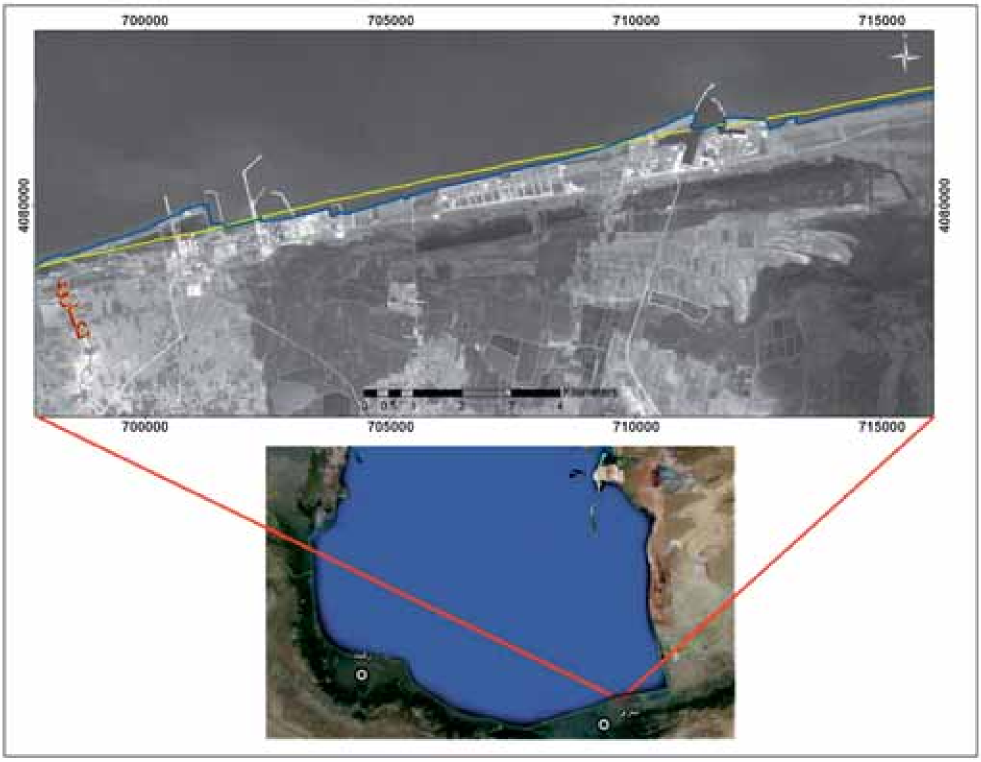

Fig. 3. Anthropogenic impact on West part of Miankaleh

have specific qualities as well as at the end eastern of Amirabad part to the central point of Tazehabad coast adjacency in Miankaleh district is formed of the Caspian primitive coastal sandy sediments. The coastal profile from Gorgan bay to the Caspian Sea shoreline orderly contains: lowland part of Gorgan bay with the dominant vegetable coverage of Xanthium shrubs and filled with calcareous shell of mollusks (bivalve and gastropod). After that we reach the primitive sandy coast of Caspian Sea with an altitude code of –24 that embraced microlithic sandy sediments and marine mussels (*Cardium edule*).

This part of Miankaleh territory is covered by prairie, raspberry bushes and sour pomegranate (Fig. 4). The surface of sandy sediments dressed in dark brown colored soil whose thickness is about 10 centimeters. After the wide area of primitive Caspian Sea berms, we arrive to the inactive sandy dunes which have extensive vegetative coverage. In the next area, active and semiactive sandy dunes could be seen. Ultimately, the coastal profile leads to a slight sloped beam which has reversed slope towards coastal berm along Caspian Sea shoreline with the coverage of halophytes such as *Xantium* plants.

This kind of biomorphological state exists in whole of western parts of Miankaleh. In fact, the morphological feature assessment of western parts of Miankaleh shows the function of Caspian Sea water level rise excessive phases in the past whose altitude code is changed of –24 m to present –26.5 m.

Coming a large amount of sandy sediments out of sea surface, is the cause of sandy dunes formation. The widthwise expanding of sandy dunes territory is strongly related to the vegetative coverage enlargement. Due to reduction of sandy sedimentary substances, coastal berms deform to marginal wetlands in central parts of Miankaleh coast. Faraway from shoreline, sand spits are formed by coast paralleled flows in west direction to

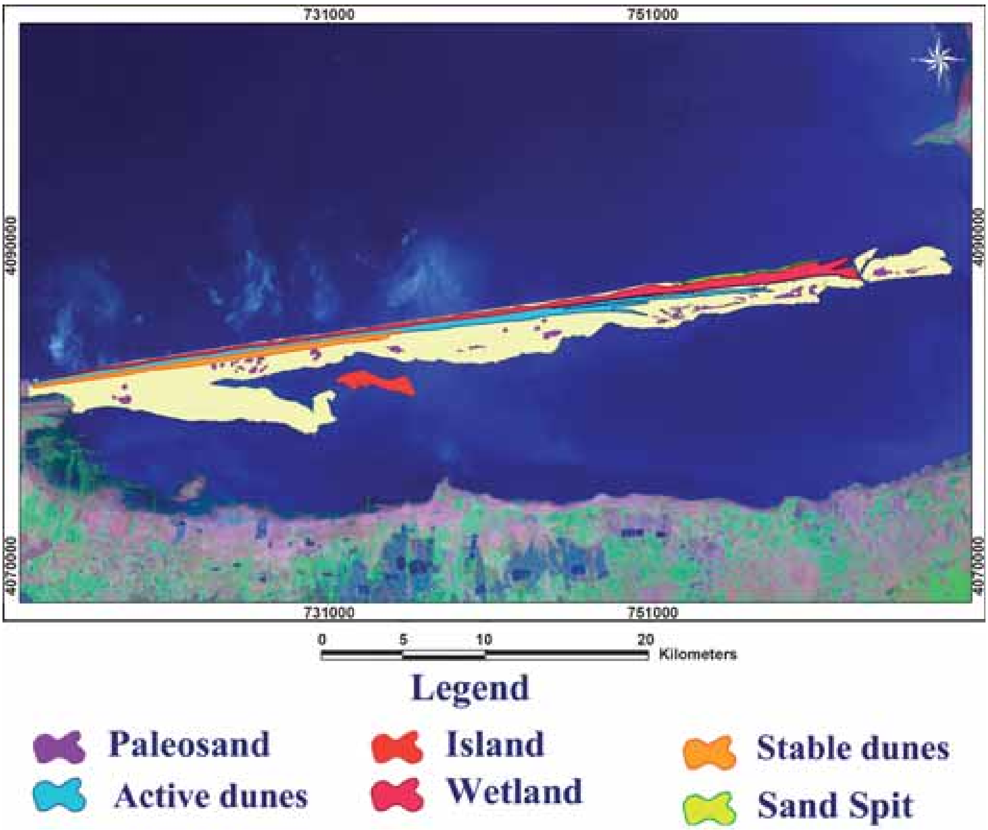

Fig. 4. Morphological subunits of Miankaleh territory

the east (Fig. 5). At the back of these sand spits, strip wetlands have been created with the average depth of 1.5 meters. The accumulation of vegetative coverage and the permeability of coastal lands in this area have been caused the decrease and dispersion of sandy dunes in Caspian Sea primitive coast. On the other hand, marginal basins such as wetland appear strongly in eastern slight sloped parts, while coastal sands have been disappeared. Submergence situation of this part of Miankaleh coast has been so fragile that a vast part of this area has sunk since 1978 when Caspian Sea water level has increased 2.5 meters up to now. Consequently, Khozeiny canal and aquatic

Fig. 5. Sand spit generation in the central part of Miankaleh

connection width between Gorgan bay and Caspian Sea has been developed. One of the morphodynamic features of this area is the creation of erosive bays in south–eastern part of Miankaleh. The penetration of sea brine is the cause of salty land generation in lowland around Gorgan bay. Salty crystals appear in the mentioned salty lands at aridity time. Therefore Miankaleh contains three morphological subunits, including beach, transition zone and lagoon, in direction of west to east. And the flood vulnerability is increasing from west to east. So Ashoradeh peninsula is the most vital region to rapid sea level changing impact.

Comparing of the aerial photos analysis results

The comparing results of aerial photos processing during 40 years (1965–2005) which include two important Caspian Sea water level rise and down phases, prove deformation manner of Miankaleh district related to Caspian rapid Sea level changing. The collected data from limnograph stations show about 3 meters depression in sea water level from 1940 to 1979, whereas; Caspian Sea water level has got a rapid rise about 2.5 meters from 1979 to present. The examination of morphodynamic deformation rate in Miankaleh coast indicates that erosive vulnerability mostly exists close to the eastern regions between Torkaman port and Ashooradeh in the mentioned times. The slight slope of this region helps speed rate of marining and generally morphological features have been changed seriously as connecting canals (Khozeiny) and wetlands widthwise have been developed.

Shoreline morphodynamic deformation rate is more expanded in eastern parts in compare of western parts in as much as the shoreline has moved only 60 meters up to now. In consequence, marining is seen fewer in western parts. In the case of sea level regression, raspberry bush lands and sour pomegranate shrubs are expanded through the berm, however; owing to the water level rise and soil salinization, the mentioned vegetative coverage are destroyed and the bodies can be found under sediments. Meanwhile; it is proven that the most Vulnerability towards sea water level rise seems from the end of eastern to central part of Miankaleh peninsula. Other regions have lesser vulnerability risk.

Anthropogenic impacts on erosive vulnerability

Port constructions, groins building, coastal break water obstacles, coastal guard constructions, land surfacing and sand takings, increase erosive Vulnerability in western parts of Miankaleh close to the multipurpose Amirabad port. Actually Amirabad port (in the end western part) and Ashooradeh peninsula (in the eastern part) are affected more by anthropogenic activities. In addition; erosion phenomena has been seen more in Amirabad free zone in compare of eastern parts of Miankaleh. The rest area of Miankaleh is under protection with no human access and damages. The measurements of geometrical structure in western coast of Miankaleh indicate that quay and coastal break water obstacles induce radically berm deformation and shoreline strike deviations. There is sedimentary accumulation in west of Neka power plant. To the west, the affection of coastal flows causes coastal disruption and erosion of central parts. The main morphodynamic features, which have been obtained from human activities, are known as appearance of vast erosive terraces, developed crescent beach cusps and disappearance of berm and sandy dunes. Dramatically the effect of constructions on coast is reduced by going far from central part. Actually the impact of marine constructions is caused the movement of shoreline about 900 meters exactly in central regions (Fig. 3). Therefore; the western coast of Miankaleh is vulnerable and dangerous in view point of anthropogenic activity expansion. Finally; because of gentle slope in littoral zone which generated by coastal break water obstacles and quay, provide artificial condition of coastal land submergence.

CONCLUSIONS

The morphological subunits and shoreline position of Miankaleh accumulative form have been recognized by comparing and processing of aerial photos related to 2 periods of expanded Caspian Sea level fluctuation(1966–2005). The observational works and surface geology have been done along the eight transects from extremity of western to eastern of mentioned area. Main results show the tendency of flooding vulnerability and shoreline displacement increase at the end of eastern region of Miankaleh near Ashooradeh peninsula where there is an interaction with Caspian rapid sea level changing. In the direction of west, shoreline deformation degree declines gradually. ■

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CASPIAN SEA LEVEL PREDICTION USING ARTIFICIAL NEURAL NETWORK AND EMPIRICAL MODE DECOMPOSITION

ABSTRACT

This paper demonstrates the possibility of using nonlinear modeling for prediction of the Caspian Sea level. Phase space geometry of the of a model can be reconstructed by the embedology methods. Dynamical invariants, such as the Lyapunov exponents, the Kaplan-Yorke dimension, and the prediction horizon were estimated from reconstruction. Fractal and multifractal analyses were carried out for various time intervals of the Caspian Sea level and multifractal spectra were calculated. Then, historical data resolution was improved with the help of fractal approximation. The EMD method was used to reduce noise of the time series. Global nonlinear predictions were made with the help of Artificial Neural Network for combinations of different empirical modes.

KEY WORDS: Caspian Sea level, Fractal Approximation, Multifractal Analysis, Empirical Mode Decomposition, Embedology, Nonlinear prediction

INTRODUCTION

The Caspian Sea is the largest intercontinental reservoir without water outflow which exhibits a unique global evolution over an extremely long interval of time. On geological scale, the history of the Caspian Sea is represented by alternations of transgressive and regressive phases reflected clearly by paleodata, reflected in scanty historical records, and shown by instrumental measurements during recent and a relatively short monitoring period. In Holocene, for example, the fluctuations of the Caspian Sea Level (CSL) were caused by climate changes. It is possible that the CSL was influenced not only by water balance, but also by tectonic changes of the seabed, and that these factors did not necessarily coincide in time [Golitsyn, 1995]. Up to date, the CSL has being raising for already 18 years. By the beginning of 1996 year, the CSL has reached –26,6 meters and the area of the Caspian Sea has increased by 40 000 square kilometers. The rising sea level and strong winds resulted in multiple problems for economic development. Economics of the regions near the Caspian Sea depended on modern sea fluctuations. Modeling the dynamics of a closed reservoir without outflows may appear straightforward on the first sight. However, simple balance models may not adequately describe the situation. Only nonlinear models may be applied to describe a chaotic dynamics of the CSL [Makarenko et al., 2004; Kozhevnikova & Shveikina, 2008]. Thus, in this paper, we applied nonlinear modeling to predict the CSL. This approach was based on reconstruction of phase dynamics from observed time series by means of topological embedding methods. A nonlinear global forecast has been made with the help of Artificial Neural Network (ANN). The CSL time series were constructed by fractal approximation.

EMBEDOLOGY AND NONLINEAR PREDICTION

The nonlinear approach for modeling and prediction of dynamic regimes of sea level can be based on chaotic dynamics [Makarenko, et al., 2004]. According to general assumptions about properties of an unknown dynamic model of sea level we can reconstruct the diffeomorphic copy of its attractor in an n-dimensional space. This technique, called embedology, is widely known [Sauer et al., 1991]. We used it to create the nonlinear scheme of sea level prediction. Embedology methods assume that an observed variable is typical and contains all characteristic elements of dynamics. However, the CSL data have being measured only since 1830 and they do not contain information about global variations of sea level. Thus, one can hope only for a short-term forecast. In fact, the prediction horizon is determined by the maximum positive value of the Lyapunov exponent [Schaw, 1981] according to $T \gg \log_2 N/kl^{+}_{max}$, where N is time series length, k = [1÷3]. Applying the embedding dimension with m = 3, τ = 2, and a number of nearest neighbors of 20, we obtained Lyapunov exponents: l_1^+ = 0.302797, l_2^- = –0.14458, l_3^- = –0.838176 for the instrumental time series. The Kaplan-Yorke dimension is 2.18876 that is close to the embedding dimension. In our case, the length is N = 1955 and the prediction horizon is $T \approx$ 12–36 months [Makarenko, et al., 2004].

The reconstruction of the copy of the attractor into Euclidian space R^m gives possibility to obtain the following predictor [Sauer et al., 1991, Makarenko, 2003]:

$$y((k + l)\Delta t) =$$

$$= F(\mathbf{y}(k), \mathbf{y}(k - \tau), \mathbf{y}(k - 2\tau), ..., \mathbf{y}(k - m\tau)).$$

We used $m = 27$ and $\tau = 37$ to construct delay vectors **y.** Unknown function F-predictor is nonlinear and continuous function of m vectors of the reconstruction. Their best approximation is found by ANN [Poggio & Girosi, 1989; Bishop, 2006]. ANN training was carried out using a set from available values of the CSL data. In the case when a lag of $\tau \neq 1$, one can obtain τ predicted points simultaneously, i.e. can construct a vector prediction. The lower estimate of the embedding dimension $m > 8$ was obtained with the help of the False Nearest Neighbors method. The prediction horizon is limited by the time series length and rate of divergence of close reconstructed trajectories. The prediction horizon of instrumental monthly CSL data was estimated at 12–36 months, as mentioned above.

FRACTAL APPROXIMATION OF THE CSL HISTORICAL DATA

In order to use a nonlinear context and obtain a nonlinear prediction for historical data from 600 BC, we applied fractal approximation [Barnsly, 2000; Karimova et al., 2003; Makarenko et al. 2004]. The latter could enhance the historical data that are poor in accuracy and have low time-resolution (a point per ten years). The usage of historical data in the prediction task is very important, because its accurate instrumental measurements reflect short time variations of the CSL and does not trace its global evolution. The main ideas of fractal approximation is as follows. The interpolation problem deals with a set of input pairs $\{(x_i, y_i)\}_{i=0}^{N}$ where the $0 = x_0 < x_1 < ... < x_N = 1$ are nodes and $y_i = F(x_i) \in R$ ordinates with some continuous function F:[0, 1] $\to R$. As a rule, in the case of smooth data, the input points are interpolated by a single-degree N polynomial, or by piecewise interpolations with a low-degree polynomial. Recent research has provided an alternative assumption that the interpolation function F is self-similar, and typically not smooth, but fractal. We note that a function F:[0, 1] $\to R$ is well defined by its graph, and use the same symbol to denote the set of points in its graph. Hence a point $(x, y) \in F$ if and only if. We also use the notation $F[x_1, x_2]$ to denote the graph of F over the interval $[x_1, x_2]$. Hence a point $(x, y) \in F[x_1, x_2]$ if $(x, y) \in F$ and $x \in [x_1, x_2]$. We construct an *Iterated Function System* (IFS)) [Barnsly, 2000] whose attractor is the graph of a function $F:[0, 1] \to R$. Such a function is called a *Fractal Interpolating Function* (FIF) [Cochran, W.O. et al. 1998]. For $i = 1, 2, ..., N$, let $T_i:[0, 1] \times R \to [0, 1] \times R$ has the form

$$T_i : \begin{bmatrix} t \\ x \end{bmatrix} \propto \begin{bmatrix} a & 0 \\ b_i & c_i \end{bmatrix} \begin{bmatrix} t \\ x \end{bmatrix} + \begin{bmatrix} d_i \\ e_i \end{bmatrix},$$

where $c_i < 1$ is given as a parameter controlling the roughness of the function, and a_i, b_i, d_i and e_i are determined either by the constraints

$$T_i(0, x_0) = (t_{i-1}, x_{i-1}),\ T_i(1, x_N) = (t_{i-1}, x_{i-1}),$$

or the "reflected" constraints

$$T_i(1, x_N) = (t_i, x_i),\ T_i(0, x_N) = (t_i, x_i).$$

Given a metric $d((t_1, x_1), (t_2, x_2)) = |t_1 - t_2| + \frac{(1-A)}{2B}|x_1 - x_2|$, where $A = \max_i|a_i|$ and $B = \max_i|b_i|$, it can be shown that each T_i has contractility $s = \max\{(1 + A)/2, C\}, 1$, where $C = \max_i|c_i|$. Hence, by the fixed point theorem, there exists one and only one function F satisfying the invariance $F = U_i T_i(F)$.

Fractal approximation can be used in the case of prior uncertainty, when available measurements are insufficient for determination of statistical characteristics of the concerned process. And it is the best tool for data approximation when the mean square of process augments depends on correlation interval according to the scaling law, i.e. $E[(x(t+\tau) - x(t))^2] \approx \tau^\gamma$, where γ is the Levy index and inverse value to the Hurst exponent.

In the case of the CSL, it has been shown that such time series satisfy the latter condition and we applied fractal approximation technique. The approximated data were historical decennial CSL time series measured from 600 BC to 2000 AD (261 records). The output of the fractal approximation procedure was the annual CSL time series, 2601 records in length. The time series of the annual CSL was obtained directly from the original historical time series**.**

MULTIFRACTAL CHARACTERISTICS

Multifractal formalism [Halsey et al., 1968; Riedi & Scheuring, 1997; Karimova et al., 2007] has proved to be a very useful technique in the study of both measures functions, deterministic as well as random. Multifractal analysis connects pointwise regularity of the function with a "size" of sets where regularity possesses some value. Function regularity may change abruptly from one point to the next. Pointwise regularity [Karimova et al., 2007] is a positive real number $\alpha(x)$, which describes a certain smoothness of the graph of a function at a point x. In general, let h be a nonnegative real number, $x_0 \in R$, a function $F(x):R \to R$ is $C^h(x_0)$ if there exists $C > 0$, $\delta > 0$ and a polynomial $P(x)$ of the order smaller than h so that if

$$|x - x_0| \le \delta,\ |F(x) - P(x - x_0)| \le C|x - x_0|^h,$$

then the Hölder exponent of F at x_0 is $a(x_0) = \sup\{h{:}FisC^h(x_0)\}$.

Let $E_\alpha = \{x \in R{:}\alpha(x) = \alpha\}$, then the fine (Hausdorff) multifractal spectrum [Riedi & Scheuring, 1997] is $f_H(\alpha) = \dim_H E_\alpha$, where $\dim_H E_\alpha$ is the Hausdorff dimension of the set E_α. Because $\dim_H$ of the set is never greater than its box dimension, one can estimate it by counting the boxes (or intervals) over F, the number of which increases roughly with the "right" Hölder exponent. In applications, however, one considers a *course grained version* f_G which is:

$$f_G(\alpha) = \lim_{\varepsilon\to\infty}\lim_{\delta\to\infty} \sup \frac{\log N_\delta(\alpha, \varepsilon)}{\log(1/\delta)}.$$

Here N_δ denotes the number of cubes of size δ with the coarse Hölder exponent roughly equal to α. Let $\mu(N_\delta)$ be a measure contained in a δ-cube, then $a = \log\mu(N_\delta)/\log\delta$.

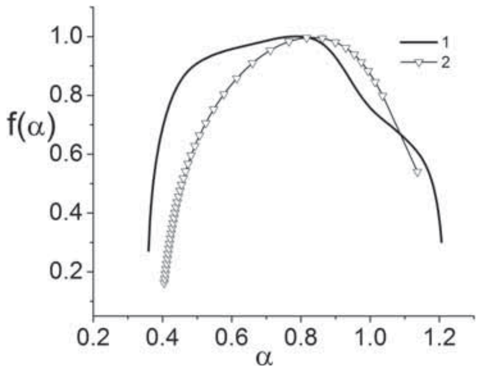

Fig. 1. The large deviation $f_G(\alpha)$ (1) and the Legendre $f_L(\alpha)$ (2) spectra for the fragment of the annual data constructed by fractal approximation using 1500-yr long decennial data

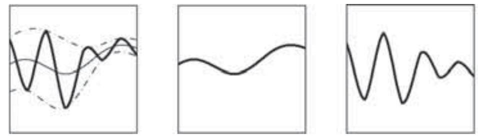

Fig. 2. Decomposition of the signal by means of empirical modes. From [Flandrin et al., 2004]

We computed the large deviation spectrum $f_G(\alpha)$ and the Legendre spectrum $f_L(\alpha)$ using FracLab software (http://fraclab.saclay.inria.fr/). Both Legendre and large deviation spectra of the time series are presented in Fig. 1. The multifractal spectra were computed for the fragment of the annual data constructed by fractal approximation using 1500-yr long decennial data. Fig. 1 shows that these spectra have similar maxima corresponding approximately to the Hölder exponent equal to 0.8.

EMPIRICAL MODE DECOMPOSITION (EMD) FOR THE CSL

The main difficulty for construction of the global nonlinear prediction is an uncertainty associated with monthly instrumental time series. To avoid this difficulty we apply the well known Empirical Mode (EMD) decomposition [Huang et al., 1998] and approximate time series by the sum of smooth empirical modes. According to this method, it is possible to use a coarse-grained approximation of a signal, excluding high-frequency details, without breaking global structure of the signal (Fig. 2).

Thus, the method of decomposition of a signal by means of empirical modes [Huang et al., 1998; Flandrin et al., 2003] represents the signal as a set of functions corresponding to various oscillations in observed signal. A basic operation in EMD is the estimation of the upper and lower "envelopes" as interpolated curves between extremes. The nature of the chosen interpolation plays an important role, and our experiments tend to confirm (and are in agreement with) what is recommended in [Huang et al., 1998], specifically, that cubic splines are to be preferred. Other types of interpolation (linear or polynomial) tend to increase the required number of sifting iterations and to "over-decompose" signals by spreading out their components over adjacent modes.

Given a signal $x(t)$, the effective algorithm of EMD can be summarized as follows [Flandrin, et al., 2004]:

1. identify all extremes e_{min}, e_{max} of signal $x(t)$.

2. interpolate between minima and maxima, ending up with some envelope $e_{min}(t)$, $e_{max}(t)$.

3. compute the mean $m(t) = (\boldsymbol{e}_{min} + \boldsymbol{e}_{max})/2$.

4. extract the detail $d(t) = x(t) - m(t)$.

5. iterate on the residual $m(t)$.

In practice, the above procedure has to be refined by a *sifting* process which amounts to first iterating steps 1 to 4 upon the detail signal $d(t)$, until this latter can be considered as zero-mean according to some stopping criterion. Once this is achieved, the detail is referred to as an *Intrinsic Mode Function* (IMF), the corresponding residual is computed and step 5 is applied. By construction, the number of extremes is decreased when going from one residual to the next, and the whole decomposition is guaranteed to be completed with a finite number of modes. For calculation of empirical components software batch http://perso.ens-lyon.fr/patrick.flandrin/emd.html was applied.

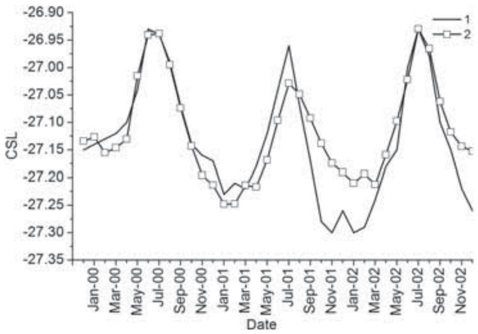

Fig. 3. The CSL real monthly data (1) and the prediction (2)

NUMERICAL RESULTS

During the experiment, the monthly data from January 1837 to December of 2002 were used. From 8 constructed empirical modes, the sum of modes 2, 4, 5, 6, 7, and 8 were taken, for which the correlation coefficient with the original data was 99,8%. For selected delay interval $\tau = 37$, the prediction interval was 37 months: December 1999 – December 2003.

All predictions of the CSL time series were carried out by ANN, namely *Statistica Neural Network v4.0E*. Fig. 3 demonstrates real CSL month data (1) and the prediction (2). Fig. 4 shows the CSL real monthly data, the sum of 2, 4, 5, 6, 7, and 8 modes of EMD decomposition and the mean values of three predictions made with the help of EMD. Deviation of predicted values from the real data did not exceed 1%.

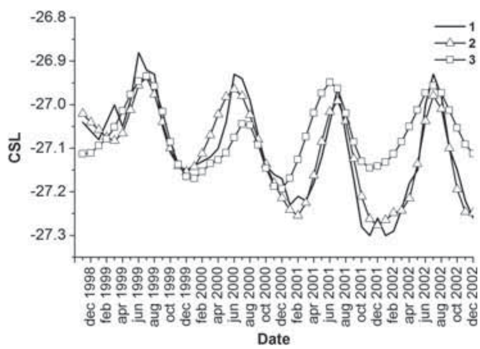

Fig. 4. Comparison of the real CSL monthly data (1), the sum of 2, 4, 5, 6, 7, and 8 modes of EMD decomposition (2) and the mean value of three predictions based on EMD decomposition (3)

CONCLUSION

We have discussed the method of the CSLs predictions based on the reconstruction of a dynamical system with the help of embedding time series in Euclidian space of an appropriate dimension. This approach makes it possible to construct vector prediction, i.e. to forecast a consecutive set at the same time. Therefore, one can avoid an exponential increase of errors inherent in a step-by-step prediction. The prediction is realized by means of the ANNs, that are optimal approximating tool for an unknown continuous and multivariable function, i.e. a nonlinear predictor.

The ANN is trained by transforming input examples into the outputs as the known answer of the training set constructed by the known records from the past. To use the decennial historical data together with the annual instrumental data, we constructed fractal approximation of the decennial data that allowed increasing the time series. The necessary property of statistical scale invariance was verified by multifractal spectra. Additional improvement of the data was implemented with the help of EMD technique that allowed delicate noise filtration without disturbance of correlation of the time series. The global nonlinear predictions were made with the help of ANN for combinations of different empirical modes.

Our experiments based on the approaches mentioned above have shown possibility to forecast the CSLs at 1–3 yrs intervals, which is extremely useful in practice. It is necessary to point out that a nonlinear prediction represents an ill-posed problem as it produces a great number of possible variants. Selection of the most probable variant from a set of predictions remains an open challenge.

