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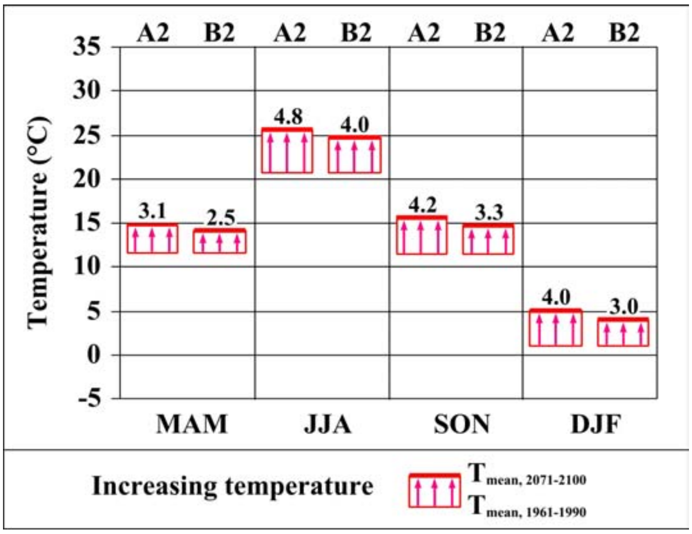

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REGIONAL CLIMATE CHANGE EXPECTED IN HUNGARY FOR 2071-2100

J. BARTHOLY* – R. PONGRÁCZ – GY. GELYBÓ

[1]*Department of Meteorology, Eötvös Loránd University*
H-1117 Budapest, Pázmány Péter sétány 1/a.
(phone: +36-1-372-2945; fax: +36-1-372-2904)

e-mail: bari@ludens.elte.hu

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Abstract. Expected climate change estimations for the Carpathian basin and especially, Hungary, are summarized for the 2071-2100 period on the basis of the results from the project PRUDENCE. Different regional climate models (RCMs) used 50 km as the horizontal spatial resolution, and evaluated the A2 and B2 global emission scenarios. Results suggest that in case of temperature, a warming trend is evident in the Carpathian basin. The largest warming is expected in summer. The expected change of annual total precipitation is not significant. However, significantly large and opposite trends are expected in different seasons. Seasonal precipitation amount is very likely to increase in winter, while it is expected to decrease in summer, which implies that the annual distribution of precipitation is expected to be restructured. The wettest summer season may become the driest (especially in case of A2 scenario), and the driest winter is expected to be the wettest by the end of the 21st century. It is evident that all these climate processes affect agricultural activity and disaster management strategy. In order to prepare for the changing climate conditions, results of this regional climate change analysis may serve as basic information.
Keywords: *Regional climate change, temperature, precipitation, Carpathian basin, regional climate model*

Introduction

The Fourth Assessment Report of the Intergovermental Panel on Climate Change (IPCC) was published in February 2, 2007. According to the report of the Working Group I [1], the main key processes influencing the European climate include (i) increased water vapour transport from low to high latitudes, (ii) changes of variation of the atmospheric circulation on interannual as well, as longer time scales, (iii) reduction of snow cover during winter in the northeastern part of the continent, (iv) drying of the soil in summer in the Mediterranean and central European regions. For instance, the heat wave occurred in summer 2003 in central Europe can be considered as a consequence of a long period of anticyclonic weather [2], which coincided with a severe drought in the region [3]. In case of Europe, it is likely that the increase of annual mean temperature will exceed the global warming rate in the 21st century. The largest increase is expected in winter in northern Europe [4], and in summer in the Mediterranean area. Minimum temperatures in winter are very likely to increase more than the mean winter temperature in northern Europe [5], while maximum temperatures in summer are likely to increase more than the mean summer temperature in southern and central Europe [6]. Concerning precipitation, the annual sum is very likely to increase in northern Europe [5] and decrease in the Mediterranean area. On the other hand, in central Europe, which is located at the boundary of these large regions, precipitation is likely to increase in winter, while decrease in summer. In case of the summer drought events, the risk is likely to increase in central Europe and in the Mediterranean area due to decreasing summer precipitation and increasing spring

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evaporation [7, 8]. As a consequence of the European warming, the length of the snow season and the accumulated snow depth are very likely to decrease over the entire continent [1].

Spatial resolutions of global climate models (GCMs) are inappropriate to describe regional climate processes; therefore, GCM outputs may be misleading to compose regional climate change scenarios for the 21st century [9]. In order to determine better estimations for regional climate parameters, fine resolution regional climate models (RCM) can be used. RCMs are limited area models nested in GCMs, i.e., the initial and the boundary conditions of RCMs are provided by the GCM outputs [10]. Due to computational constrains the domain of an RCM does not cover the entire globe, sometimes not even a continent. On the other hand, their horizontal resolution may be as fine as 5-10 km. The first project completed in the frame of the European Union V Program is the PRUDENCE (Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects), which involved 21 European research institutes and universities. The primary objectives of PRUDENCE were to provide high resolution (50 km × 50 km) climate change scenarios for Europe for 2071-2100 using dynamical downscaling methods with RCMs (using the reference period 1961-1990), and to explore the uncertainty in these projections [11]. Results of the project PRUDENCE are disseminated widely via Internet (http://prudence.dmi.dk) and several other media, and thus, they support socio-economic and policy related decisions.

In the frame of project PRUDENCE, the following sources of climate uncertainty were studied [11]:

- Sampling uncertainty. Simulated climate is considered as an average over 30 years (2071-2100, reference period 1961-1990).
- Regional model uncertainty. RCMs use different techniques to discretize the differential equations and to represent physical processes on sub-grid scales.
- Emission uncertainty. RCM runs used two IPCC-SRES emission scenario, namely, A2 and B2. 16 experiments from the PRUDENCE simulations considered the A2 scenario, while only 9 of them used the B2 scenario.
- Boundary uncertainty. RCMs were run with boundary conditions from different GCMs. Most of the PRUDENCE simulations used HadAM3H as the driving GCM. Only a few of them used ECHAM4 or ARPEGE [12].

In this paper, the regional climate change projections are summarized for the Carpathian basin using the outputs of all available PRUDENCE simulations. First, results of the expected temperature change by the end of the 21st century are discussed, and then, expected change of the other important climate parameter, precipitation is presented.

Data

Adaptation of RCMs with 10-25 km horizontal resolution is currently proceeding in Hungary, at the Department of Meteorology, Eötvös Loránd University [13], and at the Hungarian Meteorological Service [14]. Results of these RCM experiments are expected within 2-4 years, however, impact studies and end-users need and would like to have access to climate change scenario data much earlier. Therefore, in order to fulfill this instant demand with preliminary information, outputs of PRUDENCE simulations are evaluated and offered for the Carpathian basin. In case of the A2 scenario 16 RCM experiments are used, while in case of B2, only outputs of 8 RCM simulations are available. Since the project PRUDENCE used only these two emission scenarios, no other scenario is discussed in this paper. *Table 1* lists the name of the contributing institutes, the RCMs, the driving GCMs, and the available scenarios we used in the composite maps. Composite maps of expected temperature and precipitation change cover the Carpathian basin (45.25°-49.25°N, 13.75°-26.50°E). The climate projections of PRUDENCE are available for the end of the 21st century (2071-2100) using the reference period of 1961-1990.

Table 1. *List of RCMs with their driving GCMs used in the composite analysis*

	Institute	RCM	Driving GCM	Scenario
1	Danish Meteorological Institute	HIRHAM	HadAM3H	A2, B2
2		HIRHAM	ECHAM5	A2
3		HIRHAM high resolution	HadAM3H	A2
4		HIRHAM extra high res.	HadAM3H	A2
5	Hadley Centre of the UK Met Office	HadRM3P (ensemble/1)	HadAM3P	A2, B2
6		HadRM3P (ensemble/2)	HadAM3P	A2
7	ETH (Eidgenössische Technische Hochschule)	CHRM	HadAM3H	A2
8	GKSS (Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt)	CLM	HadAM3H	A2
9		CLM improved	HadAM3H	A2
10	Max Planck Institute	REMO	HadAM3H	A2
11	Swedish Meteorological and Hydrological Inst.	RCAO	HadAM3H	A2, B2
12		RCAO	ECHAM4/OPYC	B2
13	UCM (Universidad Complutense Madrid)	PROMES	HadAM3H	A2, B2
14	International Centre for Theoretical Physics	RegCM	HadAM3H	A2, B2
15	Norwegian Meteorological Institute	HIRHAM	HadAM3H	A2
16	KNMI (Koninklijk Nederlands Meteorologisch Inst.)	RACMO	HadAM3H	A2
17	Météo-France	ARPEGE	HadCM3	A2, B2
18		ARPEGE	ARPEGE/OPA	B2

Temperature projections for the Carpathian basin

Composites of the mean seasonal temperature change are mapped for both A2 and B2 scenarios. In order to represent the uncertainty of the composite maps, standard deviations of the RCM model results are also determined and mapped for all seasons. *Fig. 1* presents the expected seasonal temperature change for A2 scenario, while *Fig. 2* shows the seasonal standard deviation values for the Carpathian basin. Similar seasonal maps for the B2 scenario can be seen in *Figs. 3* and *4*. Similarly to the global and the European climate change results, larger warming can be expected for A2 scenario in the Carpathian basin than for B2 scenario. The largest temperature increase is expected in summer, while the smallest increase in spring. The same conclusion can be drawn from *Table 2* where the intervals of the seasonal temperature increase are summarized for the area of Hungary. The expected summer warming ranges are 4.5-5.1°C and 3.7-4.2°C for the A2 and B2 scenario, respectively. In case of spring, the expected temperature increase inside Hungary is 2.9-3.2°C (for A2 scenario) and 2.4-2.7°C (for B2 scenario). On the basis of seasonal standard deviation fields (*Figs. 2* and *4*), the largest uncertainty of the expected temperature change occurs in summer for both emission scenarios.

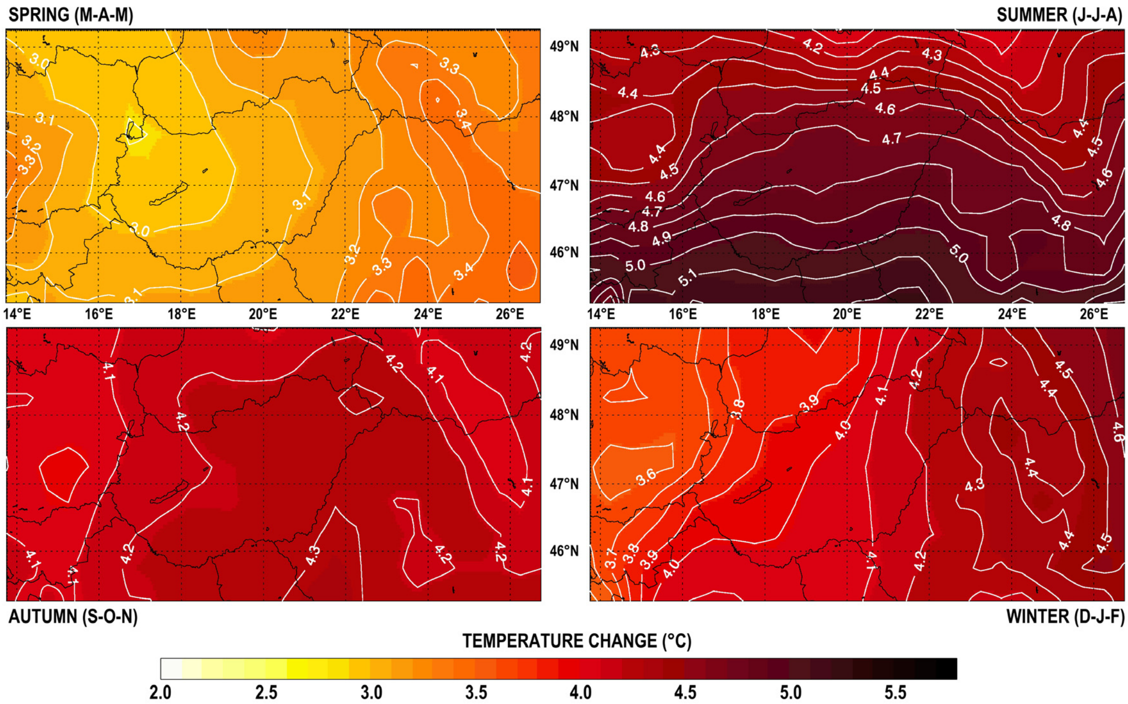

Figure 1. *Seasonal temperature change (°C) expected by 2071-2100 for the Carpathian basin using the outputs of 16 RCM simulations, A2 scenario*

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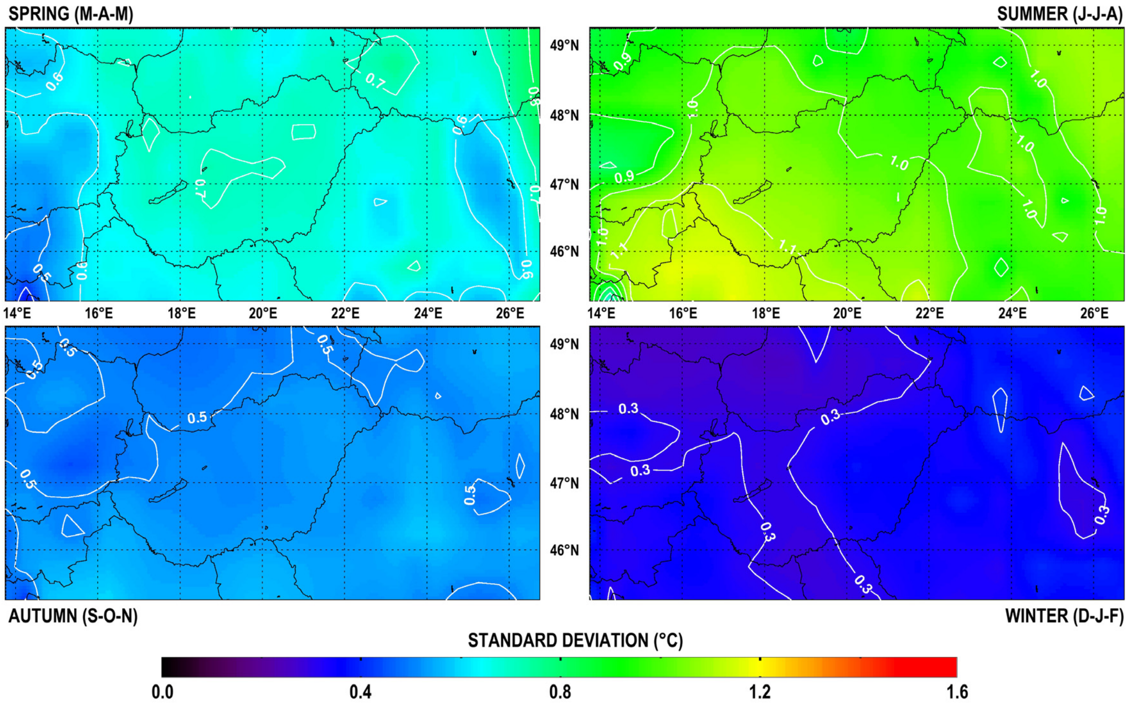

Figure 2. *Standard deviation of seasonal temperature change (°C) expected by 2071-2100 for the Carpathian basin using the outputs of 16 RCM simulations, A2 scenario*

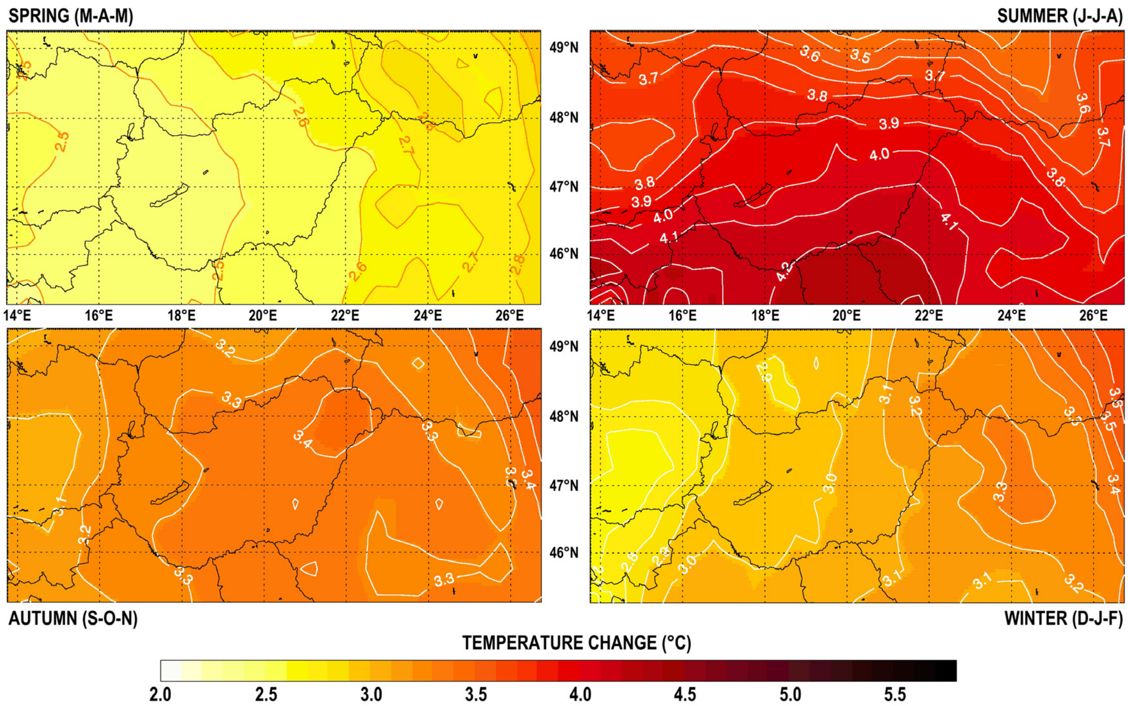

Figure 3. *Seasonal temperature change (°C) expected by 2071-2100 for the Carpathian basin using the outputs of 8 RCM simulations, B2 scenario*

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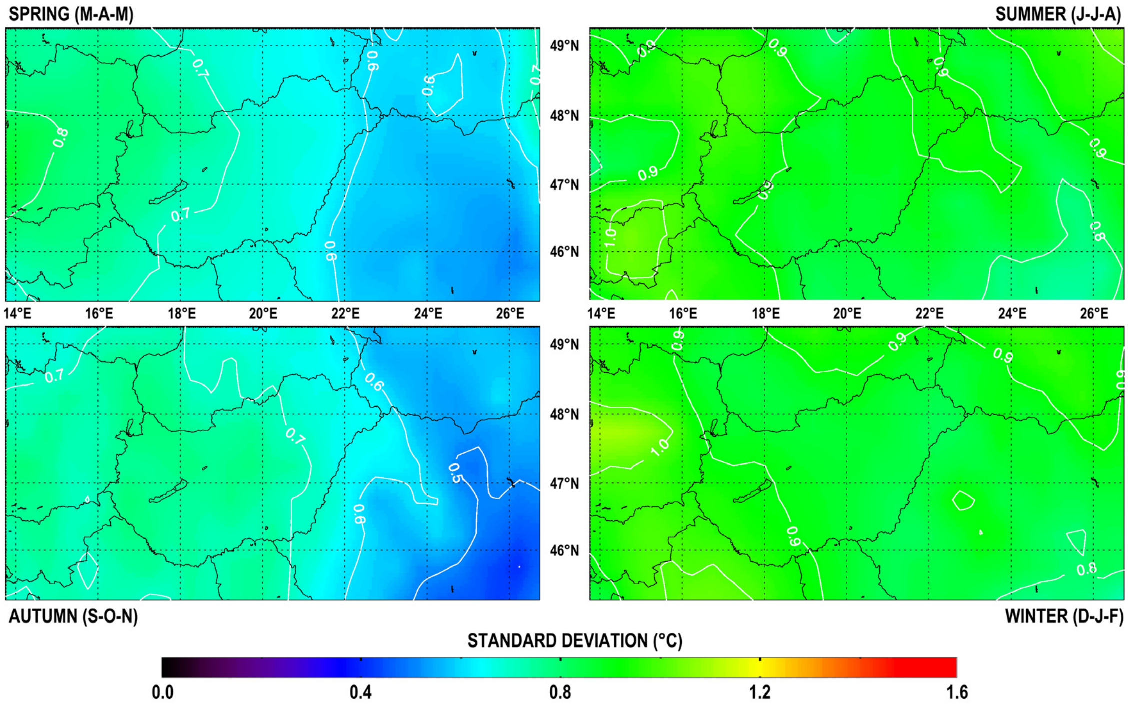

Figure 4. *Standard deviation of seasonal temperature change (°C) expected by 2071-2100 for the Carpathian basin using the outputs of 8 RCM simulations, B2 scenario*

Table 2. *Expected mean temperature increase by 2071-2100 for Hungary in case of A2 and B2 scenario using 16 and 8 RCM simulations, respectively*

Scenario	Spring (MAM)	Summer (JJA)	Autumn (SON)	Winter (DJF)
A2	2.9-3.2 °C	4.5-5.1 °C	4.1-4.3 °C	3.7-4.3 °C
B2	2.4-2.7 °C	3.7-4.2 °C	3.2-3.4 °C	2.9-3.2 °C

Fig. 5 summarizes the expected mean seasonal warming for Hungary in case of A2 and B2 scenarios. In general, the expected warming by 2071-2100 is more than 2.5°C and less than 4.8°C for all seasons and for both scenarios. Expected temperature changes for the A2 scenario are larger than for the B2 scenarios. The smallest difference is expected in spring (0.6°C), while the largest in winter (1°C). The largest temperature increase is expected in summer, 4.8°C (A2) and 4.0°C (B2). The smallest temperature increase is expected in spring (3.1°C and 2.5°C in case of A2 and B2 scenario, respectively).

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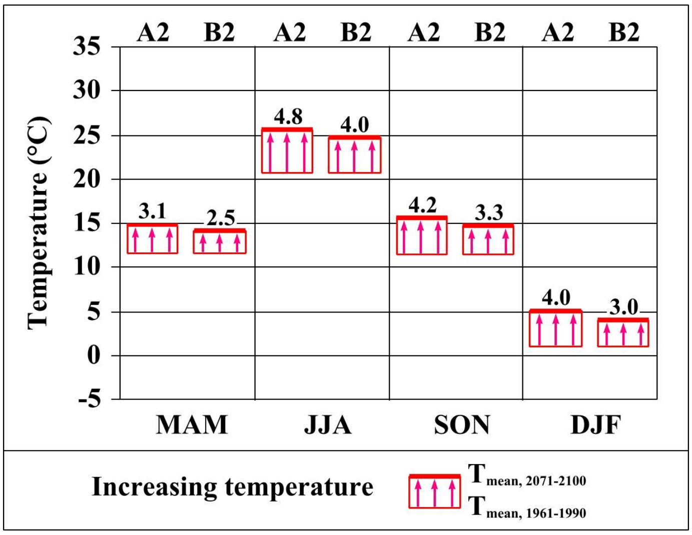

Figure 5. *Expected seasonal increase of mean temperature (°C) for Hungary (temperature values of the reference period, 1961-1990, represent the seasonal mean temperature in Budapest)*

In order to evaluate the model performance, temperature bias is determined for each RCM output fields using the simulations for the reference period (1961-1990), and the CRU (Climate Research Unit of the University of East Anglia) database [15]. *Fig. 6* presents the composite of the RCM biases. In general, the RCM simulations overestimate the temperature in most of the Carpathian basin, however, small underestimation can be seen in the western and northeastern boundary of the selected domain. The largest overestimation can be detected in the southern part of Hungary (1.0-1.5°C). In the northern part of Transdanubia and the northern part of the Great Plains the temperature is overestimated by 0.5-1.0°C, while in the northeastern part of the country the overestimation is only 0-0.5°C.

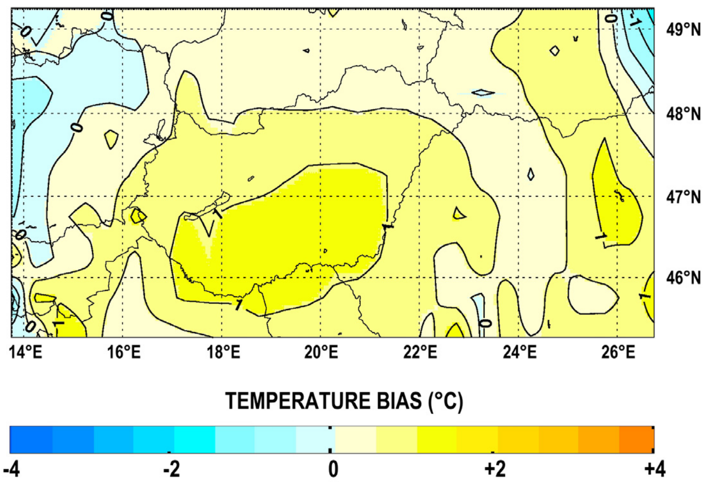

Figure 6. *Average seasonal temperature bias (°C) for the Carpathian basin using the outputs of 16 RCM simulations and the CRU data (1961-1990)*

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Similarly to mean temperature, expected seasonal warming of daily maximum and minimum temperatures in the Carpathian basin were mapped. Although these maps are not shown here, the maximum and minimum temperature increase expected in Hungary is summarized in *Table 3* and *Fig. 7* (similarly to *Table 2* and *Fig. 5* for the mean temperature). According to *Table 3*, the largest warming is expected in summer for both scenario: in case of maximum temperature the interval of the expected increase is 4.9-5.3°C (A2) and 4.0-4.4 (B2), while in case of minimum temperature these intervals are 4.2-4.8°C (A2) and 3.5-4.0°C (B2). The expected increase of mean temperature in summer (from *Table 2*) is between the expected warming of the maximum temperature and that of the minimum temperature. Summarizing the expected mean seasonal increase of daily extreme temperature for Hungary (in *Fig. 7*), the entire interval of the expected warming include values from 2.4°C to 5.1°C, which is 0.4°C larger than in case of the mean temperature. The largest temperature increases are expected in summer for both scenario, which is not surprising if the above results are considered. The expected increase of the maximum temperature generally is not smaller than the expected increase of the minimum temperature, the only exception is winter.

Table 3. *Expected increase in maximum and minimum temperature by 2071-2100 for Hungary in case of A2 and B2 scenario using 16 and 8 RCM simulations, respectively*

	Scenario	Spring (MAM)	Summer (JJA)	Autumn (SON)	Winter (DJF)
Maximum	A2	2.8-3.3 °C	4.9-5.3 °C	4.3-4.6 °C	3.7-4.2 °C
	B2	2.4-2.6 °C	4.0-4.4 °C	3.3-3.5 °C	2.6-3.0 °C
Minimum	A2	3.0-3.2 °C	4.2-4.8 °C	4.0-4.2 °C	3.8-4.6 °C
	B2	2.3-2.7 °C	3.5-4.0 °C	3.0-3.2 °C	2.8-3.5 °C

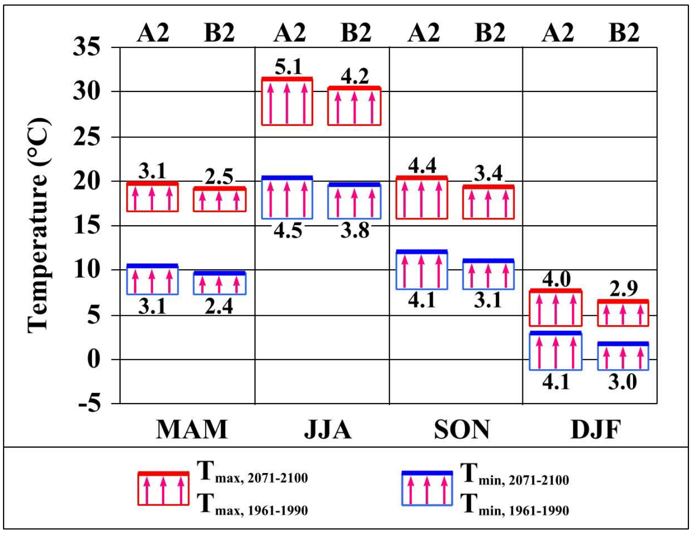

Figure 7. *Expected seasonal increase of daily minimum and maximum temperature (°C) for Hungary (temperature values of the reference period, 1961-1990, represent the seasonal mean temperature in Budapest)*

In order to provide a better overview on the spatial differences of expected temperature changes (both mean and extremes) for Hungary by the end of the 21st century, *Table 4* summarizes the spatial gradients of warming for summer and winter. In summer, zonal structure of warming (i.e., increasing values from north to south) can be detected in case of all parameters. On the other hand, in winter, generally a meridional structure of warming is expected (i.e., increasing values from west to east). The only exception is the spatial structure of expected maximum temperature increase in case of B2 scenario, which shows a zonal structure instead. If a larger domain is considered, the meridional gradient dominates the European region in case of this map as well, as the other expected winter temperature change fields [11]. In spring and autumn, the gradient values are much smaller, they do not exceed 0.4 and 0.3, respectively.

Table 4. *Spatial gradients of expected summer and winter temperature change for the Carpathian basin for 2071-2100 (zonal gradient is positive in case of increasing change from north to south, while meridional gradient is positive in case of increasing change from west to east)*

	Scenario	**Summer (JJA)**	**Winter (DJF)**
Mean temperature	A2	Zonal: +0.7 °C	Meridional: +0.6 °C
	B2	Zonal: +0.5 °C	Meridional: +0.5 °C
Maximum temperature	A2	Zonal: +0.6 °C	Meridional: +0.5 °C
	B2	Zonal: +0.4 °C	Zonal: +0.4 °C
Mininimum temperature	A2	Zonal: +0.7 °C	Meridional: +0.8 °C
	B2	Zonal: +0.6 °C	Meridional: +0.7 °C

Precipitation projections for the Carpathian basin

Similarly to temperature projections, composites of mean seasonal precipitation change and standard deviations are mapped for both A2 and B2 scenarios for the 2071-2100 period. *Fig. 8* presents the expected seasonal precipitation change for A2 scenario, while *Fig. 9* shows the seasonal standard deviation values for the Carpathian basin. Similar seasonal maps for the B2 scenario can be seen in *Figs. 10* and *11*. The annual precipitation sum is not expected to change significantly in this region [16], but it is not valid for seasonal precipitation. According to the results shown in *Figs. 8* and *10*, summer precipitation is very likely to decrease (also, slight decrease of autumn precipitation is expected), while winter precipitation is likely to increase considerably (slight increase in spring is also expected). *Table 5* summarizes the intervals of seasonal precipitation change for Hungary. In summer, the projected precipitation decrease is 24-33% (A2) and 10-20% (B2). In winter, the expected precipitation increase is 23-37% (A2) and 20-27% (B2). Based on the seasonal standard deviation values (*Figs. 9* and *11*), the largest uncertainty of precipitation change is expected in summer, especially, in case of A2 scenario (the standard deviation of the RCM results exceeds 20%).

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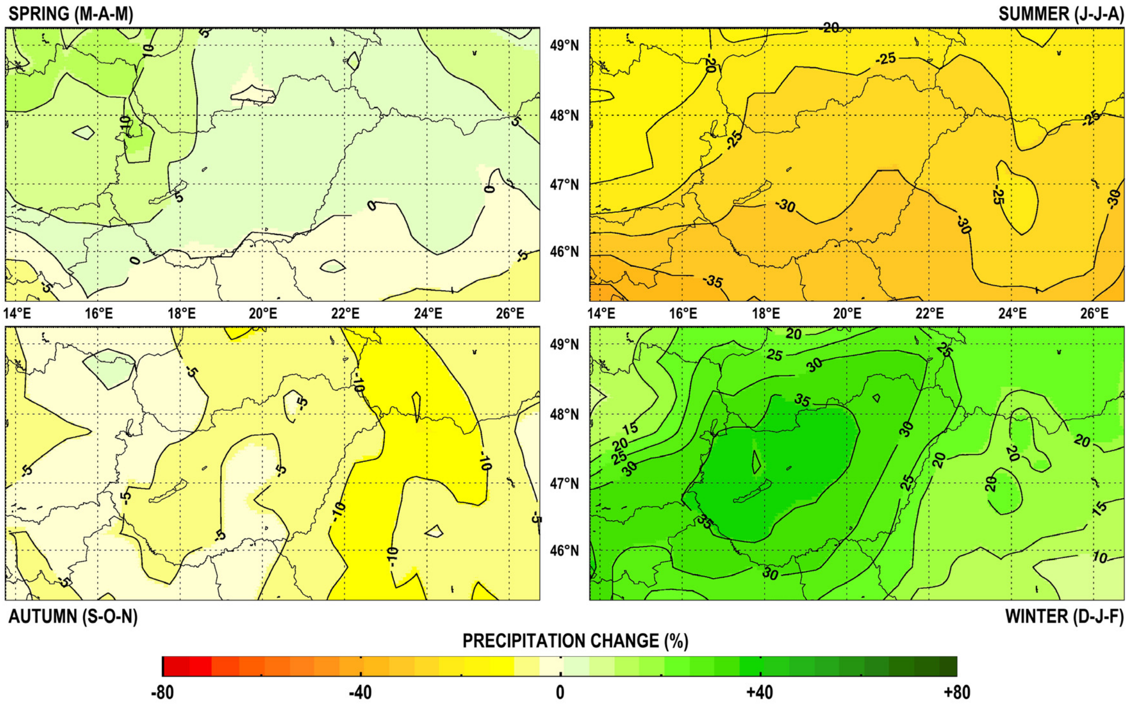

Figure 8. *Seasonal precipitation change (%) expected by 2071-2100 for the Carpathian basin using the outputs of 16 RCM simulations, A2 scenario*

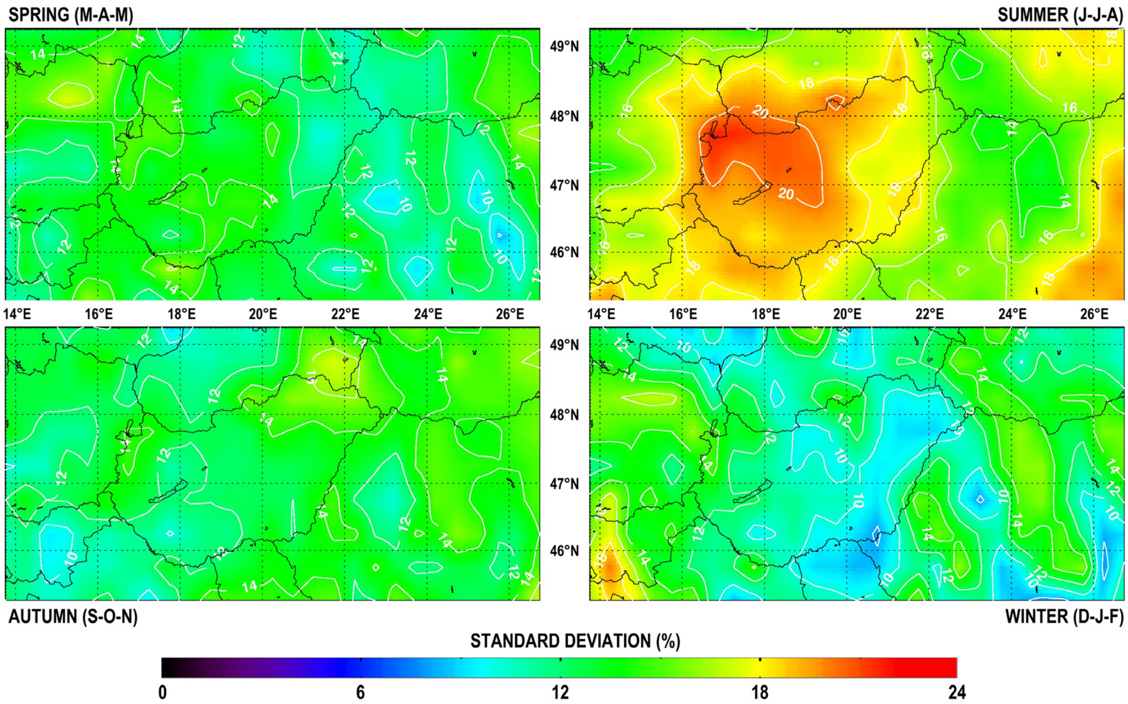

Figure 9. *Standard deviation of seasonal precipitation change (%) expected by 2071-2100 for the Carpathian basin using the outputs of 16 RCM simulations, A2 scenario*

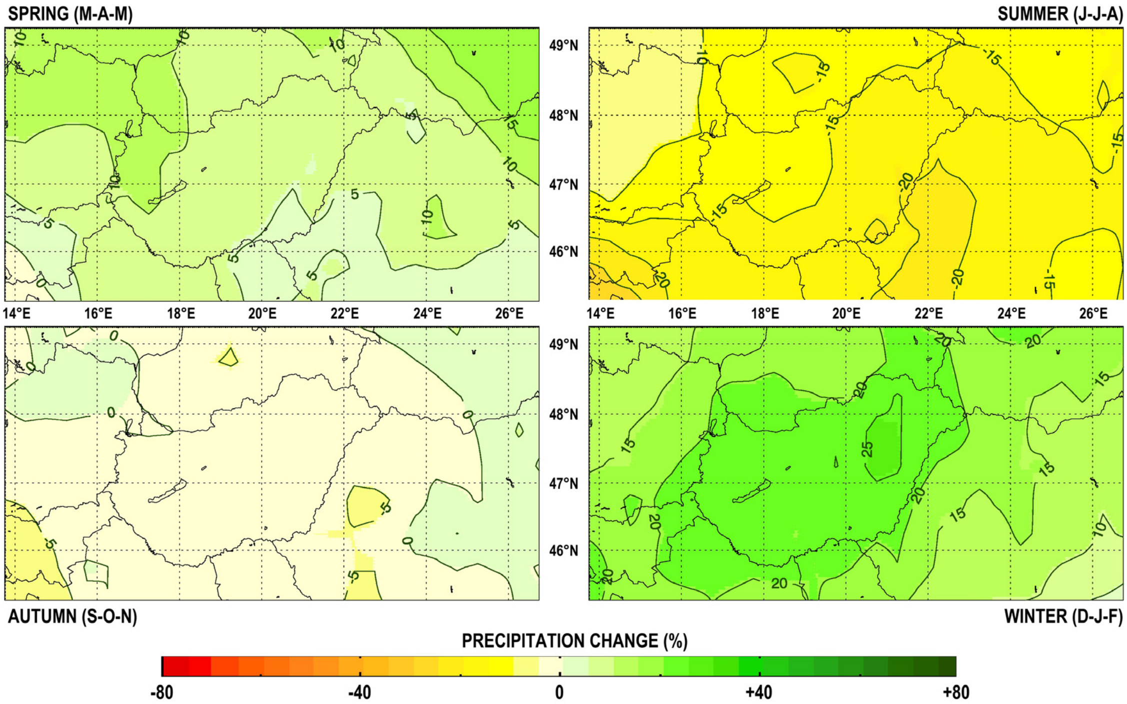

Figure 10. *Seasonal precipitation change (%) expected by 2071-2100 for the Carpathian basin using the outputs of 8 RCM simulations, B2 scenario*

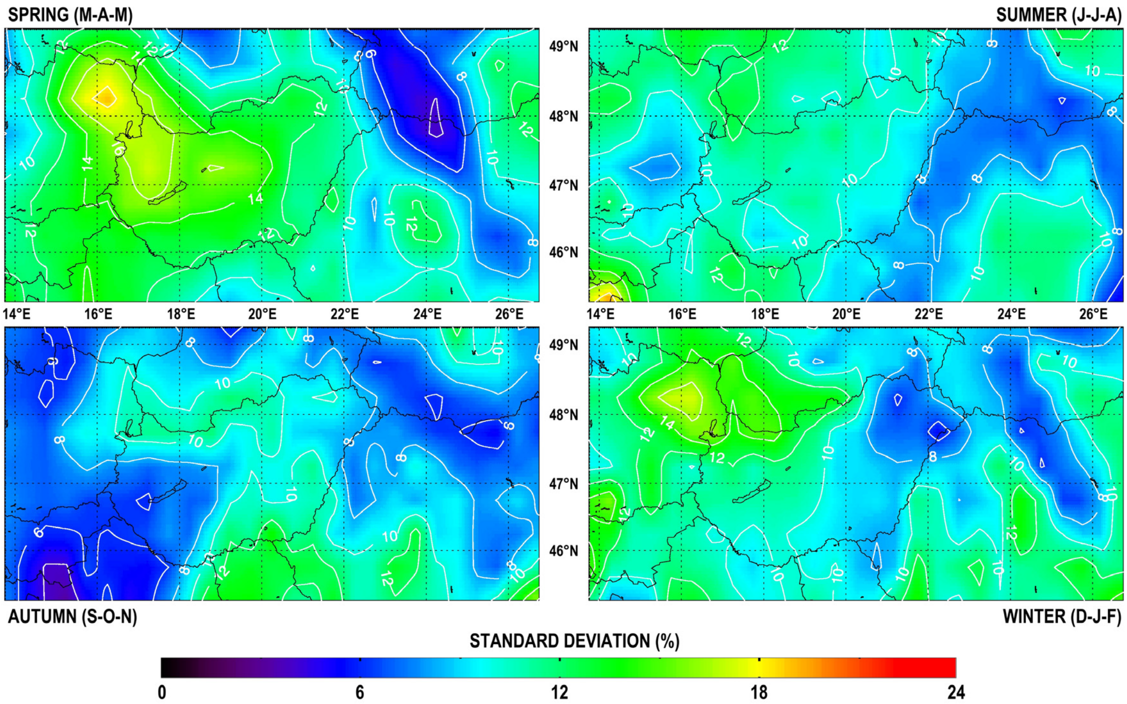

Figure 11. *Standard deviation of seasonal precipitation change (%) expected by 2071-2100 for the Carpathian basin using the outputs of 8 RCM simulations, B2 scenario*

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Table 5. *Expected mean precipitation change by 2071-2100 for Hungary in case of A2 and B2 scenario using 16 and 8 RCM simulations, respectively*

Scenario	Spring (MAM)	Summer (JJA)	Autumn (SON)	Winter (DJF)
A2	0 – (+10) %	(-24) – (-33) %	(-3) – (-10) %	(+23) – (+37) %
B2	(+3) – (+12) %	(-10) – (-20) %	(-5) – 0 %	(+20) – (+27) %

Fig. 12 summarizes the expected seasonal change of precipitation for Hungary in case of A2 and B2 scenarios. Red and blue arrows indicate increase and decrease of precipitation, respectively. According to the reference period, 1961-1990, the wettest season was summer, then, less precipitation was observed in spring, even less in autumn, and the driest season was winter. If the projections are realized then the annual distribution of precipitation will be totally restructured, namely, the wettest seasons will be winter and spring (in this order) in case of both A2 and B2 scenarios. The driest season will be summer in case of A2 scenario, while autumn in case of B2 scenario. On the base of the projections, the annual difference between the seasonal precipitation amounts is expected to decrease significantly (by half) in case of B2 scenario (which implies more similar seasonal amounts), while it is not expected to change in case of A2 scenario (nevertheless, the wettest and the driest seasons are completely changed).