ACKNOWLEDGEMENTS

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DISTRIBUTION OF HYDROCARBONS IN PARTICULATE MATTER AND BOTTOM SEDIMENTS OF THE VOLGA DELTA

ABSTRACT

Data are presented on the content and composition of hydrocarbons (aliphatic and polyaromatic) in the filtered particulate matter and in the surface layer of the bottom sediments of the Volga River and the northern shelf of the Caspian Sea. Because of transformation and precipitation of anthropogenic and natural compounds, the HC composition in particulate matter and bottom sediments undergoes changes caused by precipitation of particulate matter, varying temperatures, and mixing of fresh and saline waters. It appeared that the greatest accumulation of the HC proceeds in the region of avalanche sedimentation, and their content is independent of the grain-size type of the sediments. The anthropogenic HC (oil and pyrogenous) do not pass the marginal filter of the Volga River and do not enter the open part of the sea.

KEY WORDS: geochemical barrier, marginal filters, oil, hydrocarbons, aliphatic hydrocarbons, alkane, polycyclic aromatic hydrocarbons, suspended particulate matter, bottom sediments

INTRODUCTION

The Caspian Sea is one of the richest oil-and-gas bearing regions with the hydrocarbon potential estimated at 16–32 billion barrels [Efimov, 2000]. Here, natural oil seepage can occur, as well as the entry of oil hydrocarbons (HC) with pollutants as a result of intense oil extraction and transportation of hydrocarbon fuel [Dumont, 1998]. The main pollution sources for the northern part of the Caspian Sea are the coastal oil production, navigation, and the Volga River runoff [Dumont, 1998; Tolosa et al, 2004]. The northern part of the Caspian Sea containing a little more than 1% of the water of the sea (because of the shallowness) receives about 90% of the total riverine runoff, and 80% of the biogenic organic matter (OM) is supplied by the Volga River runoff alone [Shiganova et al, 2003]. In the transformed Volga waters supplied from the avandelta, the content of dissolved C_{org} varies from 500 to 667 μM [Agatova et al, 2005].

According to the model proposed by Academician A.P. Lisitsyn, the area of riverine and marine water mixing (marginal filter [Lisitsyn, 1995]) consists of three basic zones with specific functions: gravitational, physicochemical, and biological. In the gravitational zone, because of the damming of riverine water by marine water, sedimentation of sand–silty fractions occurs; this area has high water turbidity and hindered photosynthesis. In the physicochemical zone, colloids and dissolved compounds are captured (the zone of flocculation and coagulation). After sedimentation of various compounds and water clearing, phytoplankton develops and the biological zone emerges (assimilation and transformation of dissolved substances of mineral and organic composition). The studies performed earlier in the coastal waters of the Caspian Sea showed that the sandy bottom sediments (2003, Fig. 1) had rather low concentrations of organic compounds and contained from 0.031 to 0.59% C_{org} and from 19.8 to 142.1 μg/g of

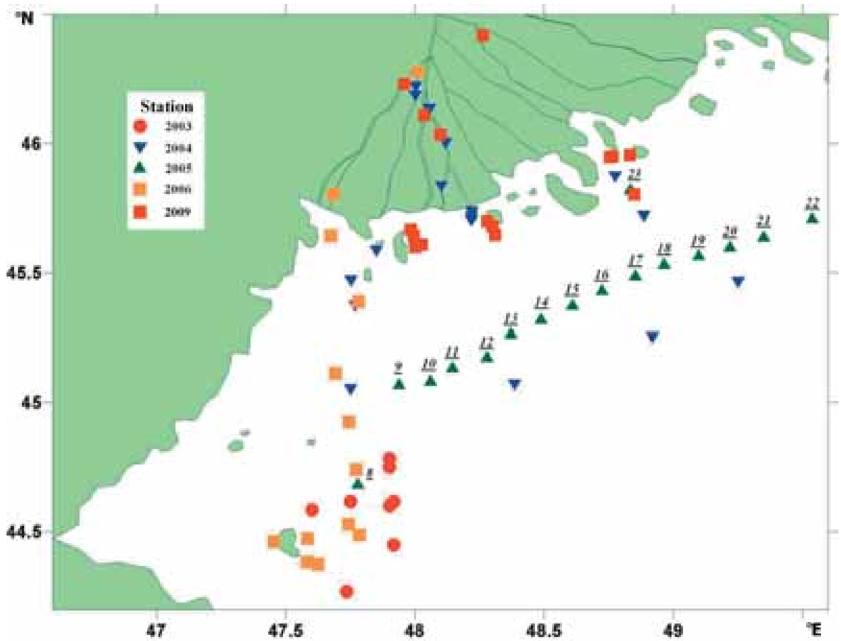

Fig. 1. The sampling scheme of the northern shelf of the Caspian Sea (2003–2009 – bottom sediments; 2006 – filtered particulate matter).

8–22 – station nos. where the bottom sediments were sampled in 2005

aliphatic hydrocarbons (AHC) [Nemirovskaya and Brekhovskikh, 2008]. A weak statistical correlation between the distribution of C_{org} and AHC (r = 0.14) indicated different origins of these compounds. On the contrary, the sediments sampled in 2004 in the channels of the Volga River (the gravitation part of the marginal filter) had high concentrations of both C_{org} (up to 8.6%) and AHC (up to 3881µg/g). The AHC fraction in the Volga River channels was, in several cases, as high as 16.8–23.9% of C_{org}, which was considerably higher than that in other aquatic areas with a permanent oil supply [Nemirovskaya, 2004; Tolosa et al, 2004].

In 2005, 2006, and 2009, the studies of the northern shelf of the Caspian Sea were continued and samples of particulate matter and bottom sediments were collected. In 2009, the studies of the Volga River (from Konakovo to channels of the Delta Volga) took place. These studies were aimed at identification of the genesis of AHC and polycyclic aromatic HC (PAH) and their transformation in the Volga Delta (Fig. 1).

Because of their hydrophobic properties, HC are easily sorbed by particulate matter and, during the sedimentation, fall to bottom sediments, which accumulate these compounds. Therefore, the processes of OM transfer and transformation may be identified through comparison of molecular tracers within the HC composition in particulate matter and bottom sediments [Nemirovskaya, 2004; Tolosa et al, 2004; Winkels et al, 1998]. Moreover, the HC of aquatic particulate matter is a necessary part of the biogeochemical carbon cycle, because particulate matter represents a transit form of OM on the path from photosynthesis sources to bottom sediments (i.e., the transporting form) [Shiganova et al, 2003].

METHODS

Particulate matter was concentrated on fiberglass filters GF/F. Bottom sediments (oxidized surface and reduced subsurface layers) were collected by an “Ocean” grab.

The procedure of HC extraction and concentration from water, particulate matter, and bottom sediments was strictly standardized. HC were extracted with dichloromethane directly after sampling. Sodium sulfate was added for dehydration during the HC extraction from particulate matter and bottom sediments [Nemirovskaya, 2004].

The extract after dichloromethane removal was dissolved in CCl4, and the bulk extractable fraction (lipids) was determined by IR spectrophotometry at 2930 cm-1 band using a Shimadzu IRAffinity-1 spectrometer. The HC fraction was separated on silica gel using column chromatography. The AHC concentrations were also determined using IR spectrophotometry. A mixture of isooctane, hexadecane, and benzene (37.5, 37.5, and 25 vol. %, respectively) was used as a standard. The alkane concentrations and composition were determined by capillary gas chromatography with an Intersmat GC 121-2 chromatograph (France) using squalane as a standard.

The polycyclic aromatic hydrocarbon (PAH) concentrations and composition were determined by high performance liquid chromatography using a Milikhrom (AcoNova, Novosibirsk, Russia); Nucleosil 100-5C18PAH column; the elutriation media was a mixture of acetonitrile with water (in a 75 : 25 volume proportion). Measurements were performed at 254 nm using a standard of a mixture of individual polyarenes received from a laboratory of the US Environmental Protection Agency. The following unsubstituted polyarenes were identified: naphthalene (NA), phenanthrene (PH), fluoranthene (FL), pyrene (P), chrysene (CHR), perylene (PL), benzo(a)pyrene (BP), anthracene (AN), and triphenylene (TRF) .

RESULTS

The contents of organic compounds in particulate matter varied within the following ranges: 0.18–5.77 mg/l of C_{org}, 130–710 μg/l l of lipids, 90–500 μg/l of AHC and 20–108.6 ng/l of PAH in 2006; and 0.006–0.114 mg/l of C_{org} and 6.2–39.2 μg/l of AHC in 2009. In 2006, the highest concentrations in the coastal waters of the Caspian Sea were found near Tyulenii Island with the maximum at a station where ground dumping takes place because of the navigable canal dredging. In 2003, at a station in the same area [Nemirovskaya and Brekhovskikh, 2008], the AHC content in the bottom sediments was as low as 55.5 μg/g, their fraction within the OM composition was as high as 39.4%, which is usually observed in near-harbor aquatic areas. In the most recent samples of marine bottom sediments from unpolluted areas, the AHC content is only tenths or even hundredth parts of C_{org} [Nemirovskaya, 2004].

Increased AHC concentrations in particulate matter were also registered at a station near the exit from the navigable canal and at a station in the Bakhtemir channel: AHC was 140 μg/l on average with the standard deviation (σ) of 20 μg/l. In the area of riverine and marine water mixing, the content of dissolved and particulate forms of various compounds is controlled by salinity (S) [Lisitsyn, 1995]. At S = 0.2‰, their concentrations grow, which is caused by sorption of emulsified, mainly anthropogenic components, on fine particulate matter (1–10 μm) [Nemirovskaya, 2004]. This is promoted by the presence of large amounts of particulate matter, humic and fulvic acids, iron, and bacteria in the freshwater part of the marginal filter [Lisitsyn, 1995]. At S >0.2‰, due to the loss of aggregative stability of the particles, particulate matter precipitates causing a decrease in the AHC concentrations. Later, at S = 4.6–5.4‰ in the "ooze plug," the AHC concentrations increase again. With the distance from the zones of increased AHC concentrations in the direction of the main water flow, their concentrations varied insignificantly, which may be caused by the small depths and by the supply from the bottom sediments during formation of the nepheloid layer [Kravchishina, 2009; Lisitsyn, 1995]. In the coastal waters of the Caspian Sea, the lipids of particulate matter consist mainly of AHC and a strict correlation between the contents of these compounds was observed: r(lipids–AHC) = 0.93. Their fraction within the lipid composition was 74.7% on average (in oil-polluted areas, the fraction of AHC is usually increased [Nemirovskaya, 2004]). On the contrary, in the composition of C_{org}, lipids were not the prevailing fraction. In most of the samples, their fraction was 25% or below (21.4% on average); the fraction of AHC was 23.4% or below (16.5% on average). The exceptions were found at stations in the Bakhtemir channel, where the fractions of lipids and AHC increased to 65.3 and 48.3%, respectively, which may indirectly point to the presence of oil HC. AHC of particulate matter were characterized by a uniform distribution of alkanes, because the ratio of odd to even homologues (CPI, or the carbon preference index in the high-molecular range) in most of the samples varied within 1.0–1.3, which is characteristic of HC of oil and phytoplankton [Kennicutt and Jeffrey, 1988]. At the stations near Tyulenii Island, the composition of the alkanes is the closest to that of the biogenic substance and shows a bimodal distribution of the homologues (Fig. 2). In the low-molecular range, the maximum is associated with n-C17–C18 (autochthonous alkanes of phytoplankton), while in the high-molecular range the maximum is confined to the n-C25–C27 odd homologues (CPI = = 1.2). High-molecular alkanes prevail: the ratio Σ(C12 +C22)/Σ(C23 + C37) = 0.39. The content of n-alkanes is higher than that of iso-compounds: the ratios i-C19/n-C17 = 0.53, i-C20/n-C18 = 0.33, and i-C19/i-C20 = 1.7 (prystane/phytane), which is characteristic of autochthonous compounds [Bouloubassi and Saliot, 1993; Kennicutt and Jeffrey, 1988]. The cogged shape of the hump and the presence of the series of iso-compounds are characteristic of biotransformed residues of light oil products [Nemirovskaya, 2004].

In 2006, the content of total PAH (43.7 ng/l on average) was higher than that in open seawaters (20 ng/l) [Nemirovskaya, 2004]. In harbor areas and coastal zones, the concentrations of polyarenes is usually increased. For example, in the Gulf of Riga, the average PAH concentrations in filtered particulate matter were 56 ng/l in the surface and 73 ng/l in the near-bottom waters; the concentration was 70 ng/l in the surface waters of the Sakhalin shelf [Nemirovskaya, 2004]. The variations of the PAH concentrations generally follow the distribution of lipids and AHC, which may point either to the same sources of their formation or to a high degree of transformation of different HC classes.

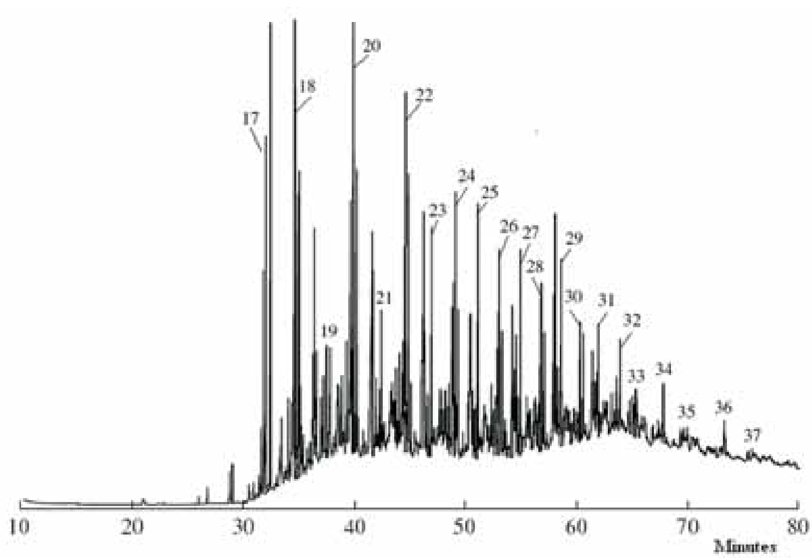

Fig. 2. Chromatogram of the alkanes in an integrated sample of particulate matter from the aquatic area near Tyulenii Island

It is believed that AHC are supplied to the marine environment through their synthesis by phytoplankton, or by oil pollution, and PAH are formed either in pyrolytic processes or under abiogenous natural synthesis [Rovinskii, 1988; Tolosa et al, 2004]. In late summer, with the increase in the air and water temperatures, decomposition of most unstable hydrocarbons takes place [Rovinskii, 1988]. Therefore, the amount and composition of HC depend not only on the sources of their formation but also on their stability in the marine environment. Because of this, the content of prevailing PAH in particulate matter in the area studied decrease in general as the sequence (in %): Ph (34.4) > Fl (20.1) > N (10.8) > BaAn (9.6) > Py (9.4) > An (7.5) >Chr (6.5) > Bp (1.5) > Pl (1.1). We assume that a selective transformation of light polyarenes from dissolved forms into particulate matter by sorption and sedimentation, or by bioaccumulation and biosedimentation takes place [Lipiatou et al, 1993]. The low values of the Fl/(Fl + Py) ratio at stations 9 and 12 (respectively, 0.33 and 0.43) may point to the influence of pyrogenous sources (with the supply of newly-formed combustion products, the value of the Fl/(Fl + Py) ratio is below 0.5) [Tolosa et al, 2004].

The bottom sediments of the coastal waters of the northern part of the Caspian Sea studied in 2005 are mainly presented by sandy sediments containing shells and algae, with a relatively low C_{org} content (0.197–0.582%). The exception is the silty–clayey sediment from station 5, in which C_{org} concentrations increased to 1.199%. The distribution of organic compounds depends, to a great extent, on the degree of sediment dispersion. When passing from sands to silts, the C_{org} value usually increases [Nemirovskaya, 2004]. There was a correlation between sediment dispersion and C_{org} in the area studied: r(C_{org}–moisture) = 0.92 (in 2005), r(C_{org}–moisture) = 0.96 (in 2009). The sediments moisture is determined mainly by their grain-size type. According to our data of 2004, for the surface layer of the sediments from the coastal waters of the Volga River mouth area, r(C_{org}–moisture) = 0.96 [Nemirovskaya and Brekhovskikh, 2008].

The distribution of HC, in most cases, is also determined by the grain-size type of sediments (Fig. 3). Silty sediments (especially when the fraction <0.1 mm prevails) easily absorb organic compounds, including the pollutants from the water mass containing particulate matter. Kaolin and illite have the maximum sorption capability for oil products. Nevertheless, in the area studied, the AHC concentrations in coarse-grained sediments appeared to be higher than those in a fine-grained substance. Their values varied widely both with respect to dry sediment and to the OM composition: 70–4557 μg/g, 3.55–62.5% of C_{org}, in 2005 and 2.0-101.4 μg/g, 03-33.8% of C_{org}, in 2009 (Table 1). In the sediments from the Volga River channels in 2004, in one case, the AHC fraction comprised 24% of C_{org} [Nemirovskaya and Brekhovskikh, 2008]. Only in the sediments of the mouth area of the Severnaya Dvina River, during the spring flood and near oil storages, the fraction of AHC reached 74.5% of C_{org} with the AHC content of 544 μg/g. In marine bottom sediments, the AHC fraction is usually 1% or below, with even lower average values in biological objects. In the planktonic C_{org} and in phytobenthos it is respectively 0.14% and 0.048% decreasing in higher terrestrial plants (tree foliage) to 0.01% [Nemirovskaya, 2004]. The high AHC content in the C_{org} composition of the bottom sediments from the northern shelf of the Caspian Sea and the Volga River may also indicate the impact of oil HC.

In 2005, the maximum of the AHC concentrations was found in the sediments from station 19 (see Fig. 1). In the same area, at the closely located stations 18 and 19, a C_{org} content change by a factor of 1.5 corresponded to a change in the AHC content by a factor of 26.6, which was probably caused by the local supply of oil HC to the bottom sediments. Therefore, only a weak correlation between the distribution of C_{org} and AHC was observed (r = 0.26, n = 16).

The content of alkanes and naphthenic compounds (unresolved complex mixture – UCM) was also maximal at station 19: 194.7

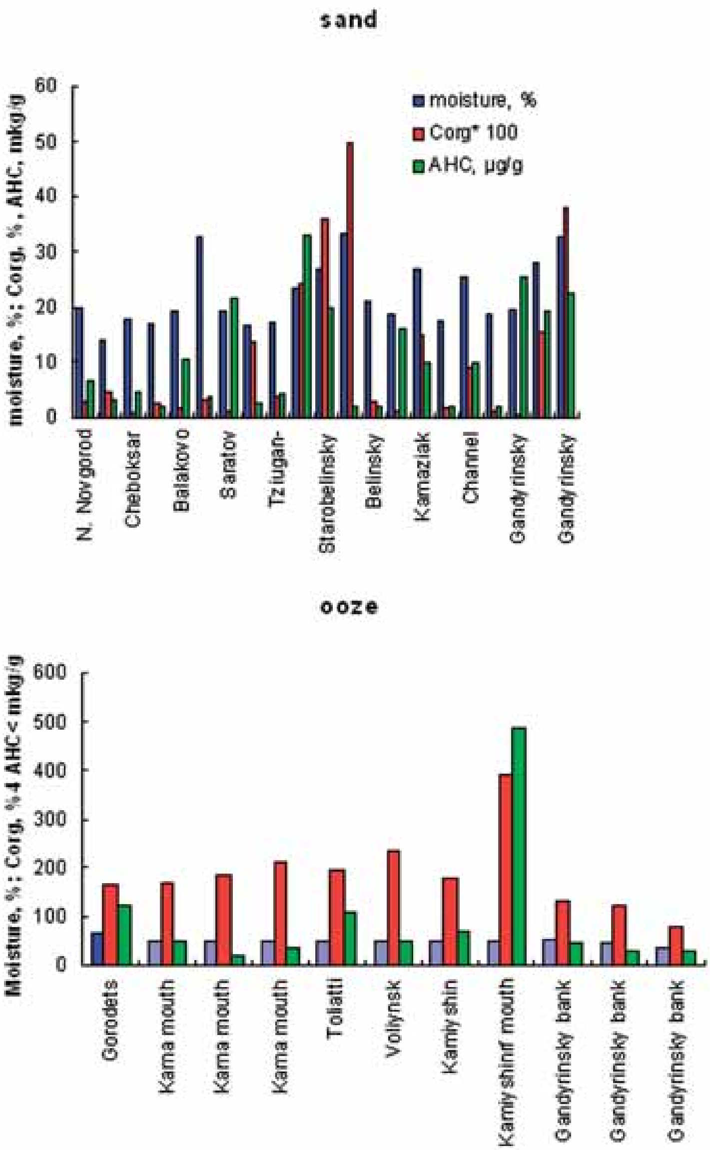

Fig. 3. The distribution of moisture content, C_{org}, and AHC in different grain-size types of sediments in 2009

and 8597 µg/g, respectively, with a maximum naphthene/n-alkane ratio of 44.2, which is characteristic of the HC transformation in the marine environment (for transformed oil alkanes, this ratio is >10 [Tolosa et al, 2004]). Near Baku, at the total n-alkane concentrations in the sediments within 15–17 µg/g, the content of the naphthene–aromatic hump was as high as 1300–1500 µg/g. The values of the ratios of light to heavy homologues in the bottom sediments of this area were quite low (within 0.19–0.69), which also confirms the degree of n-alkane transformation.

According to the distribution of homologues, n-alkanes in the sediments of station 19, as well as in those at stations 17 and 23, were of a mixed origin (Fig. 4). The markers in their composition pointed to the prevalence of biogenic HC: the CPI values varied within

Table 1. Content of C_{org}, AHC and PAH in the surface layer of bottom sediments

Station	Location	Sediment type	C_{org}, %	Moisture,%	AHC,µg/g	AHC, % of C_{org}	PAH, ng/g
1	Gorodez	Gray silt	1.660	65.92	121.4	0.59	32
2	Above N.Novgorod	Sand	0.029	19.95	6.7	1.85	undefined.
3	Oka River mouth	Sand	0.048	14.0	3.0	0.50	"
4	Below Cheboksary	Sand	0.009		4.9	4.36	"
5	Kama River mouth	Gray silt	1.690	50.9	46.8	0.28	33
6	Kama River mouth	Gray silt	1.856	47.7	18.6	0.10	35
7	Confluence of Kama and Volga	Gray silt	2.133	47.29	34.9	0.16	33
8	Tolyatty outer harbour	Gray silt	1.937	46.12	107.4	0.55	145
9	Below Syzran	Sand with shells	2.46	51.18	50.9	0.22	undefined
10	Volynsk outer harbour	Oxidized silt	1.789	49.5	71.3	0.40	"
11	Above Balakovo	Brown fine sand	0.016	19.29	10.6	5.30	16
12	B.Irgiz	Brown fine sand	0.031	32.83	4.02	1.03	26
13	Above Saratov	Brown fine sand	0.012	19.33	21.7	14.47	57
14	Kamishin	Gray silt	1.789	49.5	71.3	0.40	85
15	Confluence of Kamishinka and Volga	Gray silt	3.899	50.24	485.4	1.24	178
16	Below Volgograd	Sand with pebble	0.136	16.55	2.40	0.14	13
17	Zagan-Aman village	Sand with black inclusions	0.036	17.43	4.50	1.00	21
3У	Akhtuba channel	Silty sand with shells	0.245	23.2	33.1	1.08	12
7У	Starobelinsky channel	Silty sand	0.359	27.0	20.2	0.44	2
6У	Joltaya stream (3 km from Starobelinsky channel)	Black ooze	0.499	33.5	2.0	0.03	undefined
9У	Belinsky channel (to the left from waterway)	Dark silty sand	0.029	20.9	2.0	0.55	"
11У	Kamyziak channel (Tabola)	Fine light sand with shell fragments	0.012	18.7	16.1	10.71	"
12У	Kamyziak channel (Verkhnekalinoovsky village)	Sandy silt with clay	0.15	26.8	9.8	0.52	"
14У	Ryty channel	Fine clean sand	0.018	17.8	2.0	0.89	"
15У	3 km above station 14	Dark silty sand	0.091	25.6	9.7	0.85	"
16У	Staraya Volga channel	Fine clean sand	0.011	18.9	2.1	1.45	"
19У	Gandurinsky channel	Clay with fine sand	0.006	19.7	25.3	33.81	"
20У	To the right from station 19 (in macrophyte thicket)	Sand	0.155	28.1	19.0	1.00	29
21У	The same (in open water)	Muddy sand	1.348	54.5	43.0	0.26	24
22У	To the left from station 19 (in a bay)	Muddy sand	1.192	44.1	28.1	0.19	252
23У	The same (in the stream)	Sand	0.38	32.7	23.0	0.47	120
24У	7 km below station 19 (in the channel)	Dark clay	0.807	35.4	29.2	0.29	24

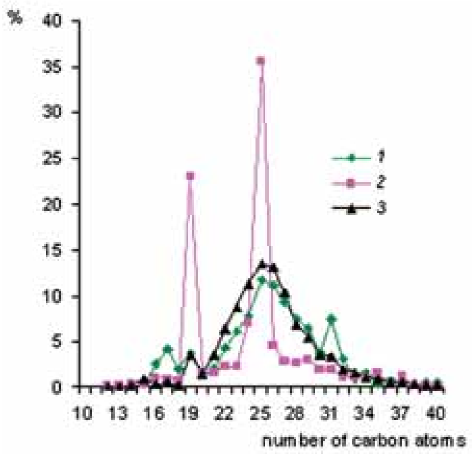

Fig. 4. Composition of the alkanes separated from the bottom sediments in 2005 at stations:

1—18, 2—19, and 3—8 (stations' positions at Fig. 1)

3.05–6.97, and prystane prevailed over phytane (i-C19/i-C20 > 1). Moreover, the maxima at n-C19 and n-C25 may indicate the influence of auto- and allochthonous processes on their composition. In several cases, the maxima were observed in the range of the n-C29–C31 odd alkanes, which is usually related to the contribution of waxes of higher plants [Bouloubassi and Saliot, 1993; Sokolova, Grichyk, 2006]. On shoals, within sandy sediments, oil HC precipitate together with terrigenous substances.

According to the markers, the closest to oil HC were the n-alkanes of the bottom sediments from stations 8, 11, 13, 14, and 18, where CPI ≈ 1 and the naphthene/alkane ratio varied within 10–35.2. Being unresolved by gas chromatography, the UCM is caused by the permanent oil supply in the high-molecular range, and by the transformation natural terrigenous compounds in the low-molecular range [Bouloubassi and Saliot, 1993].

In 2009, in spite of lower concentrations, the composition n-alkane also points to oil origin of AHC (Fig. 5).

In 2005, the dispersion of the PAH concentrations in the bottom sediments was so wide (4–4800 ng/g, see Table. 3) that the average value (948.6 ng/g) was comparable to the standard deviation (σ – 951.2 ng/g). The distribution of PAH, as well as that of AHC, was independent of the grain-size type of sediment, and the maximal values were also found in the sandy sediment of station 19. The content of Bp (the most carcinogenic among the polyarenes identified) at this station was as high as 382 ng/g (12.2% of ΣPAH). The pyrogenous composition of polyarenes in the sediments of this station confirmed the minimal value of Fl/(Fl + Py) ratio, equal to 0.36. At the same time, the (Py + Bp)/(Ph + + Chr) ratio was maximal at station 8, which may point to a high degree of the Tyulenii

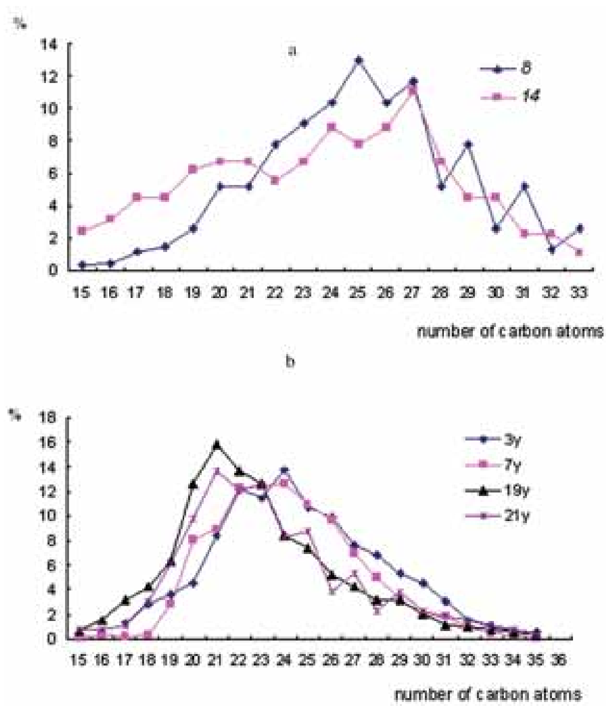

Fig. 5. Composition of the alkanes separated from the bottom sediments in 2009:

station 8 - Tolyatty outer harbor; station 14 – Kamishin; station 3y – Akhtuba channel; station 7y – Starobelinsky channel; station 19y – Gandurinsky channel; and station 21y – Gandurinsky channel (in open water)

Island area pollution with the products of pyrolysis of organic raw materials. The effect of pyrogenous polyarenes was also traced in other areas of the northern part of the Caspian Sea, because (Py + Bp)/(Ph + Chr) ratio in the bottom sediments was over 1 (2.2 on average).