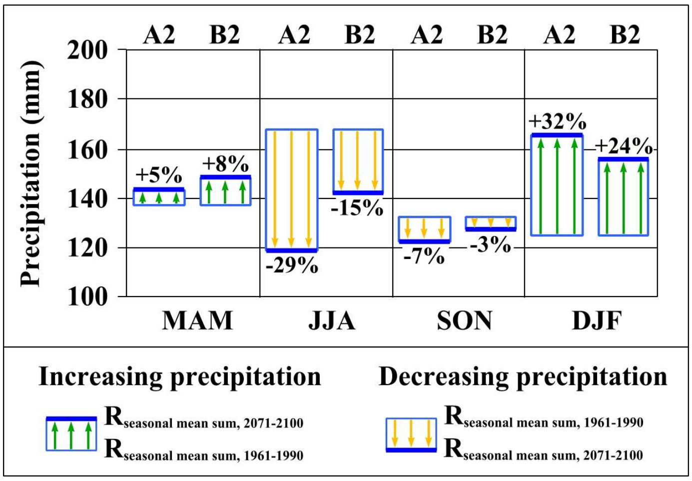

Figure 12. *Expected seasonal change of mean precipitation (mm) for Hungary (increasing or decreasing precipitation is also indicated in %). Precipitation values of the reference period, 1961-1990, represent the seasonal mean precipitation amount in Budapest.*

In order to evaluate the model performance, precipitation bias is determined for all the RCM output fields using the simulations for the reference period (1961-1990), and the CRU database [15]. *Fig. 13* presents the composite of the RCM biases. In general, the RCM simulations overestimate the precipitation in most of the Carpathian basin, however, underestimation can be seen in the southwestern part of the region. In Hungary, the bias is not exceeding 15% in absolute terms. The precipitation is slightly underestimated in the western/southwestern part of the country, while precipitation in the other large parts (including the entire Great Plains and the eastern part of Transdanubia) is slightly overestimated.

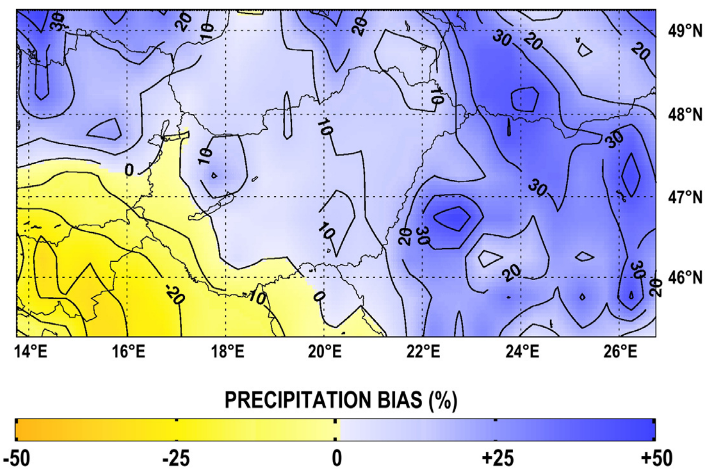

Figure 13. *Average seasonal precipitation bias (°C) for the Carpathian basin using the outputs of 16 RCM simulations and the CRU data (1961-1990)*

Table 6 summarizes the spatial gradients of expected seasonal precipitation change. Precipitation is a highly variable meteorological parameter, therefore, the spatial structure is more complex than in case of temperature. In winter and in spring, the spatial structures of expected precipitation change (for both A2 and B2 scenarios) are dominated by radial and zonal gradients, respectively. In summer, zonal structure can be seen in case of A2 scenario, while radial structure is expected in case of B2 scenario.

Table 6. *Spatial gradients of expected seasonal precipitation change for the Carpathian basin for 2071-2100 (zonal gradient is positive in case of increasing change from north to south, meridional gradient is positive in case of increasing change from west to east, and radial gradient is positive in case of increasing change from the boundary to the center)*

Scenario	Spring (MAM)	Summer (JJA)	Autumn (SON)	Winter (DJF)
A2	Zonal: –10%	Zonal: –8%	Meridional: –7%	Radial: +13%
B2	Zonal: –5%	Radial: –10%	Radial: 0%	Radial: +5%

Discussion and conclusions

The target period of PRUDENCE simulations covers the end of the 21st century (2071-2100), thus, the above results presented for the Carpathian basin provide projections for this period. On the other hand, impact studies would require regional climate change scenarios for earlier periods, preferably for the next few decades. The only information source currently available with fine (i.e., 50 km) horizontal resolution for Hungary and other European countries is a special comprehensive assessment based on the PRUDENCE simulations [11]. This country-by-country based analysis is conducted for both the mean temperature and the precipitation amounts. In order to avoid the specific characteristics of A2 or B2 scenario, a pattern scaling technique has been applied, thus, the changes are expressed relative to a 1 °C global warming. Uncertainties in the estimates of projected changes are due to the use of different GCMs and RCMs, as well, as natural variability. As a result, mean and standard deviation of 25 estimates of temperature and precipitation change are provided for each country. Furthermore, these main statistical parameters are used to fit a normal probability distribution function for the projected change. *Table 7* summarizes the mean, the standard deviation, the 5th and the 95th percentiles of the seasonal and annual projected temperature changes for Hungary, while *Table 8* contains the same information for precipitation. In case of the percentile values, their associated 95% confidence intervals are also provided.

Table 7. *Statistical characteristics of expected increase of temperature for Hungary relative to 1°C global warming using 25 RCM simulations [11]. In case of percentiles, the values in brackets indicate the 95% confidence intervals.*

	Annual	**Spring (MAM)**	**Summer (JJA)**	**Autumn (SON)**	**Winter (DJF)**
Mean	1.4	1.1	1.7	1.5	1.3
Standard deviation	0.3	0.3	0.4	0.3	0.3
95th percentile	1.9 [1.8-2.1]	1.6 [1.5-1.8]	2.4 [2.2-2.6]	2.0 [1.8-2.1]	1.9 [1.7-2.1]
5th percentile	0.9 [0.7-1.0]	0.6 [0.5-0.8]	1.0 [0.8-1.2]	1.0 [0.8-1.1]	0.8 [0.6-0.9]

In case of temperature (*Table 7*), all seasonal, as well, as annual temperature increase expected in Hungary is larger than the global 1°C warming, which implies that this region is quite sensitive to the global environmental change. The projected summer and autumn regional warming (1.7°C and 1.5°C, respectively) is larger than the annual increase (1.4°C), while the expected winter (1.3°C) and spring (1.1°C) warming is smaller than the annual temperature increase. According to the results presented in *Table 8* for the precipitation, the annual amount in Hungary is not expected to change significantly. On the other hand, considerable precipitation decrease and increase are projected for summer and for winter, respectively. Slight changes are expected for autumn (some decrease) and for spring (some increase). These results confirm the conclusions drawn from the precipitation maps in the previous section, which implies that the expected shift in the annual distribution of precipitation starts quite early.

Table 8. *Statistical characteristics of expected change of precipitation for Hungary relative to 1°C global warming using 25 RCM simulations [11]. In case of percentiles, the values in brackets indicate the 95% confidence intervals.*

	Annual	**Spring (MAM)**	**Summer (JJA)**	**Autumn (SON)**	**Winter (DJF)**
Mean	-0.3	0.9	-8.2	-1.9	9.0
Standard deviation	2.2	3.7	5.3	2.1	3.7
95th percentile	3.4 [2.2-4.6]	7.0 [5.0-9.0]	0.5 [(-2.3)-(3.2)]	1.5 [0.4-2.7]	15.0 [13.0-16.9]
5th percentile	-3.9 [(-5.1)-(-2.8)]	-5.2 [(-7.2)-(-3.3)]	-16.9 [(-19.5)-(-14.1)]	-5.3 [(-6.4)-(-4.2)]	3.0 [1.0-5.0]

On the basis of the results shown in this paper, the following conclusions can be drawn.

- Expected seasonal temperature increase for the Carpathian basin in case of the A2 scenario is larger than in case of the B2 scenario, which is in good agreement with the global and the European climate change results. The largest and the smallest warming is expected in summer and in spring, respectively.
- For all the four seasons and for both scenarios, the expected warming by 2071-2100 is between 2.5°C and 4.8°C. The largest temperature increase is projected for summer, 4.8°C (A2) and 4.0°C (B2), while the smallest seasonal warming is expected in spring, 3.1°C (A2) and 2.5°C (B2). The smallest difference between the A2 and B2 scenarios is projected for spring (0.6°C), while the largest for winter (1°C).
- In the reference period (1961-1990), RCM simulations overestimate the temperature in most of the Carpathian basin, however, small underestimation can be seen in the western and the northeastern boundaries of the selected domain.
- The largest increase of maximum and minimum temperatures is expected in summer for both scenario. In case of maximum temperature, the interval of the expected warming is 4.9-5.3°C (A2) and 4.0-4.4 (B2), while in case of minimum temperature, these intervals are 4.2-4.8°C (A2) and 3.5-4.0°C (B2). In general, the expected increase of maximum temperature is not smaller than the expected increase of minimum temperature, the only exception is winter.
- In summer, zonal structure of projected warming (i.e., increasing values from north to south) can be expected in case of all temperature parameters. On the other hand, in winter, generally a meridional structure of warming is expected (i.e., increasing values from west to east). In spring and autumn, the gradient values are much smaller, they do not exceed 0.4 and 0.3, respectively.
- The annual precipitation sum is not expected to change significantly in this region, but it is not valid for seasonal precipitation sums. Summer precipitation is very likely to decrease, furthermore, slight decrease of autumn precipitation is expected. On the other hand, winter precipitation is likely to increase considerably, and slight increase in spring is also expected.
- The projected summer precipitation decrease is 24-33% (A2) and 10-20% (B2), while the expected winter precipitation increase is 23-37% (A2) and 20-27% (B2).
- In the reference period (1961-1990), the wettest season was summer, while the driest season was winter. If the projections are realized then the annual distribution of precipitation will be totally restructured. Namely, the wettest season will be winter in case of both A2 and B2 scenarios. The driest season will be summer in case of A2 scenario, while autumn in case of B2 scenario.
- In winter and in spring, the spatial structures of expected precipitation change (for both A2 and B2 scenarios) are dominated by radial and zonal gradients, respectively. In summer, zonal structure can be seen in case of A2 scenario, while radial structure is expected in case of B2 scenario.

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USING CARBONIZED REFUSE DERIVED FUEL TO RESTORE SEAWEED FORESTS: A POTENTIAL CONSERVATION TECHNIQUE

T. TOGASHI[1,4*] – T. MIYAZAKI[1] – J. YOSHIMURA[1,2] – K. YUDATE[3] – P. A. COX[4]

[1]Marine Biosystems Research Center, Chiba University, Kamogawa, 299-5502, Japan
[2]Faculty of Engineering, Shizuoka University, Hamamatsu, 432-8561, Japan
[3]JFE Steel Corporation, Uchisaiwaicho 2-2-3, Tokyo, 100-0011, Japan
[4]Institute for Ethnomedicine, Box 3464, Jackson Hole, Wyoming 83001, USA
(phone: +81-4-7095-2201; fax: +81-4-7095-2271)

e-mail: togashi@faculty.chiba-u.jp

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Abstract. We have recently developed a new material by carbonizing refuse derived fuel (RDF) not discharging dioxin and other toxic fine particles. This recycled carbonaceous material (CRDF) has two major good points: 1) rich in the three chemical elements of fertilizer (nitrogen, phosphoric acid and potassium) and 2) a good adsorbent like activated charcoal. In this study, making the best use of these merits, we looked into the possibility of using this material to restore seaweed forests that were damaged by human activities. We confirmed that no toxic substance was liquated out from this material. In the laboratory experiments, the growth of a species of marine green algae (*Derbesia tenuissima* (Moris et De Notaris) Crouan) was accelerated by this material. CRDF might supply nitrogen short in seawater as the form of nitrate. Our technique was actually effective to introduce marine algae in the fields using a series of test plates that included this material ranging from 0 to 8.2 % (w/w). We might not only recover biodiversity in coastal ecosystems by restoring seaweed forests but also remarkably reduce atmospheric CO_2 released in the process of the incineration of waste with this technique.
Keyword: *atmospheric CO_2, biodiversity, coastal ecosystems, carbonaceous material, water pollution*

Introduction

Refuse derived fuel (RDF) is produced from municipal solid waste (MSW) through following processes: separating at source; sorting or mechanical separation; size reduction (shredding, chipping and milling); separation and screening; blending; drying and palletizing [3]. The waste material is screened to remove the recyclable fractions (e.g. metals), the inert fractions (e.g. glass) and the fine wet putrescible fractions (e.g. food) before being pulverized. The calorific power of RDF is approximately 5000 kcal kg^{-1}, which is similar to that of coal. RDF is often used to generate electricity. In Japan, however, since a serious accident at an electric power plant using RDF in Mie prefecture in 2003, the demand of RDF is decreasing. It would be, therefore, important to find another way to use RDF effectively and safely.

We have recently developed a new carbonaceous material with RDF. In the producing process, we pyrolyze RDF without oxygen at a very high temperature (>1000˚C), so dioxin and other toxic gasses are not produced. We can also use thermal energy left over in the iron manufacture processes not to generate additional CO_2. By carbonization, the weight of waste is decreased by ca. 12.5 %. We call this material CRDF. We found that CRDF has some chemical and physical good points. First, it is rich in the three chemical elements of fertilizer (i.e. nitrogen, phosphoric acid and potassium). In our preliminary research, these percentages are 1.7, 3.0 and 1.1 % (w/w), respectively. Second, it is a good adsorbent like activated charcoal. This appears to be due to a large surface area (i.e. 140 m^2 g^{-1} in our preliminary research).

The inshore fishery is one of very important industries in many countries including Japan. Fishery products have been key sources of food since early times, constituting 20% of the Japanese people's protein consumption (see the Japanese government annual report on the fisheries at http://www.maff.go.jp/eindex.html). Many commercially important fish populations, however, have been declining in the past several decades [5, 10]. One of the major reasons for decreasing fisheries is destruction of seaweed forests by human activities. Seaweed forests play significant roles in maintaining biodiversity of coastal marine ecosystems (e.g. [7]). Marine algae are not only foods for herbivores, but also provide spawning and hiding places for juveniles of many marine organisms. For instance, settlement and germination of seaweed spores are seriously disturbed by species of coralline red algae (e.g. [6] for *Lithophyllum yessoense* Foslie), which is exacerbated by human activities (see [8]). In this study, we carefully examine whether CRDF could be used to solve these crucial environmental problems restoring seaweed forests.

Materials and methods

Scanning electron microscope observations

The surface ultrastructures of the carbonaceous material were observed using a scanning electron microscope (SEM, Hitachi S-2050). We prepared a series of samples varying the proportion of the carbonaceous material (i.e. 3, 20 and 90 % w/w) using starch as a binder.

Eluent test

We checked whether 24 chemical compounds were eluted from CRDF: alkylmercury, organic mercury, inorganic mercury, cadmium, lead, organophosphorus, chromium 6, arsenic, total cyanide, poly chlorinated biphenyl, trichloroethylene, tetrachloroethylene, 1,2-dichloroethane, 1,1-dichloroethylene, cis-1,2-dichloroethylene, 1,1,1-trichloroethane, 1,1,2-trichloroethane, 1,3-dichloropropene, thiuram, simazine, thiobencarb, benzene and selenium. Such tests are necessary for materials made from municipal solid waste (MSW). For the metals, Inductively Coupled Plasma Mass Spectrometer (ICP-MS) was used and a Mass Spec was used for the rest.

Laboratory study

Materials

We used male gametophytes of a dioecious marine green alga, *Derbesia tenuissima* (Derbesiaceae) in our laboratory experiments. They usually do not branch out (*Fig. 1*; [16]). We safely estimated their biomass (volume) assuming the shape of each gametophyte as ellipsoidal (volume (V) = $4/3\ \pi ab^2$, a: radius on the minor axis; b: radius on the major axis) [4], and easily and correctly measured the growth rate of this alga. We used only male gametophytes because female gametes parthenogenetically develop into filamentous sporophytes. For each culture experiment, we prepared even-sized small ellipsoidal male gametophytes of *D. tenuissima*, culturing protoplasts in PES medium at 25˚C under a 14:10, light : dark condition using an incubator (NK system) [17].

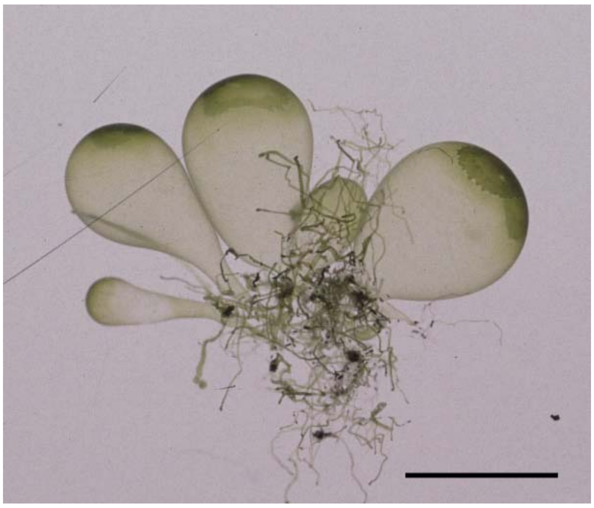

Figure 1. *Male gametophytes of Derbesia tenuissima. Both male and female gametophytes are similarly ellipsoidal in shape. Scale bar=2cm.*

Culture experiments

The grained CRDF was fixed on the bottom of cylindrical glass vessels (3 cm in radius and 8.5 cm in depth) with 50 mL of 1 % agar (Wako). Five male gametophytes of *D. tenuissima* were cultured in each vessel with 100 mL seawater at 25 ˚C under a 14:10, light : dark condition. We explored three different experimental regimes: 1) 5 g of CRDF; 2) 15 g of CRDF; 3) 1 % agar only (control). The size of each gametophyte (i.e. radii on the minor and major axes) was measured every week and the volume was calculated. At the beginning of the experiments, there was no significant difference in the mean volumes of gametophytes among the regimes. Seawater used in the culture experiments was drawn at the field study site (below) and autoclaved (121 ˚C, 20 min) before use. Chemical characters of seawater (i.e. pH and the densities of NO_3^-, NO_2^-, PO_4^{3-} and NH_4^+) after the two experiments (i.e. 15 g of CRDF and 1 % agar only) were analyzed using High Performance Liquid Chromatography (HPLC).

Field study

Our field study was carried out at our study site in the preserved area of the Marine Biosystems Research Center of Chiba University located in the Boso peninsula, Japan (35˚08'N, 140˚11'E) in 2004. Samples of seawater were weekly collected from July to December. Ammonium, Nitrate, Nitrite and Reactive phosphorus were quantitatively analyzed using HPLC. We calculated the ratios of TIN (N = Ammonium + Nitrate + Nitrite) to RP (P = Reactive phosphorus) and compared them with the Redfield ratio [13]. [The Redfield ratio refers to the molar ratio of carbon (C), nitrogen (N) and phosphorus (P) in plants estimated by using phytoplankton. When nutrients are not limiting, they have the following molar ratio of elements: C : N : P = 106 : 16 : 1. Thus N:P ratios less than 16 mean they are under nitrogen limiting conditions, and *vice versa*.]

We made a series of test plates that include the carbonaceous material (i.e. 0, 2.7, 2.9, 5.3 and 8.2 % w/w) with the 'eco-concrete' that was made from ash of waste to keep the shape in sea (*Fig. 2*). These five plates were fixed in the upper intertidal zone during a low tide using stainless bolts making a pentagon [12]. We visited them monthly and counted the numbers of individuals of each species of seaweeds growing on each plate.

Figure 2. *Plates for the field test.*

Results

Ultrastructure

In a case where the proportion of CRDF was low (3%), the surface of the sample was very smooth with few particles (*Fig. 3a*). As the proportion of CRDF increased (20%), carbonaceous grains were observed on the surface of the sample (*Fig. 3b*). In the sample with 90 % of CRDF, there were many finely uneven surface structures (*Fig. 3c*).

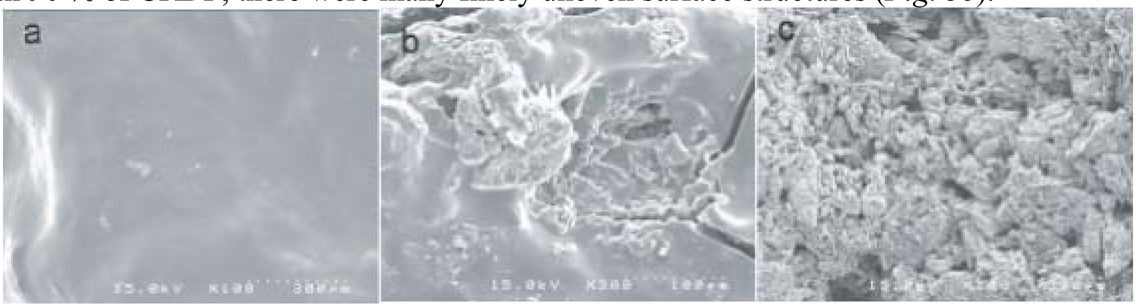

Figure 3. *SEM images. a) 3% CRDF; b) 20% CRDF; c) 90% CRDF.*

Water analyses

We confirmed that none of the chemical compounds listed above were eluted out from CRDF. The pH and the concentrations of ionized chemical compounds in seawater after the two of the culture experiments (i.e. with and without CRDF) are shown in the *Table 1*. Comparing the results between these two experiments, there was no critical difference in the pH and the concentrations of ionized chemical compounds except for NO_3^-. In both experiments, data on pH indicate seawater was weakly alkaline. The concentrations of NO_2^-, PO_4^{3-} and NH_4^+ were remarkably low. Only the concentration of

NO_3^- was, however, notably increased in the experiment with CRDF. The ratios of TIN to RP of seawater at our field study site from July to December are shown in the *Table 2*. All of them were lower than the Redfield ratio.