The rather high concentrations of naphthalene characteristic of fresh oil products [AMAP, 2007; Rovinskii et al, 1988] appeared to be unexpected in the sediments of the area studied, because this volatile arene is easily decomposable in the course of natural processes. Its accumulation was noted earlier in the bottom sediments from the shoals of the Apsheron Peninsula and related to oil origin of the polyarenes [Tolosa et al., 2004]. Under the intense transformation in diagenetic processes and with the supply of great amounts of fresh oil compounds, the Ph/An ratio is usually over 10 [Tolosa et al, 2004]. In most of the samples, this value is below 10. Only at station 22, which is the farthest from the main navigable waterways, the Ph/An ratio was as high as 21.7, which may indicate the high degree of transformation of polyarenes in the bottom sediments of this area. According to the markers, the supply of pyrogenous and oil polyarenes to the bottom sediments occurs in the same areas, and a significant correlation between these parameters was observed ($r = 0.61$, $n = 16$). Perylene does not belong to the prevailing polyarenes, despite the fact that significant amounts of it are usually present in the sediments enriched with terrigenous plant matter [Nemirovskaya, 2004; Bouloubassi and Saliot, 1993; Lipiatou et al, 1993; Oros and Ross, 2004]. With the diagenetic origin, the fraction of perylene is over 10% of the total PAH [Tolosa et al, 2004]. In the sediments studied, its content was 6.3% on average. The supply of pyrogenous polyarenes decreases the share of perylene; therefore, the maximal value of the Py/Pl ratio was found in the sediments of station 20 (8.1 at an average of 3.1), which may be related to their supply due to fuel combustion in the navigable areas. At the river–sea boundary (marginal filters [Lisitsyn, 1995]), the principal changes take place in the contents and compositions of the substances supplied by the rivers. Here, in a very narrow zone, the flux of riverine matter decreases by a factor of 10. The AHC sedimentation may reach 80% from their amounts supplied by the rivers [Nemirovskaya, 2004]. In the area of the northern part of the Caspian Sea studied, the effect of the Volga River is expressed in the spread of the flows from the eastern and western channels of the delta, with the latter being more powerful [Shiganova et al, 2003]. This probably resulted in relatively high contents of organic compounds in particulate matter samples collected from the western part of the sea studied. Evidently, intensification of navigation in harbor areas promotes the increase in the HC concentrations in particulate matter.

In riverine waters, particulate OM is usually of a terrigenous nature [Kravchishina, 2009]. In the northern part of the Caspian Sea, the terrigenous OM represented by anthropogenic compounds causes not only an increase in the HC concentrations in particulate matter but also changes in their composition. Oil alkanes become degraded through physical and biochemical processes, especially fast in the surface waters [AMAP, 2007; Nemirovskaya, 2004]. In filtered particulate matter, the autochthonous AHC rarely prevail; mostly, this is a highmolecular anthropogenic group with some components of marine origin [Kennicutt and Jeffrey, 1981], because the content (by mass) of the clayey fraction is negligible [Kravchishina, 2009]. Therefore, in all the samples of particulate matter, high-molecular homologues characteristic of the coastal macrophytes and grassy plants prevail (see Fig. 2). These HC show great capability for hydrophobic binding at the water–particulate matter interface as compared to low-molecular compounds. Only as all the fractions of particulate matter (including fine silt) are precipitated, at the final step of sedimentation, the supply of oil AHC to the bottom may be registered.

In contrast to AHC, in the PAH composition, the light homologues – PH and NA prevail in the composition of PAH of particulate matter. PH is formed in soils from buried biomass [Rovinskii et al, 1988; Venkatesan and Kaplan, 1987] and a high content of it in particulate matter as well as the AHC composition confirm the land origin of aeolic matter. NA and its homologues belong to the arenes prevailing in oil products. The high concentrations of FL may be caused both by anthropogenic impact and by the transformation of the PAH composition during a distant air transfer [Nemirovskaya, 2004], because FL features high stability [Rovinskii et al, 1988]. Hence, the PAH composition in particulate matter is of mixed origin.

The HC content in the bottom sediments appeared to be the highest over the entire time of the studies performed on the northern shelf of the Caspian Sea (see Table 2). Evidently, the area studied in 2005 is associated with the avalanche sedimentation zone, which includes the physicochemical part of the marginal filter [Lisitsyn, 1995]. Here, during the processes of flocculation and coagulation, the bulk of HC is precipitated. Because of this, there is no correlation between the HC distribution and the grain-size composition of the sediments, as well as between HC and C_{org}, which is usually observed in the bottom sediments, even in the areas subject to oil pollution. Thus, a correlation was found between the OM and PAH concentrations in the coastal sediments of Marsalla Lagoon (Italy), although the authors considered the pyrolytical processes to be the main source of PAH [Culotta et al, 2006]. In the mouth of the Severnaya Dvina River, during the spring flood, the composition of n-alkanes conformed to weathered oil HC; at the same time a correlation between C_{org} and AHC was observed (r = 0.72).

In 2005, the content of AHC at stations 10, 17, 19 (1940–4558 µg/g) in coarse-grained sediments was comparable to the concentrations registered in the most polluted harbor aquatic areas [Nemirovskaya, 2004; Nemirovskaya et al, 2007; Tolosa et al, 2004]. The average value of 895.9 µg/g exceeded the background level in silt sediments (50 µg/g). Even at the AHC concentrations of 100 µg/g, the silt sediments are said to be polluted [Tolosa et al, 2004]. In sandy sediments of the Gulf of Riga, the AHC background level was 20 µg/g or below, and only in the sandy– silt matter of harbor aquatic areas did their content increase to 108 µg/g [Nemirovskaya et al, 2007].

In 2005, the composition of AHC in the bottom sediments was of a mixed genesis. Probably, there is a limit to the degree of anthropogenic AHC accumulation. This is true for oil products mainly consisting of HC. Hydrophobic binding of high-molecular alkanes is characteristic, to various degrees, of different fractions of particulate matter, and the bulk of anthropogenic compounds precipitate in the shallow-water zone. In 2009, in spite of lower concentrations, the composition of n-alkane also points to oil origin AHC (Fig. 5).

Moreover, the accumulation of anthropogenic AHC together with terrigenous matter may be explained by poor sorting of the sandy–silt matter in the mouth area of the Volga River. At increased concentrations of anthropogenic AHC in water, even due to passive sorption, their content in sandy sediments may increase [Nemirovskaya, 2004]. Therefore, the degree of anthropogenic pollution of coarse-grained sediments appeared to be higher than that for silt substances. The maximal value of CPI = 6.97, i.e., the maximal value of terrigenous HC, was found in the sediments at station 23 which is the closest to the coast in 2005. Supply of oil HC decreases the CPI value, therefore, the chain length of n-alkanes may be used as a marker of their origin. Thus, in the riverine sediments and in the marine samples near Taiwan Island, the CPI values were 4.08 and 1.70 on average, respectively [Jeng, 2006].

The concentrations of PAH in the bottom sediments sampled in 2005 (on average, 948.6 ng/g), as well as those of AHC, appeared to be the highest during the entire period of the studies since 2003. At stations 10, 11, 17, and 23, the content of PAH was over 1000 ng/g, and over 4000 ng/g, at station 19. Therefore, the fractions of individual polyarenes decreased in the order (in %): Py

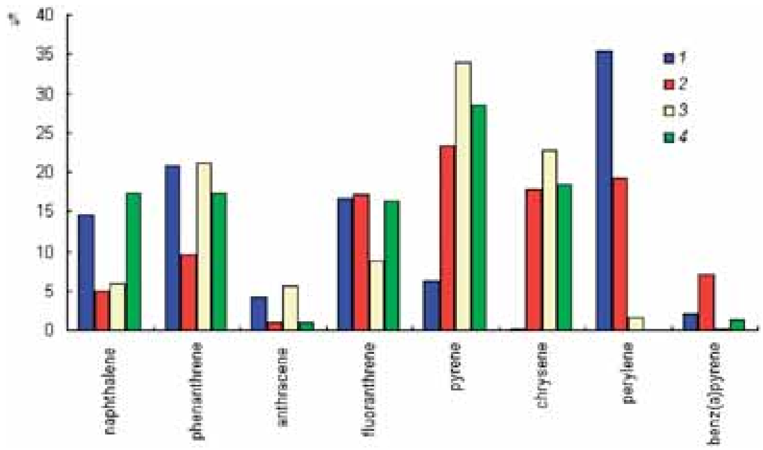

Fig. 6. Composition of PAH separated from the bottom sediments in 2009:

1, 2, 3, 4 — stations: 1 — station 7, confluence of the Kama and the Volga; 2 — station 8, Tolyatty outer harbor; 3 — station 22y, Gandurinsky channel (in the bay); and 4 — station 23y, Gandurinsky channel (in the stream)

(21.1) > Fl (20.1) > NA (19.2) > Pl (6.3) > Bpl (6.0) > Bp (5.6) >An (5.3) > Chr (4.2).

In 2009 in the Volga Delta and the Volga River, the concentrations of PAH in the bottom sediments varied between 2-25 ng/g and 13-178 ng/g, respectively. The markers in the PAH composition of the zone of the avalanche sedimentation mainly pointed to a mixed origin of polyarenes (oil and pyrogenous with a small inclusion of biogenic HC (Fig. 6), that agrees with earlier received results [Sokolova, Ablia, 2007].

The sediments are considered as low-polluted at the content of the sum of 3–6-cyclic polyarenes below 100 ng/g [Tolosa et al, 2004]. In the areas of a permanent supply of pollutants, the concentrations of PAH in the bottom sediments are usually >1000 ng/g; at the values over 4000 ng/g, the sediments become toxic. The content of Bp in the bottom sediments of the area considered exceeded the maximal allowable content for soils (20 ng/g) by factors of 8–19. The concentrations obtained are comparable to those of the most polluted bottom sediments of the Mediterranean Sea. In the area of the northwestern coasts of France, their concentrations varied within 6900–48090 ng/g, and within 72–18381 ng/g, off the Italian coasts [Culotta et al, 2006]. However, despite the high HC concentrations in the area of the avalanche sedimentation, the markers within their composition pointed to their mixed origin (anthropogenic and biogenic).

This may be explained by the fact that, in all natural objects, HC are subject to various physical (weathering and erosion) and chemical (oxidation and photo-oxidation) transformations, as well as to biodegradation by micro-, plant, and animal organisms. Even for the more stable polyarenes, the rate of PAH photochemical transformation is comparable to that of microbiological oxidation of nonaromatic HC of oil. In simulation experiments, it was shown that the destruction of Bp mainly proceeds in the surface layer of the water (53%/h) and, to a considerably lower degree, at a depth of 30 cm (5.6%). The microbial Bp destruction in the surface seawater is about 400 t/year, i.e., about 8% of the total Bp supply from natural and anthropogenic sources [Rovinskii et al, 1988]. Only on the shelf of the Caspian Sea (according to the studies performed in 2004), after passing through the marginal filter, did the AHC concentrations in the bottom sediments decrease, and the alkanes of land vegetation prevailed in their composition. The content of PAH in sandy sediments also decreased here to 3–17 ng/g. The (Py + Bp)/(Ph + Chr)

Table 2. Content of AHC (μg/g of dry weight) in the surface layer of the bottom sediments of the Caspian Sea

Region	Year	AHC	Reference
Azerbaijan shelf	2000	39–1515	Tolosa et al, 2004*
Iranian shelf	2001	14–113	«
Northern part (Russian aquatic area)	2000	1–42*	«
Kazakhstan shelf	2001	2–14*	«
Northern shelf	2003	20–142	Nemirovskaya and Brekhovskikh, 2008
Volga River channels	2004	59–3881	
Northern shelf	2004	94–136	«
Northern shelf	2005	70–4558	«
Volga River	2009	3–121.4	This study
Volga Delta	2009	2–43	«
Antarctica, background	2001, 2003	12–210	Nemirovskaya, 2004

Note: * total alkanes.

ratio decreased from 0.6–11.5 to 0.3–0.5 due to the precipitation of P and BP in the area of the marine and riverine water mixing. Barrier of the Volga River–Caspian shelf acts as a filter preventing the input of anthropogenic HC from the Volga River.

Thus, during the period of the studies from 2003 to 2009, the Volga River and all three areas of the marginal filters of the Volga River – Northern Shelf of the Caspian Sea were examined. The gravitational area, which included the river channels; the physicochemical area, or the zone of the avalanche sedimentation with the highest HC concentrations; and the biological area, where the markers point, to the highest degree, to a natural origin of HC in the bottom sediments. In 2005, the HC content in the bottom sediments appeared to be the highest over all the time of the surveys performed on the northern shelf of the Caspian Sea (Tables 2, 3). Evidently, the area treated in 2005 is associated to the avalanche sedimentation zone, which includes the physicochemical part of the marginal filter [Lisitsyn, 1995]. Here, during the processes of

Table 3. Content of PAH (ng/g of dry weight) in the surface layer of bottom sediments of the Caspian Sea

Region	Year	PAH	Reference
Volga River mouth	1993	40	Winkels, et al, 1998
Azerbaijan shelf	2000	338–2988 (Σ15 PAH)	Tolosa et al, 2004*
Iranian shelf	2001	94–1789 (Σ15 PAH)	
Northern part (Russian aquatic area)	2000	6–345 (Σ15 PAH)	
Kazakhstan shelf	2001	7–294 (Σ15 PAH)	
Northern shelf	2003	3–17 (Σ8 PAH)	Nemirovskaya and Brehovskikh, 2008
Volga River channels	2004	8–154 (Σ8 PAH)	
Northern shelf	2004	6–76 (Σ8 PAH)	
Northern shelf	2005	4–4800(Σ10 PAH)	
River Volga	2009	3–121.4(Σ10 PAH)	This study
Delta Volga	2009	2–43(Σ10 PAH)	

flocculation and coagulation, the bulk of HC is precipitated.

The low concentrations of suspended substances in the surface waters are characteristic of summer steady low water level of the Volga River. Diffusion and dilution play leading role at the confluence of the Volga River and its inflows. The concentration of HC in the surface waters and sediments corresponded to their background levels that indicate insignificant oil pollution. The parameters studied undergo changes under the influence of natural processes. However, increased role of HC in C_{org} in arenaceous sediments of the Volga Delta probably were due to the influence of polluting oil compounds.

CONCLUSIONS

The composition of HC in particulate matter and the bottom sediments in the area of the Volga River estuary undergoes regular changes due to the transformation and precipitation of both anthropogenic and natural compounds. Particulate matter is considerably finer than the bottom sediments, and the grains of biogenic particulate matter do not reach the bottom because of the dissolution in the water mass. Therefore, pronounced distinctions were observed in the composition of filtered particulate matter and the bottom sediments.

The deviations from a simple dilution of riverine OM with marine substances are caused by gravitational, physicochemical, and biological processes. As a result, in the physicochemical part of the marginal filter, in the area of the avalanche sedimentation, the highest degree of the HC accumulation in the bottom sediments takes place (up to 4557.9 µg/g for AHC and up to 4800 ng/g for the total PAH). Because of this, no correlation was observed between the HC content and the grain-size composition of the bottom sediments.

The synthesis of the data obtained in 2003–2009 showed that the geochemical barrier of the Volga River–Caspian shelf acts as a filter preventing the anthropogenic HC from entering the sea.

It is possible that because of this and despite the Volga River supplying a great amount of anthropogenic compounds, the northern shelf is one of the least polluted areas of the Caspian Sea [Tolosa et al, 2004].

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THE NECESSITY OF SPECIAL DISCOUNTING TREATMENT FOR NATURE TO ASSESS THE FLOW OF INVESTMENTS

ABSTRACT

The purpose of the paper is to justify special ***natural*** discount rates in the efficiency assessment of conservation activities. Nowadays, the ***social rate of discounting*** suggested by D. Pearce is often used. However, many ecosystem values differ in such aspects as absence of high-grade anthropogenic substitutes and conservative character of natural "technologies", and consequently simple, not expanded, reproduction. As a result, there exists the need for special discounting rate for non-replaceable production and services restricted in their reprocessing and consumption. This follows from the analysis of a consumer choice trajectory in the course of budget growth over a level at which the maximum of consumption of the limited good is reached. The paper estimates the reduction value for discounting rates for renewable natural resources restricted in regeneration in the special case of individual utility functions of the Cobb-Douglas type and, for a collective consumption, using equal-parts resource sharing among consuming community members. The idea of special discount rates for the production and non-material services of ecosystems is useful both for economic efficiency assessment of nature conservation activities and for calculation of compensations from the activities that adversely affect environment quality.

KEY WORDS: discounting, natural discount rate, investments, ecosystem production, ecosystem services, effective strength of environmental activity

INTRODUCTION

There is often a need to evaluate future or past projects from aprioristic or posterioristic points of view in comparison with baseline scenarios that assume absence of such project activities. Some of typical situation are presented below.

1. ***Nature in the Future (NF).*** For example, it may be necessary to compare some scenarios of national park organization or of realization of tree-planting works. It is implied that any of these scenarios increases the value received from functioning of conserved, improved, restored, or established ecosystems, but probably leads to losses from the missed opportunities of alternative use of the occupied lands or of the resources located on them.

2. ***Economic activities in the Future (EF).*** A private or public investment project, which may lead to reduction in a stream of products and services of destroyed or modified ecosystems or to deterioration of environment characteristics, has to be evaluated. It is required to estimate practicability of the project from a complex ecological economics point of view: whether planned new values of anthropogenic origin will outweigh ecological losses.

Both of described variants *NF* and *EF* plainly demand for putting to the current time the estimations of various scenarios of planned conditions of natural stocks and streams of ecosystem products and services. Thus, a hectare of a forest today and a hectare of the same forest to be planted in 70 years have apparently different current, normalized to today's perception, value. So, here arises the problem of correct discounting.

Let us consider two other situations.

3. ***Nature in the Past (NP)***. This situation arises when nature protection or environmental engineering actions have been carried out, which has led to increase of steady streams of resources and services of ecosystem origin useful for human beings or to the occurrence of a predictable trend in increase of stocks of such resources in comparison with a baseline scenario that assumes absence of such measures.

4. ***Economic activities in the Past (EP)***. This situation is associated with realization of an investment project or with economic activities that resulted in outcomes (often unforeseen) that have led to decrease in stocks of resources or steady streams of products and services of ecosystem origin or to occurrence of a predicted trend of such resources or flows reduction. In this case, it may be necessary to estimate sizes of indemnifications from initiators of such changes.

Situations *NP* and *EP* also need selection of the rate of discounting for the goods of ecosystem origin (or of a set of various rates for the natural goods of different types) which are affected by the activity of these two mentioned types. (It is important to notice that when actions of types *NP* or *EP* lead to a simple lump-sum change of material stocks of ecosystem origin, the problem of the correct discounting does not rise.)

THEORETICAL ANALYSIS OF THE PROBLEM: STARTING POSITIONS

This paper is not concerned with the tendency of the rate of social discounting to change (namely – to abate) with increase in horizon of planning or may be simply with a course of normal economic development. Pearce et al. [2003] and Groom et al. [2005] provide a good review of such research approaches.

The goal of our paper is to demonstrate that discounting of non-replaceable products and services of ecosystem origin is different from that of socially consumed goods of anthropogenic origin. In addition, we tried to estimate discounting comparators in some typical situations.

This material may seem as incomplete or debatable. However, we hope that it will highlight a number of specific features of ecosystem goods which have been lacking attention in the past. This paper also attempts to identify possible steps to develop further approaches to discounting.

At the present time, the term most often used is the so-called social rate of discounting suggested originally by D. Pearce. This approach considers that goods of ecosystem origin have the same social importance as, for example, free parking for personal motor transport. It is assumed that the rate of social discounting reflects pure intertemporal preferences of a society which is different from the commercial rates that reflect possible speed of the capital gain at its alternative investment.

However, unlike paved parking, many of ecosystem goods differ in such aspects as, *first*, in the absence of full-value substitutes of anthropogenic origin, *second*, in conservative character of natural "technologies" and, *third*, as a consequence, in mechanisms for reproduction of these goods (simple vs. expanded, for anthropogenic goods).

For any of the types of assessments mentioned in the Introduction, setting a *low and the same for all goods* of natural and anthropogenic origin discounting rate (though possibly changing from year to year) will inevitably lead to losses in the near planning horizon.

First, it is reasonable to assume that for conventional replaceable goods that can be produced on sustainable basis, one will, most likely, prefer to have some of their quantity today rather than in some uncertain future.

Second, when the rate of discounting is made compulsorily low without the distinction concerning the type of discounted goods, the opportunity of reinvestment of financial assets, which can be received from the projects with fast feedback, is underestimated.

NEED TO DECREASE THE RATE OF DISCOUNTING FOR THE GOODS LIMITED IN CAPABILITY OF REPRODUCTION

Let us consider a typical, a well-known from many basic level textbooks on economics, situation of the individual choice between consumption and non-consumption (and spending the remaining part of expense budget for other goods) of some fixed good presented on Fig. 1.

In this figure, each curve sets some fixed level of total satisfaction from simultaneous consumption of all goods. Therewith, one *fixed* good is opposed to all other goods consumed by an individual, and their consumption is *measured* by the sum of money spent on them. Any of the points at any fixed curve on the diagram are of equal preference for the individual, and a real choice is determined by aspiration of expenses minimization. We consider that money acts as a uniform measuring instrument for expenses of various sorts. Expenses can be financial, temporal, physical, "moral", and possibly other. The individual has to choose between consumption of some chosen product and consumption of other goods over any time interval, for example, over a month. For simplification, it may be assumed that the total expenses to maintain consumption of an individual product are directly proportional to the quantity of consumed units and that consumption of other goods is measured directly by their money's worth. Descending inclined straight lines display budgetary restrictions at various levels of a consumption budget. The osculation points of these straight lines to the curves of maximally accessible utility level represent real consumer selections at various levels of the budget. The consumer choice trajectory is presented on our diagram by an ascending inclined straight line (generally the trajectory of a choice can be a line of more complex configuration) connecting these points. The slope of the indifference curve in its arbitrary point characterizes the

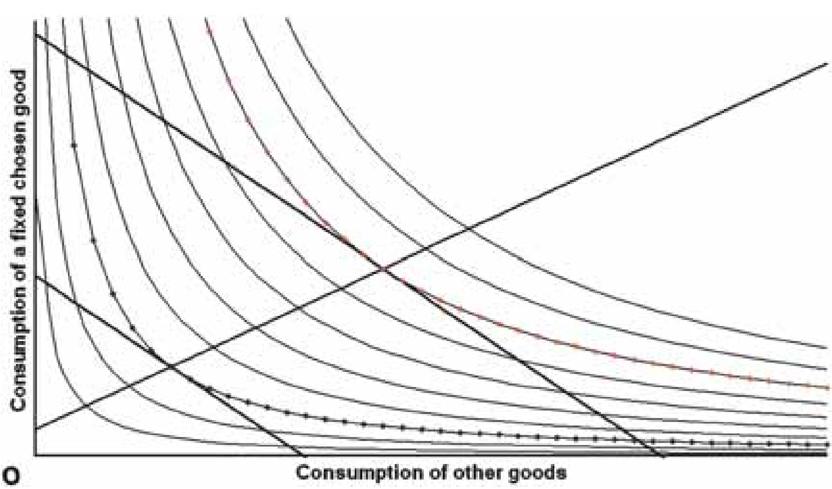

Fig. 1: The indifference curves graph, budgetary restrictions, and a consumer choice trajectory associated with consumption of the fixed chosen good in comparison with expenses on consumption of others goods

value of an additional unit of the fixed good. Specifically, the steeper the backslope of a curve, the more valuable to the individual is consumption of an additional unit of other goods in comparison with consumption of a unit of the fixed chosen good. The backslope of an indifference curve shows a marginal relative value of the good represented on the horizontal axis.

Let us assume now, that the fixed chosen good is trips to nature with restricted maximal number of trips per month (for example, by a number of days in a month [for a person with a flexible schedule] or by a number of weekends [when only they are available for travel]). The consumer choice trajectory is now transformed approaching the shape presented on Fig. 2.

Until the consumer budget reaches a critical value at which the individual chooses distribution of expenditures that maximizes the general utility and achieves the greatest possible consumption of the restricted good, the point of the consumer choice moves along the segment OA_{crit} of the choice trajectory. Therewith, in a point of choice, the relative value of the consumed goods is determined by the parity of the expenses associated with consumption of a chosen good and all other goods. In theory, i.e., in the absence of time, "moral", and other transactional costs, it is determined by the price of the limited good expressed in monetary units. Further, when the budget critical level is exceeded, the consumer choice trajectory is forced to follow the horizontal half-line $A_{crit.}A_{+}$, and in a choice point, the marginal relative value of the restricted good against all other goods, equal to the reciprocal of the crossed indifference curve obliquity tangent, starts to grow.

APPRAISAL OF THE DEGREE OF EFFECT MANIFESTATION

The single consumer case

The case of restricted resources consumed individually

In economic textbooks (see, for example, [Nicholson, 1995]) the representation of indifference curves through the assemblage of graphs of equi-potential values of the Cobb-Douglas type utility function

$$U = K \cdot L^{\alpha} \cdot M^{\beta}$$

is very popular as illustrative. Here, K is a non-dimensional constant factor; L is the consumption of one good, for example,

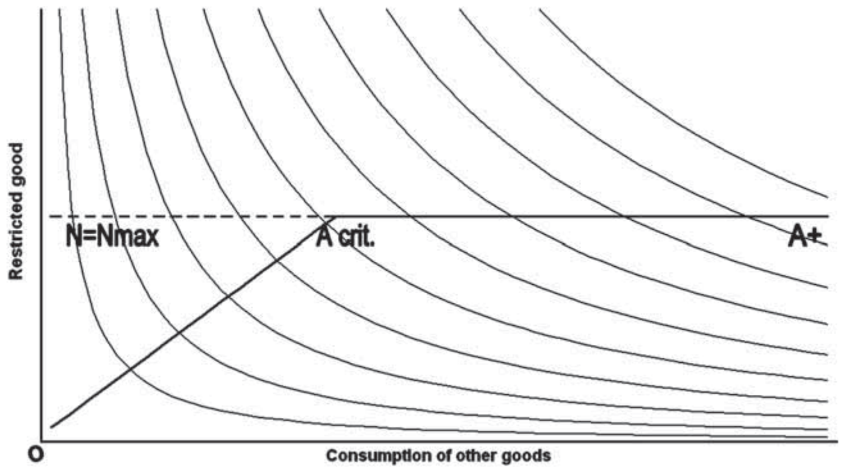

Fig. 2. The indifference curves graph and a consumer choice trajectory when consumption restrictions exist for a fixed chosen good (a case of a homothetic utility function)

quantity of trips to the nature; M is the consumption of another good, in our example, it is the consumption of all other goods estimated by money's worth of the expenses, associated with its realization; α and β are the power indices greater than zero.

Assuming a cost of a trip to a suburb equals p, and general budget spent for the consumption equals B, we arrive at an optimization problem:

$$p \cdot L + M = B$$

$$L \leqslant L_{\max}$$

$$L^{\alpha} \cdot M^{\beta} \rightarrow \max.$$

While the budget is does not exceed critical $B_{crit.} = \dfrac{pL_{\max}(\alpha+\beta)}{\alpha}$, then the solution to this problem will be $L_{opt.} = \dfrac{\alpha\beta}{(\alpha+\beta)p}$. The marginal value of an additional trip to the nature suburb in the point of the optimum will now be equal to p, i.e., to the costs of its realization. Let now $B > B_{crit}$.

Thereafter,

$$L = L_{max},$$

$$M = B - p \cdot L_{\max},$$

$$V_{L/M} = \frac{\alpha}{\beta} M/L = \frac{\alpha\left(B - pL_{\max}\right)}{\beta L_{\max}}. \qquad (1)$$

If $B = B_{crit.} + \Delta B$, where ΔB is the budget excess above the critical value, we can transform the formula (1) to

$$V_{L/M} = p + \frac{\alpha}{\beta}\frac{\Delta B}{L_{\max}},$$

which evidently shows the dependence of growth of the limited product value beginning from the point of excess over the critical budget: the increase of the value is in direct proportion to the increase of the budget.

THE CASE OF A COMMON-POOL RESOURCE AND A GROWING NUMBER OF CONSUMERS

Let us consider an elementary model of how a renewable common-pool resource (i.e. reproducible, and non-excludable, but rival) with the annual productivity of A units is used.

The annual production of this resource is shared among $N(t)$ members of a local community. Let us assume that the number $N(t)$ grows with time in a geometrical progression

$$N(t) = N_0(1 + \nu)^t.$$

The consumer budget of each community member also grows in a geometrical progression:

$$B(t) = B_0(1 + \gamma)^t.$$

Let us also assume that a) consumption of a common-pool resource has already reached the stage of its possible maximum, and it is equally shared among the community members:

$$A_j(t) = A/N(t),$$

where j is the index of a community individual member; and b) general individual utility from the consumption of an investigated resource and the total consumption of all other goods is described for every community member by the same time-constant utility function of the Cobb-Douglas type:

$$U_j = KL_j^{\alpha} \cdot M_j^{\beta}.$$

Then, for the time moment t: $L_j(t) = A/N(t)$, $M_j(t) = B(t) - p_j(t)L_j(t)$,

$$\begin{aligned} V_L^j(t) &= \frac{\alpha}{\beta}\frac{B_0(1+\gamma)^t - p_j(t)L_j(t)}{L_j(t)} = \\ &= \frac{\alpha}{\beta}\left(\frac{B_0N_0(1+\gamma)^t(1+v)^t}{A} - p_j(t)\right) \end{aligned} \qquad (2)$$

Here, $p_j(t)$ is the j-th community member's size of expenses for withdrawal or consumption of the last common-pool use resource unit, i. e., is the marginal value of the resource.

If the size of $p_j(t)$ is or eventually becomes negligible in comparison with $\frac{B_0 N_0 (1+\gamma)^t (1+v)^t}{A}$, then the formula (1) can be transformed to the form of

$$V_L^j(t) \cong \frac{\alpha}{\beta} \frac{B_0 N_0}{A} (1+\gamma)^t \cdot (1+v)^t, \qquad (3)$$

and the individual coefficient of discounting factor reduction for the resource marginal value will become equal to $(1+\gamma) \cdot (1+\nu)$. So, the corresponding discounting factor seems to be equal approximately to $r - (\gamma + \nu)$, where r is the discounting rate for conventional goods in socially-oriented projects.

The degree of effect manifestation for a social community in whole

The case of a common-pool resource

Let us note that formulas (2) and (3) in the assumption of simple additivity, used usually by default, of a public utility function in reference to individual utilities composing it, also give us the appraisal of the effect for the community in whole for the case when the marginal effect of the actions directed on improvement of resource functioning or on reduction of the tendency to its disruption is estimated for a common-pool type of resources, because the arising marginal effect is consumed competitively, i.e. only once, either by strictly one member of the community, or by several members in some proportion.

The case of real public goods

Let now A to be a productivity of a service providing a real public good (i.e. non-rival and non-excludable).

Let us also assume that the consumer budget of each community member also grows in a geometrical progression:

$$B(t) = B_0(1+\gamma)^t.$$

Furthermore, let assume that a) consumption of a real public good (something like visiting scenic places or enjoying safety from floods) has already reached the stage of admissible maximum (in other words, community members are rich enough to allow themselves some amount of these products, but further rise of their consumption is restricted by non-economic reasons), and all members consume these products to the full extent:

$$A_j(t) = A,$$

where j is the index of a community individual member; and b) the general individual utility from the consumption of an investigated resource L and the total consumption of all other goods M is time-constant and is described for every community member by the same utility function of the Cobb-Douglas type:

$$U_j = K L_j^{\alpha} \cdot M_j^{\beta}.$$

Then for the time moment t: $L_j(t) = A$, $M_j(t) = B(t) - p_j(t) - p_i(t)L_j(t)$,

$$V_L^j(t) = \frac{\alpha}{\beta} \frac{B_0(1+\gamma)^t - p_j(t)A}{A} =$$

$$= \frac{\alpha}{\beta}\left(\frac{B_0(1+\lambda)^t}{A} - p_j(t)\right)$$

Once again $p_j(t)$ is the j-th community member's size of expenses for consumption of the last unit of public resource, that is, the individual marginal value of the resource.

If the size of $p_j(t)$ is or eventually becomes negligible in comparison with $\frac{B_0(1+\gamma)^t}{A}$, then the formula (4) may be transformed to the form of

$$V_L^j(t) \cong \frac{\alpha}{\beta}\frac{B_0}{A}(1+\gamma)^t,$$

and the ratio to lower the discounting factor for the public resource marginal value will be $(1 + \gamma)$. So the corresponding individual discounting rate will be near $r - \gamma$, where r is the discounting rate for conventional goods in socially-oriented projects.

But, again, if the number $N(t)$ of community members grows in a geometrical progression

$$N(t) = N_0(1 + \nu)^t,$$

the total public marginal value, which is now the sum of the individual values, grows as $\sim (1 + \gamma)^t \cdot (1 + \nu)^t$, and $(1 + \gamma)^t \cdot (1 + \nu)^t$ corresponds to the lowering ratio, and the discounting rate is near $r - (\gamma + \nu)$, that is, the discounting rate for conventional goods in socially-oriented projects minus the rate of growth of the total public consumption.

Important remark

The important remark here is that nature protection projects not so much create ecosystem production and functions, as support and improve their renewal. Therefore, exactly the consideration of the marginal, instead of the average values is valid for the assessment of these goods relatively to the conventional ones.

Consideration for projects that worsen environment conditions

In order to further elaboration on the statements about the distinction between different kinds of discounting rates and to emphasize the need of compensations for natural ecosystems losses during realization of projects that worsen environment conditions, we offer the following formula of settlement payments to ecosystems' proprietors or users from investors in such projects (the case of pure financial indemnifications is considered):

$$\sum_{i-0}^{T} P_i/(1+\theta)^i = \Delta S + \frac{\Delta F}{\eta} + Ex\ .$$

Here ΔS are the losses of "environmental stocks". These are all kinds of the losses associated with non-recurrent incomplete recycling of values of destroyed natural resources, and also with changes in components of the total value: option value, value of current existence, and bequest value. ΔF are losses in "ecological stream", i.e., annual productivity of destroyed plus productivity reduction of disturbed ecosystems. η is the *natural* discounting rate for ecosystem goods expressed in unit fraction. Ex ("externalities") is a current estimation of the difference of the positive and negative external effects connected with the project realization. T is the planned duration of the project realization, i is the number of year of the project realization, at the end of which the payment P_i is made, P_0 is the project starting payment, $1/(1+\theta)^i$ is the i-th year discounting multiplier for financial indemnifications, and θ is the *financial* rate of discounting, taking into account the inflation.

CONCLUSIONS

The main conclusion derived from the discussions presented above is:

Continuous growth of productivity of human economic activities and continuity of natural ecosystems' specific potential, difficulty of ecosystem production and services replacement and public character of their consumption lead to a naturally occurring distinction between corresponding discounting rates.

The idea of special discount rates for production and non-material services of ecosystems is useful both for economic efficiency assessment of nature conservation activities and for calculation of compensations from the activities that worsen environment quality.

Speaking of perspectives for research in this area, first of all, we note the necessity of specification of real indifference curves and of approaching functional dependences for typical individual and public (if exist) utility functions with inclusion of the quantity of consumed production and services of natural ecosystems as one of the parameters for these functions.

Assessments of investment risks may also become the important direction of development. As an initial frame position of such research, we should mention that in conventional investment projects, the consideration of risks of a project failure or profits cut short leads to increase in the discounting rates for anticipated values. On the contrary, in nature protection projects and projects affecting ecology, risks of irreversible ecosystems' losses, most possibly, should decrease the rates of discounting of the corresponding values produced by the ecosystems. Therefore, distinctions in the risks of the ecosystems' losses and in times of their self-regeneration should lead to a spatial differentiation in corresponding discounting rates. Development of methods for quantitative estimation of resulting effect is necessary.

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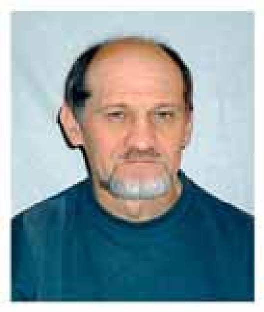

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DETERMINATION OF HYDRO-ECOLOGICAL FACTORS OF THE VOLGA-CASPIAN AQUATIC ECOSYSTEMS STABILITY IN DESIGNING THEIR PROTECTION

ABSTRACT

This paper discusses possible consequences of changes in the Volga-Caspian aquatic ecosystems resulting from climate change according to the data scenarios of the Worldwide Meteorological Organization. Main hydro-ecological factors of stability of the Northern Caspian Sea ecosystems have been determined. It appears that ecosystem stability in the Northern Caspian Sea is primarily affected by natural conditions. It is essential to model riparian ecosystem processes and winter regime of reservoirs to develop strategies for mitigation of negative impacts of climate change. Such measures may include improvement of existing dams in the Volga region.

KEY WORDS: Volga River, the Caspian Sea, aquatic ecosystems stability, hydro-ecological factors, climate change, sturgeon distribution.

Various scenarios of the Worldwide Meteorological Organization predict that mean annual air temperatures may rise by 4 to 8 °C [IPCC, 2001] during the nearest several decades in the region of the Caspian Sea and its watershed area. This climate warming may cause the volume of the annual water flow of the Volga to increase by 15–20%. However, this volume will not be evenly distributed through the year. During the spring flooding caused by snow melting, the volume of flow may be 40% higher than today, while during the summer rain floods, the volume of flow may decrease by 20% compared to the current values [Kuchment et al., 1990]. These processes will influence aquatic ecosystems causing changes that may be region specific.

In the area of the Upper Volga (Fig. 1.), increase in the flow due to snow melting and temperature rise together with greater precipitation and changes in snow melting processes may cause serious inundation. Inundation will widen the zones of underflooding, which may rise the ground water table and lead to expansion of swamp areas. This situation may negatively influence the aquatic flora and fauna. The region of the Upper Volga has vast wetland areas that may be very sensitive to climate fluctuations. In fact, according to E.V. Meyerner [1971] the characteristic feature of the Upper Volga reservoirs is the presence in their beds of a significant number of swamps. After navigation ends and waterways freeze and through the spring floods, the reservoirs are drawn down. For example, in Ivankovo reservoir, the uppermost reservoir on the Volga River, the water drop reaches six meters. The water from the shallow floodplain territories, including the wetland areas, flows into the deep channel part of the reservoirs causing oxygen deficit and massive fish kill. Therefore, it is very important to work-out a

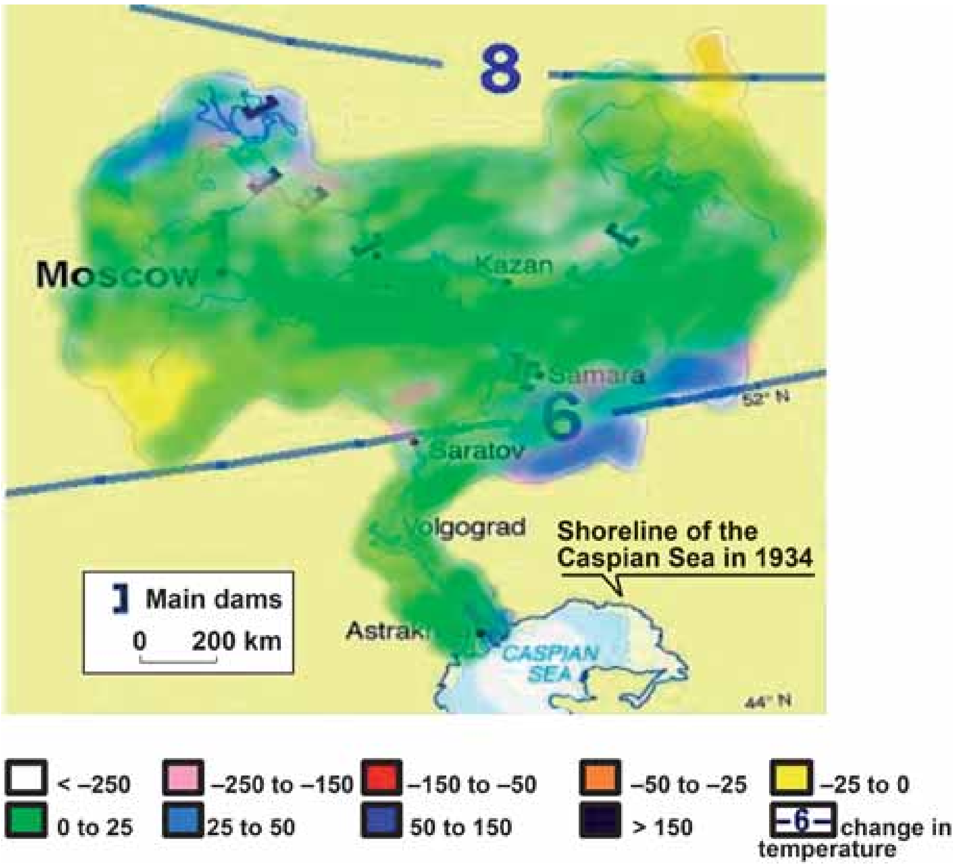

Fig. 1. Change in average annual runoff by 2050 in mm yr^{-1} and the change of annual mean temperature (isolines) in °C for the Volga River basin (according to [IPCC, 2001])

proper drawdown regime for the reservoirs considering possible riparian swamping and hydro-meteorological conditions.

Biodiversity and water quality may be also affected by climate change and by its impact on the aquatic ecosystems [IPCC, 1996]. Some researchers indicate that in the Middle Volga River region, higher water temperature may increase nitrogen and ammonium levels while decreasing the level of dissolved oxygen, especially during the dry and warm periods of the year [Ivanov, et. al., 2001] which ultimately leads to river water pollution. However, there is a lack of modeling efforts of river water quality under changing climate.

In the region of the Lower Volga, existing problems may intensify and new problems may arise. Thus, the projected temperature increase and decrease in the surface flow during summer may cause a greater demand for water in irrigated areas, which suffer from droughts even now. Climate change may lead to additional increase in water consumption [Ivanov, et. al., 2001] as water demand rises with population growth and economic development. In some countries, these two factors are considered more important than consequences of climate change. Changes in the level of inner waters may influence navigation regime, endanger fisheries, and alter spawning of existing and promote expansion of more heat-loving species of fish.

Parameters of the Caspian Sea hydrologic regime are determined by the global macro-circulation processes within the Atlantic-

European sector. The hydrological regime of the Caspian Sea has been projected through 2015 using a statistic model of the linear Marcov processes [Ivanov et al., 2001]. The Caspian Sea level that has been increasing in recent years (by 0,8–1,0 m over the last 10 to 15 years) due to the increase in the average air temperatures, the inflow of fresh waters, and the increase in the winters' severity is expected to stabilize at the average mark of 27,44 m by 2013. At the same time, decrease in salinity and increase in the surface sea stratum temperature will take place and will worsen the deep strata ventilation. Over the nearest years, complete oxygen depletion, emergence of the reduced form of sulfur and, possibly, free hydrogen sulfide in the deep-sea waters may be anticipated. Reduction in the thickness of a quasi-homogeneous layer and intensification of the summer thermocline as well as weakening of the autumn-winter convection will promote the lower delusion of polluted surface waters, which may endanger the Caspian Sea ecosystems.

Anthropogenic impact in the Caspian Sea is mostly associated with hydrocarbon and heavy metal pollution. This impact will inevitably intensify with growth of resources utilization and increase in oil pollution of the Caspian Sea surface.

The Volga River runoff is the most important pollution factor in the Northern Caspian Sea due to the river mouth location. River mouth areas represent natural complexes that have characteristic landscape structure which formation is influenced by mixing of fresh and marine waters, by complicated system of currents, and by dynamics of sediments. The important components of these complexes are the unique freshwater-marine ecosystems. Special hydro-chemical regime, biogen material brought by the rivers, and well-heated shallow-waters promote high bio-productivity of the river mouths that play major role in development of these ecosystems and have important ecological significance for large areas occupied by the river systems and seas. At the same time, the river mouths are especially sensible to anthropogenic impacts on the river basins and, first of all, to anthropogenic changes in the runoff. Even in the regions of sparsely populated seacoasts where industrial activities are absent, the consequences of anthropogenic impact on the runoff and water quality can lead to a noticeable degradation of the ecosystems of the mouth areas. Besides, natural resources of the sea shallows and the shelf oil fields, in particular, are the primary targets for intensive exploitation. This exploitation undoubtedly contributes to the deterioration and pollution of the adjacent river mouth areas.

The purpose of this work was to define factors of stability to anthropogenic impact of the most productive Northern Caspian ecosystems in order to design environmental protection measures. The term "stability" includes the ability of the ecosystem to maintain its structure, i.e., a set of components and their interworking, under anthropogenic load by changing individual parameters and properties and compensating for consequences that arise from incorporation of new elements different in origin [Odum, 1975; Reimers, 1990]. According to the founder of the modern hydrobiology academician S.A. Zernov [1949], conditions favorable for valuable commercial fish are also favorable, as a rule, to the entire biocenosis. Sturgeon species (*Acipenseridae*) are extremely long-lived commercial fish that are at the upper trophic level of the Caspian Sea. These fish are currently experiencing strong anthropogenic impact. Therefore, conditions that provide for stable existence of ***Acipenserida*** over its entire life cycle are also assumed to characterize stability of aquatic ecosystems of the northern part of the Caspian Sea. According to A. Poddubny [1971], even during volleys of sewage, some fish can identify the danger and escape from the polluted zone, which is possible as the oil pollution is still mosaic. It is possible that the ability to identify the polluted zone and to escape from this region makes the "factor of anthropogenic load" not so significant for the distribution of the *Acipenseridae*.

Table 1. Factors selected for analysis

Hydro-ecological factors	Factor load, %	Variables that have load on the factor (*r* > 0,6)	Factor characteristics
Natural conditions	39,7	X3 (–0,74) X4 (–0,63) X5 (0,79) X6 (0,71) X10 (–0,61) X11 (0,70)	Characterizes the influence of hydro-chemical, natural-climatic, biotic, and food supply features of the Caspian Sea on the distribution of sturgeon fish
Wintering/post-wintering	15,5	X1 (0,85) X2 (–0,67) X7 (0,65) X9 (0,69)	Enables assessment of the influence of temperature, drops of depth (presence of wintering pits), ice cover, and abundance of zooplankton on the distribution of sturgeon fish during the winter.
Anthropogenic load	12,7	X8 (–0,70) X12 (–0,81) X13 (0,72)	Shows the determining influence of the Volga River flow on the influx and spread of pollutants in the water body of the Northern Caspian Sea

Six species and one subspecies of sturgeon population in the Caspian Sea, which belong to two genera, i.e., ***Huso*** and ***Acipenser***, were selected to study and assess principal hydro-ecological factors that influence the distribution of *Acipenseridae* in the northern part of the Caspian Sea. For each location (we studied 260 location points in the Northern Caspian Sea), we received data on 76 parameters, including physical-geographical, hydro-chemical, hydro-biological characteristics, which have been analyzed using a pair correlation method. The results of these analyses were used to select several main hydro-ecological variables that characterize the ecosystem according to its principal functional features. These variables are: X1 – average long-term temperature of the water surface during February (°C); X2 – ice cover distribution (specifically, thickness of ice during harsh and mild winters entered with numeric scores); X3 – NO_2 on the sea surface (mkg NO_2/l); X4 – O_2 (mg/l) on the sea surface; X5 – average annual salinity (°/oo) in the water body; X6 – radiation balance per year (MJ/m^2); X7 – depth, (m); X8 – distance from the Volga-Caspian main canal (km); X9 – total zooplankton biomass (g/m^2) in the Caspian Sea; X10 – phytoplankton biomass (mg/m^3) in the Caspian Sea; X11 – biomass of zoobentos (g/m^2); X12 – average annual content of phenols (mg/l) in the water body; X13 – average annual distribution of oil hydrocarbons (mg/l) in the water body; X14 – average annual data on five sturgeon species catch. In order to assess the influence of abiotic environmental factors on the survival of ***Acipenseridae,*** we processed the obtained basic variables that characterize the integral state of ecosystems using factor analyses, where the dependent variable У = catch of *Acipenseridae*. We assigned factor loads of 13 parameters on three common factors received using the method of principle components. Then, the final factor loads were received in the result of three rotations. The rotations were performed for more accurate estimation of the loads of individual variables of the main components. The analysis showed that all significant variables (1 to 13) can be combined into three integral hydro-ecological factors according to the loads (Table 1).

Each group of parameters contributes to some factor and has its own meaning. Factor 1 has the greatest value of the total dispersion in the factor matrix – it defines 39.7% of the variables. Variables X3, X4, X5, X6, X10, and X11 have the highest load on the factor. Taking into consideration the meaning of the parameters included into this factor, we can say that this factor characterizes the influence of hydro-chemical, natural-climatic, biotic, and food supply properties of the Caspian Sea on the distribution of

Acipenseridae. We defined this factor as "natural conditions".

Factor 2 has the second degree of importance; it defines 15,5% of the total dispersion (Table 1). Variables X1, X2, X7, and X9 have the highest significance which enabled us to define it as "wintering/post-wintering" factor. This factor evaluates the influence of temperature, drops of depth (presence of wintering pits), ice cover distribution, and abundance of zooplankton on the distribution of sturgeon during winter. This factor defines the seasonal migration of sturgeon in the Caspian Sea water as well as the conditions of formation of the food supply for the next feeding period.

Factor 3 represents the third significant factor. Its input to the total dispersion in the factor matrix is 12,7%. The maximum load of variables (r > 0,7) of parameters X8, X12, and X13 on this factor indicates that it could be defined as "anthropogenic load" factor. This factor includes not only variables that characterize distribution of oil and phenols in the water body, but the variables that characterize the influence of the Volga flow as well. Our studies show that the annual dynamics of oil hydrocarbon content in the Volga and the Northern Caspian Sea are synchronized. Fluctuations in concentrations of oil hydrocarbons and phenols in the Volga River during each specific year are accompanied by a similar trend in changes of concentrations of these substances in the Northern Caspian Sea.

CONCLUSIONS

It is possible to mitigate negative impact of climate change. The following measures may contribute to development of such policies:

- modeling the processes of riparian swamping and winter regime of the reservoirs drawdown in the Upper Volga River region under climate change;
- reconstruction of existing dams in the Middle and Lower Volga River regions that are essential for conservation of water resources for consumption and for enhancing water quality (dilution of industrial, municipal, and agricultural waste) as well as for maintenance of spawning areas;
- urgent measures for reduction of man-caused impact on the Caspian Sea environment.

The main hydro-ecological factor of ecosystem stability in the Northern Caspian Sea is the "natural conditions" factor. It means that the process of dynamics of natural conditions in the region (including climate change) can lead to the most significant changes in the ecosystems. It is also important to model the influence of climate change on sub-aquatic conditions which may lead to changes in aquatic ecosystem composition and their health and stability.

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SUSTAINING CLIMATE CHANGE MITIGATION – POLICY, TECHNOLOGY, AND SOCIETY

ABSTRACT

In a world that is becoming more and more exposed and vulnerable to the effects of global climate change, combining integrated risk assessment tools with effective strategies for both mitigation and adaptation is a key prerogative for policy-making. With the focus of both researchers and decision-makers gradually shifting from observing and assessing the bio-physical aspects of climate change to a more human and society centered understanding of the nature of the problem, the social, behavioral, economic and technological aspects have entered center stage of the public discourse. Responses to the climate change challenge have to establish an optimal interplay between mitigation, adaptation and socio-economic instruments. Yet, given the band-width and scale of the climate problematique and its projected impacts, very ambitious mitigation measures have to be undertaken without delays, a fact that is particularly true for emerging economies with their very rapid and unprecedented growth rates, both in GDP and GHG emissions terms.

The challenge for the next years is to harmonize poverty eradication and attaining the Millenium Development Goals through stable economic growth with mitigating the effects of climate change. Therefore, "inclusive green growth" has become the motto of the day. But how can this goal be achieved? Obviously, quite fundamental changes have to be introduced that affect both the production and the consumption sectors and allow for real innovation in technologies and energy, in urban mobility, infrastructure and transportation grids. This paper illustrates the deep social and societal nature of climate change response strategies, especially in the area of mitigation, and shows that transitions to green and low-carbon economies will have to embed policies, incentive schemes and economic instruments in a larger societal context of social learning and behavioral change.

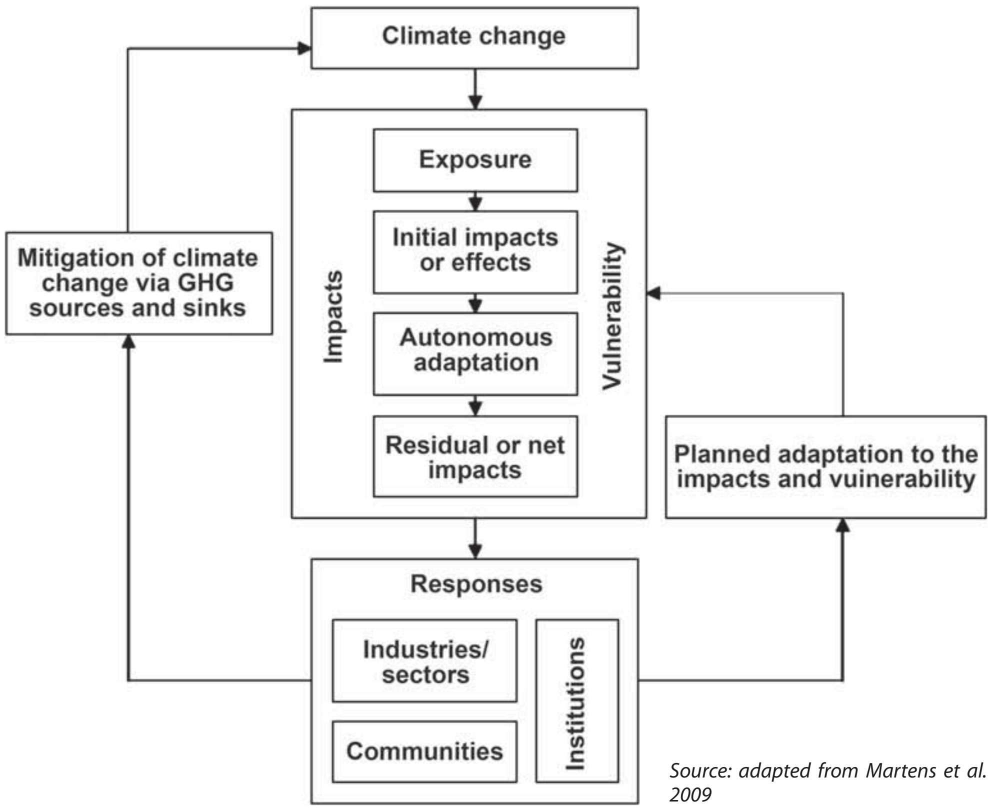
KEY WORDS: climate change, mitigation strategies, Millenium Development Goals, inclusive green growth, social learning, innovations

INTRODUCTION[1]

Intelligently designed processes of linking state-of-the-art vulnerability assessments with highly effective adaptation and mitigation measures at very large scales will become a key challenge for societies and policy-makers in the years to come, and will require the art of combining integrated risk assessment tools with an advanced approach to adaptive governance and policy-making processes. Ultimately, climate change and its adverse effects on people is becoming more and more a social and societal paradigm rather than just a "natural" or biophysical one. Indeed, the social and behavioral aspects of climate change and its societal dimensions have entered center stage in the public discourse [Martens and Chang, 2010].

The chart (after Martens and Chang [2010]) represents the classic conceptual matrix

[1] This paper represents a modified and abbreviated version of a study that was prepared for the Asian Development Bank (ADB). While the ADB study focuses on policy and development financing practice aspects in an Asian context, this version can be considered more generic and academic in its focus.



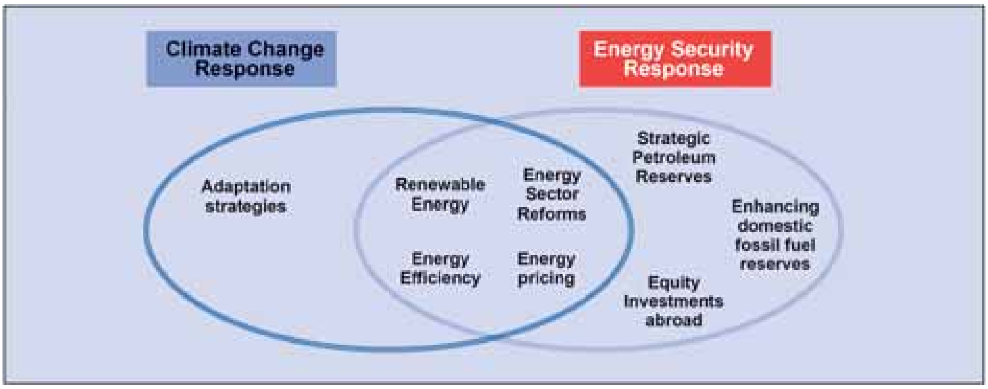
Source: adapted from Martens et al. 2009

Figure 1. The analytical framework for vulnerability–adaptation–mitigation research in the context of climate change

of the vulnerability-adaptation-mitigation nexus and illustrates the predominantly social and societal nature of this set of phenomena and their interaction. Social and societal dynamics constitute the climate change problematique and also hold vulnerability, adaptation and mitigation together.