Table 1. *Water analysis in the culture experiments.*

	pH	NO_3^- (mg L^{-1})	NO_2^- (mg L^{-1})	PO_4^{3-} (mg L^{-1})	NH_4^+ (mg L^{-1})
Experimental	8.33	23	<0.1	<0.1	<10
Control	8.77	<0.1	<0.1	<0.1	<10

Table 2. *The ratios of TIN (=Ammonium + Nitrate + Nitrite) to RP (=Reactive phosphorus) of seawater at our field study site from July to December.*

Month	**July**	**August**	**September**	**October**	**November**	**December**
TIN:RP	6	7.3	9.9	11.2	8.2	5.2

Gametophyte growth rate

The mean volumes of gametophytes of each experimental regime were plotted (*Fig. 4*). In the experiment with 5 g of CRDF, the growth rate was constantly low. The difference between the experiment and the control (i.e. agar only) was not clear. In contrast, in the experiment with 15 g of CRDF, the gametophyte growth rate was remarkably higher than the other two experiments, accelerating from the 2nd to 3rd week, and then decelerating and leveling-off after the 5th week. The mean volume of gametophytes was approximately three times larger than that of the control at the beginning of 6th week.

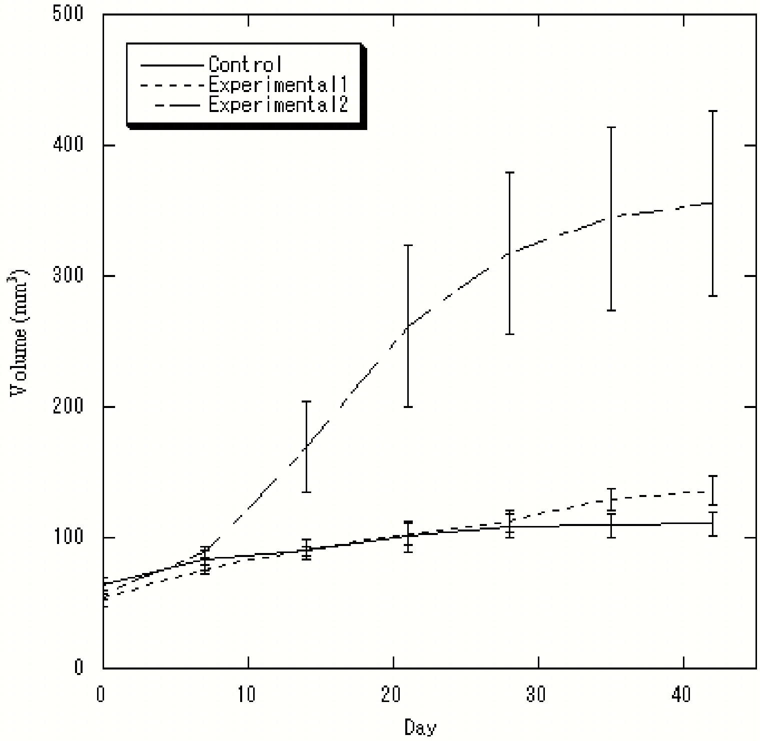

Figure 4. *The growth rates of male gametophytes of D. tenuissima with and without CRDF. Experimental 1: with 5 g of CRDF; Experimental 2: with 15 g of CRDF; Control: 1% agar only. Mean±SD (n=5).*

Field tests

The numbers of macroalgae that were growing on the surface of the test plates after two months are shown in the *Fig. 5*. The results of the field tests might be appropriately shown by these numbers as a whole because only one species of a green alga, *Ulva conglobata* Kjellman, migrated on the plates by the end of this study and their size was still too small to compare their size. *Ulva* is an isomorphic alga. So we identified individuals, but, did not distinguish gametophytes and sporophytes. A large number of *U. conglobata* plants (85 individuals) were observed on the plate with 8.20 % of CRDF. Their numbers decreased as the percentage of CRDF. We found no *U. conglobata* plant on the plate that did not include CRDF at the end of this study. We tested another series of plates which were different in shape and located in a different place within the same study site. The results were similar to those here (data not shown).

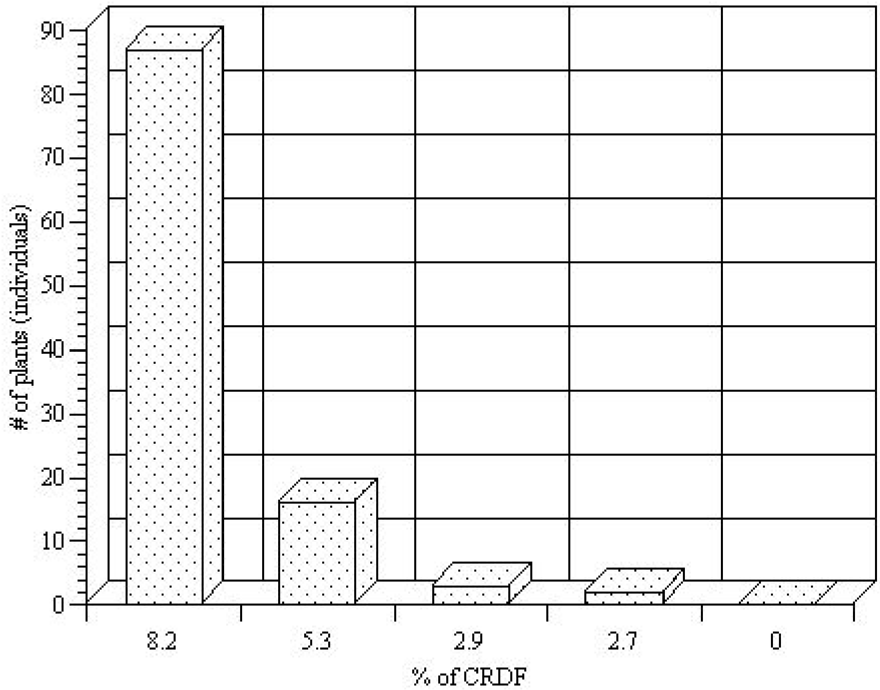

Figure 5. *The numbers of Ulva conglobata plants migrated on the test plates (Fig. 2) after 2 months.*

Discussion

Our culture experiments suggest that some substances eluted from CRDF are effective to accelerate the growth rate of algae (*Fig. 4*). The effects of dissolving substances seem to continue at least for several weeks. During the culture experiments, we have scarcely observed sexual reproduction. Therefore, most of the energy that *Derbesia* plants have might be spent for the growth. The growth was, however, inhibited by excess amounts of CRDF (e.g. 100 g per vessel in our experimental method) (data not shown). Thus, there might be the most suitable condition for growth of algae with this material.

In general, shallow-seawater habitats have relatively low N:P ratios [1]. Therefore, nitrogen is the element that most frequently limits algal growth in the sea [8]. Our

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analyses of seawater at our field study site confirm nitrogen is limited (*Table 2*). Meanwhile, our analyses of seawater after the culture experiments suggest that CRDF might supply nitrogen short as the form of nitrate (*Table 1*). Thus, in our culture experiments, the growth of *Derbesia* plants might be accelerated by such nitrogen. It has been suggested that nitrogen supply will be also an important constraint on global responses of terrestrial plants to elevated CO_2 [9, 14]. Another possible reason is that the quality of seawater is improved by the carbonaceous material that works as an absorbent. However, it might be less likely because there are few factors that cause serious water pollution near our field site (seawater is usually very clear). The surface structures of CRDF can not be considered here because the material was completely covered with agar. Additionally, we should note that the pH of seawater is not dramatically changed by CRDF (*Table 1*). It would be important for many aquatic organisms including algae (see [18]). The pH of seawater after the culture experiments appear to be slightly higher than the average pH of seawater (i.e. 7.7 ranging from 7.2 to 8.2). This might be caused through the rapid abstraction of CO_2 from seawater during photosynthesis of algae (see [1]).

Also, our field tests suggest that CRDF is useful to introduce seaweeds in the field, and that there may be the most suitable combination of CRDF and other materials for seaweeds to migrate on the plates, because, as the percentage of CRDF was increased, the number of migrated plants was increased (*Fig. 5*). In this study, we adduce the following three major reasons for these results. 1) Some of chemical compounds eluted from CRDF may be effective for seaweeds to grow on the plates as shown in the culture experiments. 2) CRDF may improve the quality of seawater as good adsorbent. 3) Because the surface of CRDF is rich in ultrastructural pores (*Fig. 3*) it may have a good affinity for zoospores of seaweeds as shown in activated carbon for marine microorganisms [2].

We have observed only *Ulva conglobata* plants on the test plates during our field experiment. It may be because they can flourish at the early stage of the secondary succession as a pioneer species. Actually, some other species were found on the plates after this study (e.g. *Colpomenia bullosa* (Saunders) Yamada). At our field study site, *Sargassum fusiformis* (Harvey) Sethchell, which is an economically important perennial brown alga as a good food material in eastern Asia (e.g. Japan and Korea), is one of the major dominant species. We try to introduce such species with future long-term endurance tests. There are many other reports on methods to restore seaweed forests so far (e.g. [11]). The most important merit of our study is that we use municipal solid waste (MSW) as the main ingradient. This is useful not only to reduce the costs, but also to solve two important environmental problems: atmospheric CO_2 and biodiversity. In this sense, our approach is a new type of win-win (reconciliation) ecology in marine ecosystems [15].

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METAL ACCUMULATION IN 5 NATIVE PLANTS GROWING ON ABANDONED CU-TAILINGS PONDS

MANAB DAS[1]*-SUBODH KUMAR MAITI[1]

[1]*Centre of Mining Environment*
Indian School of Mines, Dhanbad, Jharkhand, INDIA.
(+91 0326-22063720)

e-mail: manab_ism@rediffmail.com

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Abstract: Tailings and plants were sampled from the abandoned Cu-tailing ponds of Rakha mines, Jharkhand, India. Tailings have high concentration of Cu, Ni and characterized by moderately acid environment and low nutrient contents. Plants belonging to 5 genera and 4 families were collected and analysed for metals in their above and underground tissues. Plant communities respond differently depending on their ability to uptake or exclude a variety of metals. Accumulated metals were mostly retained in root tissue indicating that an exclusion mechanism for metal tolerance widely exists in them. Retention of some metals more than toxic level in the above ground tissues of some plants suggests the presence of internal metal detoxification and tolerance mechanisms in them.

Keywords: *Cu-tailings, heavy metal, metal tolerance, natural vegetation*.

Introduction

Mill tailings are generally characterised by high metal content, low fertility and obviously low water holding capacity. A vegetative cover on such tailings may play an important role in metal removal via filtration, adsorption and cation exchange, and through plant induced chemical changes in the rhizosphere. Additionally, it helps to avoid dispersion of contaminants through wind erosion and by reducing water percolating through the soil. This may keep contaminants away from underlying ground water by stabilising them in the soil profile [27]. Some plants phytostabilise heavy metals in the rhizosphere through root exudates immobilisation [4] whilst other species incorporate them into root tissues [16]. Some plant species also transfer metals to their aboveground tissues, potentially allowing the soil to be decontaminated by harvesting the aboveground parts of the plants. The success of any phytoremediation technique depends upon the identification of suitable species that hyperaccumulate trace elements and produce large amount of biomass using established crop production and management practices [3,8,9]. Thus collecting plant species on contaminated sites prior to evaluation of plant metal concentration can be used to get information about specific plant behavior in this environment, which may be effective for selecting potential plants to be used in mine remediation and also to complete data about metal dispersion, with reference to their mobility to biomass [12,14]. There are many evidences that plants grown on metal enriched soil can accumulate high amount of heavy metals in their tissues such as *Silene armeria* [12], *Typha latifolia* [29], *Festuca sp*. [2], *Salix viminalis* [20], *Vetiveria zizanioides* [28], *Juncus conglomerates* [14]. In Rakha mines area, Jharkhand there are several abandoned Cu-tailings ponds that caused severe metal pollution to the nearby areas. Our investigation in Cu-tailings ponds revealed that many plant species could thrive in heavily metal enriched tailings. Henceforth, the concentration of Cu, Ni, Mn, Zn, Pb and Cd were examined in both the above and

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underground tissues of 5 naturally growing plant species. The main objectives of our study were:

- to evaluate the different form of toxic metals present in Cu tailings and their bioavailability;
- to identify plant species grown naturally on abandoned Cu-tailings and to determine the ability of these species to accumulate and tolerate Cu, Ni, Mn and Zn in their tissue.
- to examine the extent of metal translocation from underground tissue to aboveground tissue in different plants for different metals.

The above information could be used for selection of appropriate plant species in metal enriched Cu-tailing ponds to exploit removal potential of heavy metals by naturally growing vegetation combined with other chemical and biological process.

Materials and methods

Sampling location and plant species

The Rakha Cu mines located at about 50 km away from Tatanagar by road and at a distance of 7 km from Rakha mines railway station, East Singhbhum, Jharkhand. According to Dunn and Dey [13] and Deb and Sarkar [10] the mineral distribution of Rakha ore follow the order as silicious gangue (85.12%) > chalcopyrite (8.48%) > magnetite (3.82%) > pyrite and marcasite (2.37%) > covellite, vellerite and cubanite (0.12%) > molybdenite (0.06%) > violarite, linnacite and tellurites (0.03%). The climate is humid tropical, temperature variation lies between 39^0C (max) and 11^0C (min). Rainy season experiences during June, July, August and September and average rainfall is 1800mm per annum. The tailing ponds studied had been abandoned from 2001, remained mostly dry, barren and growth of some metal and draught tolerant species had been observed. Five plants were collected from the selected site during winter season (December 2004) which belonged to five genera and four families (Table 1).

Plant sampling and analysis

Plant samples were collected in at least three replicates and each replicate consisted of subsamples. The herbaria were prepared for all the species and identified at Botanical Survey of India (BSI, Howrah). Individual plants were divided into two components root and shoot, carefully washed in deionized water and attention was given to washing, until visual inspection revealed that no solid particles remained adhering to the roots or shoots. Plant samples were then oven dried at 80^0C overnight and ground into powder for metal concentration analysis. Metal analysis of the plant samples was carried out by acid digestion (5: 1 conc. HNO_3 and conc. $HClO_4$, v/v) of accurately 0.5 g of plant tissue [28] followed by measurement of metal concentration using Atomic Absorption Spectrometry (AAS).

Tailing sampling and analysis

The tailings loosely adhered to roots were gently shaken off and the rhizosphere tailings adhering to roots were separated by hand. Rhizosphere soils were then air-dried and sieved through 500-micron nylon mesh. Samples were then analysed for total metals, DTPA and $CaCl_2$ extractable fractions, pH, electrical conductivity (EC), organic carbon (OC), available N, exchangeable cations (Ca, Mg, Na and K) and cation exchange capacity (CEC). The pH was measured using 1:2.5 (w/v) soil/deionised water ratio by a pH meter and the same was also used for conductivity measurement in an EC meter. OC was determined by the Walkley-Black procedure [18], CEC by ammonium acetate method, available N by the alkaline permanganate method [23]. Exchangeable cations were extracted with 1N neutral NH_4OAc (pH 7) in 1:5 (w/v) soil: extracting solution ratio prior to analysis of Ca and Mg in AAS and Na and K in flame photometer. For total metal content, accurately 0.5g oven dried (80 ^{0}C for overnight) tailings was digested twice with 5ml of 3:1:1 HCl: HNO_3: HF and once with 5ml aqua regia in a covered teflon-beaker. Digested mass was then boiled with 1% HNO_3 solution, filtered in a volumetric flask followed by addition of 1% HNO_3 solution to make a final volume of 100 ml. For DTPA and $CaCl_2$ extractable fractions oven dried tailings were extracted with 0.005 *M* DTPA (20g tailings extracted by 40ml solution) and 0.01005 *M* $CaCl_2$ (5g tailings extracted by 50ml solution) respectively [17]. Total and extractable metal contents were measured by using Atomic Absorption Spectrometry (AAS) for Cu, Ni, Mn, Zn Pb and Cd.

Translocation factor

The translocation factor for metals within a plant was determined as the ratio of $[Metal]_{Shoot}/[Metal]_{Root}$ to evaluate the extent of metal translocation from roots to shoots [22,11].

Results

Characteristics of tailings

The tailings at the abandoned Cu-tailings ponds are slightly acidic with an average pH of 6.3 and EC 0.32 dSm^{-1} (Table 2). Organic carbon content varied widely (0.12 - 1.3%) with an average value of 0.5%. The available nitrogen in tailings was very low ranging from 41 to 219 ppm with an average of 103 ppm. This macronutrient most often limits plant establishment, either because of its low content or because of a lack of the microorganisms which make it bioavailable [6]. Regarding exchangeable cations, Ca was the most abundant among alkaline-earth cations followed by Mg, K and Na. K contents in almost all the samples were lower than 0.2 cmol (+) kg^{-1} revealing a deficiency of this element [21]. The average cation exchange capacity observed as 4.39 cmol (+) kg^{-1}. The heavy metal content in tailings was very high and varied widely (Table 3). With regard to total concentration tailings was characterised by high Cu (1008-1803 mg kg^{-1}) followed by Ni (323-656 mg kg^{-1}), Mn (142-179 mg kg^{-1}), Zn (66-82 mg kg^{-1}), Pb (26-51 mg kg^{-1}) and Cd (7-11 mg kg^{-1}). However, in the DTPA and $CaCl_2$ fraction Cu, Ni, Mn and Zn concentration attained slightly different order. Pb and Cd in $CaCl_2$ extracts were below the detection limit.

***Table 1**: General characteristics of plant species identified at abandoned Rakha Cu-tailings pond.*

Scientific name	Common name	Family	Characteristics
Ammania baccifera Linn	Blistering ammania	Lytheraceae	Herbaceous plant acrid and vesicant, common in rice fields and has irritant properties.
Fimbristylis dichotoma (L) Vahl	Tall-fringe rush	Cyperaceae	Annual sedge, culms, slender, tufted, 20-50 cm tall, leaves, well developed, shorter than the stem, prefers wet conditions.
Pycreus flavidus (Retz) Koyama	Yellow Flat-sedge	Poaceae	Tufted, small annual, or sometimes caespitose perennial, 15-50 cm, stem 1-2 mm diam., grows along riversides and brooklets, rice fields.

Typha latifolia Linn.	Cattail	Typhaceae	Perennial plants mostly 1.5-3 m tall, leaves erect, green, mostly 3-10 mm wide, the auricles of the leaf sheath rounded and surpassing the base of the blade, grow in marshes, shores, stream banks, ditches and margins of lakes and ponds, usually in shallow water, more tolerant of brackish or saline conditions.
Echinochola colona (L) Link	Jungle rice	Poaceae	Tufted annual 20-90cm tall, flowers in summer and winter, grows in loams, silts and clays in low places

***Table 2**. General properties of tailings.*

Parameters	Mean ± sd (min-max)
pH (1: 2.5)	6.29 ± 0.6 (4.8 –7.2)
EC (dS m^{-1})	0.32 ± 0.14 (0.17 – 0.68)
Organic carbon (%)	0.5 ± 0.4 (0.12 – 1.3)
Available nitrogen (ppm)	103 ± 68 (41 – 219)
Exchangeable cations [cmol(+) kg^{-1}]	
Ca	2.0 ± 1.0 (0.8 – 4.1)
Mg	0.8 ± 0.6 (0.14 – 2.34)
Na	0.09 ± 0.04 (0.02 – 0.16)
K	0.11 ± 0.09 (0.03 – 0.3)
CEC [cmol(+) kg^{-1}]	4.39 ± 2.5 (1.75 – 9.43)

***Table 3**: The total, DTPA and $CaCl_2$ metal contents in tailings (mg kg^{-1}, dw).*

	Total metal	DTPA (0.005 ***M***) extractable metal	$CaCl_2$ (0.01 ***M***) extractable metal
Cu	1008 - 1803	11 – 199	0.3 - 30
Ni	323 – 656	0.3 – 25	0.2 – 24
Mn	142 – 179	0.5 – 20	0.02 – 15
Zn	66 – 82	0.3 – 1.3	0.07 – 3.5
Pb	26 – 51	0.7 – 4.3	bdl
Cd	7 - 11	0.3 – 0.6	bdl

bdl = below detection limit

***Table 4**: Translocation factor (TF $[Metal]_{Shoot}/[Metal]_{Root}$) in plant species grown on Cu-tailings pond of Rakha mines.*

Plant species	TF			
	Cu	Ni	Mn	Zn
Ammania baccifera	0.06	0.37	1.70	0.20
Fimbristylis dichotoma	0.20	0.36	1.45	1.0
Pycreus flavidus	0.09	0.09	2.71	2.46
Typha latifolia	0.02	0.04	2.71	0.16
Echinocola cholona	0.12	0.46	1.30	0.96

Metal accumulation and translocation by plants

Metal accumulation in plant tissue collected from the tailing pond is shown in Figure 1. The data show that metal contents in the plant tissues varied widely among species, indicating their different capacities for metal uptake. *T. latifolia* accumulated significantly higher Ni (129 mg kg^{-1}) and Zn (125 mg kg^{-1}) in its root and higher Mn in both above- and underground tissues than the other species. *A. baccifera* attained an average concentration of 1613 mg kg^{-1} Cu in the underground tissues, which was much higher than that of the other four species, while *F. dichotoma* accumulated significantly higher Cu and Ni in its above ground tissues than the other species. On the other hand *P. flavidus* and *E. colona* accumulated higher Zn in their aboveground tissues than others.