The Intergovernmental Panel on Climate Change (IPCC) in its Third Assessment Report (TAR) in 2001 defined vulnerability as 'the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes'. IPCC lead authors have coined our understanding of vulnerability as being composed of exposure, sensitivity and adaptive capacity. Our societies' policy responses aiming to reduce vulnerability to climate change usually target one of these three. Martens and Chang [2010] write: "Exposure can be reduced (e.g. by changing the sectoral composition of the economy), sensitivity can be reduced (e.g. by making operational adjustments), and the adaptive capacity can be increased (e.g. by making contingency plans)."

However, the adaptive capacity of a social-ecological system depends on the effective interplay between mitigation and adaptation dynamics mostly expressed by devising such factors as economy, technology, human and social capital, and governance tools [Martens and Chang, 2010]. Therefore, effective policy responses to climate change always have to strive a balance and a harmonious interplay between mitigation and adaptation strategies, essentially using the same toolkit for both. Technological innovation, greening economies and businesses, and ultimately the dynamics of inclusive green growth are playing a key role in any climate regime, including in adaptation regimes. They are as good and effective as much as they operate



Source: ADB

on the system-inherent dynamic of the social and societal sphere. Negligence of the societal roots of any of the climate change cluster related factors, whether in terms of impacts, policy or technology is likely to lead into the wrong direction, i.e. on presumably less effective trajectories. Martens and Chang write: "The willingness and capacity of society to change is critical. Information and awareness-raising can be useful tools to stimulate individual and collective climate action... Mitigation, being an action targeting the long term, means attaching value to the interests of future generations and ... can be considered an altruistic response by society".

Such findings illustrate and underline the deep social and societal nature of climate change response strategies. If these assumptions are correct, paying due attention to the social and societal factors will be of critical importance when identifying ambitious strategies toward sustainable changes in the technology and energy sectors, low carbon intensity and green growth, especially in the rapidly emerging and developing Asian countries. The challenge in the years to come, given the very particular nature and dynamic of development trajectories particularly in emerging countries, is to balance poverty eradication and progress toward achieving the MDGs through economic growth with mitigating the effects of climate change, which is still largely coupled with precisely this trajectory of growth. "Green growth" and "inclusive growth" are the buzzwords of the day, but how are these concepts at all to become real? Clearly, there is no simple answer to this question. However, it is obvious that integration is key: integrating policy with vulnerability and risk assessment, mitigation and adaptation. Without paying due attention to the underlying human, social and societal factors those goals will not be reached.

The dynamics at play in this matrix largely build on convergence between policy frameworks, economic incentives, technological innovation and efficiency, all of which have societal connotations and draw upon the ability of humans and societies to change cultural constructs, attitudes and behavior through social learning. These dynamics and their inter-linkages are the focus of this article, which aims to shed light on the sometimes hidden or unseen human and social forces behind phenomena that we often enough consider as merely technical in nature.

THE GOVERNANCE CHALLENGE

As the Kyoto Protocol, which governs global emission reduction goals and policies, runs out, the UNFCCC process is expected to provide guidance for the future. However, it so far has not resulted in a new legally-binding protocol. The recent climate summit in Cancun, Mexico (UNFCCC COP 16) finally endorsed the 2 °C goal. However, it does not foresee any peak year or any collective target for cutting emissions. As a result, the concept and vision that global sustainable development affairs should be addressed primordially on a collective and truly international basis is still under threat. It seems unclear whether the approach of consensus driven inter-governmental decision-making has a meaningful future in global climate politics, or whether nation states will decide on their own, or in small groups, by how much they are willing to cut emissions. The concept and notion of Global Governance could well face a new paradigm shift and gradually be replaced by a "Club Governance" mode, i.e. world politics in smaller, exclusive circles.

At this juncture, the following questions seem prudent, and effective mitigation and adaptation policies will largely depend on answering them in a satisfying manner: How can global climate change, its manifold threats and adverse impacts still be met and tackled? What are promising strategies well outside the routines and path-dependencies of global climate negotiations? What are the potential and roles for technical and technological solutions and their social and societal acceptance? In the absence of a global breakthrough, additional negotiations in smaller circles, for instance within the G-20, or between developed and developing countries, and the formation of so-called "coalitions of the willing" could lead to partial results and should therefore not be generally dismissed. Especially at regional scale, intense talks between policy makers and a variety of stakeholders are necessary and have potential to advance solution-oriented efforts world-wide. By the same token, it is important to realize that the global climate change agenda is quite convoluted and has reached a state of almost incomprehensible complexity. It may therefore be fruitful to disentangle some of the most controversial issues and, for instance, yield to strive global agreements on questions of financial subsidies or compensation, on the harmonization of national adaptation policies, on technology transfer, or on the creation of new carbon markets, in separate fora.

We will have to "re-marry" the climate change agenda with those on development and human security. Climate change is, of course, not only about the environment. For instance, it results in the degradation of ecosystem services with direct impact on human wellbeing, and in growing human and social vulnerability, particularly in developing countries. This means costs for prosperity, economic development and human security. Climate change thus severely undermines the achievement of the Millennium Development Goals (MDGs). Moreover, we risk derailment of the MDGs if we fail to mitigate and adapt to climate change effectively. Therefore, an integral approach is much needed at the level of global and regional governance systems and collective political action. In the absence of a truly functional global approach to effective management of the climate change crisis, particular in terms of mitigation regimes, the geographical regions are carrying responsibility, Asia in particular given its unique growth rates and carbon related dynamics on the one hand side, and rapid development of key technological skills and resources on the other.

Recent leading-edge science suggests that even if global green house gas (GHG) concentrations can be stabilized at the level of 450 ppm CO_2 equivalents (CO_2e) by means of very ambitous mitigation efforts, we will still have to deal with a ca. 50% chance of surpassing the globally recognized 2 °C target. If such probability is to be decreased to less than 30%, stabilization at 400 ppm CO_2e will be required. The Wuppertal Institute concludes: "However, for the 400 ppm CO_2e scenario to be feasible, most probably negative emissions would be required by the end of the century, which could be achieved by combining the use of bio-energy and carbon capture and storage (CCS)" [Sterk, 2009]. What both the 450 ppm and the 400 ppm CO_2e scenarios have in common is a peak in global GHG emissions around 2020. This means that all the countries with significant GHG emissions will have to reduce their emissions by that time. To make this scenario a reality, a global and binding deal implying reliable collective action by basically all net emitters is a key. The fact that this deal would have to become effective in less than a decade poses an enormous challenge for policy makers but also society at large. It appears almost self-evident that ambitious targets will most likely not be achieved by governmental and inter-governmental policy-making and regulation alone. Even a very ambitious and legally binding UN treaty of the Kyoto kind will most likely not lead to the level of changes and reductions described above without the mobilization of a drastic change in the production-consumption nexus of GHG emitting countries. Success in this context certainly means to be able to surpass certain societal tipping points to trigger genuine green growth and large-scale behavioral changes.

It seems impossible to meet ambitious targets without drastic and transformative changes in policy, society, technology, economy and human behavior. Also, it will be necessary to develop a variety of different scenarios and trajectories for change, depending on the geographical regions, as it will hardly make sense to simply apply a German or European model to, say, Asian countries and subregions. Martens and Chang conclude: "The impacts of climate change are felt more immediately by individuals in society and adaptation is typically viewed as obeying the everyday 'self-interests' of individuals. As such, studies on risk perception by individuals, industries and organizations will be critical to understand its influence on the acceptability and ultimate effectiveness of different responses. Mitigation policy is primarily focused on decarbonization and involves interaction among the large emitting sectors such as energy and transport, or else targets efficiency improvements according to specific end-users, commercial and residential" (p. 7).

FROM POLICY TO BEHAVIORAL CHANGE AND SOCIAL LEARNING

The Centre for European Policy Studies (CEPS) states: "All public policy seeks to influence behavior – investment, innovation, consumption – to achieve some socially-desired outcome. If policy is very successful it becomes embedded in social and economic norms and behavior. But it is also important to remember that policy is always acting in a broader economic and social context. This makes it hard to measure the impact of policy because the phenomenon that policy is seeking to influence – in this case GHG emissions – is also affected by many other factors. A more specific reason why measuring *policy effectiveness* is difficult is our still incomplete knowledge about how policy signals affect the behavior of economic actors, not only through prices, but through the relative incentives and penalties they generate, and the expectations they shape over the longer term" [CEPS, 2009]. It appears difficult to measure policy effectiveness – whether that of an individual or a clustered nature – especially if innovative policies are analyzed. It is even harder to project the impact and effectiveness of future policies, for instance in the context of climate change mitigation. Policy analysts usually tend to apply a larger theoretical and analytical framework than economic modelers, to include such variables as power, interest, rules of the game, or normative considerations. It is conceivable that these factors can indeed influence the creation of markets and opportunities, for instance for sustainable investments in new technologies, or energy. While projections or predictions regarding the effectiveness of policies are difficult, no one would challenge the fact that pro-active climate policies are a critical component of larger incentivizing schemes and frameworks. Other important components of such schemes are, inter alia, "high energy prices, investment in greener infrastructures, increasing competitiveness of renewable energy technologies ... as world markets expand, [or] growing concern about energy security" [CEPS, 2009]. Neither policy frameworks nor economic measures alone are likely to create enough potential to trigger significant change in the respective areas of both technological and behavioral patterns, but together can form a strong regime of authoritative forces that indeed do influence the behavior of individuals and societies, and the emergence and diffusion of powerful technological alternatives and green growth, both leading to significant emission reductions.

Given the nature, magnitude and scale of the climate change problematique, large-scale behavioral change is required from the individual to the societal and supra-societal levels across all geographical regions. In this context it is prerequisite to take into account that changes arising from new behaviors are often multifaceted and need the right institutional arrangements and incentive schemes to make them effective and sustainable. This is the point where both pro-active policy making and good incentives for innovative investments have to come in and play out their strength. Integrative approaches, triggered by the right set of policies and economic and financial incentives, can link technological innovation and behavioral solutions and thereby simultaneously address the changes needed to initiate effective mitigation measures. For public policy makers, entrepreneurs and investors alike, the key question in this regard is: How can we avoid the disruption of the economy and turn the desired and necessary changes into a competitive advantage?[2] If the assumption is correct that the root cause of anthropogenic climate change lies in the implications of the unsustainable trajectory of industrial revolutions in the 19th and 20th centuries, and therefore in the so-called "Western economic paradigm", climate change is ultimately a deeply societal and behavioral issue, which means that any solution will have to fully imbibe societal and behavioral factors, and their relation to energy, technology, and production and consumption. Geologists call our time the Holocene but Nobel Laureate Paul Crutzen noted that the last two hundred years have been a really unique era, not only in human history but in the Earth's physical history as well. He coined the term *Anthropocene* to signify the fact that human beings for the first time have taken hold not only of the economy and of population dynamics but of all the planet's physical systems as well: "The Anthropocene is the period when human activity has overtaken vast parts of the natural cycles on the planet, and has done so in ways that disrupt those cycles and fundamentally threaten us in the years ahead" [Sachs, 2007].

Inter-disciplinary research shows that behavioral changes can be catalyzed through processes of social learning. Social learning theory focuses on the learning that occurs within a social (or societal) context. It assumes that human beings learn from one another through observational learning, imitation, and modeling. Albert Bandura is considered the leading proponent of this theory. As it comprises attention, memory and motivation, social learning theory combines both cognitive as well as behavioral frameworks. Social learning theorists say that both awareness on the one side but also expectations of future reinforcements or punishments on the other influence the behaviors that people exhibit [Ormrod, 1999]. In social learning theory, modeling is a powerful means to generate new behavior and influence the frequency of previously learned behaviors. People are more likely to engage in new behaviors when they have high self-efficacy, i.e. when they feel that

Box 1

Necessary conditions for effective modeling:

– **Attention**: Various factors increase or decrease the amount of attention paid, e.g. distinctiveness, affective valence, prevalence, complexity, functional value.
– **Retention**: Remembering what you paid attention to. Includes symbolic coding, mental images, cognitive organization, symbolic rehearsal, motor rehearsal.
– **Reproduction**: Reproducing the image. Including physical capabilities, and self-observation of reproduction.
– **Motivation**: Having a good reason to imitate. Includes motives such as past (i.e. traditional behaviorism), promised (imagined incentives) and vicarious (seeing and recalling the reinforced model).

[2] For more information please refer to the work and findings of the ***Industrial Transformation (IT) project*** of the International Human Dimensions Programme on Global Environmental Change (IHDP), at website: www.ihdp-it.org.

they will be successful in performing them. The box below shows the necessary conditions for successful i.e. effective modeling in social contexts [Ormrod, 1999].

In *Learning to Manage Global Environmental Risks,* the Harvard University-based "Social Learning Group" provided a functional analysis of social responses to climate change, ozone depletion, and acid rain, and analyzed a variety of empirical case studies. The authors examined how the interplay of ideas and actions applied to major environmental problems, by means of social learning, laid the foundations for effective global environmental governance and successful risk management. Their study has great potential and significance for the question of how policy innovation and major technological shifts can lead to effective climate change mitigation through social learning [The Social Learning Group, 2001]. Moreover, Howard Gardner's research suggests that social learning and behavioral change can be achieved through what he calls *representational redescriptions:* "Get the message out in lots and lots of different ways, lots of different symbol systems, lots of different intelligences and lots of different embodiments. The notion that you say it once and it gets through is just wrong. You have to be extremely resourceful in finding diverse ways to get the same desired mind-change across" (please refer to www.cio.com, Issue of 1 April 2004, p. 73 ff). It is self-evident that social learning and large-scale behavioral changes have to be embedded in specific socio-economic landscapes and the larger societal changes of which they are part. This means that different approaches will have to be identified for poor or extremely poor countries, for emerging economies, and for developed countries, respectively.

A rich body of experience is health where social learning and behavioral change have been studied extensively. From health related behavioral issues we know that factors such as perceived threats and benefits or self-efficacy can be strong an lasting drivers for behavioral changes. Major studies in the areas of changed attitudes towards smoking or sexual behavior in connection with HIV prevention, for example, have impressively demonstrated that en masse changes in attitude, lifestyle and behavior can occur relatively rapidly and in a non-linear fashion. The famous *Health Belief Model* (HBM, see box below) highlights some of the most important drivers for change and learning. It is fully conceivable that the mechanics at play during such change processes can be of equal or similar value and function for changes that need to occur with regard to climate change mitigation, adaptation and energy efficiency, although long-term studies with similar epistemological value as is the case in the health sector do not yet exist due to the fact that climate change related behavioral change is a relatively recent phenomenon [Rosenstock et al., 1994].

Box 2

Health Belief Model (HBM)

[Rosenstock, Strecher and Becker, 1994]

– **Perceived Threat:** Consists of two parts: perceived susceptibility and perceived severity of a health condition.
– **Perceived Benefits:** The believed effectiveness of strategies designed to reduce the threat of illness.
– **Perceived Barriers:** The potential negative consequences that may result from taking particular health actions, including physical, psychological, and financial demands.
– **Cues to Action:** Events, either bodily (e.g., physical symptoms of a health condition) or environmental (e.g., media publicity) that motivate people to take action.
– **Other Variables:** Diverse demographic, sociopsychological, and structural variables that affect an individual's perceptions and thus indirectly influence health-related behavior.
– **Self-Efficacy:** The belief in being able to successfully execute the behavior required to produce the desired outcomes. [Bandura, 1977].

A "translation" of the Health Belief Model into a climate change context could look as follows: ***Perceived Threats***: This could be developed societies perceiving scrutiny for their lifestyles' contribution to climate change or developing societies that perceive exploitation by affluent nations; could also be the threat felt by more vulnerable nations to the effects of climate change (i.e. coastal zones). *Perceived Benefits:* One potentially all-inclusive benefit of the climate change crisis could be the global governance system, which requires all countries to work together to reach a common goal. Climate conferences can help to set a precedent, making future global discussions and goal setting run more smoothly. Huge potential benefits lie in the development and application of carbon efficient technologies and related economic benefits and return on investments. *Perceived Barriers:* Perceived barriers with regards to climate change, like in the health sector, include economic demand. Aside from this, the perceived barriers having to do with climate change are not as easily penetrated as in the HBM model. Climate change problems require a lot more effort and commitment. A great barrier of climate change is that it mandates global citizens to not only recognize the faults of their lifestyles, but also the dedication to change. *Cues to Action:* Can be physical or social. Physical cues include the consequences of climate change (i.e. sea-level). Since physical cues are not easily observed by all, social cues like the media publicity observed in Copenhagen are necessary to spread awareness. *Other Variables:* Another variable could be the fact that many people cannot directly observe the effects of climate change. *Self-Efficacy:* "The belief in being able to successfully execute the behaviour required to produce the desired outcomes." [Bandura, 1977] The MDGs could be an example of this; a plan of action that individuals can depend on and institutions can strive to achieve.[3]

In conclusion, we understand that effective innovation in the area of technology and energy requires social learning and the right governance (or policy) environment in order to become effective and sustainable. Especially the social and behavioral aspect is often neglected or underestimated, which is a mistake. Technological innovation works through imagination, niches and novelties. Societies can develop diverse pathways of technological and economic development and adapt within certain conditions. Social learning plays a key role in this context as it allows establishing and maintaining a collective memory of previous adaptive responses. This often happens through institutions, norms and values, and social traditions. Various social groups have introduced changes and new behavioral patterns to resource use and environmental protection. These actions, by means of social learning processes as described above, have no doubt created a different level of public awareness, which can be replicated in other contexts.

SOCIO-TECHNICAL REGIMES AND INNOVATION

The role of knowledge co-production and dissemination, and the mechanisms and mechanics of social learning require more attention, as the foregoing chapter has shown. Yet the emergence of so-called "socio-technical regimes" for sustainability and low carbon economies, and a truly dramatic increase of energy efficiency and productivity around the globe, but especially in Asia, seem critical. New and smart green technologies, energy forms and production means are performing effectively and achieve their best results once they are embedded in a well-educated and sustainability oriented societal framework. Yet this poses some challenges to our governance systems. Our political, legal and economic institutions have to [4]feature a certain amount of adaptive capacity paired with provisions that foster knowledge production and diffusion and technological innovation on the one hand side, and individual and collective learning and behavioral adaptability on the other.

[3] Special thanks to Ms. Kyr Hudson, University of Michigan, for her input.

[4] This paragraphs draws on the work and findings of the Industrial Transformation project (IHDP-IT), at website: www.ihdp-it.org.

Box 3

A larger governance context

Institutions and global governance:

– Changes in institutional and environmental governance frameworks for effective management of ecosystems.

Economics and incentives:

– Economic and financial interventions as instruments to regulate the use of ecosystem goods and services.

Knowledge responses:

– Effective management of ecosystems is constrained by a lack of knowledge and information.

Technological responses:

– Development of technologies designed to increase the efficiency of resource use and reduce impacts of drivers of environmental change.

Social and behavioural responses:

– Public education, civil society action and empowerment of communities can be instrumental in responding to ecosystem degradation.

Source: IHDP

This requires a balance between policy making, economy, technology, and social learning and acceptance. A key question in this context is the one on how societies can effectively link human, economic and social development with environmental sustainability and bold climate change mitigation efforts. The research agenda of the "Industrial Transformation Project" of the International Human Dimensions Programme on Global Environmental Change (IHDP-IT), has triggered remarkable work in the fields of energy and material flows, food, cities with focus of water and transportation, information and communication, governance and transformation processes [IT 1999]. IHDP-IT defines the foundation of industrial transformation research, particularly in Asia, as follows: "Industrial Transformation research starts with the notion that changes in technologies, put differently, changes in the ways in which humans use environmental resources and services, are embedded in the socio-economic realm and modify the natural environment. This embraces processes and products, production and consumption chains and distribution and disposal activities. IT research is also interested in the institutions and incentives that shape these systems (i.e. property, liability, regulations), and how these situate and influence social actors (government, producers, and consumers)" [Asian Transitions and Globalization, 2006]. It is critical to understand how these systems might be able to change without producing significant additional GHG emissions and ecosystem failure. In other words, the interaction of economy driven innovation with change processes in provisional systems influenced by societal development (e.g. energy, mobility, food) is at the heart of these questions [Olsthoorn and Wieczorek, 2006].

Industrial transformation and sustainability transitions have been an important focus of the research and policy communities in a number of European countries already for some time, especially regarding the aspect of large-scale innovation in production and consumption. Such research and policy debates have not only included technological aspects, but also the roles of institutions and behavior. However, "there is a need to connect these 'western' debates about transitions and sustainability with current understandings of processes of social, political and economic development in other parts of the world. Given the transformative changes are most manifested in the rapidly urbanizing and developing Asia, this part of the world appeared particularly challenging. A characteristic feature of much of the current Asian policies and research linked to technology, industry and sustainability relates to product-process innovation and to the question of how to achieve near-term improvements in energy-, resource- and pollution-intensities through the adoption of best available technologies. The achievement of higher-level environmental and sustainability targets – including low-carbon or less resource-intensive development pathways – has [so far] attracted less attention, partly because these economies are still relatively less resource-intensive per capita than most industrialized economies" [Olsthoorn and Wieczorek, 2006].

The term "transitions" usually refers to long-term and large-scale changes in human environment-interactions. Transitions touch upon deeply cultural, social, behavioral and institutional aspects in building upon or bringing about novelty and innovation, especially in the areas of energy, technology, infrastructure and transport. Their co-efficient can be measured in a variety of ways, but in the context of climate change energy and resource intensity are a key. Asia matters because of the sheer scale and rate of urban and industrial growth and "their profound implications for environmental quality and resources locally, regionally and globally, which make Asia central to sustainable development on a global scale. Asia is in the midst of a massive urban-industrial transition that in absolute terms of urban population growth and scale of economic activity is historically unprecedented". Can this period of industrial transformation in Asia be useful for sustainable development world-wide? From research in East Asia we know that pro-poor economic growth and technological capability development have worked if and where the right institutional set-up was provided. "The relevant institutional conditions range from fundamental starting conditions for industrial-environmental capabilities building (such as political stability, rule of law, and control of corruption), effectiveness of government institutions in carrying out policies, availability of information around technology choices..., to the degree to which development options are structured by international agreements" [Olsthoorn and Wieczorek, 2006].

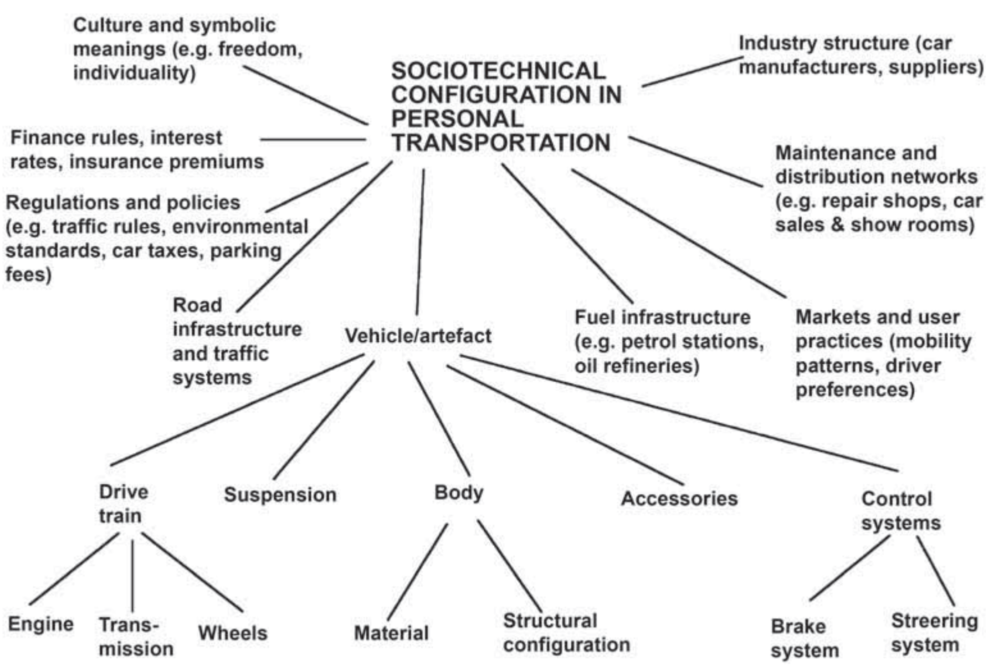
Taking the sustainability dimension to both consumption and production as well as to both social and technical change must be the overarching goal of every low-carbon development approach. What is needed is a long-term perspective of big change however occurring in a relatively short run. The history of technological change and innovation is quite promising in this regard as it shows in a number of cases that even radical and relatively abrupt changes are possible, e.g. the transitions from sail based to steam based intercontinental transport, from horse based to automobile based mobility, from home based to city grid based sanitation, or from note-pad based to PC based information systems. According to Fred Steward, "we can look at these examples and can get hold of some patterns such as e.g. the dynamics of transformative innovation and search guidance as to a possible point of intervention. We see that radical change is systemic in nature, takes time, embraces technological and social innovation, involves diversity of actors – on both the production and the consumption side – and disrupts certain social arrangements." Steward states that the merit of this approach to transitions is that it conceptualizes innovation in relation to a prevailing domain of socio-technical practice in contrast to a more traditional perspective on single technologies or sectors, which is far too narrow a vision. The transitions approach takes note of the complexity of systems and the huge diversity of involved actors. Applying this approach to the question of climate-resilient and inclusive economic growth and innovation seems promising. It is about purposive, not merely emergent change as such change has to be induced.[5]

The transitions approach thus suggests that any technical innovation is embedded in a larger frame of socio-economic conditions and the dynamics of social change. In other words, social change and technological change usually go hand in hand, as the cases from technological history have shown. Important in this connection is the concept "socio-technical regime" which refers to a relatively stable configuration of institutions, technologies, rules, practices and networks of cooperation that determine the evolution

[5] The Steward quotes are taken from the report Asian Transitions and Globalisation: Towards an Analytical Framework. Workshop report (6–7 July 2006, Chiang Mai, Thailand), ed. by Anna J. Wieczorek.

and use of technology [Kemp et al., 1998]. In its entirety a socio-technical regime includes production, diffusion and use of technology [Geels, 2002 and 2004]. Please refer to Stamboulis Y. and Papachristos G. [2008]: Investigation and modelling framework of biofuels as a new socio-technical regime, the 2008 Conference of the System Dynamics Society (conference paper). To illustrate how such regimes work, the example of a typical configuration (or "regime") in the car-manufacturing sector is given below.

The picture shows the wider "landscape" in which the development, production and diffusion of a car is typically embedded. This scheme can be applied to any (new) technology. The purposive selection and development of new technologies has to take into account and model a variety of non-tech factors, incuding such things as culture and symbolic meanings, user practices and policies alongside finance rules and markets etc. Such a configuration around an artefact or technology hence can be called a socio-rechnical regime. Regimes tend to be stable and sometimes even "sticky". Replacing existing regimes by new ones – in the given case more climate-friendly ones – is essentially like initiating paradigm shifts. To yield real green and low-carbon growth in rapidly emerging countries, the wider production-consumption field will have to undergo a number of such paradigm shifts, i.e. regime changes. Smith et al. write: "We understand regime change to be a function of two processes: (1.) Shifting selection pressures bearing on the regime; and (2.) The coordination of resources available inside and outside the regime to adapt to these pressures. Conventional economic analysis of technical change tends to focus on pressures that operate visibly at the level of the firm (such as pricing, competition, contracts, taxes and charges, regulations, standards, lia- bility, profitability, skills and knowledge). Analysis at the level of the socio-technical regime, on the other hand, includes such factors, but goes beyond them to consider less economically visible pressures emanating from institutional structures and conventions, including changes in broad political economic 'landscapes', or wider socio-cultural attitudes and trends [Geels, 2004]. These can be directed at specific regimes, like the activities of the anti-nuclear



Source: Geels, 2004

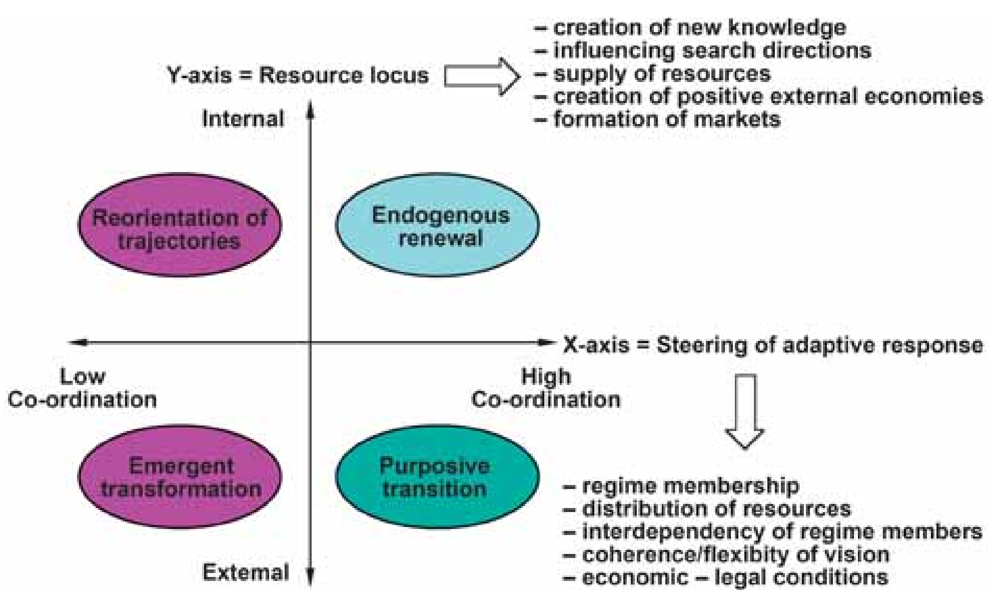
movement. Or they can be more general, like the ebb and flow of environmental attitudes in society" [Smith et al., 2005].

Smith et al. continue: "All regimes have some capacity and resources to respond to the selection pressures bearing on them. We refer to this feature as the ***adaptive capacity of a regime.*** In developing Asian economies we observe the rapid growth [...] of socio-technical systems... The specific nature of these socio-technical systems, the technologies they are based on, and the patterns of economic growth and consumption they foster, will have a profound influence on the resources and energy profile of the developing economy." Economic development in Asia has been analyzed as a process of systems innovation featuring the emergence of "new socio-technical systems, replacing or radically altering traditional and early-modern systems in key sectors, including energy, transport, agriculture and food, water and urban development" [Berkhout et al., 2008]. New knowledge comes to bear on changing policy settings and institutions as well as a changing social or societal context. "The central elements of these systems – socio-technical regimes – are the embedded outcomes of processes occurring at different levels of the system, including innovation in niches and adjustment of landscapes (systems of innovation)" [Berkhout et al., 2008].

CONCLUSION

The systems innovation approach helps us understand economic development as an ongoing and iterative process of formation and/or reconfiguration of so-called socio-technical regimes. The below chart by Smith et al. [2005] maps out four types of transitional development trajectories. It appears that "purposive transition", which requires a ligh level of coordination between regime members (e.g. from public authorities via technological communities, the finance sector to consumers), and a relatively high level of external resources, is the most promising one.

According to Jacobsson and Johnson [2000], innovation is supported by the following functions: Creation of new knowledge; Influence over search processes among consumers and producers; Supply of resources; Creation of positive external economies; and Formation of new markets. It is quite essential to work across all of these functions to establish a framework of policy,



investment and targeted action to stimulate technological change. Berkhout et al. [2008] conclude: "It becomes possible to envisage the emergence of new, more resource-efficient socio- technical systems as the basis of more sustainable development pathways in developing Asia. Such sustainable socio-technical systems will emerge in the context of interaction between domestic and globalized markets, knowledge flows and governance". Emerging socio-technical regimes and transition contexts will vary significantly. It is remarkable that precisely this context of variation has given rise to numerous "sustainability experiments", such as eco-cities, biofuel initiatives and sustainable forestry projects [Berkhout et al., 2008] that not only demonstrate what is possible in terms of transitions and regime change, but also how policy frameworks, investment schemes and assistance will have to vary.

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L'EUROPE DANS LA RÉGIONALISATION DE L'ÉCONOMIE MONDIALE

EUROPE WITHIN THE GLOBAL ECONOMIC REGIONALIZATION

ABSTRACT

The economists have thoroughly studied the relations between economic globalization and the regionalization of international trade exchanges. Geographers have started studying the process of regionalization in the 1990s. Nevertheless, most of their studies are based on the row value of trade exchanges of goods. This indicator is quite useful but it suffers from major shortcomings. For instance, it is biased by the size of the economies involved in these exchanges. In order to display a more nuanced picture of globalization, it is necessary to combine it with another indicator: the bilateral intensity of trade exchanges. Both indicators are applied to Europe in order to see to which extent it is concerned by the regionalization of the global economy, especially since the end of the cold war and the end of the ideological blocs.

KEY WORDS: regionalization, trade exchanges of goods, bilateral intensity of exchanges, Europe, neighbourhood, Russia

INTRODUCTION

La mondialisation et la régionalisation de l'économie mondiale vont de pair [Siroön, 2000]. Les économistes ont montré que la régionalisation correspondait à une augmentation des échanges et des interactions économiques et sociales entre des pays qui appartiennent à une même région du monde [Balassa, 1962; Frankel *et al.,* 1995; Baldwin, 1997; Frankel, 1998; Krugman, 1991]. Ils ont tenté de la mesurer et d'en saisir les effets sur les échanges commerciaux [Viner, 1950; Anderson, 1979; Drysdale & Garnaud, 1982; Stein & Wei, 1996; Freudenberg *et al.,* 1998; Maurel, 1998] et sur le développement économique en général [Bhagwati, 1992; Mashayeki, 2005; Banque mondiale, 2009, Newfarmer *et al.,* 2005].

Les géographes se sont intéressés tardivement à la régionalisation [O'Loughlin & Van der Wusten, 1990; O'Loughlin, Anselin, 1996; Poon *et al.,* 2000; Taillard, 2004; Didelon & Grasland, 2007; Beckouche, 2008; Beckouche & Richard, 2008; Taglioni & Théodat, 2008]. Ils y consacrent encore peu d'études, préférant étudier la mondialisation à l'échelle globale et ses effets à l'échelle locale [Dollfus, 2007; Lévy, 2008]. Parmi eux, à part quelques exceptions, beaucoup utilisent des indicateurs intéressants comme la valeur brute des échanges commerciaux. Mais celle-ci est insuffisante et biaisée car elle présente l'inconvénient d'être fortement biaisée par des effets de taille [Richard & Tobelem Zanin, 2007]. C'est d'autant plus regrettable que les économistes ont mis au point des indicateurs qui permettent de dépasser cette difficulté [Freudenberg, 1998] et que la géographie est elle-même une discipline assez bien outillée pour participer utilement aux débats sur ce théme.

L'objectif de cet article est de vérifier la validité de l'hypothése de la régionalisation à travers l'exemple de l'Europe. Comment cette partie du monde participe-t-elle à ce processus? La disparition de l'URSS et la fin de la guerre froide ont-elles eu un impact sur la régionalisation du commerce international en Europe? On utilisera deux

Tabl. 1. Part du commerce interne (exportations) de plusieurs ensembles régionaux dans le commerce mondial total[1]

Exportateurs	Moyenne 1967–1976	Moyenne 1977–1986	Moyenne 1997–1996	Moyenne 1997–2006
Amérique	11,3	10,2	10,2	12
Asie Océanie	5,2	7,1	10,5	12,3
Eurafrique	48,6	44,8	42,1	38,5

[1]La Russie et la Turquie sont incluses dans l'ensemble Eurafrique.

Source : CHELEM-CEPII, 2009

Tabl. 2. Part du commerce interne (exportations) de plusieurs ensembles régionaux dans les exportations mondiales

Exportateurs	Moyenne 1967–1976	Moyenne 1977–1986	Moyenne 1997–1996	Moyenne 1997–2006
Afrique subsah	0,1	0,1	0,1	0,1
Monde arabe	0,1	0,1	0	0,1
Amérique latine	1	0,9	0,8	1
Asie du sud est	0,8	1,5	2,5	3,1
Alena	7,1	6,6	7,5	8,9
UE 15	24,6	22,5	26,6	22,5
UE 27	–	–	28,8	26,6

Source : CHELEM-CEPII, 2009.

indicateurs du commerce afin de donner une représentation nuancée de la régionalisation. Dans les deux premiéres parties, on s'intéressera à l'évolution de la valeur brute des échanges de marchandises. Dans les deux derniéres, on s'intéressera à l'intensité des échanges commerciaux bilatéraux. On ne présupposera par l'existence d'une région européenne dans le commerce mondial de marchandise. C'est la cartographie des deux indicateurs choisis qui permettra de vérifier son existence et d'en saisir les limites éventuelles.

L'UNION EUROPÉENNE DANS LA RÉGIONALISATION DES ÉCHANGES COMMERCIAUX: UN GÉANT EN REPLI?

Que pése l'Europe dans la régionalisation du commerce mondial?

La tendance à la régionalisation n'est pas claire partout dans le monde (tabl. 1). La part des exportations internes de l'Eurafrique (Europe + Proche et Moyen Orient + Afrique) dans les exportations mondiales a reculé sensiblement depuis la fin des années 1960. Pour l'Amérique, elle est stable. L'Asie orientale (comprenant l'Australie et la Nouvelle-Zélande) fait exception puisque ses exportations internes moyennes annuelles sont passées de 5,2% à 12 ,3% du total mondial.

Pour des ensembles géographiques plus petits, les tendances sont contrastées. Les exportations internes de l'UE 15 représentent une part décroissante des exportations mondiales depuis les années 1970 (tabl. 2). Et l'évolution de la part du commerce interne de l'UE 27[1] aussi connaît une baisse depuis les années 1990, au contraire d'autres régions.

[1] Il peut sembler artificiel de faire des comparaisons décennales pour l'UE 27 alors que celle-ci n'existe que depuis janvier 2007. Pour être plus rigoureux, on devrait dire plutôt qu'il s'agit de "l'ensemble régional constitué par les 27 pays actuellement membres de l'Union européenne ".

Tabl. 3. Part du commerce intrarégional dans le commerce total de plusieurs ensembles régionaux

Exportateurs	Moy 1967–1976	Moy 1977–1986	Moy 1997–1996	Moy 1997–2006
Alena	39,3	38,2	41,4	36,7
Amérique latine	17,5	17,5	16,9	18,6
MERCOSUR	8,4	8,6	15,5	18,7
ASEAN	15,1	17,7	18,3	21
UE 15	58,1	58,1	64,3	60,5
UE 27			66,3	66,2
Source : CHELEM-CEPII, 2009				

L'Europe : un commerce international en voie de dérégionalisation?

Si on observe la part du commerce intra régional dans la commerce total des pays membres de plusieurs ensembles régionaux (tabl. 3), on peut distinguer trois types de situations.

Dans certaines parties du monde, la part du commerce interne a augmenté en proportion du commerce international total des pays membres (ALENA, MERCOSUR, ASEAN). En Amérique latine, elle est restée stable. En revanche, l'UE 15 et l'UE 27 sont en voie de *dérégionalisation* (tabl. 3, graph. 1 et 2).

Un élargissement géographiquement différencié de la région commerciale européenne

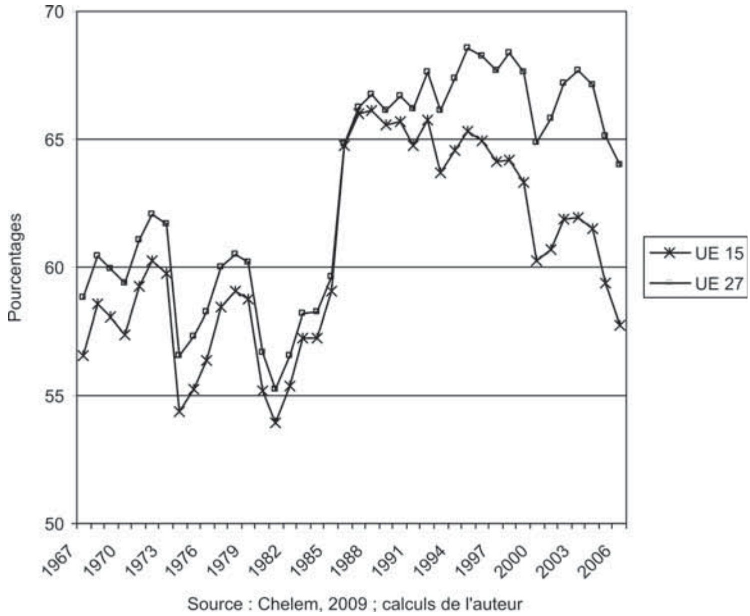
A l'intérieur de l'ensemble composé par l'UE et les régions voisines, les évolutions du commerce sont contrastées. Depuis plus d'une vingtaine d'années, le voisinage de l'UE 15 [2] représente une part croissante de son commerce extérieur (graph. 3). Cela s'explique en partie par la réorientation du commerce des anciens satellites de l'URSS (PECO) vers l'Europe de l'Ouest. Parallélement, la part du commerce intrarégional de l'UE 15 baisse depuis le début des années 1990. L'UE 15 est donc en train d'élargir son assiette territoriale aux espaces les plus proches: la baisse de la part du commerce intra régional de l'UE 15 est corrélée avec l'augmentation de la part des voisinages dans son commerce extérieur. A la *dérégionalisation* de l'Union européenne correspond une *rerégionalisation* dessinant un ensemble géographique plus étendu.

Dans le détail, la régionalisation du commerce extérieur de l'UE 15 progresse trés vite vers l'est alors qu'elle stagne ou recule au sud et au sud-est (graph. 4). La part des NEI occidentaux (Belarus, Moldavie, Russie, Ukraine) et du Caucase (Arménie, Azerbaïdjan, Géorgie) dans le commerce extérieur de l'Union est passée de 1 % à 3% en 6 années seulement. C'est la Russie qui a le plus contribué à cette évolution. La part des pays méditerranéens est restée stable autour de 3% pendant une vingtaine d'années.

Inversement, les régions du voisinage sont en train de diversifier la géographie de leur commerce extérieur depuis les années 1990 (graph. 5). L'UE est un partenaire toujours important mais en recul, à l'exception des NEI occidentaux et du Caucase.

Pour l'UE 27, les évolutions sont concordantes. La part de l'UE 27 dans le commerce extérieur des régions voisines baisse ou stagne depuis les années 1990 à l'exception des NEI occidentaux (graph. 6). Dans l'autre sens, la part des voisinages en général dans le commerce extérieur de l'UE 27 (graph. 7) est passée de 3,6% à 5% (en ne comptant pas la région du Golfe). Cela confirme l'hypothése d'une régionalisation du commerce international

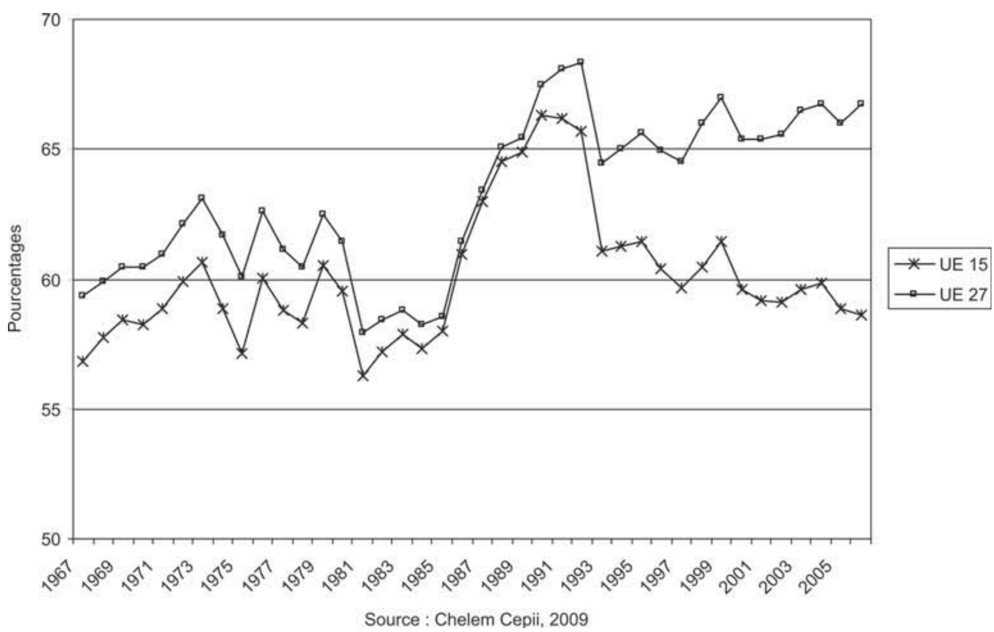
[2] Pays de l'AELE, Balkans occidentaux, CEI occidentale et Caucase, PECO, pays méditerranéens.



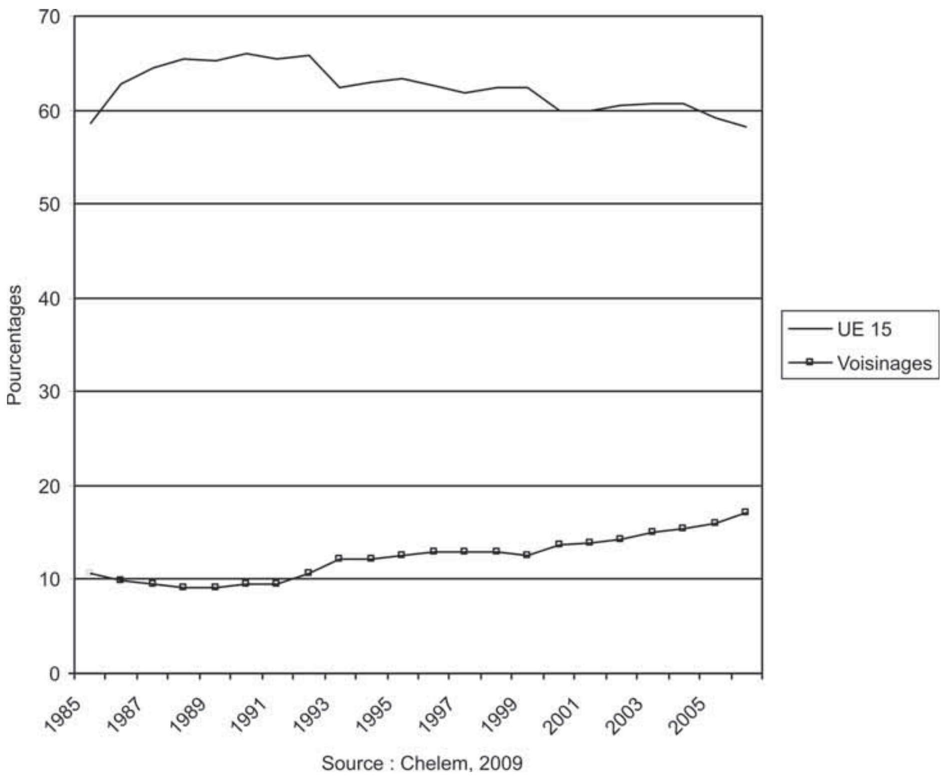
Graph. 1. Part des importations intrarégionales dans les importations totales de deuz ensembles régionaux

européen en direction de l'est, tandis la part des pays méditerranéens et des Balkans occidentaux est stable et que celle du Golfe et de l'ensemble Norvége – Suisse baisse.

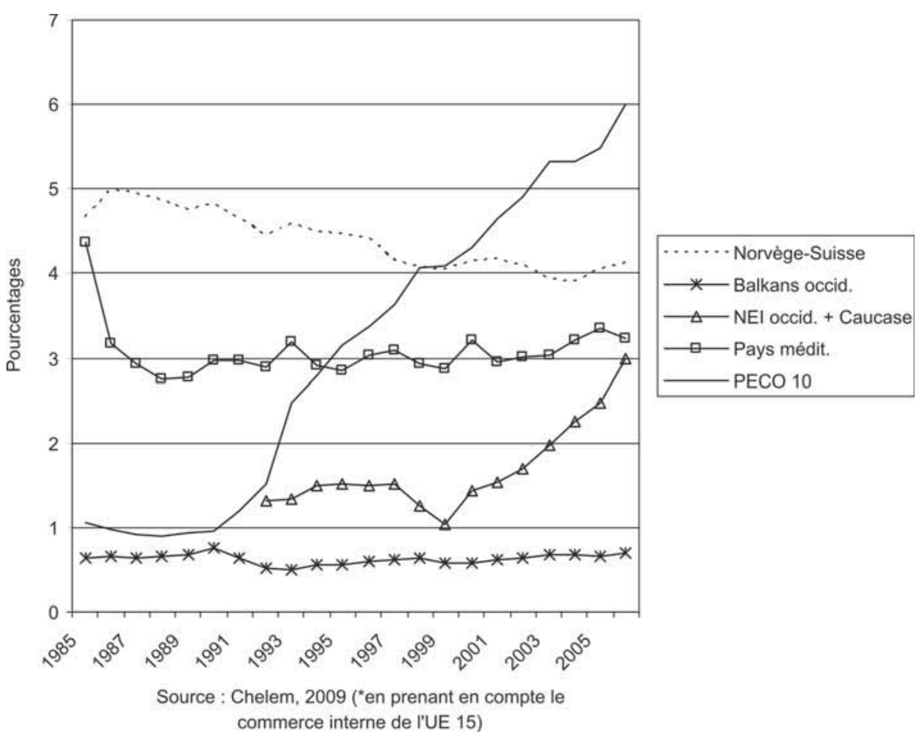
On peut donc formuler une hypothése. Il y aurait un processus de régionalisation commerciale en cours entre l'Union européenne et l'ex-URSS avec une intégration économique des deux



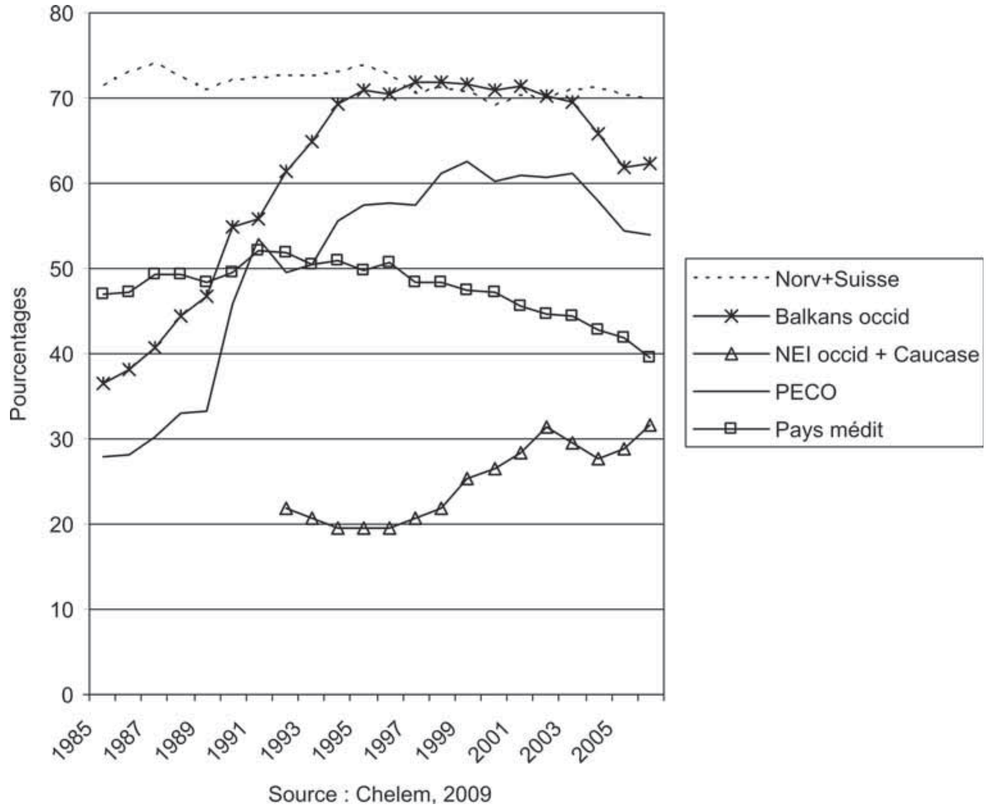
Graph. 2. Part des exportations intrarégionales dans deuz ensembles régionaux



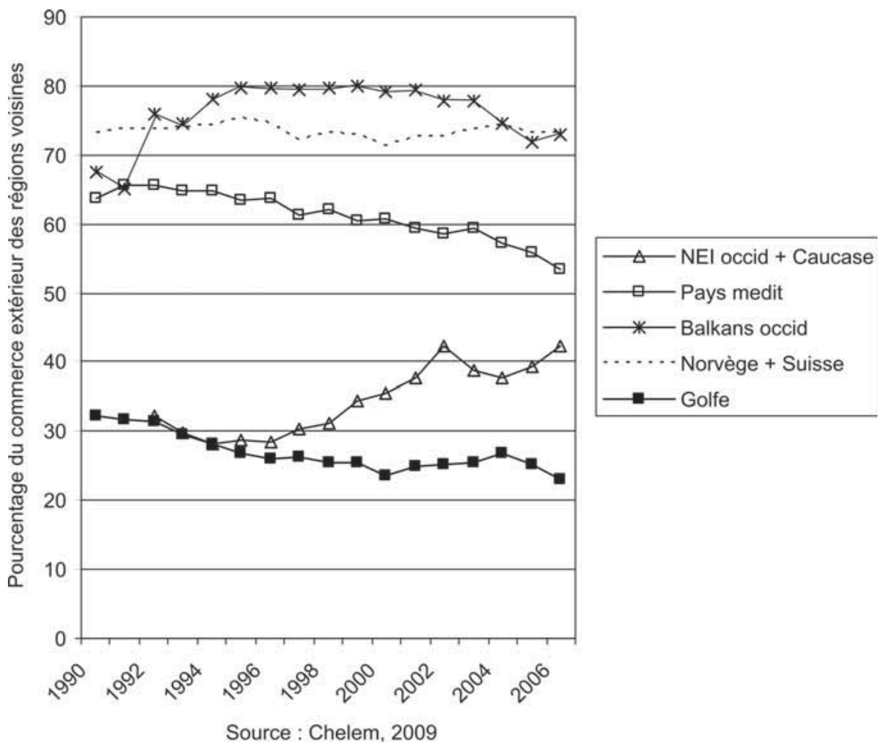
Graph. 3. Part du voisinage consolidé dans le commerce extérieur de l'UE 15



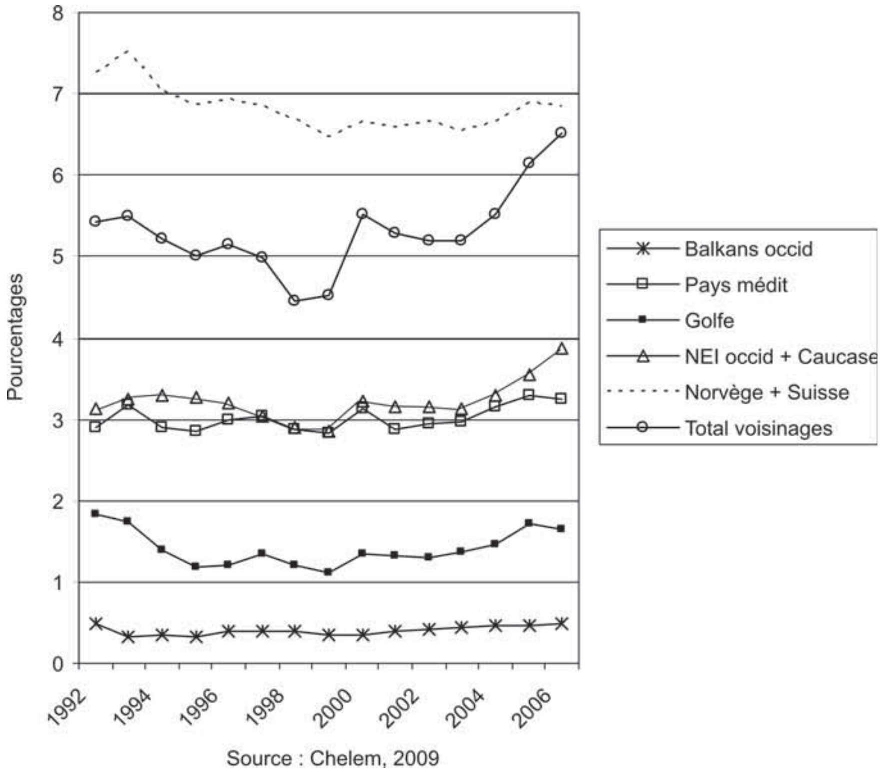
Graph. 4. Part des voisinages dans le commerce extérieur (imp + exp) de l'UE 15*



Graph. 5. Part de l'UE 15 dans le commerce extérieur des voisinages

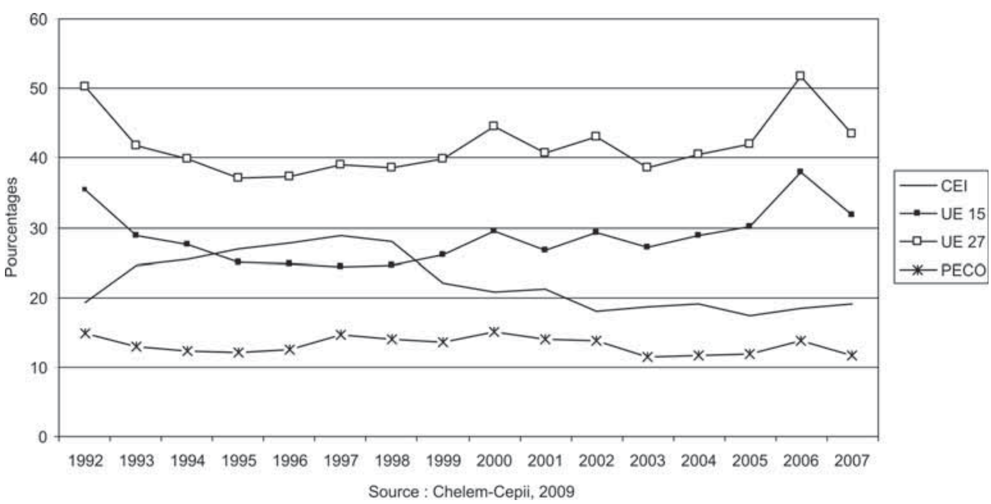


Graph. 6. Part de l'UE 27 dans le commerce de plusieurs ensembles régionaux

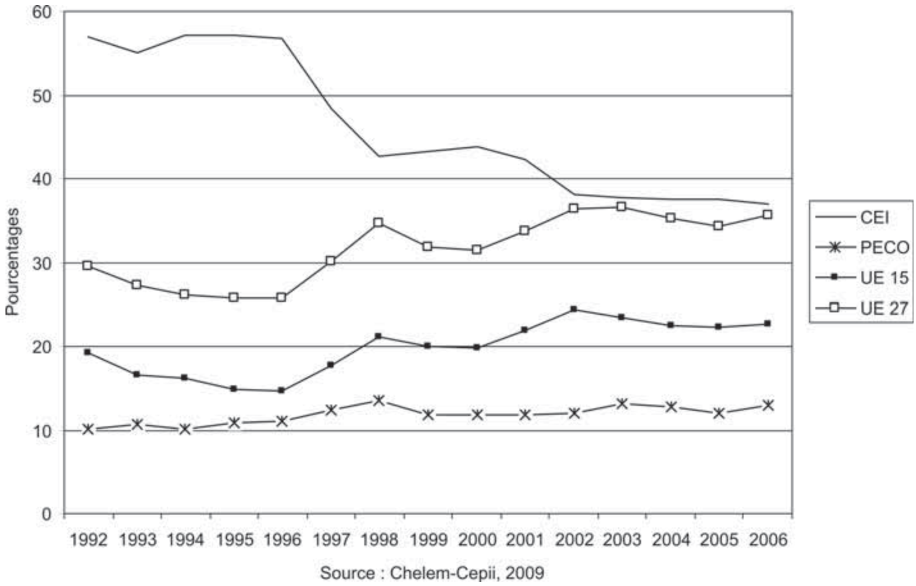


Graph. 7. Part des voisinages dans le commerce extérieur de l'UE 27

ensembles dans une seule et même région à l'intérieure de laquelle les interactions entre économies iraient croissant. Cette hypothése retient l'attention car l'augmentation des échanges commerciaux avec l'UE est corrélée à une baisse du commerce intrarégional de la CEI (graph. 8 et 9). La *dérégionalisation* de l'UE vient rencontrer celle de l'ancienne URSS.