The translocation factor (TF), the ratio of shoot to root metals indicates internal metal transportation. Present study indicate that Cu, Ni, Zn accumulated by the plants growing on Cu-tailings, were largely retained in roots as shown by general TF values < 1 (Table 4). Exceptions occurred in *F. dichotoma* (1.0) and *P. flavidus* (2.46) for Zn. However, in all the plants TF for Mn was greater than 1 and varied with in the range of 1.3 to 2.7. Among Cu, Ni and Zn, TF for Cu was the lowest while Zn was highest in the species studied whereas in *A. baccifera* TF value for Ni was found higher than Zn. The TF values also varied among the plant species. For instance, TF values for Zn in *A. baccifera* and *F. dichotoma* were 0.2 and 1.0 respectively, although both are collected from the same tailings pond.

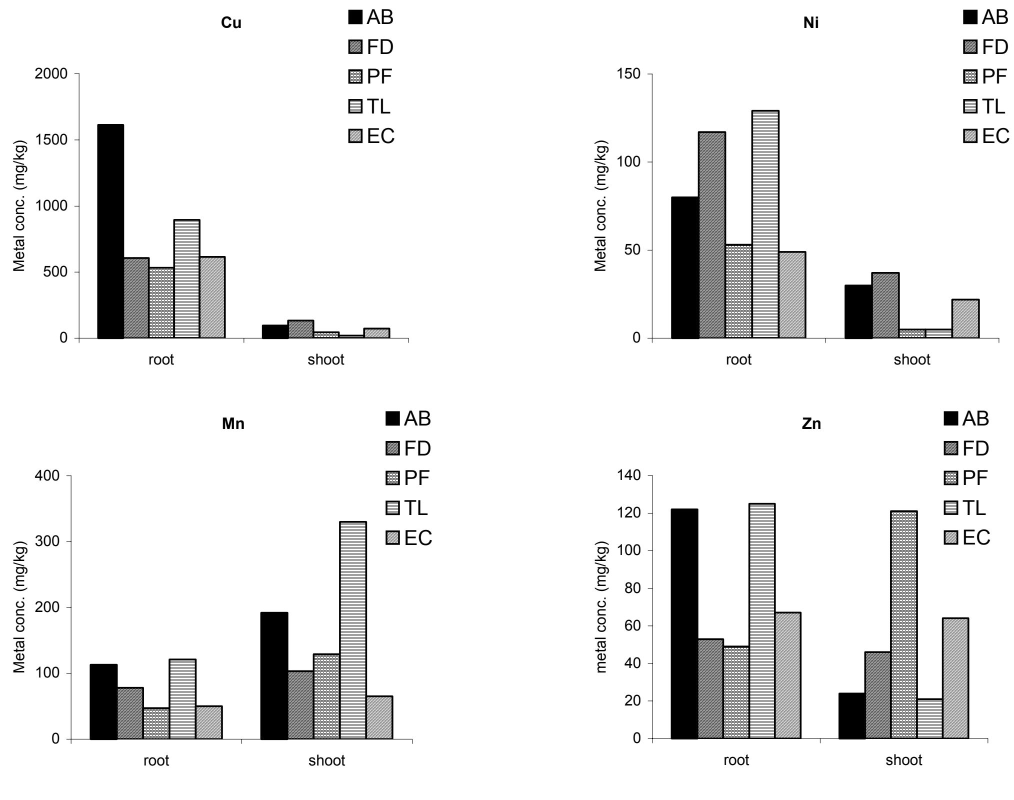

Figure 1*: Metal concentrations in roots and shoots of plants collected from abandoned Cu tailing pond of Rakha mines area.*
AB: Ammania baccifera; FD: Fimbristylis dichotoma; PF: Prcreus flavidus; TL: Typha latifolia; EC: Echinochola colona.

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Discussion

The present study reveals that plants like *A. baccifera*, *F. dichotoma*, *P. flavidus*, *T. latifolia* and *E. colona* can colonize sites with low organic carbon and macronutrients but a wide range of metal concentrations (Table 3). According to Tietjen [26] and Kabata-Pendias and Pendias [15] 100 mg kg^{-1} Cu, 100 mg kg^{-1} Ni based on total fraction in soil, would be considered toxic to plants. Concentration of Cu, Ni in the tailings greatly exceeds these values; therefore the five plants grown in the study area have exhibited high metal tolerance.

The general trend (Figure 1) shows that the root tissue accumulate significantly greater concentration of metals than shoots indicating high plant availability of the substrate metals as well as its limited mobility once inside the plant. Except Mn, concentration of other metals in aboveground tissues were maintained at low levels and varied in a short range compared to underground tissues (Figure 1). Such, exclusions of metals from above ground tissues has been suggested as a metal tolerant strategy adopted by different plants [24,25]. Therefore, the elevated metal concentrations in the root tissue and low translocation to the aboveground tissue in the five plants examined might suggest that they are capable of rather well balanced uptake and translocation of metals under heavily metal-enriched substrate. Cu is an essential element to plant growth but will cause toxic effects when shoots or leaves accumulate more than 20 mg kg^{-1} [5]. In almost all the plant species examined, Cu concentration in aboveground tissues were found significantly higher than the above-mentioned value. Compared to shoots, Cu concentration in the under ground tissues were maintained at higher level and varied widel in the range of 532 -1613 mg kg^{-1}. The concentration of Ni in plants generally reflects the concentration of the element in the soil and the mobility of Ni in soil increases as the pH and CEC decreases [1]. Except *F. dichotoma* and *T. latifolia*, Ni concentration in above- and underground tissue were below or within the toxicity range of 10-100 mg kg^{-1} [15]. The average Ni concentration in the underground tissue of the above two plants was 117 and 129 mg kg^{-1} respectively. However, Ni in the aboveground tissue of *T. latifolia* was found less than the toxic level indicating restricted translocation of Ni from root to shoot. Existence of such a mechanism is the result of evolution rather than an innate physiological tolerance [7]. Uptake of Mn by plants is a function of the concentration of this element present in ionic form in the soil solution and the concentration present on the exchange sites of the cation exchange complex, i.e. the available or labile pool. The highest concentration of Mn was found in the aboveground tissue of *T. latifolia* whereas lowest value corresponded to *E. colona.* Although in *T. latifolia*, Mn accumulation was within the range considered as toxic by Kabata-Pendias and Pendias [15], in the other species the Mn concentrations were in the range of (20-300mg kg^{-1}) considered as normal by these authors. In comparison with the tailings and the underground tissues, the concentration of Mn in shoots were maintained at higher level and varied within range 49-341 mg kg^{-1} in the plants investigated. It is to be pointed out that the limits of Mn toxicity were also never reached in the total Mn concentration in tailings. Zn is an essential element to all plants. Plants predominantly absorb Zn as a divalent cation which act either as a metal component of enzymes or as a functional, structural or regulatory co-factor of a large number of enzymes [1]. The concentrations of Zn in the examined plants were within the normal values (20-400 mg kg^{-1}) reported by Reeves and Baker [19]. The highest concentration of Zn (121mg kg^{-1}) in the aboveground tissue was found in *P. flavidus*. Plants like *A. baccifera* and *T. latifolia* were found to accumulate more Zn in their underground tissue than compare to shoot whereas in *F. dichotoma* and *E. colona*, Zn attained nearly equal distribution.

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Present investigation reveals that all the plant species studied could tolerate excess Cu both in their root as well as shoot. *A. baccifera*, *F. dichotoma* and *T. latifolia* were the species accumulating Ni higher than toxic levels (100 mg kg^{-1}) in their underground tissues. The higher than toxic levels of metal concentration in some species indicate that internal metal detoxification tolerance mechanisms might exists in these naturally colonising plants, in addition to their exclusion strategies [24,25].

Conclusions

The present study shows that tailings in abandoned Cu-tailings ponds are slightly acidic, contain low N, Ca, Mg, K and are heavily enriched with toxic metals. Concentration of Cu, Ni and Cd in total fraction in most cases exceeded the toxicity threshold limits. The most abandoned metal in total fraction of tailings was Cu followed by Ni with comparatively lower amount of Mn, Zn, Pb and Cd. Despite the chemical limitation many plants can colonize this heavy metal enriched tailings pond and are found to accumulate a wide range of toxic metals. Low metal translocation into shoots indicates that metal tolerance in natural vegetation grown on tailings may mainly depend on the metal exclusion ability of underground tissue. Metal accumulation higher than toxic level in some plants indicates that they might have developed some internal detoxification metal tolerance mechanisms. These species therefore, may be considered as tolerant to some elements and hence can be used for detoxification of metal enriched Cu-tailings.

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LEAF AREA FOR PHYTOPUMPING OF WASTEWATER

SARWOKO MANGKOEDIHARDJO

Laboratory of Environmental Technology and Process Engineering,Department of Environmental Engineering,
Institut Teknologi Sepuluh Nopember (ITS) Surabaya, Indonesia
(phone: +62-31-594-8886; fax: +62-31-592-8387)

e-mail: doctorsarwoko@gmail.com

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Abstract. This report presents novel parameters for evapotranspiration-mediated wastewater phytotreament. Leaf area capacity could be used to measure the water loss from phytotreatment tank. Relative effect concentration was a measure the reduction of leaf area capacity due to increasing COD level. Additional advantage of using the two parameters was to address the suitability of various types of wastewater in phytotreatment by means of COD equivalent.
Keywords: *evapotranspiration, plant capacity, relative effect*

Introduction

Phytotreatment, aiming to pump wastewater was far behind the progress of improving quality. Investigation on the capacity of plant to treat chemicals has been carried out intensively [1, 2, 6, 7, 8, 10, 11, 12, 13, 14, 16, 17]. However, an upward flow through plant roots, the so called transpiration stream plays an important role aiming to divert wastewater flow into the air. The collective flow of transpiration stream within the plant and evaporation to the air is the so called evapotranspiration. This represents evaporated volume, or weight, of wastewater which detaches from wastewater surface. Therefore the overall treated effluent will be discharged to environmental multimedia, i.e. soil and/or water bodies and air.

The transpiration stream flows at high rate when a plant has its stomates open, normally during the sunny day for the exchange of gases in photosynthesis. Higher transpiration stream is an indication of enhanced chemical uptake by plants [2]. The stream still occurs at a much slower rate through the cellular path [9] when stomates are closed at night, suggesting low chemical uptake. Thus, transpiration stream loading is fluctuated during the day. Moreover, the chemicals-containing transpiration stream may undergo covalent bonding into the lignin of the plant (lignification), and, or transformation to carbon dioxide and water. As a result, a low chemical concentration will detach from the leaf surface. Hence, leaf area capacity should be defined to what extent of the evapotranspiration is partly evaporated from leaves surface. However, the fluctuation of transpiration stream loading may affect the leaf area capacity. In addition, the intensity of the stream may change substantially hydraulic properties of plant tissues and organs, leading to malfunction of leaf for carrying out transpiration. Accordingly, the effect concentration of chemicals should be determined to what extent the leaf area capacity is reduced.

Therefore, the objective of this study was to define leaf area capacity and to assess the effect concentration of chemicals on the leaf area capacity. The inclusion of these

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two parameters in wastewater phytotreatment will increase the suitability of treatment system.

Materials and methods

Greenhouse experiments were carried out in Pasuruan Industrial Estate at Rembang (PIER), East Java, during the period of July to August 2001 (dry season) and February to March 2002 (rainy season). The experiments were updated in the Laboratory of Environmental Technology and Process Engineering, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, East Java, at the same period in 2003 and 2004.

It was important referring to evapotranspiration of water in order to assess various wastewater characteristics on the flow and leaf area. Moreover, wastewater characteristics could be assessed based on their relative concentration in the water. To this purpose destilate water was used as the control test.

Artificial wastewaters were made of glucose monohydrate (pro analysis) and acetic acid 99.8 %, 60.5 M (pro analysis) solutions. These were used for reasons that both are highly hidrophilic, hence it should be able to be carried along transpiration stream. The artificial solutions were organized for COD concentration ranging from 20 mg L^{-1} to 1000 mg L^{-1}. COD measurement was carried out using dichromate method [15]. In addition, collected domestic and industrial wastewaters were tested for this study.

Waterhyacinth was assigned to be the test plant for those solutes for a reason that the plant has a well known capacity to absorb large amounts of water [7, 8]. Hyacinths were collected from a natural watercourse. They were cleaned and placed in nutrient rich water. The plants were placed in nutrient rich water containing Huttner's solution [5] for a week to encourage growth and to ensure that the plants were healthy before placing them in test solutions. After a week of incubation, two propagules of waterhyacinth were selected and placed in the test solution tanks.

The test solution tanks were made of black plastic material of working capacity of 90 l. Each tank had a surface area of 60 sq-cm and water depth of 30 cm. There were three tanks for each solute, each tanks contained 95 % test solution and 5 % nutrient water to ensure that the availability of nutrients would not be the limiting factor for the growth of the plants. Three replicates were organized simultaneously. Daily observation on temperature, pH, and dissolved oxygen (DO) were measured by means of electronic probes using Water Quality Checker, TOA WQC-22A. The three parameters were useful to confirm growth conditions during the experiment.

Evapotranspiration was measured based on the water loss from the tank. The water loss was measured as the changes of weight for two consecutive period. One period was three days in order to have measurable evaporated weight. The experiment was run for thirty-three days (eleven period) to take plants' acclimatization into account.

Leaf area was measured by means of non-destructive leaf area correction factor. Sixty-four leaf area were drawn in a white paper, having known area (A) and weight (B). Width (W) and length (L) of the drawn leaves were measured. Then the drawn leaf were cut and weighted (C). The leaf area correction factor (cLA) was determined using the following equation:

$$cLA = \frac{\left(\frac{C}{B}\right).A}{(W.L)} \qquad \text{(Eq.1)}$$

Therefore leaf area (LA) measurements for the running experiment were carried out by means of measuring W and L and multiplied by cLA using an equation as follows:

$$LA = cLA.W.L \quad \text{(Eq. 2)}$$

Results and discussion

Under the tropical conditions, the solute temperatures for all treatment during exposure were ranging from 25 ^oC and 35 ^oC. Observation on pH levels in all solutes were shown to decrease from 7.3 ± 0.1 to 6.8 ± 0.1. Decreasing DO levels from 6.5 ± 0.1 to 4.3 ± 0.1 were observed even no mechanical aeration was carried out during the experiment. All the hyacinths were healthy and green during the experiment and most of the plants appeared to grow showing new shoots after a week of exposure. Therefore the solute quality parameters of temperature, pH, and DO were not limiting conditions for hyacinth growth.

Leaf area capacity

Results of the cumulative evapotranspiration (ET) in kg water loss from the tank were presented in *Table 1*. Periodically the values were fluctuated, expressed as CV, due to the prevailing environmental conditions. The fluctuation of ET for a given period was similar characteristic to the fluctuation of drinking water use. One of the purposes of drinking water use fluctuation was to determine reservoir capacity. Accordingly the fluctuation of ET could be treated to calculate the air and plant capacity (APC).

Table 1. *Air and plant capacity*

Solutes	Period	1	2	3	4	5	6	7	8	9	10	11
Control	CV	1.80	3.40	5.40	6.60	7.40	8.00	8.60	10.20	11.40	12.40	13.70
	CA	1.25	2.49	3.74	4.98	6.23	7.47	8.72	9.96	11.21	12.45	13.70
	APC	0.55	0.91	1.66	1.62	1.17	0.53	-0.12	0.24	0.19	-0.05	0.00
20 mg COD L^{-1}	CV	1.60	3.20	5.10	5.00	7.00	7.30	8.30	9.50	10.90	12.00	13.30
	CA	1.21	2.42	3.63	4.84	6.05	7.25	8.46	9.67	10.88	12.09	13.30
	APC	0.39	0.78	1.47	0.16	0.95	0.05	-0.16	-0.17	0.02	-0.09	0.00
100 mg COD L^{-1}	CV	1.20	1.90	2.70	3.50	4.40	6.80	6.90	7.40	8.00	9.10	10.00
	CA	0.91	1.82	2.73	3.64	4.55	5.45	6.36	7.27	8.18	9.09	10.00
	APC	0.29	0.08	-0.03	-0.14	-0.15	1.35	0.54	0.13	-0.18	0.01	0.00
500 mg COD L^{-1}	CV	0.80	2.00	1.90	2.80	4.40	5.70	5.90	7.30	7.80	8.00	8.10
	CA	0.74	1.47	2.21	2.95	3.68	4.42	5.15	5.89	6.63	7.36	8.10
	APC	0.06	0.53	-0.31	-0.15	0.72	1.28	0.75	1.41	1.17	0.64	0.00
1000 mg COD L^{-1}	CV	0.50	0.40	0.60	1.00	1.80	2.50	3.00	3.80	5.30	5.50	5.90
	CA	0.54	1.07	1.61	2.15	2.68	3.22	3.75	4.29	4.83	5.36	5.90
	APC	-0.04	-0.67	-1.01	-1.15	-0.88	-0.72	-0.75	-0.49	0.47	0.14	0.00
Domestic waste	CV	0.90	0.40	1.20	1.30	1.80	2.30	2.50	4.20	4.10	4.50	4.40
	CA	0.40	0.80	1.20	1.60	2.00	2.40	2.80	3.20	3.60	4.00	4.40
	APC	0.50	-0.40	0.00	-0.30	-0.20	-0.10	-0.30	1.00	0.50	0.50	0.00
Industrial waste	CV	1.00	1.10	1.50	1.90	1.70	2.00	2.10	2.40	3.00	3.40	3.80
	CA	0.35	0.69	1.04	1.38	1.73	2.07	2.42	2.76	3.11	3.45	3.80
	APC	0.65	0.41	0.46	0.52	-0.03	-0.07	-0.32	-0.36	-0.11	-0.05	0.00

APC was determined as shown in *Table 1*. The fluctuated CV was substracted by the cumulative average (CA) of ET for a given period. The CA was a constant flow,

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representing balancing flow between CV and CA. The sum of maximum surplus (+) and maximum deficit (-) was nothing less than APC in kg. The method of this research did not measure the transpiration stream, hence APC consisted of evaporation to the air and upward flow through the plant roots as transpiration stream, each were not known.

In order to assess the plant capacity to conduct transpiration stream, therefore the APC would be correlated to leaf area capacity (LAC) in sq-cm. The LAC was obtained using the same method of calculating APC and presented in Table 2. The significant correlation (R^2 = 0.9391) between APC and LAC for COD-containing solutes resulted in the following equation:

$$LAC = 43\,APC - 38 \qquad \text{(Eq. 3)}$$

Thus each kg of APC was corresponded to LAC of 5 sq-cm. This LAC was responsible to store transpiration stream. Hence, LAC was nothing less than a reservoir for transpiration stream, regardless the proportion of evaporation and transpiration stream and the fate of the stream in the plant. This result was a proposed parameter of assessing wastewater phytotreatment, aiming to split wastewater flow into environmental multimedia, by means of evapotranspiration measurement.

Relative effect concentration

Plant can increase the removal of chemical compounds from transpiration stream during uptake, storage, and transpiration; it was the reason why phytotreatment was applied. However, the chemical concentration-containing transpiration stream could have adverse effect on the structure and/or function of the plant. Decreasing LAC due to increasing chemical concentration ranging from 20 mg L^{-1} and 1000 mg L^{-1}, and introducing wastewaters were representing the adverse effect of chemicals (see *Table 2*).

Table 2. *Leaf area capacity*

Solutes	Period	1	2	3	4	5	6	7	8	9	10	11
Control	CV	30.90	37.08	48.20	65.08	87.85	109.81	137.27	164.72	189.43	217.84	250.52
	CA	22.77	45.55	68.32	91.10	113.87	136.65	159.42	182.20	204.97	227.75	250.52
	LAC	8.13	-8.47	-20.12	-26.02	-26.02	-26.83	-22.15	-17.48	-15.54	-9.90	0.00
20 mg COD L^{-1}	CV	29.90	35.88	44.85	58.31	75.80	98.54	123.17	150.27	180.32	198.35	218.19
	CA	19.84	39.67	59.51	79.34	99.18	119.01	138.85	158.68	178.52	198.35	218.19
	LAC	10.06	-3.79	-14.66	-21.04	-23.38	-20.48	-15.68	-8.41	1.80	0.00	0.00
100 mg COD L^{-1}	CV	31.20	34.32	41.18	51.48	66.92	87.00	108.75	130.50	150.08	165.08	173.34
	CA	15.76	31.52	47.27	63.03	78.79	94.55	110.31	126.06	141.82	157.58	173.34
	LAC	15.44	2.80	-6.09	-11.55	-11.87	-7.55	-1.56	4.44	8.25	7.50	0.00
500 mg COD L^{-1}	CV	31.60	33.18	36.50	43.80	52.56	63.07	74.42	87.82	100.99	111.09	122.20
	CA	11.11	22.22	33.33	44.44	55.54	66.65	77.76	88.87	99.98	111.09	122.20
	LAC	20.49	10.96	3.17	-0.64	-2.99	-3.58	-3.34	-1.05	1.01	0.00	0.00
1000 mg COD L^{-1}	CV	31.90	33.50	36.84	42.37	50.00	60.00	70.80	81.42	89.56	98.51	108.37
	CA	9.85	19.70	29.55	39.41	49.26	59.11	68.96	78.81	88.66	98.51	108.37
	LAC	22.05	13.79	7.29	2.97	0.74	0.89	1.84	2.61	0.90	0.00	0.00
Domestic waste	CV	30.40	31.92	35.11	40.38	46.44	53.40	64.08	76.90	88.43	97.28	107.00
	CA	9.73	19.46	29.18	38.91	48.64	58.37	68.09	77.82	87.55	97.28	107.00
	LAC	20.67	12.46	5.93	1.47	-2.20	-4.96	-4.01	-0.92	0.88	0.00	0.00
Industrial waste	CV	29.30	30.77	33.53	37.89	43.20	49.25	56.63	65.13	72.29	80.24	88.27
	CA	8.02	16.05	24.07	32.10	40.12	48.15	56.17	64.20	72.22	80.24	88.27
	LAC	21.28	14.72	9.46	5.80	3.08	1.10	0.46	0.93	0.07	0.00	0.00

The relative concentration was used in order to compare the extent of effect for various types of solutes which referred to the control solute. All LACs of chemical-containing solute were divided by LAC of control solute. It follows that LACs of chemical-containing solute were lower than 1.0. The relative effect concentration of one kg COD L^{-1} on LAC (RELAC) was formulated in the following equation (R^2 = 0.8018):

$$RELAC = 0.9 \exp - 0.4[COD] \qquad \text{(Eq. 4)}$$

It follows that increasing COD concentration would bring about decreasing of RELAC. The adverse effect of COD on LAC was considered due to an increase in hydraulic resistance of the cellular plant. This compares favorably with [9] in their work with abscisic acid (ABA).