Graph. 8. Ventilation géographique du commerce extérieur de la CEI



Graph. 9. Ventilation géographique du commerce extérieur de l'Ukraine

LA RÉGIONALISATION DE L'ÉCONOMIE MONDIALE VUE À TRAVERS LES INTENSITÉS D'ÉCHANGES BILATÉRAUX

Un indicateur plus nuancé que la valeur des échanges : l'intensité des échanges bilatéraux

La valeur des échanges commerciaux présente un inconvénient. Elle est influencée par la taille des pays qui échangent et donne une vision partielle de l'intensité réelle des relations commerciales. Il faut donc utiliser des indicateurs qui permettent de neutraliser l'effet de taille. C'est possible avec le birapport d'intensité bilatérale des échanges [Freudenberg, Gaulier & Unal-Kesenci, 1998 ; Gaulier, Jean & Ünal-Kesenci, 2004]. Il permet de rapporter la valeur observée d'un flux d'échange bilatéral (exportation + importation) entre deux pays à la valeur théorique de ce même échange, elle-même estimée par la taille commerciale des pays (c'est-à-dire leur poids relatif dans le commerce mondial) dans le commerce mondial. Dans cette partie, on cartographie et on analyse de la répartition de la différence entre la valeur observée des échanges commerciaux entre pays et la valeur attendue telle que calculée selon le modéle. On tient compte du résidu relatif (l'écart en pourcentage entre valeur théorique et valeur observée).

La région commerciale européenne et les interactions Union européenne – Voisinages

A l'échelle mondiale, les intensités d'échanges commerciaux de marchandises font apparaître plusieurs ensembles régionaux. La carte 01 montre la répartition des intensités d'échange en 2004-2006 entre tous les pays ou groupes de pays du monde. Tous les birapports supérieurs à 1 sont représentés, ce qui revient à montrer tous les couples de pays dont la valeur des échanges bilatéraux observés est égale ou supérieure à la valeur attendue selon le modéle. Mais ce seuil est trop bas pour faire émerger des paquets de pays qui entretiennent des relations commerciales privilégiées.

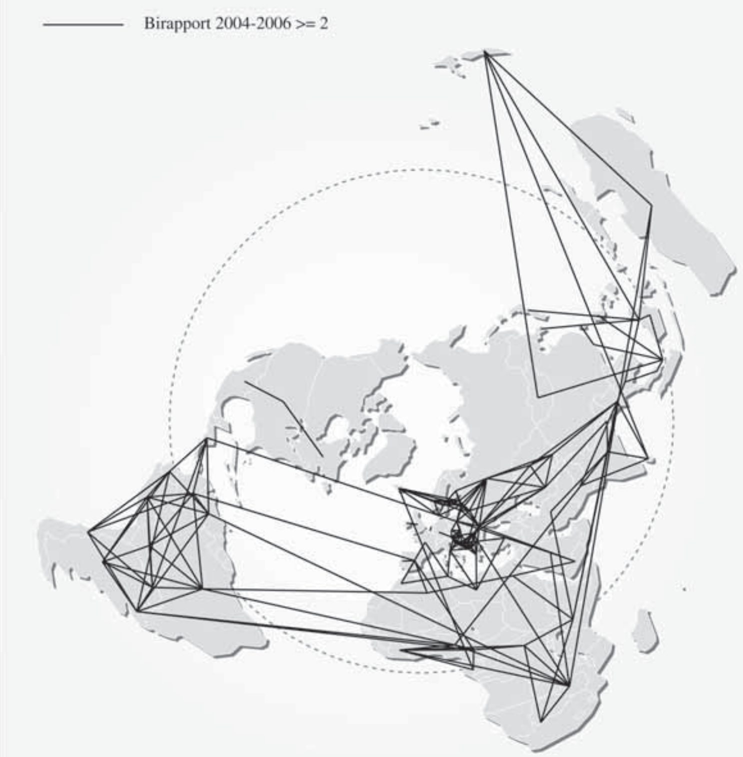
La carte 02 est plus discriminante et permet de distinguer un ensemble latino-américain (comprenant l'Amérique centrale et les Caraïbes), l'ALENA, un ensemble pacifico-asiatique et un ensemble européen dont les limites excédent largement celles de l'Europe conventionnelle. On voit sur la carte de fortes interactions commerciales entre les pays de l'Union européenne et l'Afrique du Nord, la Turquie et les pays de l'ancienne Union soviétique. Cela confirme l'existence d'une région commerciale européenne composée de pays qui ont davantage d'interaction entre eux qu'avec le reste du monde. Cette carte montre aussi qu'il existe des paquets de pays à l'intérieur de cette région. C'est ce que confirme la carte 03 réalisée à partir du même indicateur mais à l'échelle de l'Europe élargie aux voisinages géographiques. On peut voir par exemple que l'ex-URSS est sous ensemble encore fortement intégré en 2004–2006.

Régionalisation versus dérégionalisation en Europe

La comparaison entre la situation du milieu des années 2000 et celle du début des années 1990 montre des évolutions sensibles. La carte 04 montre que les ensembles régionaux relevés ci-dessus

01 - Couples de pays pour lesquels le commerce bilatéral observé (en valeur) est au moins égal au commerce attendu, selon le modèle

02 - Couples de pays pour lesquels le commerce bilatéral observé (en valeur) est au moins deux fois superieur au commerce attendu, selon le modèle

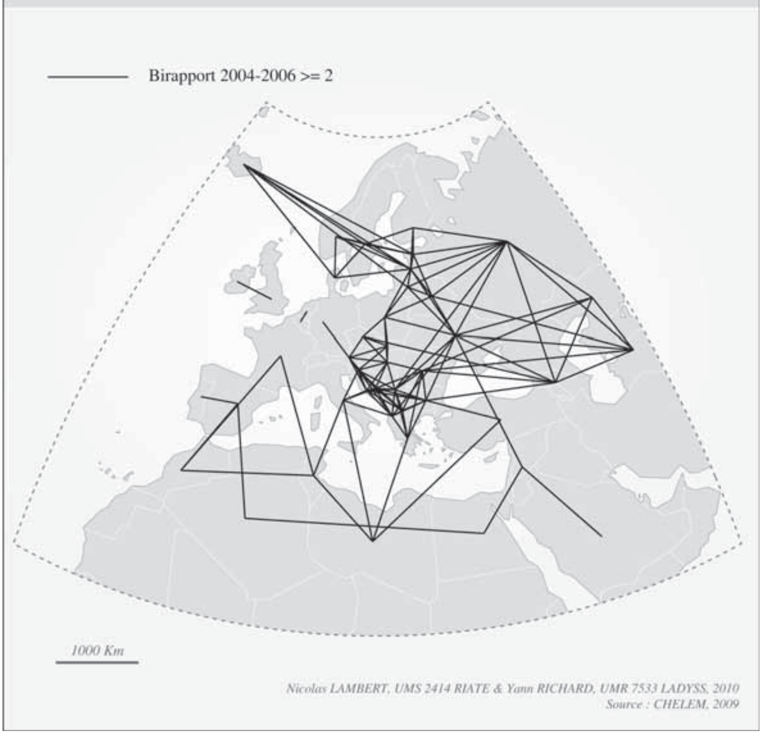


Nicolas LAMBERT, UMS 2414 RIATE & Yann RICHARD, UMR 7533 LADYSS, 2010
Source : CHELEM, 2009

étaient déjá bien identifiables au début des années 1990. La région commerciale européenne s'étendait de l'Afrique du Nord à l'Asie centrale au Proche Orient. En une quinzaine d'années, le nombre des relations commerciales privilégiées a baissé dans cette région du monde alors qu'il est stable (Amérique centrale et du sud) ou qu'il augmente (Asie de l'est et du sud-est) dans d'autres régions. On constate un rétrécissement de la région européenne au sud et au sud-est. La comparaison des cartes 01 et 05 confirme cette tendance. On voit en particulier un recul sensible des liens privilégiés entre la France et le Maghreb. De même, les liens commerciaux privilégiés à l'intérieur de l'ex-URSS sont moins nombreux.

Le recul est spectaculaire pour les couples de pays dont les échanges bilatéraux observés étaient et sont au moins deux fois supérieurs aux échanges attendus selon le modéle. C'est ce que montre la comparaison des cartes 02 et 05. La réduction des interactions commerciales à l'intérieur de la région européenne et son rétrécissement sur les marges

03 - Couples de pays pour lesquels le commerce bilatéral observé (en valeur) est au moins deux fois superieur au commerce attendu, selon le modèle



est trés spectaculaire si on compare ces deux évolutions avec l'étonnante stabilité de l'ensemble latino américain. Cela confirme l'hypothése la *dérégionalisation* de l'Europe. La distribution du résidu relatif à l'échelle macrorégionale permet de cerner ces évolutions avec plus de précision.

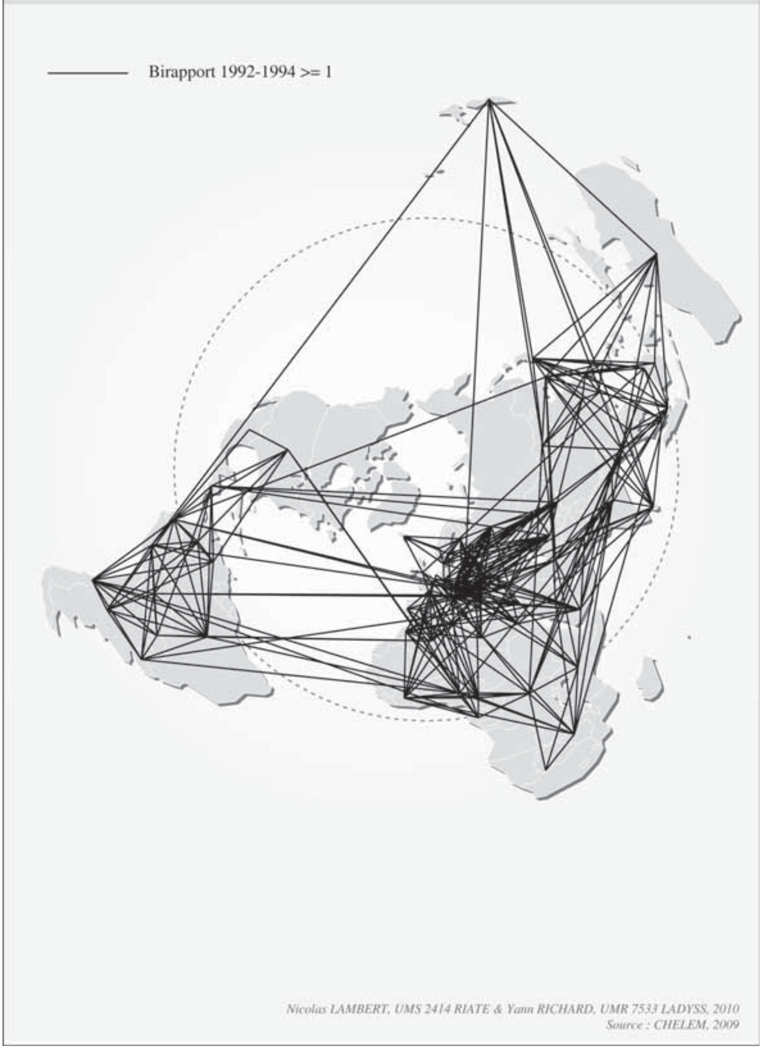
La comparaison des cartes 03 et 06 confirme la rétraction nette de la région commerciale européenne au sud et au sud-est. Elle montre surtout des évolutions contrastées dans les différentes sous-régions de ce grand ensemble : recul des traditionnelles relations commerciales trés privilégiées entre pays de la rive nord et pays de la rive sud de la Méditerranée ; intensité stable des échanges commerciaux entre les pays de l'Europe centrale (Pologne, République Tchéque, Slovaquie, Hongrie, Slovénie, Roumanie, Bulgarie); baisse sensible du nombre de liens commerciaux privilégiés à l'intérieur de la région ex-soviétique; dissolution rapide des échanges bilatéraux privilégiés entre l'ancienne URSS et les PECO (anciennes démocraties populaires). On en retire nette impression de "détricotage" de l'héritage soviétique dans le voisinage oriental.

L'idée de régionalisation doit donc être trés sérieusement nuancée. La région commerciale européenne élargie montre des évolutions contrastées apparemment contradictoires. Le modéle retenu permet de confirmer son existence, mais les cartes montrent aussi des évolutions trés rapides aussi bien en interne que sur les marges.

Les voisins orientaux dans la recomposition géographique du commerce international de la région européenne

Malgré ces évolutions, le voisinage oriental forme encore un ensemble trés visible et trés intégré dans l'Europe élargie. Alors que les voisinages sud (rive sud de la Méditerranée)

04 - Couples de pays pour lesquels le commerce bilatéral observé (en valeur) est au moins égal au commerce attendu, selon le modèle



ou sud-est (Machrek) montrent davantage de liens privilégiés avec l'Europe qu'entre eux. Toutefois, l'analyse détaillée de l'évolution des intensités bilatérales d'échanges de plusieurs pays (Russie, Ukraine, Belarus, Kazakhstan) ou groupes de pays (Caucase) montre qu'il n'y a pas un voisinage oriental mais plutôt des voisinages orientaux de l'Union européenne. Au sein de l'ancienne URSS, on peut distinguer au cas par cas des évolutions diverses.

En ce qui concerne la Russie, les évolutions sont sensibles mais pas radicales (carte 07). Les intensités bilatérales d'échanges entre la Russie et les économies de l'ancienne URSS ont baissé, surtout pour le groupe des pays du sud de l'Asie centrale (Tadjikistan, Turkménistan, Ouzbékistan) et pour la Lituanie. On remarque aussi une baisse des intensités d'échanges bilatéraux avec les pays de l'Europe centrale (surtout l'ancienne Tchécoslovaquie, la Hongrie, la Bulgarie et la Roumanie). Avec l'Europe de l'Ouest, les intensités d'échange ont évolué à la hausse ou à la baisse, mais ces évolutions ne sont pas significatives car les birapports d'intensité d'échange restent bas.

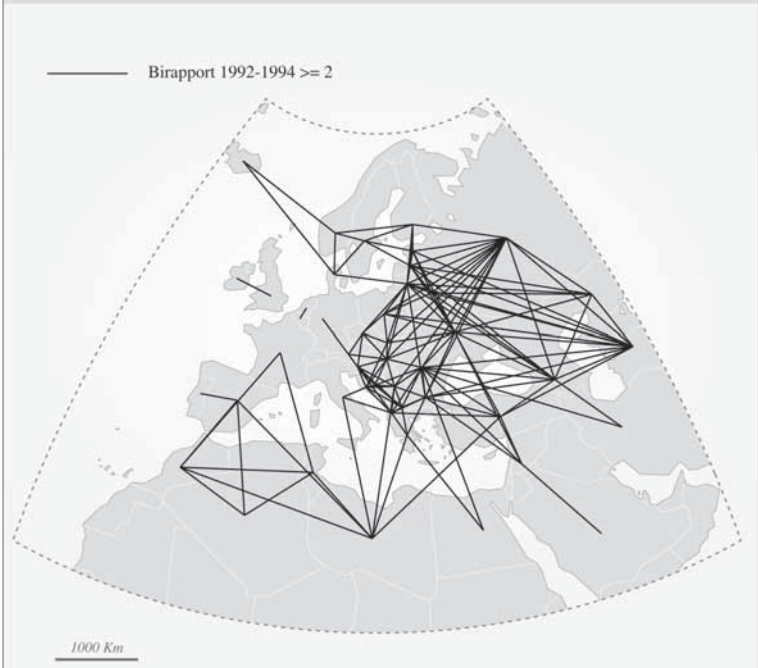
05 - Couples de pays pour lesquels le commerce bilatéral observé (en valeur) est au moins deux fois superieur au commerce attendu, selon le modèle

Nicolas LAMBERT, UMS 2414 RIATE & Yann RICHARD, UMR 7533 LADYSS, 2010
Source : CHELEM, 2009

L'impression de "détricotage" de l'espace économique soviétique est tempérée par la stabilité de la répartition géographique des intensités d'échanges commerciaux. Malgré la baisse décrite ci-dessus, c'est toujours avec les pays de l'ancienne Union soviétique que la Russie commerce avec la plus grande intensité. On voit que les liens restent privilégiés avec le Kazakhstan, l'Ukraine et le Belarus. Les intensités d'échanges restent moyennes avec les pays de l'Europe centrale anciennement socialiste et basses voire trés basses avec les pays de l'ancienne Europe de l'Ouest, à une exception prés (Suéde). On peut donc parler d'un processus de *dérégionalisation* dans la partie est de l'Europe et dans l'ancienne URSS, mais ce processus prend la forme d'un repli en bon ordre avec des contours géographiques stables. Les évolutions relevées pour les autres pays de la CEI sont presque identiques, à l'exception du Belarus. Dans ce cas, on constate une baisse de l'intensité des échanges bilatéraux avec la plupart des pays d'Europe, mais une augmentation avec la Russie.

Le recul continu de l'intensité des échanges commerciaux de marchandises

06 - Couples de pays pour lesquels le commerce bilatéral observé (en valeur) est au moins deux fois superieur au commerce attendu, selon le modèle



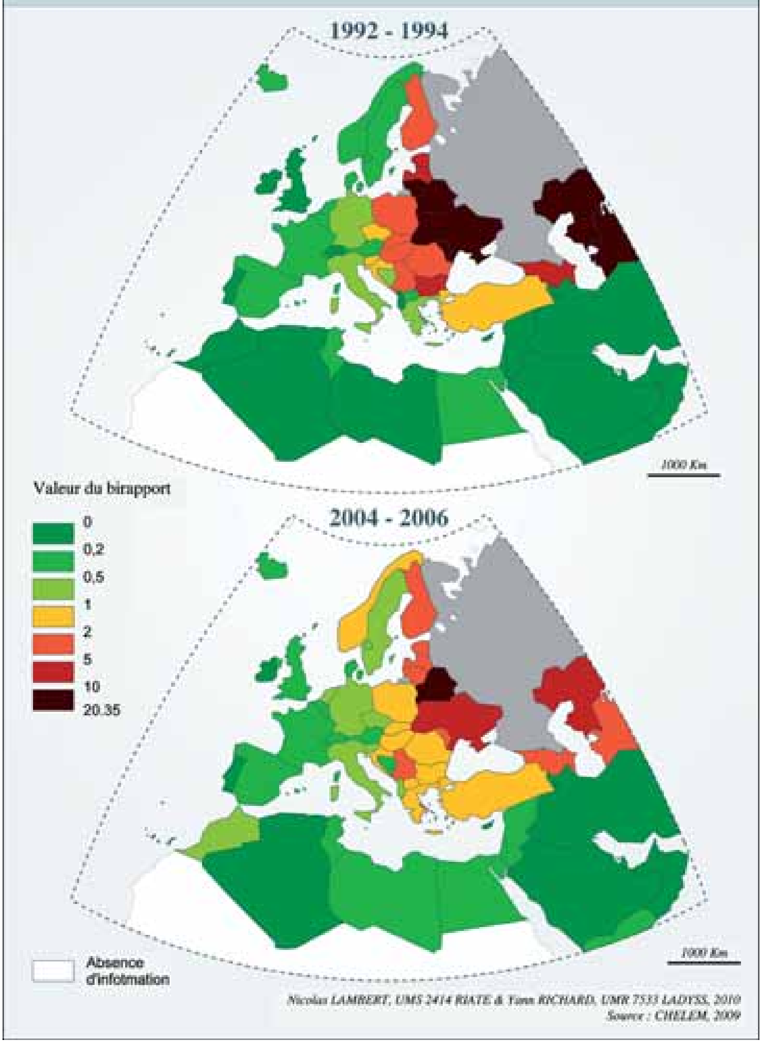
Nicolas LAMBERT, UMS 2414 RIATE & Yann RICHARD, UMR 7533 LADYSS, 2010
Source : CHELEM, 2009

au sein de l'ancienne URSS. Cette évolution a plusieurs causes. Premiérement, l'éclatement de l'Union soviétique a rendu à toutes les anciennes républiques soviétiques leur souveraineté en matiére économique et commerciale. Elles sont libres d'orienter leur commerce comme elles le souhaitent au gré de l'activité de leurs agents économiques. Cette évolution est trés claire dans le cas des pays Baltes. Liés dès le milieu des années 1990 à l'Union européenne par des accords européens d'association, leur commerce s'est massivement réorienté vers l'UE 15. Deuxiémement, l'intensité décroissante des échanges au sein de la CEI vient de l'incapacité des pays membres à faire fonctionner cet ensemble selon les termes des traités signés à partir de 1991 [Light, 2006]. Troisiémement, les mésententes politiques entre certains pays membres ont eu plusieurs conséquences dont on ne citera ici que quelques exemples. Les tensions récurrentes entre l'Ukraine et la Russie ont incité par exemple cette derniére à relocaliser certains industries d'armement à haute technologie sur le territoire russe. C'est autant d'échanges en moins entre les deux pays. Autre exemple, la Russie n'a jamais hésité à prendre des mesures de rétorsion commerciale à l'encontre de certains pays dont les choix politiques contreviennent à ses intérêts (embargos sur des produits moldaves et géorgiens par exemple). La sortie de plusieurs pays de la CEI (Turkménistan et Géorgie) renforcera la tendance à la dissolution des liens commerciaux entre certains membres.

QUELS SONT LES DÉTERMINANTS DE LA GÉOGRAPHIE DE L'INTENSITÉ DES ÉCHANGES BILATÉRAUX EN EUROPE ?

On peut formuler plusieurs hypothéses. L'observation des cartesaméne à formuler une hypothése : les anciennes appartenances aux blocs de la Guerre froide continuent de

07 - Évolution de l'intensité des échanges bilatéraux de la Russie



peser sur les échanges, réduisant les distances entre les économies qui appartenaient autrefois à un même bloc (Union soviétique eu Europe de l'est ou Europe de l'ouest) et augmentant les distances entre les économies qui appartenaient à des blocs différents jusque dans les années 1990.

Pour la vérifier, on peut utiliser des méthodes statistiques variées. Quelques éléments de réponses ont déjà été apportés dans un article publié de 2007 [Richard & Tobelem Zanin, 2007], où l'on étudie les interactions spatiales entre la Russie et les autres économies de l'Europe élargie. Une régression linéaire multiple permet d'étudier comment l'intensité des échanges entre la Russie et les pays de la zone Europe élargie varie en fonction non seulement de la distance euclidienne qui les sépare mais également en fonction des effets de l'appartenance de chaque pays à une zone économique particuliére (ex-URSS, ex-Europe de l'est des démocraties populaires, ex-Europe de l'ouest) ainsi que des effets de frontiére. On a pu ainsi vérifier que la distance euclidienne entre les économies jouait un rôle modeste et décroissant sur la période considérée (coefficient de détermination: 0,192 en 1994, 0,132 en 2004). Cette baisse ne signifie pas nécessairement que les échanges en valeur diminuent. Cela montre simplement que l'espace économique européen ne progresse pas vers plus de fluidité.

Le paramétre "appartenance" désigne la présence de telle ou telle économie dans un des trois ensembles régionaux européens contemporains de la Guerre froide : chacune des économies partenaires de la Russie appartient soit à la CEI, soit à l'Europe centrale et orientale (PECO) soit à l'Europe de l'Ouest (UE 15 + AELE + Turquie...), ces trois ensembles régionaux renvoyant à l'URSS, à l'Europe de l'Est et à l'Europe de l'Ouest. Le codage qualitatif de ce paramétre est effectué en attribuant à chaque ensemble régional géo-économique une valeur croissante en fonction de l'éloignement à la Russie[3]. Ce paramétre est beaucoup plus déterminant que la distance kilométrique. Il présente une plus forte corrélation (même si elle est en baisse) avec l'intensité bilatérale des échanges (0,811 pour 1994 et 0,730 pour 2004). Cela montre que les ensembles géopolitiques hérités de la Guerre froide ne sont pas encore morts du point de vue commercial. Les limites entre les anciens blocs continuent de fonctionner non comme des barriéres mais comme des freins aux échanges.

Le dernier paramétre retenu était le nombre de frontiéres qui séparent la Russie de ses partenaires. Les passages de frontiéres peuvent être faits de multiples façons. On a choisi le nombre minimum de passages entre la Russie et chacun des pays européens retenus. Dans certains cas, lorsqu'il existe une forte probabilité que les marchandises échangées passent par la mer, on n'a compté qu'un passage de frontiére. Dans la plupart des cas, on est parti de l'hypothése que les échanges se font par voie terrestre (route ou voie ferrée). On a pris en compte l'itinéraire le plus court entre le pays de départ et le pays d'arrivée. Le modéle montre que les passages de frontiéres, mê me lorsqu'ils sont peu nombreux, jouent un rôle qui n'est pas négligeable. Et il semble mê me que la relation entre le passage de frontiére et les échanges se renforce (corrélation négative entre les deux variables –0,612 pour 1994 et –0,721 pour 2004).