The RELAC for domestic and industrial wastewaters were 0.7 and 0.6 respectively. It follows that domestic wastewater was equivalent to 300 mg COD L^{-1}, whereas industrial wastewater was equivalent to 1100 mg COD L^{-1}. These results were an added value of using the leaf area capacity for predicting the potential evapotranspiration of a known COD-containing wastewater. Hence, RELAC could be used as a measure of various types of wastewater with reference to COD equivalent.

The COD equivalent sources were glucose and acetic acid and indeed any addition from plant exudate such as amino acids, organic acids, fatty acids, sterols, growth factors, nucleotides, flavanones, and enzymes [14]. Benzene, TCE, toluene, ethylbenzene, mxylene, atrazine and aniline were translocated mostly in the leaves [3, 4] that potentially could reduce the leaf area capacity. However, the chemical fate and translocation was most likely concentration-dependent, and other concentrations may give different results. Therefore further investigation is needed for those organic matters to be qualified for COD equivalent.

Conclusions

Leaf area capacity was expressed as leaf area that brought about by losing weight or volume of soluble organic matter from wastewater tank, regardless the proportion of evaporation and transpiration stream. Five sq-cm of hyacinth leaf area had been able to lose one kg of COD-containing wastewater in tropical conditions. However, increasing one kg COD L^{-1} would result in reducing leaf area capacity of one sq-cm. COD equivalent could be used to measure various types of wastewater for suitability in phytotreatment.

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SOIL MICROBIAL BIOMASS IN SEMI-ARID COMMUNAL SANDY RANGELANDS IN THE WESTERN BOPHIRIMA DISTRICT, SOUTH AFRICA

A. S. MOUSSA[1,*] – L. VAN RENSBURG[1] – K. KELLNER[1] – A. BATIONO[2]

[1] *School of Environmental Sciences and Development, North-West University (Potchefstroom Campus), Private Bag X 6001 Potchefstroom 2520, South Africa Tel/Fax + 27 18 299 2509,*
[2] *Tropical Soil Biology and Fertility, Institute of the International Center for Tropical Agriculture (TSBFI-CIAT) P.O. Box 30677 Nairobi, Kenya*

e-mail: plbasm@puk.ac.za

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Abstract. Soil microbial biomass is considered as an important early indicator of changes that may occur in the long term with regard to soil fertility and constitutes an important source and sink of nutrients. In South Africa, rangeland monitoring has mostly focused on assessing changes of aboveground vegetation in response to land uses effects, but the associated changes at belowground soil level remain a topic of further research. The aim of this study was to explore soil microbial biomass at three sites under communal grazing management. Soils from grazed and adjacent ungrazed rangeland plots were collected at a depth of 0-25 cm towards the end of the rainy season in April 2005. The soil microbial biomass was characterized by analyzing the phospholipids ester-linked fatty acids. Soils were also analyzed for organic carbon, pH, and total phosphorus. Results showed no statistically significant differences in organic carbon and soil microbial biomass between the grazed and ungrazed plots at any of the sites. Both organic carbon and soil microbial biomass were low, ranging from 0.06 to 0.11% and 489.28 pmol g^{-1} to 1823.04 pmol g^{-1}, respectively. Fourteen grass species were recorded during the vegetation surveys, and most occurred in low abundance. Plants supply organic materials as energy sources for microbial growth, so the low soil microbial biomass could be a reflection of the low vegetation abundance. This study provides essential baseline information regarding soil microbial activity never reported before in these rangelands. Further investigations are required for in-depth understanding of the underlying processes that regulate soil microbial biomass dynamics at these sites.
Keywords: *soil microbial biomass; microbial community structure; vegetation composition, abundance and cover; soil quality.*

Introduction

The management of soil as a natural resource is of utmost importance for sustainable agriculture, and an overall understanding of soil quality will allow management of the soil resource to ensure sustainable food, fiber, and feed production throughout the world. There is a global need for tools to evaluate the ramifications of soil resource management upon spatio–temporal changes in soil quality to ascertain sustainability of farm-management practices [13]. Soil quality depends on its natural composition and the changes caused by human use and management [36]. [16] indicated that as degradation takes place, soil properties change, particularly the soil microbial activity, and that high levels of microbial activity are fundamental in maintaining soil quality.

Considerable effort has been extended in the study of soil microbial processes associated with maintaining ecosystem stability with regard to the effects of anthropogenic activities [44]. There has been interest in the characterization of soil biodiversity and function in agricultural grasslands [5]. This interest has been driven by the need to develop grassland management strategies directed at manipulating the soil biota and to encourage a greater reliance on ecosystem self-regulation than on artificial inputs such as fertilizers and pesticides [53]. This interest has also come from the recognition that the organisms that live belowground regulate major ecosystem processes, but also because of the likelihood that feedbacks between aboveground and belowground communities have a key role in governing ecosystem functioning [6], [47], [17].

The soil-based biotic component is of fundamental importance on how ecosystems function, through determining nutrient cycling, decomposition and energy flow. Because of the relatively direct linkage between soils biological activity and many ecosystem-level processes (decomposition, nutrient mineralization), soils microorganisms provide a good opportunities for investigating ecosystem-level responses to disturbances and stress gradients [51]. Soil microbial biomass is the primary catalyst of biogeochemical processes as well as an energy and nutrient reservoir [44], [19], [20], [46], [55], [3], [22], [23], [31]. In low fertile soils with a high proportion of nutrients immobilized in the belowground living biomass, standard soil fertility tests are of little value. It makes more sense to measure the living soil microbial biomass and microbial activity [41], although the quantitative description of microbial diversity remains one of the most difficult tasks facing microbial ecologists [55]. Soil microbiological properties such as microbial biomass may be used as early and sensitive indicators of soil quality [8], for comparisons of soils under different managements [28], and that high levels of microbial activity are fundamental in maintaining soil quality [16]. Microbial metabolism in soil is limited by the availability and types of organic substrates [33], and the quantitative and qualitative differences in substrate supply between grasslands are responsible for the variation in microbial community [6], [29], [18], [19]. Furthermore, higher levels of plant production associated with greater plant diversity fostered a shift in microbial community composition [54].

In South Africa, rangelands are important ecosystems with more than 80% of the land used for pastoral production [43]. Three main rangeland management systems can be found: commercial and communal livestock ranching and game ranching. They differ in management structure, animal diversity, management of grazing resources and products [38]. Communal rangeland management is perceived as unproductive and unsustainable form of land use [1], [37]. In the Bophirima District, soil degradation has become of major concern, particularly in the communal managed rangelands [30]. There is considerable information on the state of the vegetation resources, but research on the associated processes that occur at belowground soil level is scarce. The purpose of this pilot study was to explore soil microbial biomass at three sites under communal grazing system. This study forms part of the Desert Margins Program (DMP) in South Africa. The aims of the DMP SA are to conserve and restore biodiversity in the desert margins through sustainable utilization, and to develop strategies to enhance ecosystem function and sustainable use in arid and semi-arid areas that are degraded and have reduced biodiversity associated with human and climate impact (K. Kellner, personal communication).

Materials and methods

Study sites

The study area is located in the western Bophirima District in the Ganyesa region (North-West Province, South Africa). Most of the land in this area is under tribal or state administration. Agriculture is mainly subsistence-oriented, and the main land use type is cattle and game farming based on extensive livestock production because of climatic constraints [30]. The climate is semi-arid, and annual rainfall ranges between 200 and 450 mm, of which 80% falls in summer (October to March) and 20% in winter (April to September). The vegetation in the area is classified as the savanna biome, and consists of the Kalahari thornveld and shrub bushveld vegetation types. *Acacia erioloba* is the most prominent tree in this area, associated with other Acacia species (*A. tortilis*, *A. mellifera* subsp. *Detinens*, *A. luderitzii*, *A. haematoxylon*) and other species such as *Gravia flava*, *Boscia albitrunca* [2], [43]. The herbaceous layer ranges from an essentially karroid type, e.g. *Rhigozum trichotomum* and the desert grasses *Stripagrostis uniplumis* and *Schmidtia kalaharensis* in the most westerly regions to a mesophytic grass layer, e.g. *Themeda triandra* and *Heterotogon contortus* in the east [43].

Three experimental rangelands sites Austrey, Southey and Tseoge implemented for the purpose of the Provincial LandCare program were selected. The sites are under communal grazing management, and their general characteristics are given in Table 1.

Table 1 *General site characteristics*

Sites	Austrey	Southey	Tseoge
Latitude/Longitude	S26°28'/ EO24°10'	S26°39'/ EO23°50'	S25°59'/ EO23°31'
Altitude (m)	1240	1148	1134
Annual rainfall (mm)	300-400	300-450	200-350
Soil forms	- Clovelly form - Hutton form - Depth 900-1200 mm	- Clovelly form - Hutton form - Depth > 1500 mm	- Mispah form - Depth < 250 mm
Grazing system	Communal	Communal	Communal

The soils are predominantly sandy (± 95% sand), with low clay (± 3%), soil organic carbon (± 0.16%) and total phosphorus (± 6.5 mg kg^{-1}). At the Austrey and Southey sites, the soils are from the Clovelly and Hutton forms, characterized by a yellow-brun apedal and a red apedal B orthic top soil horizon, respectively. At the Tseoge site, the dominant soils belong to the Mispath form, characterized by a hard rock orthic top soil horizon [39]. The three sites fall within the sweetveld category, which is defined as veld (grazing land) which remains palatable and nutritious when it is mature [43]. At the onset of this study, the herbaceous vegetation composition and cover were very low as shown in Fig 1 (e.g. Austrey site).

At each of the three sites, grazed and adjacent ungrazed plots of 110 x 20 m^2 size each were selected. They were established respectively in 2001 at Austrey and 2003 at Southey and Tseoge for the purpose of the LandCare program. Prior to the establishment of these plots, domestic livestock grazed the rangelands at each of the sites, and no specific management system was imposed.

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Figure 1. *View of the state of the vegetation in the grazed plot at Austrey site*

Soil sampling and analyses

Soils were sampled towards the end of the rainy season in mid-April 2005 in grazed and adjacent ungrazed plots. Because the plots were not replicated at each of the sites, pseudo-replicates samples were collected. The problem of pseudo-replication is omnipresent in most studies of grazing effects [42]. Each plot was divided in two sub-plots and composite sample of ten cores samples collected at a depth of 0-25 cm along two parallel transects running the length in each sub-plot was taken. Dead coarse organic materials and stones were removed from each sub-sample, which was then split in two parts, one for chemical analyses and the second one for microbial analyses. The latest one was put in sealed plastic bags and keep in icebox until transportation to the laboratory.

Chemical analysis

Soil pH (H_2O) was determined in 1:2 v/v water-extract with a calibrated pH (Radiometer PHM 80, Copenhagen) at 25ºC, as described [32]. Total phosphorus (P-Bray 1) was determined by the Bray 1 method [10] and soil organic carbon (OC) was measured by the Walkley-Black method [49].

Microbial analysis

The characterization of soil microbial biomass and community structure was done by analyzing the ester-linked phospholipids fatty acids (PLFA) composition of the soil. The concentration of PLFA is a measure of viable microbial biomass [55] and is an effective tool for monitoring microbial responses to their environment. The soil microbial biomass was determined as described in [12]. Briefly, total lipids were extracted from a 5 g lyophilized soil according to a modified method [9] as described [52]. Silicic acid column chromatography was used to fractionate the total lipid extract into neutral lipids, glycolipids and polar lipids. The polar lipid fraction was transesterified to the fatty acid methyl esters (FAMEs) by a mild alkaline methanolysis [21]. The FAMEs were analyzed by capillary gas chromatography with flame ionization detection on a Hewlett-Packard 6890 series 2 chromatograph fitted with a 60 m SPB-1 column (0.250 mm I.D., 0.250 µm film thickness). Identification of peaks was done by

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gas chromatography/mass spectrometry of selected samples using a Hewlett-Packard 6890 interfaced with a Hewlett-Packard 5973 mass selective detector. Methyl nonadecanonate (C19:0) was used as the internal standard and the PLFA were expressed as equivalent peak responses to the internal standard. The total microbial biomass was expressed as pmol PLFA g^{-1} dry weight soil.

Herbaceous composition

The herbaceous composition was determined towards the end of the rainy season in mid-April 2005. The wheel-point method was used as described [27]. The survey was done along parallel transects running the length in each of the grazed and ungrazed plots. The nearest grass plant in a 45 cm radius was identified and recorded, and when no grass plant was present, it was considered as a bare ground. The survey was completed when 98% of the total variation in species composition had been sampled. The similarities in herbaceous composition between the grazed and ungrazed plots were determined using the Z-index value:

$$Z (\%) = [(b/a*100)*(a+b)]/ \sum(a+b)$$

where a and b represent, respectively, the highest and the lowest frequency values of each grass identified. The more the Z-index tends towards 100%, the greater the similarity and the more it tends towards 0% the smaller the similarity [15].

Data analysis

Data of soil chemical and microbiological properties were analyzed by means of analysis of variance (ANOVA), and statistically significant differences between means were tested using Fisher Least Significant Difference (Fisher LSD) at $P < 0.05$ probability level. STATISTICA 7 (Stat Soft ®) was used for all statistics. Relationships between grass composition, soil microbial biomass and microbial community structure were investigated by means of canonical correspondence analysis (CCA) using the computer data analysis software CANOCO 4.5 [45].

Results

Soil chemical properties

Table 2 summarizes the soil chemical properties in grazed and ungrazed plots at three sites. Soil organic carbon (OC) and pH did not show any statistically significant differences between the grazed and ungrazed plots, although OC was slightly reduced in all grazed plots at all the study sites. Total phosphorus (P-Bray 1) showed a significant difference between the grazed and ungrazed plots at only Tseoge site (p=0.03).

Table 2. *Soil chemical properties (standard error in bracket) in grazed and ungrazed plots*

Sites	Plots	pH (H_2O)	Organic Carbon (%)	P-Bray 1 (mg kg^{-1})
Austrey	Grazed	5.5 (0.05)	0.09 (0.01)	6.3 (0.22)
	Ungrazed	5.5 (0.03)	0.11 (0.02)	6.6 (0.07)
Southey	Grazed	5.5 (0.02)	0.09 (0.0009)	8.5 (1.2)
	Ungrazed	5.6 (0.07)	0.09 (0.002)	7.8 (1.1)

Tseoge	Grazed	7.1 (0.01)	0.05 (0.0009)	8.6 (0.41)*
	Ungrazed	6.6 (0.38)	0.06 (0.06)	6.4 (0.03)*

* Significantly different at p<0.05

Microbial analysis

Soil microbial biomass

The total phospholipids fatty acids (PLFA) a measure of the viable microbial biomass between the grazed and ungrazed plots are given in Fig. 2. Total PLFA ranged from 489.28 pmol g^{-1} in the grazed plot at Southey site to 1823.04 pmol g^{-1} at Austrey's grazed plot. PLFA was not statistically different between the grazed and ungrazed plots at any of the study sites. When comparing exclusively the grazed plots across the three sites, total PLFA showed statistically significant differences between the three sites (p=0.03, Fig. 2).

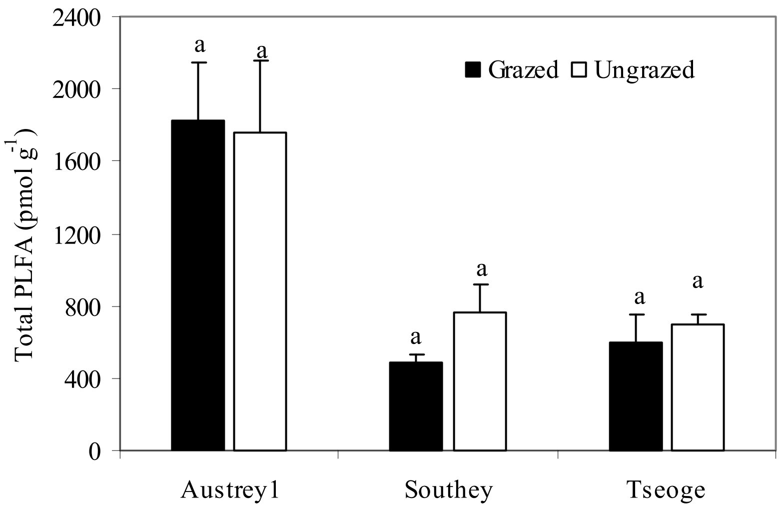

Figure 2. Total phospholipid fatty acids (Total PLFA) in grazed and ungrazed plots at the sites (values are means and bars represent standard errors). Means with same lower case letter are not statistically different between the grazed and ungrazed plots per site. P < 0.05

Soil microbial community structure

The microbial community structure expressed as the relative abundance of bacteria and fungi is presented in Fig. 3. Bacterial PLFA did not statistically vary between the grazed and ungrazed plots at any of the study sites. It ranged between 160.38 pmol g^{-1} at Southey's grazed plot to 641.61 pmol g^{-1} at Austrey site. Bacterial PLFA showed statistically significant difference between the grazed plots between the sites (p=0.02, Fig. 3a). The fungal PLFA did not differ statistically between the grazed and ungrazed rangelands at any of the three study sites, nor between the grazed plots exclusively (p=0.18). As for the bacterial PLFA, the fungal PLFA was higher in both the grazed and ungrazed rangelands at Austrey site, compared to the Southey and Tseoge sites (Fig. 3b). The fungal:bacterial ratio (F/B ratio), a measure of the proportion of fungi and bacteria within the microbial community, was not statistically different between the

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grazed and ungrazed plots at any of the sites (Fig. 3c). It did not differ significantly between the grazed plots across three sites (p=0.15).

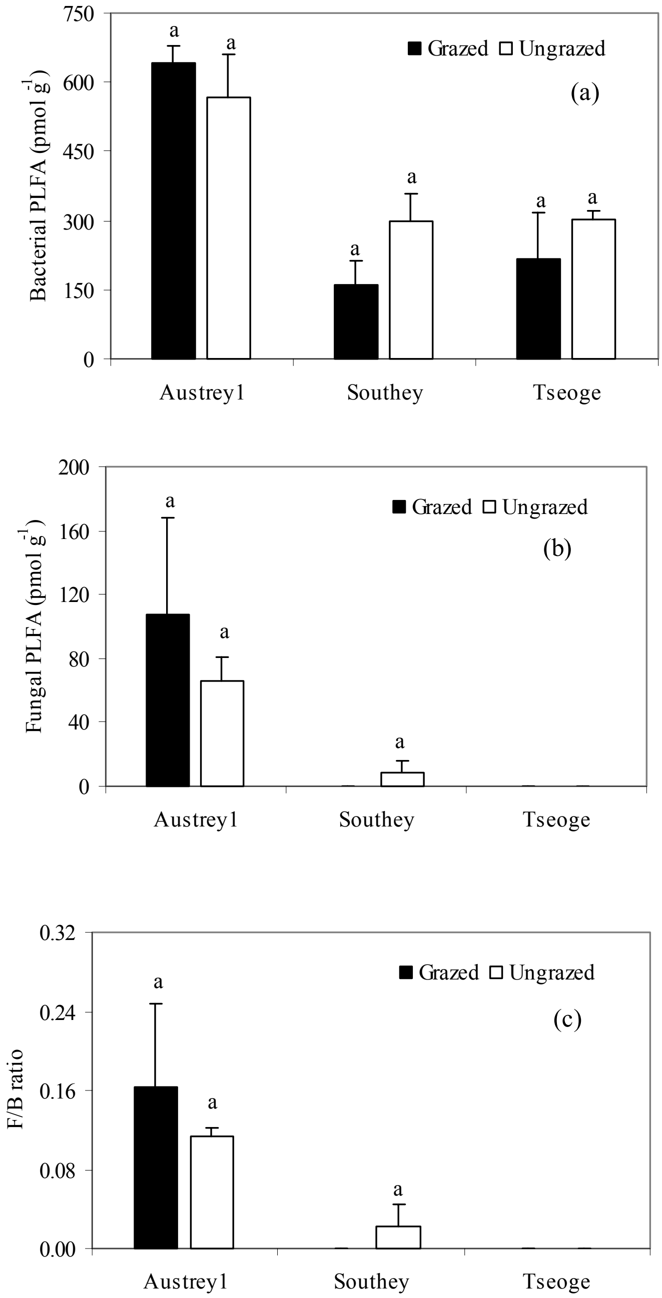

Figure 3. *The microbial community structure: (a) bacterial PLFA (b), fungal PLFA, and (c) the fungal:bacterial ratio in the grazed and ungrazed plots at the sites. Means with same lower case letter are not statistically different between the grazed and ungrazed plots per site. P < 0.05*

Herbaceous composition

Fourteen grass species were monitored during the botanical survey. Most of the grass identified, occurred in low abundance in both the grazed and ungrazed plots (Table 3). The species were unevenly distributed across the three sites. Despite the low abundance across the three sites, the site at Austrey showed “relatively” greater species abundance, in both the grazed and ungrazed plots, compared to the Southey and Tseoge sites. The

Z-indexes were 48.34%, 57.91% and 1.62%, respectively at Austrey, Southey and Tseoge sites. The low Z-index at the Tseoge site (1.62%) reflects more the high percentage of bare ground than species abundance.

***Table 3**. Grass composition, frequency (%) and Z-index in grazed and ungrazed plots per site*

Species	Austrey		Southey		Tseoge	
	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed
Digitaria eriantha	1.1	18.5	0	0	0	3.3
Schmidtia pappophoroides	4.5	11.1	1.8	4.7	0	0
Triraphis andropogonoides	0	0.8	1.8	6.7	0	0
Eragrostis lehmanniana	8.3	14.1	5.5	6	0	8.9
Eragrostis trichophora	21.7	5.9	0	0	0	0
Aristida stipitata	18.9	20	26.1	8.7	0	3.3
Melinis repens	1.1	0	3	0	0	0
Eragrostis rigidior	0.6	5.2	0	0	0	0
Pogonarthria squarrosa	0	1.5	33.9	48.7	0	0
Aristida congesta	22.2	12.6	7.9	7.3	0	7.8
Perotis patens	1.2	1.5	0	0	0	0
Tragus berteronianus	12.2	1.5	0	0	0	0
Brachiaria marlothii	1.7	0	0	0	20.6	13.3
Stripagrostis uniplumis	0	0	8.5	0.7	0	0
Bare ground	6.7	7.4	6.1	14.7	79.3	63.3
Z-index (%)	48.34		57.91		1.62	

Relations between herbaceous composition and soil microbial parameters

The relationships between vegetation composition and soil microbial biomass and bacterial and fungi PLFA are shown in the canonical correspondence analysis (Fig. 4). The eigenvalues of the two fist axes of the canonical correspondence analysis were 0.483 and 0.195, respectively. They account for 60.1% and 24.3%, respectively, thus contributng to 84.4% of the cumulative percentage variance of the species-environment relation. The first axis of the CCA was strongly correlated with total PLFA (r^2=0.93), bacterial PLFA (r^2=0.91) and fungal PLFA (r^2=0.94). Soil microbial biomass measured as total PLFA, as well as the bacterial and fungi PLFA showed strong positive correlation with the Austrey site characterized by greater species composition (both grazed and ungrazed plots), as compared to the Southey and Tseoge sites (Fig. 4).

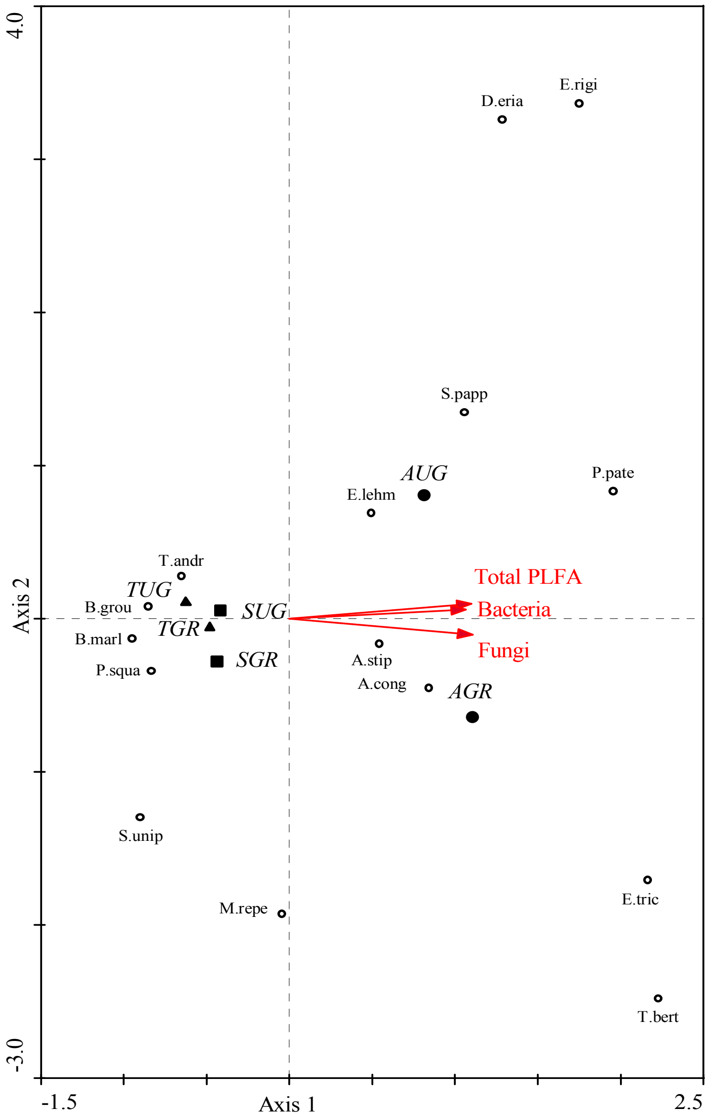

***Figure 4**. Canonical Correspondence Analysis (CCA) of plant species composition, total PLFA, bacterial and fungal PLFA. Keynote: AGR: Austrey grazed, AUG: Austrey ungrazed, SGR: Southey grazed, SUG: Southey ungrazed, TGR: Tseoge grazed, TUG: Tseoge ungrazed. Species: A.cong: Aristida congesta, A.stip: Aristida stipitata, B.marl: Brachiaria marlothii, D.erian: Digitaria eriantha, E.lehm: Eragrostis lehmanniana, E.rigi: Eragrostis rigidior, E.tric: Eragrostis trichophora, M.repe: Melinis repens, P.pate: Perotis patens, P.squa: Pogonarthria squarrosa, S.papp: Schmidtia pappophoroides, S.unip: Stripagrostis uniplumis, T.andr: Triraphis andropogonoides, T.bert: Tragus berteronianus. B.grou: Bare ground. Eigenvalues: Axis 1 = 0.483; Axis 2 = 0.195*

Discussion

Results from this study showed that soil organic carbon and soil microbial biomass measured as total PLFA did not statistically differ between the grazed and ungrazed plots at any of the three study sites (Table 2, Fig. 2). Soil microbial biomass was overall

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low in all plots at the three sites, ranging between 489.28 pmol g^{-1} and 1823.04 pmol g^{-1}. These values are far below those reported in studies of temperate grasslands across the world.

We hypothesized two factors responsible of the findings in this study. Firstly, the low vegetation abundance and cover or state of degradation (Table 3, Fig. 1), which was already extreme in the present investigation, might have induced the low soil microbial biomass at the three sites. Soil microbial biomass is considered part of the available or labile soil organic matter, the small fraction that is readily decomposed and involved in nutrient cycling [35]. Because soil microbial communities rely on materials produced by plants as energy sources for growth and reproduction, low plant cover and biomass would affect the activity of microbial communities. [4], [50] showed that differences in soil microbial biomass are due to gradients in resource availability in particular soil organic matter content. Therefore, declined and degraded plant cover means a lower soil organic matter added to the soil, which will inhibit the activity of soil microorganisms [16]. Our hypothesis was consistent with other results [48], as quoted [16] indicated that soil with a lower plant cover do not have a higher potential microbial activity. A greater depletion of organic carbon in the soil possibly due to reduced quality and quantity of organic matter in soils results in loss in microbial activity [14]. Similar results have also been reported [54], in the sense that the loss of plant species has the greatest impact on microbial communities in ecosystems containing infertile soils poor in organic matter, and that the loss of above and belowground herbaceous materials removed the energy sources required for microbial growth [34].

Soil microbial biomass is a potential source of plant nutrients, and a higher level of soil microbial biomass is an indicator of soil fertility. The soil microbial biomass was higher at Austrey, compared to Southey and Tseoge sites, irrespective of grazing or its exclusion condition. The results in Fig. 4 showed a strong correlation at Austrey site with the soil microbial biomas, as well as bacterial and fungi PLFA. It was evident from the results of Table 3, that the greater species composition and resulting biomass would result in much more organic material, which is vital to stimulate the soil microbial communities. The vegetation condition at Southey site and the higher bare ground at Tseoge (79.3%) would undoubtedly result in lower soil microbial biomass at these two sites respectively. Our results seem to confirm previous studies, which highlighted the relationships between high plant richness and increases of microbial biomass [40], [11], [7]. Floristically differences between ecosystems would produce litter with chemically distinct substrates that will differentially foster microbial growth [33]. In this study, the grazed and ungrazed plots at all three sites showed similarities in grass composition (Table 3), although Z-index at the Tseoge site was lower (1.62%) but characterized overall by high percentage of bare ground. The similarity in herbaceous composition may explain the absence of statistically significant difference in soil microbial biomass between the grazed and ungrazed plots. Our results are in concordance with [28], [46] which have reported no statistically significant difference of soil microbial biomass between grazed and ungrazed rangelands protected of grazing for 16 and 35-40 years in temperate grasslands.

Our second hypothesis referred to the effect of livestock grazing and its management between the three sites. Despite the low soil microbial biomass, there was a statistically significant difference between the grazed plots at the three sites ($p=0.03$), with the

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Austrey site showing "relatively" higher soil microbial biomass (Fig. 2). A reduction of microbial biomass carbon in soils of areas subjected to poor grazing management has been reported [25]. As grazing influences plant growth and composition, this would affect the flow of plant litter to decomposers [46], and consequently the carbon inputs to the belowground microorganisms. Other studies [24], [4] on the contrary have reported that depending on its intensity, grazing may increase the allocation of organic inputs to the soil by rapidly returning plant available nutrients in the form of dung and faeces. Resulting from this allocation, soils of grazed grasslands tend to have small amounts of dead litter on the soil surface, but contain also large amounts of organic nitrogen and carbon, which combines to produce a soil environment that sustains an abundant and diverse faunal and microbial community [5]. This might not hold true for the present investigation, as there was little vegetation to start-off; and that it was unclear whether the state of vegetation degradation is due to grazing effect and/or its combination with variation of climatic conditions.

Conclusion

To our knowledge, this study is the first conducted in these communal rangeland sites to assess the patterns of soil microbial biomass. Our results suggest that low vegetation abundance and the poor condition (degradation) was the prime determinant of the low soil microbial biomass found at the three sites. Soil microbial biomass is a potential source of plant nutrients, and higher level of soil microbial biomass is an indicator of soil fertility. In the case of this study, this implies low soil fertility, which will then affect the sustainability of these rangeland sites. Despite the short-time period of this study, our results are in concordance with global literature that plant abundance and cover determines microbial metabolism, although thorough comparisons with previous studies were very difficult, because of different soils condition, initial vegetation state and cover, duration, intensity and management of grazing. It was unclear was whether the state of the vegetation was a result of grazing influence and management or combined effects of grazing and climatic variation. Therefore, further research is required for a thorough understanding of the underlying processes (grazing, changes in vegetation condition, climate variation) that may regulate changes in the soil microbial biomass in order to promote sustainable management of these communal rangelands.

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COMPARATIVE STUDIES ON THE LEVELS OF VITAMINS DURING VERMICOMPOSTING OF FRUIT WASTES BY *EUDRILUS EUGENIAE* AND *EISENIA FETIDA*

[1]M. LAKSHMI PRABHA, [2] INDIRA A. JAYRAAJ, [3]JEYARAAJ, R AND [1]SRINIVASA RAO .D.

[1]Ph.D Research Scholars in Biochemistry,
[2]Reader in Biochemistry
[3]Reader in Zoology
Kongunadu Arts and Science College,
Coimbatore – 641 029, Tamil Nadu, India.

e-mail: jeyaraaj_indira@yahoo.co.in

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Abstract. Organic wastes are extensively increasing with increased human populations, intensive agriculture and industrialization. The disposal of wastes has become important for a healthy quality of environment. In this regard recycling of utilizable organic wastes is feasible. The recycling of wastes through vermicomposting reduces problems of disposal of organic wastes. Vermicomposting, a novel technique of converting decomposable organic wastes into valuable vermicompost through earthworm activity is a faster and better process when compared with the conventional methods of composting. Within a very short period, a good quality compost rich in nutrient and vitamins is prepared, which is a highly efficient, cost effective and ecologically sound input for agriculture. The present study was carried out to find the changes in the levels of vitamins namely vitamin A, vitamin E and vitamin C present in fruit wastes during vermicomposting at different time intervals (15, 30 and 45 days) by Eudrilus eugeniae and Eiseniae fetida. The levels of vitamin A, E, and C were found to be higher in fruit wastes degraded by Eisenia fetida than Eudrilus eugeniae.
Keywords: *Vermicomposting , fruit wastes, Eudrilus eugeniae, Eisenia fetida, Vitamins.*

Introduction

Waste is the spoilage, loss or destruction of either matter or energy, which is unusable to man. Gradually increasing civilization through industrialization and urbanization has led to increase in the generation of wastes polluting environment from various sources. The fruit wastes generated in market yards, hostels, hotels and houses are dumped into an open land. This process not only reduces the available fertile land, which was used to produce food and raw materials, but also pollutes air, water and soil. To overcome this problem wastes can be used to produce valuable organic manure by using vermitechnology [1].

Vermitechnology is an important aspect of biotechnology involving the use of earthworms for processing various types of organic wastes into valuable resources. Vermicomposting helps to process wastes simultaneously giving biofertilizers and proteins [2]. Thus vermitechnology could successfully be used to clean the environment as it uses wastes as raw material to change polluted, costly chemical farming to sustainable agriculture[3].

Soil animals are important contributors to soil fertility and humification processes. Of which, earthworms should be considered as key-stone organisms in regulating nutrient cycling processes in many eco-systems4. Earthworms can consume practically all kinds of organic wastes, consume two to five times its body weight and after using 5

- 10 percent of the feed stock for its growth, excrete mucus coated undigested matter as nutrients and vitamins rich worm casts [5]. Vermicasts are a resource that are rich in mineral nutrients, vitamins, plant growth hormones, proteins and enzymes. Thus vermicast is considered as a very good organic fertilizer and soil conditioner. Hence the present study was carried out to find the changes in the levels of vitamin A, E and C in fruit wastes during vermicomposting at different time intervals (15, 30 and 45 days) by *Eudrilus eugeniae* and *Eisenia fetida.*

Experiment

Collection and predecomposition of fruit waste

The fruit wastes were collected from Annamalai fruit stall, State Bank of India Road, Coimbatore – 641 018, Tamil Nadu, India and in Pazhamudir Nilayam, Nehru stadium, Coimbatore – 641 018, Tamil Nadu, India . The collected fruit wastes were chopped into small pieces and allowed to partial decomposition for 20 days. Then the wastes were mixed with cowdung in 3:1 ratio and used for vermicomposting.

Collection and Culturing of earthworms

The epigeic earthworms *Eudrilus eugeniae* and *Eisenia fetida* were collected from Aarthi farms, Kondegoundampalayam village, Pollachi Taluk, Coimbatore, Tamilnadu. The species were cultured at Kongunadu Arts and Science College, Coimbatore, Tamilnadu, India premises for six months.

Vermicomposting of fruit wastes

Pits of 0.75 x0.75x 0.75 m size were dug and floor of the pit was covered with the lattice of wood strips to provide drainage. Totally seven pits were maintained for experimental purposes. The pit T_1 was maintained as control for fruit wastes (without earthworm), T_2, T_3, T_4, T_5, T_6 and T_7 (with earthworm) were taken for composting of fruit wastes. In each pit a total of 60 kg of fruit wastes were taken and in T_2, T_3 and T_4 pits the earthworm *Eudrilus eugeniae* and in T_5, T_6, and T_7 pits the earthworm *Eisenia fetida* were released on the surface at the rate of 60 worms per square feet except control. Care was taken to avoid light, rainfall and natural enemies. In control as well as experimental pits, the compost samples were taken on the 15^{th}, 30^{th} and 45^{th} days for the analysis of vitamins.

Vitamin A was assayed by the method of Nield and Pearson (1963) [6], vitamin E by the method described by Varley *et al.,* (1980)[7] and C by the method described by Sadasivam and Balasubramaniam (1987) [8].

Statistical Analysis

For the purpose of statistical analysis, Duncan's multiple range test was applied for comparing the levels of vitamins at different time intervals.

Results and Discussion

Selection of earthworm species is very important factor because only few species are able to survive and adjust to a particular type of environment. *Eudrilus eugeniae* and *Eisenia fetida* can be cultured very well on fruit wastes. These species were selected and tested for biodegradation of fruit wastes. *Eudrilus eugeniae* a tropical earthworm commonly called African night crawler, is large in size, grows rapidly, breeds fast and is capable of decomposing large quantities of organic materials into usable vermicompost. *Eisenia fetida* popularly known as European worm or Tiger worm is ubiquitous and many organic wastes became colonized naturally by this species. They have a wide temperature tolerance and can live in organic wastes within a wide range of moisture content.[9] The levels of various vitamins namely Vitamin A, E and C in fruit wastes degraded by *Eudrilus eugeniae* and *Eisenia fetida* at different time intervals (15, 30 and 45 days) are depicted in Table 1 and Figure 1, 2 and 3 respectively.

Table 1. *The level of vitamin A, vitamin E and vitamin C in the fruit wastes during different time intervals (15,30and 45 days) of composting by Eudrilus eugeniae and Eisenia fetida.*

VITAMINS	**Species**	**Control (without earthworm)**	**Decompositon time (Days)**		
			15	**30**	**45**
Vitamin C	*Eudrilus eugeniae*	0.190	0.257**	0.350**	0.397 **
	Eisenia fetida	0.190	0.302**	0.394**	0.425**
Vitamin E	*Eudrilus eugeniae*	0.205	0.364 NS	0.455 NS	0.490 NS
	Eisenia fetida	0.205	0.359 NS	0.463 NS	0.502 NS
Vitamin A	*Eudrilus eugeniae*	0.038	0.050 NS	0.089 NS	0.095 NS
	Eisenia fetida	0.038	0.062 NS	0.077 NS	0.097 NS

** P<0.01

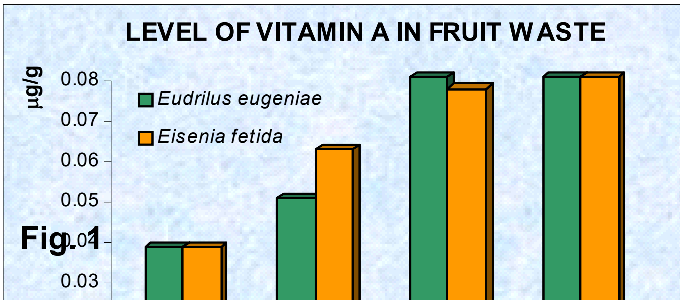
NS – Non significant

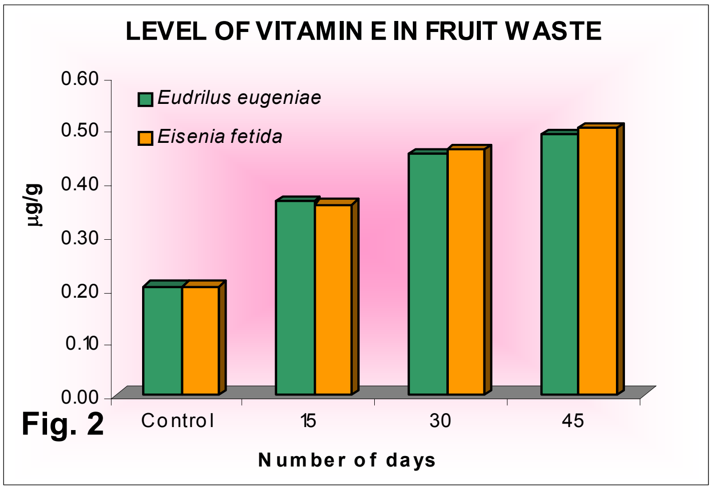
Units:

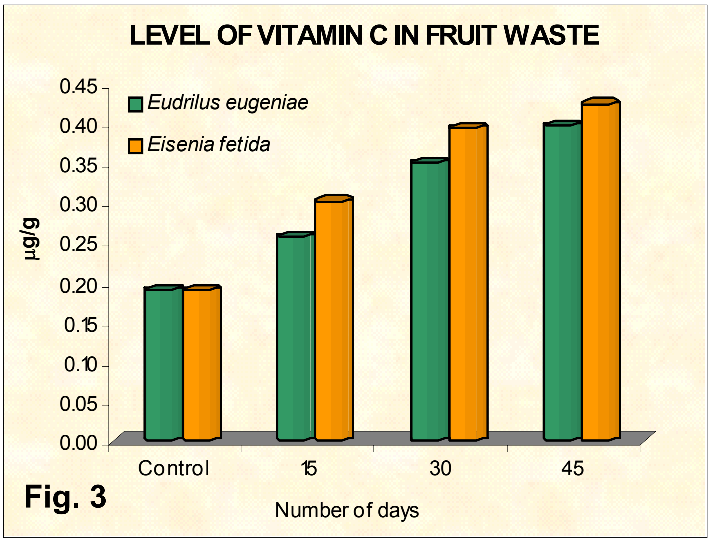
Vitamin C - unit - µg/g
Vitamin E - unit - µg/g
Vitamin A - unit - µg/g

The level of vitamin A, E and C were found to be increased significantly and reached the maximum on the 45th day of composting by *Eudrilus eugeniae* and *Eisenia fetida*. The level of vitamin C was found to be significantly increased at 1% on the 15th, 30th and 45th days of composting by *Eudrilus eugeniae* and *Eisenia fetida* when compared to control.