On peut reprendre la régression linéaire ou appliquer d'autres méthodes pour vérifier ces hypothéses. En partant de deux périodes de référence de trois ans (1994-96 et 2004-06), on peut vérifier l'évolution de l'influence de la distance euclidienne entre les économies et de l'influence des effets d'appartenance à un des blocs européens de la Guerre froide, avec des blocs définis ainsi: (1) Europe de l'Ouest (ancienne UE 15 + ex-Yougoslavie) et pays riverains de la Méditerranée, (2) PECO (ancienne Europe dite de l'Est, liée à l'URSS dans le Conseil d'Assistance économique mutuelle), (3) URSS (dont les trois pays baltes)[4]. En ce qui concerne la distance, une régression linéaire simple (dans le cadre d'une fonction log linéaire) peut ê tre appliquée à l'intensité des échanges de quatre économies du voisinage oriental avec les autres économie de la région Europe élargie: Belarus, Kazakhstan, Russie, Ukraine. Pour ces quatre pays, la régression montre que le rôle de la distance[5] est faible voire trés faible et qu'il a tendance à baisser dans certains cas (tabl. 4).[6]

Le coefficient de détermination de l'intensité des échanges par la distance est le plus élevé pour le Kazakhstan mais il a sensiblement baissé entre les deux périodes de référence et son niveau est plutôt faible. Il a baissè pour l'Ukraine pour atteindre seulement 0,15 en 2004-2006. Cela signifie que la distance entre la réion capitale de l'Ukraine et les régions capitales de tous les partenaires commerciaux de l'Ukraine n'explique que 15% de la variation de l'intensité des échanges commerciaux de marchandises entre l'Ukraine et ces mê mes économies. Le coefficient de détermination a augmenté

[3] L'éloignement est défini sur la base d'un découpage géopolitique : 1 pour l'Espace Economique Unique, 2 pour la CEI, 3 pour les PECO et 4 pour l'Europe de l'ouest.

[4] L'ex-Yougoslavie a été rangée dans le mê me groupe que l'Europe de l'Ouest car elle n'était pas un membre du CAEM. Les pays baltes ont été rangés dans le mê me groupe que le Belarus, le Kazakhstan, la Russie et l'Ukraine car ils ont fait partie de l'Union soviétique jusqu'en 1991.

[5] Dans ce cas aussi, on considére la distance kilométrique entre les régions capitales des pays considérés et les régions capitales de leurs partenaires commerciaux.

[6] D'aprés le test des valeurs critiques de Bravais Pearson montre que le coefficient de corrélation r est significatif avec des d'erreur (α) inférieures à 1%.

Tabl. 4. Coefficient de corrélation (r) et coefficient de détermination (r^2) entre le log du birapport d'intensité d'échange et le log de la distance kilométrique

	1992–1994		2004–2006	
	Coefficient corrélation	Coefficient détermination	Coefficient corrélation	Coefficient détermination
Belarus	–0,54	0,29	–0,6	0,36
Kazakhstan	–0,77	0,59	–0,72	0,52
Russie	–0,58	0,33	–0,61	0,38
Ukraine	–0,54	0,3	–0,39	0,15

pour le Belarus et la Russie mais il est actuellement trop bas (0,36 et 0,38) pour conclure qu'il joue un rôle significatif.

Pour vérifier le poids des effets d'appartenance, on peut également utiliser le test du Chi² qui mesure la déviation entre un effectif théorique et un effectif observé et permet de vérifier l'hypothése d'une relation entre deux variables, dont une au moins est une variable qualitative. L'hypothése est que plus de 15 ans aprés la disparition de l'Union soviétique et plus de 20 ans aprés la chute du mur de Berlin, les limites des grands blocs régionaux de la Guerre froide n'ont plus d'influence sur la géographie de l'intensité des échanges des quatre pays choisis. Il suffit de répartir tous les pays de la région européenne élargie dans les trois groupes susmentionnés (groupe A : ex-URSS ; groupe B : PECO; groupe C : UE 15 + ex-Yougoslavie + pays méditerranéens). Le birapport d'intensité d'échanges entre les quatre pays de référence et tous les autres est discrétisé avec une répartition dans trois classes : inférieur à 0,5, de 0,5 à 1,5, supérieur à 1,5. Cette discrétisation part du postulat que les birapports compris entre 0,5 et 1,5 indiquent des échanges bilatéraux observés dont la valeur est plus ou moins conforme à leur estimation par le modéle. Le test consiste à voir comment les birapports se répartissent dans les groupes de pays A, B et C pour les quatre pays retenus et de comparer les effectifs ainsi observés avec des effectifs théoriques (tabl. 5).

On peut tirer deux conclusions principales. Premiérement, l'écart entre les effectifs théoriques et les effectifs observés est trés fort. Les chiffres indiqués dans le tableau

Tabl. 5. Chi² observé (relation entre appartenance géopolitique des pays et intensité des échanges avec 4 pays du voisinage oriental) (marge d'erreur α = 1%)

	1992–1994	2004–2006
Belarus	53,63	43,6
Kazakhstan	45,1	35,1
Russie	30,78	32,92
Ukraine	35,23	26,38

ci-dessus indiquent que les variables " appartenance "et" intensité des échanges bilatéraux " sont bien dépendantes (avec une marge d'erreur α = 1 %). Cela signifie que l'effet d'appartenance continue de jouer un rôle dans la géographie de l'intensité des échanges commerciaux bilatéraux, notamment pour le Belarus et le Kazakhstan. On constate mê me que le Chi² observé augmente dans le cas de la Russie. En d'autres termes, si un pays appartient à l'ancienne URSS, il y a de trés fortes chances pour que ses échanges avec le Belarus, le Kazakhstan, la Russie et l'Ukraine soient intenses. Inversement, si un pays appartient à l'ancienne Europe de l'Est (PECO), il y a de fortes chances pour que ses échanges avec ces quatre économies soient moyennement intenses. Et il y a de fortes chances pour que l'intensité soit faible si le pays choisi appartient à l'ancienne Europe de l'Ouest. Deuxiémement, le Chi² baisse pour trois pays sur quatre. Ce qui confirme l'idée de "détricotage" de l'ancienne régionalisation économique de l'espace européen, notamment au sein de l'ancienne URSS. Mais on constate que le Chi² reste trés élevé et qu'il augmente pour la Russie. Dans trois cas sur quatre, l'effet appartenance est donc moins fort qu'au début des années 1990 mais il reste fort tout de même. Et pour la Russie il se renforce.

Conclusion

La régionalisation du commerce mondial est le signe d'une croissance rapide des interactions entre des économies proches les unes des autres au sein d'ensembles géographiques multiétatiques. La meilleure façon de mettre à jour ces ensembles est d'utiliser des indicateurs qui ne sont pas biaisés par la taille économique des pays. L'analyse des intensités commerciales bilatérales présente de plusieurs avantages: elle efface les effets de taille et elle permet de comparer des valeurs d'échanges observées et des valeurs prédites. A l'échelle mondiale, cet indicateur permet de faire des comparaisons entre les ensembles ainsi mis en lumière. On voit que leur organisation interne varie sensiblement d'une région à l'autre. En représentant ces mêmes indicateurs, choisis à deux périodes différentes, des évolutions parfois sensibles apparaissent clairement.

La proximité géographique (distance euclidienne) joue un rôle dans la constitution de ces ensembles macrorégionaux. Mais elle n'est pas le seul paramétre déterminant car certains pays voisins ont des intensités d'échanges trés basses alors que d'autres, pourtant éloignés, ont des intensités d'échanges élevées. D'autres paramétres entrent donc en ligne de compte parmi lesquels l'existence de liens coloniaux ou les types de spécialisation économique et commerciale des pays [Freudenberg, Gaulier & Ünal-Kensenci, 1998]. En ce qui concerne l'Europe, la distance euclidienne entre les économies joue même un rôle secondaire par rapport à des effets d'appartenance géopolitique hérités [Richard & Tobelem Zanin, 2007] qui montrent à quel point les discontinuités spatiales produites en Europe pendant la guerre froide se résorbent lentement.

L'extension géographique de la région commerciale européenne excéde largement les limites de l'Union européenne et de l'Europe elle-même. Ses limites sont instables. Cela montre à quel point la régionalisation européenne est ouverte et non fermée sur elle-même. Les interactions économiques avec le voisinage sont fortes (Afrique du Nord) voire croissantes (ex-URSS par exemple), mais elles reculent avec le Proche et le Moyen Orient. Par ailleurs, la régionalisation commerciale, dans et autour de l'Europe, n'a pas un caractére homogéne. Il vaudrait mieux parler *des régionalisations* que de la régionalisation européenne, puisque plusieurs ensembles sous régionaux ont été clairement identifiés. Enfin, on peut se demander s'il ne vaudrait pas mieux parler de *dérégionalisation* de l'Europe à l'est et de "re-régionalisation" au centre, ce qui confirmerait les résultats d'études fondées sur d'autres méthodes et d'autres indicateurs [Broadmann, 2005]. L'ancienne Europe de l'Est (celle des démocraties populaires) finit de se recoller à l'Europe de l'Ouest. L'ancien bloc soviétique, quant à lui, reste bien visible tout en continuant de se décomposer petit à petit. Les grandes discontinuités géographiques héritées des clivages politiques et idéologiques de la Guerre froide ne sont pas encore totalement effacées mais les évolutions sont sensibles.

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Main publications: Didelon, C., Richard, Y. (2008) The Enlarging European Union. How to stay a global player? *Global Studies Journal,* Vol. 1, N 4, pp. 105–123; Richard Y., Zanin, C. (2007) La Russie et l'Europe : une intégration économique encore à venir? Cybergeo. *Revue européenne éégraphie*, paper N. 402, 26 pages ; Didelon, C., Grasland, C., Richard, Y. (Eds.) (2008) Atlas de l'Europe dans le monde. Paris, Montpellier: La Documentation française, Reclus.

THE PRODUCTIVITY AND BIOGEOCHEMICAL TURNOVER OF LANDSCAPES

CONFERENCE TO THE 100TH ANNIVERSARY OF PROF. N.I. BAZILEVICH (MOSCOW REGION, APRIL 2010)

2010 is the 100th anniversary of the birth of Natalia Bazilevich, an outstanding specialist in soil science, biogeochemistry, geography, and ecology who has worthily represented the cohort of encyclopedically educated Russian scientists of the 20th century, such as V.V. Dokuchaev, V.I. Vernadsky, and A.A. Grigor'ev and contributed to the development of their ideas. To commemorate this remarkable date, the scientific community has decided to sum up advances in the scientific field pioneered, among others, by Prof. Bazilevich.

Bazilevich's studies still have a high citation index, holding due place among classic publications. For more than 40 years, her books and articles remain high on the reference lists of university courses in general soil science and soil geography, geobotany, landscape science, ecology, and biogeochemistry.

The Institute of Geography (Russian Academy of Sciences), together with the Institute of Physicochemical and Biological Problems in Soil Science (Russian Academy of Sciences), the Institute of Soil Science and Agrochemistry (Siberian Branch, Russian Academy of Sciences), and the Dokuchaev Soil Science Institute (Russian Academy of Agricultural Sciences), with participation of the Moscow State University and the Dokuchaev Society of Soil Scientists, convened a conference dedicated to the 100th anniversary of Bazilevich's birth. This conference, entitled "The Geography of Productivity and Biochemical Cycle of Terrestrial Landscapes," was held in Pushchino (Moscow Region) on April 19 to 22, 20101[1].

The conference, hosted by the Institute of Physicochemical and Biological Problems in Soil Science, proceeded in a friendly working atmosphere and was marked by a high degree of participation by young specialists. The first plenary session and round-table discussion were devoted directly to Bazilevich's scientific heritage and new aspects of her biography. Other problems addressed at the conference were as follows: the geography of landscape productivity, the biogeochemical cycle in terrestrial landscapes, carbon turnover in terrestrial landscapes, modeling of biogeochemical cycles and land ecosystem functioning, soil organic matter and role of the biota in its dynamics, and new methods for studying productivity and carbon turnover in land ecosystems. On the whole, the Organizing Committee received abstracts of 149 communications from research teams working in 20 Russian cities and also in Belarus, Norway, Germany, and Great Britain.

The accepted abstracts and invited lectures (a book with CD-ROM)[2] and the monograph by N.I. Bazilevich and A.A. Titlyanova (a book with CD-ROM)[3] were published by the beginning of the conference.

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[1] Full report is to be published in "Pochvovedenie" magazine (2011, #5).

[2] The Geography of Productivity and Biochemical Cycle of Terrestrial Landscapes. Proc. Conf. Dedicated to the 100th Anniversary of the Birth of Prof. N.I. Bazilevich, Pushchino, Moscow Region, April 19–22, 2010: Dobrovol'skii, G.V., Kudeyarov, V.N., and Tishkov, A.A., Eds., Pushchino, 2010.

[3] Bazilevich, N.I. and Titlyanova, A.A., Biotic Turnover on the Five Continents: Nitrogen and Ash Elements in Natural Land Ecosystems), Tishkov, A.A., Ed., Novosibirsk: SO RAPN, 2008.

As noted above, the first plenary session was devoted to Bazilevich's scientific heritage and the present-day significance of her ideas. After the welcome address by V.N. Kudeyarov, the session began with the lecture "Productivity of the World's Grassland Ecosystems" by A.A. Titlyanova (Institute of Soil Science and Agrochemistry, Novosibirsk). The author presented a comparative geographic analysis of parameters characterizing phytomass stocks and production in the steppes, prairies, grassland savannas, and their analogs on the five continents. Its results show that these are the most productive of all land ecosystems, with their exclusive dynamism providing for sustainability in their structure and functioning.

V.N. Kudeyarov (Institute of Physicochemical and Biological Problems in Soil Science, Pushchino) in his lecture "Assessment of Negative CO_2 Balance on the Territory of Russia" emphasized the significance of estimates made by Bazilevich for present-day models of carbon balance. Approximately 25–40% of atmospheric CO_2 in land ecosystems is of soil origin, and the soil cover as a whole hold the key position in the atmospheric turnover of CO_2 and other gases.

A.S. Vladychenskii (Faculty of Soil Science, Moscow State University) presented the lecture "Biogeochemical Turnover and Soil Formation in Mountain Conifer Forests," in which he followed the best traditions of data presentation established by Bazilevich in her comprehensive studies of the 1960s to 1980s. The author considered recent data on biogeochemical turnover in ecosystems of the forest belt (1400–1900 m a.s.l.) in the Teberda Nature Reserve and showed that the regime of ecosystem functioning observed in this region accounts for the formation of burozem soils.

The lecture "Natalia Ivanovna Bazilevich: Portrait of the Scientist, Heritage, and New Life of Ideas" by A.A. Tishkov, E.I. Pankova, and N.G. Tsarevskaya (Institute of Geography, RAS, and Dokuchaev Soil Institute, Moscow) dealt with new data for the biography of N.I. Bazilevich and the development of her ideas lying at the basis of several research fields in soil science, ecology, and geography.

The same problems were addressed at the evening round-table discussion held in April 20, where the floor was taken by A.A. Titlyanova, T.V. Tursina, E.I. Pankova, I.V. Ivanov, A.A. Tishkov, Yu.G. Puzachenko, V.A. Rozhkov, L.O. Karpachevskii, and N.V. Lukina.

The second session was devoted to studies on the productivity of zonal and intrazonal ecosystems. It opened with the lecture "The First Digital Maps of Phytomass, Mortmass, and Annual Production" (by V.A. Rozhkov and A.Z. Shvidenko (Dokuchaev Soil Science Institute, Moscow). The lecturer described the first experience in digitizing Bazilevich's database (1993) and making computer maps. Even today, decades later, these materials remain relevant and are used in attempts to gain insights into a number of global problems.

L.O. Karpachevskii (Faculty of Soil Science, Moscow State University) in his lecture "Necromass in Natural Biogeocenoses" proposed a new classification of plant necromass and expressed his understanding of its nature.

Interesting presentations at this sessions were also given by E.A. Golovatskaya (Institute for Monitoring Climatic and Ecological Systems, Siberian Branch, RAS, Tomsk); I.V. Bezkorovainaya (Sukachev Institute of Forest, Siberian Branch, RAS, Krasnoyarsk); N.V. Lukina, M.A. Orlova, T.T. Gorbacheva, and E.A. Belova (Center of Forest Ecology and Productivity, RAS, Moscow, and Institute of Industrial Ecology of the North, Kola Scientific Center, RAS, Murmansk Region); A.D. Sambuu (Tuva Institute for Exploration of Natural Resources, Siberian Branch, RAS, Kyzyl); and P.V. Kuznetsov, I.M. Yashin, and V.I. Grebenshchikova (Vinogradov Institute of Geochemistry, Siberian Branch, RAS, Irkutsk).

At the third session, the participants considered problems in the study of biogeochemical turnover in terrestrial landscapes. Among lectures presented at the session, particularly noteworthy were the following: “Turnover of Nitrogen and Ash Elements in Ecosystems of Steppe Rangelands” by N.Yu. Kulakova and B.D. Abaturov (Severtsov Institute of Ecology and Evolution, RAS, Moscow, and Institute of Forest Science, RAS, Moscow Region); “Solodized Soils of Subarid Landscales and Processes Accounting for Their Formation” by T.V. Tursina (Dokuchaev Soil Science Institute, Moscow); “Biogeochemical Turnover and Balance of Chemical Elements in Agrolandscapes” by N.K. Chertko and A.A. Karpichenko (Belarusian State University, Minsk, Belarus); and “Assessment of Parameters of Nitrogen Mass Balance in Ecosystems of the Yamal Peninsula for the Purposes of Ecological Rating” by I.V. Priputina and V.N. Bashkin (Institute of Physicochemical and Biological Problems in Soil Science, Moscow Region). It should be noted that the data reported by T.V. Tursina confirm Bazilevich’s idea that a possible way of solod soil formation is that from salinized soils of waterlogged steppe depressions.

The fourth session, dealing with carbon exchange in terrestrial landscapes and soils, was especially rich in presentations. In particular, V.M. Semenov (Institute of Physicochemical and Biological Problems in Soil Science, Pushchino) used a new methodological approach to contemplate on the nature of soil organic matter, its composition, conditions of stabilization, and capacity for mineralization. D.G. Zamolodchikov, G.N. Kraev, and D.G. Shmelev (Center of Forest Ecology and Productivity, RAS, and Faculty of Geography, Moscow State University) in the lecture “Estimations of Carbon Budget in Russian Forests: Problems and Possible Solutions” presented original calculations for estimating the contribution of Russian forests to the global carbon balance. L.S. Sharaya, E.G. Kolomyts, and G.S. Rozenberg (Institute of the Ecology of the Volga Basin, RAS, Tolyatti) considered the results of modeling and prediction of carbon balance in forest ecosystems under conditions of global warming. The lecture “Biogenic Carbon Fluxes in Boreal Forests of Central Siberia” by E.F. Vedrova (Sukachev Institute of Forest, Krasnoyarsk) provided evidence that, among fir forests, medium-aged and mature stands accumulate carbon, whereas production and mineralization in old-growth stands are close to equilibrium.

I.O. Alyabina and L.G. Bogatyrev (Institute of Ecological Soil Science, Faculty of Soil Science, Moscow State University) presented the results of constructing a map of carbon fixation in geochemical landscapes. These authors developed original cartographic and typological methods that allowed them to perform a comparative geographic analysis and obtain new data on trends in the behavior of organic carbon. Data concerning regional aspects of carbon balance were presented by Yu.B. Tsybenov et al. (Institute of General and Experimental Biology, Siberian Branch, RAS, Ulan-Ude) for Transbaikalia; by A.V. Ol’chev et al. (Severtsov Institute of Ecology and Evolution, RAS, Moscow; Technical University of Denmark, Roskilde; Faculty of Geography, Moscow State University; and Georg-August University, Goettingen, Germany) for moist tropical forests of Indonesia; by V.O. Lopez de Gerenu et al. (Severtsov Institute of Ecology and Evolution, RAS, Moscow; Institute of Physicochemical and Biological Problems in Soil Science, Moscow Region; and Joint Russo-Vietnamese Science and Technology Tropical Center, Ho Chi Minh City, Vietnam), for tropical forests of Vietnam, and by I.V. Kovda, E.G. Morgun, and N.I. Golubeva (Institute of Geography, RAS; Faculty of Soil Science, Moscow State University; and Southern Scientific Center, RAS, Rostov-on-Don) for mountain ecosystems of the Caucasus.

A number of presentations at this session were devoted to the behavior of carbon and other elements in soils in the course of agrogenic successions, including those taking place today due to large-scale abandonment of farmlands and their overgrowing by forest. In the lecture “Reflections of Recent and

Past Agrogenic Impacts in the Distribution of Biogenic Silica over the Profiles of Soddy Podzolic Soils," A.A. Gol'eva, N.P. Sorokina, and I.V. Kuznetsova (Institute of Geography, RAS, and Dokuchaev Soil Science Institute, Moscow) described the results of indication of changes in arable soils by the phytolith method. I.V. Ivanov and Yu.G. Chendeev (Institute of Physicochemical and Biological Problems in Soil Science, Pushchino, and Faculty of Geology and Geography, Belgorod State University, Belgorod) presented the lecture "Chernozem Soils of the Central Chernozem Zone: History of Formation and Current State of Humus Profile." On the basis of paleopedological data, these authors performed a detailed analysis of changes in the properties of chernozems during the Late Glacial to Subatlantic time and in the recent period, when the humus content of these soils has decreased by 25–70% as a result of plowing.

D.I. Lyuri, S.V. Goryachkin, N.A. Karavaeva, O.Yu. Kalinina, and L. Giani (Institute of Geography, RAS, Moscow, and University of Oldenburg, Germany) presented the lecture "Atmospheric Carbon Deposition in Fallow Lands of Russia." These authors evaluated the extent and potential of carbon sink in the course of restorative succession in fallow lands of European Russia and arrived at interesting conclusions as to what happens to fallow lands in terms of the fate of humus and soil organic matter.

The fifth session was devoted to new methods in studies on productivity, biological turnover, and factors determining their parameters. The opening lecture by Yu.G. Puzachenko (Severtsov Institute of Ecology and Evolution, RAS) was entitled "The Climatic Space of the Biosphere." The author presented his understanding of this space in terms of volume (entropy) and structure and showed a strong nonlinear dependence of net production on temperature, precipitation, and their ratio. Yu.A. Plyushkyavichyute, E.I. Golubeva, O.V. Tutubalina, and W.G. Rees (Faculty of Geography, Moscow State University, and Scott Polar Research Institute, University of Cambridge, UK) analyzed the possibilities of remote sensing methods in the assessment of aboveground phytomass in the taiga–tundra ecotone. Interrelations between vegetation and soil in forest–tundra ecotones were considered from new methodological positions in the lecture by M.A. Orlova et al. (Center of Forest Ecology and Productivity, Moscow; Faculty of Geography, Moscow State University; Institute of Industrial Ecology of the North, Apatity; and Norwegian Institute for Nature Research, Norway). Both were performed on the Kola Peninsula.

V.O. Lopez de Gerenu et al. (Institute of Physicochemical and Biological Problems in Soil Science, Pushchino, and Timiryazev State Agricultural University, Moscow) in the lecture "In Situ Determination of Carbon Balance Components in a Meadow Ecosystem in Central Russia" showed that field experimental methods offer ample opportunities for studies on carbon fluxes.

R.B. Sandlerskii and A.N. Krenke (Severtsov Institute of Ecology and Evolution and Institute of Geography, RAS, Moscow) demonstrated the possibility of combining remote sensing and field methods in studies on the dependence of the productivity of southern taiga landscapes on their topography and vegetation.

The sixth session – "Modeling of Biogeochemical Cycles and Ecosystem Productivity"began in the absence of A.S. Komarov, its organizer and intended chairman, who could not arrive from Europe on time because of the Eyjafjallajokull volcano eruption in Iceland. Although its program was abridged, the lectures stimulated a vivid discussion. T.A. Arkhangelskaya (Faculty of Soil Science, Moscow State University) presented a mathematical model of carbon dynamics in geochemically interrelated soils of the Vladimir Opolye region. This model made it possible to estimate the characteristic time of humus horizon formation, with the results being consistent with data by R.V. Desyatkin on dating Yakutian alass soils and with micromorphological data by A.O. Makeev and I.V. Dubrovina.

L.L. Golubyatnikov (Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences, Moscow) made a comparative analysis of global and regional model estimates of plant cover productivity, juxtaposing the results with calculations made by Bazilevich. The values of phytomass stock and production obtained with many models proved to be similar to her data. M.B. Bobrivskii et al. (Institute of Physicochemical and Biological Problems in Soil Science, Pushchino) described the results of modeling the dynamics of soil carbon in different variants of traditional agriculture and forest management practiced in central European Russia. He also presented a synopsis of A.S. Komarov's lecture "Modeling the Biogeochemical Cycles of Chemical Elements in Forest Ecosystems." A.S. Naumov (Institute of Soil Science and Agrochemistry, Novosibirsk) in the lecture "The Production–Destruction Link of the Biotic Turnover: Global Aspect" analyzed the initial data on the nitrogen contents of basic phytomass fractions in land ecosystems from the monograph Biotic Turnover on the Five Continents: Nitrogen and Ash Elements in Natural Land Ecosystems (Bazilevich and Titlyanova, 2008) and revealed new trends in the ratio between components of the nitrogen cycle in the biosphere.

In conclusion, it appears appropriate to give a brief outline of the results of the conference and the relevance and significance of Bazilevich's books, ideas, and scientific heritage in the present period.

First, the conference has provided evidence for the increasing interest in the problems of global carbon balance and the role of soils in it. The question as to what are the contributions of natural and anthropogenic factors in processes responsible for recent climate change is difficult to answer without referring to the data obtained by N.I. Bazilevich, and her name will long be mentioned in discussions on the key role of soils in the accumulation of biogenic (humus) and hydrogenic (carbonates) carbon and in global carbon fluxes. This aspect of Bazilevich's research is consistently pursued at centers engaged in the elaboration of scientific foundations for implementing the United Nations Framework Convention on Climate Change and the Kyoto Protocol to this convention. An interesting fact is that M.A. Glazovskaya in her recent monograph "Pedolithogenesis and Continental Cycles of Carbon" (2009) notes that studies on the role of pedosphere in these cycles can help reveal the causes of imbalance between carbon dioxide absorption on land and its return to the atmosphere, which has been observed in the past decades. Bazilevich also paid attention to this aspect but limited herself to the assessment of soil carbon in the upper 100-cm layer, as do many authors of recent studies.

Second, consisten10t attention is paid to the results of Bazilevich's studies on the productivity of zonal landscapes, which have been processed and systematized. In particular, they are used for interpretation and comparative analysis of data on the assessment of net primary production by means of the normalized difference vegetation index (NDVI), which is determined on the basis of remote sensing data (from the difference between signals in the visible red and infrared spectral channels of the SPOT, Landsat, Terra, IRS, Aqua, and other satellite systems). Research in landscape productivity is carried out at major scientific centres of RAS.

Third, N.I. Bazilevich initiated the construction of conceptual balance models of zonal and intrazonal ecosystems, and her data were included in mathematical models constructed in the 1980s. Thereafter, this research field has been successfully explored by Yu.M. Svirezhev, A.M. Tarko, A.S. Komarov, D.O. Logofet, L.L. Golubyatnikov, T.G. Gil'manov, and their followers. Today, such studies are underway at many institutes of the RAS.

Fourth, the line of Bazilevich's research concerning the geography of biogeochemical turnover is also being developed today. As noted above, the conference was marked by the publication of the monograph "Biotic Turnover on the Five Continents: Nitrogen and Ash Elements in Natural Land Ecosystems" (Bazilevich and Titlyanova, 2008) based on materials from N.I. Bazilevich's archive. This book has attracted great interest because of its global scope and the opportunity provided for a researcher to compare the results of his/her own local observations with generalized data obtained in studies of biogeochemical cycles in zonal ecosystems on other continents, including those with convergent structure. New methods and analytical technologies make it possible to promptly obtain detailed data on the element composition of plants, animals, soils, and natural waters as well as to make gas measurements to determine soil respiration and concentrations of various chemical compounds in the atmosphere. Such studies are actively performed at the Institute of Physicochemical and Biological Problems in Soil Science, Vernadsky Institute of Geochemistry and Analytical Chemistry, Department of Soil Geography and Evolution of the Institute of Geography (Russian Academy of Sciences); Dokuchaev Soil Science Institute (Russian Academy of Agricultural Sciences); Institute of Geochemistry, Institute of Soil Science and Agrochemistry, Institute of Geography (Siberian Branch, Russian Academy of Sciences); Department of General Soil Science, Faculty of Soil Science; Department of Landscape Geochemistry and Soil Geography, Faculty of Geography; Laboratory of Matter Turnover and Energy Fluxes in the Pedosphere, Institute of Ecological Soil Science (Moscow State University); and many other centers.

It is noteworthy that Bazilevich's personality and her pioneering studies attracted major interest from young scientists. At every session, they were offered an opportunity to give two to three lectures, and the poster session (a total of about 20 presentations) was focused on achievements made by postgraduate students and young researchers specialized in soil science, geography, and ecology.

Summing up the results of the conference, it should be noted that the biological line of research in soil science has been developed extensively, covering all geographic regions of Russia and territories of bordering countries. The large proportion of young scientists among the participants and the high scientific level of their presentations are prerequisites for further advancement of Bazilevich's ideas. Her studies in different branches of biogeochemistry have a very high citation index both in Russia and abroad, ranking high above publications of other authors working in this field, which is additional evidence for the profound views and extensive foresight of this great woman scientist.

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