Figure 1. *Represents the level of vitamin A, E and C*







Fruits are rich source of vitamin A, E and C. When the earthworms feed on the vitamins rich fruit wastes, they excrete mucus coated undigested matter as worm casts, rich in nutrient and vitamins. Between the two species selected for the study more levels of vitamin A, E and C were found in the fruit wastes degraded by *Eisenia fetida* as compared to *Eudrilus eugeniae*. As a conclusion, vermicompost can be considered as nutritionally superior as other kinds of organic manures.

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GARCINIA KOLA HECKEL SEEDS DORMANCY-BREAKING

O. EYOG-MATIG[1]* – A.K.N. AOUDJI[1] – C. LINSOUSSI[2]

[1]*Sub-Saharan Africa Forest Genetic Resource Programme, International Plant Genetic Resource Institute for West and Central Africa, 08BP: 0932 Cotonou, Benin*
[2]*Département d'Aménagement et Gestion de l'Environnement, Faculté des Sciences Agronomiques Université d'Abomey-Calavi, BP 526 Cotonou*

e-mail: o.eyog-matig@cgiar.org

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Abstract. Seeds dormancy-breaking was investigated for *Garcinia kola* Heckel by using techniques that can afford small farmers for domestication. *Garcinia kola* seeds in their natural habitat have 6 weeks to 18 months dormancy. The methods experimented to overcome seed dormancy included conservation or removal of seed coat followed by pre-germination treatments including soaking for 24 hours in cold water (25°C), or in hot water (70°C); immersion in pineapple juice or incorporation in banana false trunk for one week. Sand mixed with compost and sawdust were used as germination substrata. The germination rates were quite low (0-40%) due to poor seed quality. Seed coat removal followed by soaking in cold water affected positively dormancy-breaking while the warm treatment caused embryo destruction and failure of seed germination. The effective dormancy-breaking methods to be recommended were decoated seeds soaked in cold water, coated seeds placed in banana false trunk and coated seeds soaked in pineapple juice where germination started 95, 102 and 110 days respectively from sowing with 130-141 days as mean germination time. The germination substratum irrespective of dormancy-breaking method didn't affect significantly either the germination percentage or the germination time. Further investigation is necessary to improve dormancy-breaking.
Keywords. *Garcinia kola, seed dormancy-breaking, germination rate, germination time, seedling growth.*

Introduction

Garcinia is a tropical plant genus including several species in Africa, America and Asia. These species are commonly useful for many purposes [12]. *Garcinia kola* Heckel is a highly valued and multi-purpose tree for its fruits, seeds, stems, roots and barks that are used in Western and Central African regions. *Garcinia kola*'s interest is proved as one of the many non-timber forest products that are of high socio-economic importance [1]. It occupies the third rank of medicinal plants in Benin in terms of number of recipes in which the species is incorporated [14] and investigations proved that *Garcinia kola* seeds contain compounds useful in curing several diseases [4, 6].

Because of its high interest resulting in its overexploitation, *Garcinia kola* is extinction-threatened in several West and Central African countries such as Ivory Coast [5], Togo [8], Congo and Cameroon [15]. Considering its importance and to prevent genetic erosion, appropriate strategies should be developed to promote its sustainable use. It is therefore useful to undertake *on farm* conservation by small farmers through agroforestry systems. This will decrease the pressure on wild individuals. However such methods require an accurate knowledge of its propagation.

The major difficulty in *Garcinia kola* propagation as for several species of *Garcinia* genus is related to seeds germination. Due to dormancy, *Garcinia kola* seeds can take

18 months to germinate [2]. It is therefore necessary to find out adequate solutions to overcome seed dormancy.

Previous studies investigated on *Garcinia kola* Heckel and *Garcinia cowa* Roxb. seeds germination [7, 11]. Both studies were carried out in laboratory conditions and part of the outcomes couldn't be implemented by small farmers. There was therefore need to develop new techniques. The present study was carried out to partially fill this gap of knowledge. It aimed at improving seed germination by using techniques that can afford small farmers.

Materials and methods

Studied material: Garcinia kola Heckel

Garcinia kola Heckel (Guttiferae) commonly occurs in humid lowland rainforests or gallery forests of West and Central African sub-regions. Its geographical distribution area (*Fig. 1*) extends from Congo to Sierra Leone [16].

Figure 1. *Garcinia kola geographical distribution*

It grows in coastal areas and lowland plains up to 300 m above sea level with average water availability equivalent to 2,000-2,500 mm of rainfall per annum. Temperature in theses regions ranges from 32.15°C to 21.4°C with a minimum relative humidity of 76.34% [10].

Garcinia kola is a medium-sized and shade-tolerant tree with a cylindrical trunk that is slightly buttressed to the ground. The tree has a dense crown which is compact, but not spreading. Male and female flowers are separate. Fruits are smooth, reddish yellow; seed coat is brown with branched lines. The fruits usually fall to the ground where animals feed on them and disperse the seeds.

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Two types of seeds were used: fresh and dried seeds. The sample was homogenized by mixing the two categories before starting the experiment.

Study of dormancy-breaking

The treatments tested were selected based on firstly the information published in scientific papers [11] and secondly non-published information provided by scientists. Dormancy-breaking techniques combined seed coat treatment and pre-germination treatment. Seed coat treatment included seeds with and without seed coat. Then seed coat treatments were matched with pre-germination treatments including: (i) seeds soaking for 24 hours in water at ambient temperature (about 25°C: cold water); (ii) seeds soaking for 24 hours in hot water previously boiled at 70°C; (iii) seeds soaking for one week in pineapple juice; (iv) seeds incorporation for one week within banana false trunk; except decoated seeds in pineapple juice and within banana false trunk (*Table 1*). These two treatments were not used because not significantly different from coated seeds according to non-published information.

Table 1. *Factors and treatments description*

Treatment number	Seed coat treatment	Dormancy-breaking method
1	Decoated seeds	Cold water (30°C)[1]
2	Decoated seeds	Boiled water (70°C)[1]
3	Coated seeds	Cold water (30°C)[1]
4	Coated seeds	Boiled water (70°C)[1]
5	Coated seeds	Pineapple juice[2]
6	Coated seeds	Banana false trunk[2]

[1] *Duration of the pre-treatment = 24 hours*
[2] *Duration of the pre-treatment = one week*

Two substrata were used in nursery: sand mixed with compost and sawdust. Polyethylene containers were filled in with substratum. The containers had 8 cm diameter, 23 cm height with two rows of small holes (3 mm diameter) for drainage; the first row of holes was situated at 3 cm above the bottom and the second at 7 cm.

One seed was sown per container. The number of replications per dormancy-breaking treatment and substratum was 25 seeds/containers or a total of 300 containers for the whole experiment. Containers were watered on a daily basis and saturated with water.

Observations were made on a daily basis and the seed germination date was recorded for each container. The germination date was confounded with seed levee date. The experiment was stopped when no new germinated seed occurred for a consecutive 20 days period. The germination rate and the mean germination time were calculated.

Germination rate (%): $GRi=(n_i/N)\times 100$; where *GRi* is the germination rate of the treatment *i*; n_i is the number of germinated seeds of the treatment *i* and *N* is the total number of seeds.

Mean germination time (days): $MGTi = \sum (tj \times nij)/ni$; where *MGTi* is the mean germination time of the treatment *i*; t_j is the j^{th} day from sowing; n_{ij} is the number of germinated seeds of the treatment *i* at the is the j^{th} day from sowing and n_i is the total number of germinated seeds of the treatment *i*.

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Germination trends over time were analyzed. Germination counts were analyzed with Chi square test; germination times were compared with analysis of variance completed by Newman-Keuls mean comparison test. Minitab software was used to perform statistical analyses.

Results

Germination start

Germination occurred (*Table 2*) from sowing after 95 days for decoated seeds soaked in cold water, 102 days for coated seeds placed within banana false trunk, 110 days for coated seeds soaked in pineapple juice and 153 days for coated seeds soaked in cold and hot water. Decoated seeds maintained in hot water failed to germinate.

Table 2. *Germination start*

Dormancy-breaking methods	First germination (days)
Decoated seeds in cold water	95
Coated seeds in banana trunk	102
Coated seeds in pineapple juice	110
Coated seeds in cold water	153
Coated seeds in hot water	153
Decoated seeds in hot water	-

Germination spread over time

Germination trend analysis (Fig. 2) revealed germination spread over time. Coated seeds incorporated in banana false trunk showed several stages of synchronous germination. Similar trend was observed for coated seeds soaked in cold water. Coated seeds soaked in pineapple juice showed synchronous germination at the beginning (110th day) followed by regular germination occurrence until the 180th day. Germination occurrence was irregular for decoated seeds soaked in cold water and coated seeds soaked in hot water showing no clear synchronous germination.

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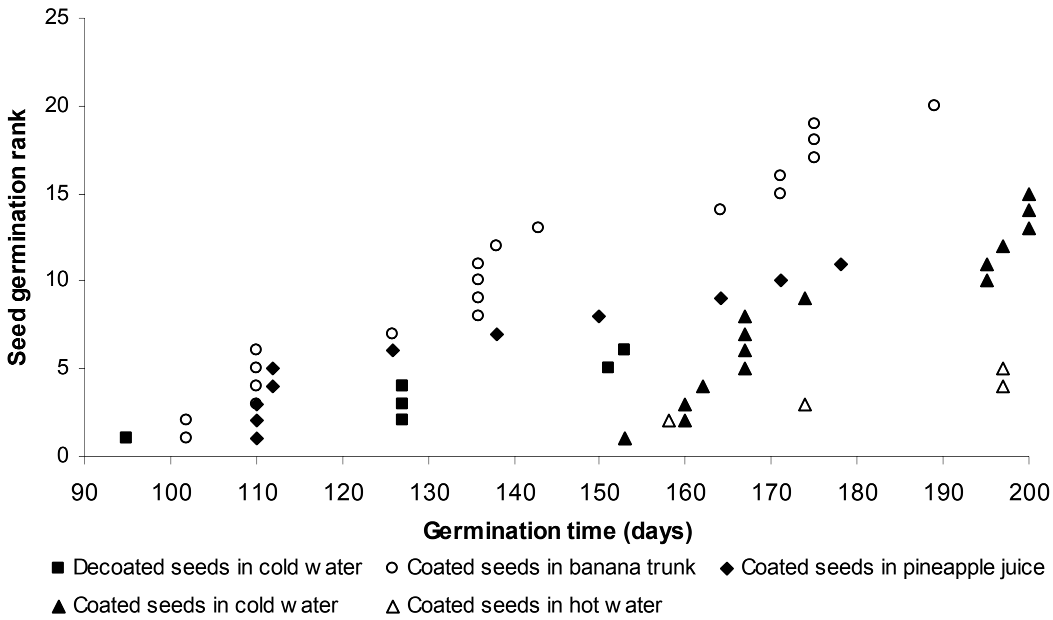

Figure 2. *Seeds germination over time*

Germination rate

Seed germination varied significantly according to dormancy-breaking methods (table 3). Except decoated seeds soaked in hot water where germination failed, the germination percentage (*Table 3*) ranged from 10% (coated seeds soaked in hot water) to 40% (coated seeds placed in banana false trunk). Dormancy-breaking treatments could be ranged in four levels of effectiveness according to germination percentage. The first level was for coated seeds placed in banana false trunk (40%); the second was for coated seeds soaked in cold (30%); the third germination level was that of coated seeds soaked in pineapple juice (24%) and the last level included decoated seeds soaked in cold water and coated seeds soaked in hot water (10-12%).

Table 3. *Seed germination*
Chi square test on seed germination: Chi square value= 17.645; P=0.001

Dormancy-breaking methods	Seed germination (counts)		Germ. rate (%)
	Non germ. seeds	Germ. seeds	
Coated seeds in banana trunk	30	20	40±11.31
Coated seeds in cold water	35	15	30±8.49
Coated seeds in pineapple juice	38	12	24±0.00
Decoated seeds in cold water	44	6	12±11.31
Coated seeds in hot water	45	5	10±8.49

The assessment of substratum effect revealed that sand mixed with compost or sawdust irrespective of dormancy-breaking methods didn't affect significantly seed germination (Chi square = 0.541; P = 0.462).

Germination time

The mean germination time (*Table 4*) varied significantly according to dormancy-breaking methods (P=0.000). The mean germination time was lower for decoated seeds in cold water, coated seeds in pineapple juice and coated seeds in banana false trunk (130-141 days) than for coated seeds in cold water and in hot water (176-178 days).

Table 4. *Mean germination time*

Dormancy-breaking methods	Mean germination time (days)
Decoated seeds in cold water	130 a
Coated seeds within banana trunk	141 a
Coated seeds in pineapple juice	135 a
Coated seeds in cold water	176 b
Coated seeds in hot water	178 b

**Treatments followed by the same letters are not significantly different.*

The assessment of substratum effect revealed that sand mixed with compost or sawdust irrespective of dormancy-breaking methods didn't affect significantly the germination time (P=0.99).

Discussion

The analysis of germination trends showed spreading over time. The spreading of seed germination was reported to be due to variability in dormancy depth [3]. Basic pattern with respect to temporal distribution were distinguished [13]: quasi-simultaneous, when germination of all the seeds occurs over a relative brief period; intermittent, irregular germination over long time periods, showing essentially multi modal distribution; continuous, in which members of the population germinate over an extended time period, with no clear peaks and periodic germination, which is multi modal but shows more regular periodicity. *Garcinia kola* seeds germination in the trial can be classified as periodic.

The germination rates were quite low (0-40%). The failure of seeds germination may be due to embryo death or deep seed dormancy. The test of ungerminated seeds viability is usually performed by using tetrazolium chloride [7, 9]. The high proportion of ungerminated seeds may be a consequence of a high proportion of dead seeds; however the non-implementation of the tetrazolium chloride test limits this hypothesis.

Germination spreading and poor seed quality may be correlated to seed moisture content. *Garcinia kola* seeds are sensitive to desiccation that usually decreases seed viability. It was revealed that the germination rate decreased with the seed moisture content and at 20.2% moisture content every seeds died and failed to germinate; the seed water content at harvest (50.4%) allowed the best germination rate and the shortest spreading out of the germination period [11]. Comparable results were obtained for *Garcinia cowa*, a tropical recalcitrant seed. Below 40% of moisture content, seeds viability decreased rapidly and all seeds died at approximately 17% of moisture content [7]. Dried seeds used in the experiment were responsible of poor seed germination and germination spread. Further investigation will enable to assess more accurately how seed viability and dormancy depth vary according to the seed moisture content to determine the suitable seeds storage conditions.

Decoated seeds soaked in hot water (70°C) failed to germinate due to embryos destruction by the warm treatment. Germination failure was previously reported when soaking *Garcinia kola* seeds in warm water (60°C) for 8 hours [11] and this confirm that the warm water treatment affected negatively *Garcinia kola* seeds germination. Coated seeds in hot water could germinate showing that seed coat may protect in certain extent embryo from destruction by warm.

Germination started early for decoated seeds in cold water (95 days) while for coated seeds in cold water it occurred 58 days later. The mean germination time was therefore significantly lower for decoated seeds soaked in cold water (130 days) than for coated seeds soaked in cold water (176 days). Seed coat removal therefore affected positively dormancy-breaking by reducing the mean germination time of 46 days. Comparable result was obtained for *Garcinia cowa* seeds where the total removal of seed coat was revealed as the most effective dormancy-breaking treatment [7]. Germination occurred also quite early for coated seeds placed in banana false trunk and coated seeds soaked in pineapple juice.

The effectiveness of seed coat removal treatment enabled to assume that part of seed dormancy mechanism is external or coat-imposed. The effectiveness of the pineapple juice and the banana trunk treatments may be due to the presence of some compounds that reduce the dormancy-induction properties in the seeds. The hypothesis of embryo dormancy on *Garcinia kola* seeds was reported basing on the presence of substance associated with germination inhibition such as phenol in the seeds [11]. In this case decoated seeds soaking in cold water may decrease the content of such compounds and promote seed germination. The same mechanism may explain the effectiveness of pineapple juice and banana trunk treatment.

Basing on the germination time, as the germination percentage was affected by poor seed quality, the effective dormancy-breaking treatments to be recommended for propagation by small farmers are decoated seeds soaked in cold water, coated seeds in banana false trunk and coated seeds in pineapple juice. Nevertheless, these methods are less efficient when compared with previous study having reported mean germination time of 26-72 days [11]. The difference may derive from the fact that these authors worked in seed tray with laboratory conditions while our study was carried out in nursery where environmental conditions are subjected to less control. Moreover the germination date was not determined accurately and confounded to the levee date and until 10 days may separate germination from seed levee. The seed tray step stage may improve *G. kola* seed germination. However, the efficiency of the treatments implemented may be improved to shorten the germination time and increase the germination percentage. To this end, the understanding of dormancy mechanism will be necessary basing on natural processes; for instance to investigate whether seeds ingestion by elephants and other animals affected in certain extent dormancy-breaking.

In the appraisal of substratum effect, sand mixed with compost or sawdust didn't significantly affect either the germination occurrence or the germination time. The reason is that water availability for seed germination was enough in both substrata. The role of substratum is to provide favorable environment especially moisture and air required for seed germination. In the experiment water was artificially provided and containers were saturated daily so that even seeds germinating in substratum with low water-holding capacity were not disadvantaged.

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Conclusion

Garcinia kola seeds had poor germination due to dormancy and poor seed quality. Seed viability is affected by desiccation. The germination rate was 0-40% and the mean germination time 130-178 days. Dormancy-breaking was improved by seed coat removal followed by soaking in cold water (25°C). Germination was affected negatively by soaking decoated seed in warm water where seeds failed to germinate. The most effective treatments to overcome seed dormancy were seed coat removal followed by soaking in cold water for 24 hours in cold water and seed incorporation within banana false trunk or immersion in pineapple juice for one week. The efficiency of these treatments may be improved.

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LOW DENSITY CATTLE GRAZING ENHANCES ARTHROPOD DIVERSITY OF ABANDONED WETLAND

A. ZAHN[1] *-A. JUEN[2]- M. TRAUGOTT[2] & A. LANG[3]

[1]Bund Naturschutz, Kreisgruppe Mühldorf, Graslitzerstr. 35, D-84478 Waldkraiburg
Tel. 0049 8638-3701Fax: 0049 8638-3701
[2] Institut of Ecology, Mountain Agriculture Research Unit, University of Innsbruck, Technikerstraße 25, 6020 Innsbruck
[3]Institute of Environmental Geosciences, University of Basel, Bernouillistr. 30, CH-4055 Basel
Tel. 0041 61 267 0477 Fax: 0041 61 267 0479

e-mail: Andreas.Zahn@iiv.de

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Abstract. We studied the impact of low-density grazing on arthropod diversity in a small wetland (7 ha) in South Germany. The location was abandoned for 20 years, and was then grazed by Galloway for 4 to 5 years. The study site included the following habitat types: open land, a stand of alder (Alnus glutinosa), a stand of willows (Salix spec) and alder and a brookside. We counted higher species numbers on grazed than on neighbouring abandoned areas in ground beetles, rove beetles and spiders. Grazing explained a considerable amount of the variance of the species composition, and species typical for grazed plots could be identified. We found higher frequencies of insects during winter in Cirsium stems from grazed than from ungrazed areas. Grasshoppers and katydids (Saltatoria) of the grazed open land showed a general trend of increasing species number during the study period. Our findings show that low density grazing by cattle can favour habitat diversity even in small areas which enhances species numbers. However, special habitat types such as reed may need to be excluded from grazing in order to maintain the associated specific invertebrate community.
Key words: *Grazing, arthropods, insects, diversity, wetland*

Introduction

In many wetlands species richness and diversity depend on traditional land use patterns such as mowing and grazing (35). In Central Europe changing land use and intensification of agriculture have dramatically reduced the area of traditionally used wetlands (25), consequently many wetland species are highly endangered nowadays. Since long, mowing was regarded the most suitable conservation tool to preserve open wetland habitats (5, 28). However, sporadically mowing nowadays fully depends on financial support, while extensive grazing can be partly included in agricultural production and may be a less expensive tool for nature conservation (41). Especially in restoration projects for abandoned wetlands, where the re-establishment of mowing is very expensive, grazing comes more and more into practice (3, 15, 19, 38). Many studies investigated the fauna of dry habitats demonstrating that extensive grazing can be an adequate management method (e.g. 2, 8, 12, 24). In contrast, literature on the influence of low density grazing on the fauna of wetlands is scarce, in spite of the fact that grazing was the traditional land use in many wetlands in the past (25, 29). The few studies conducted about the fauna of grazed wetlands in Central Europe focused on medium sized and large areas (>30ha). Regarding large areas, low density grazing is assumed to favour species diversity by the creation of diverse habitats (1, 11, 18, 27). However, approaches are needed in Central Europe for the management of small wetland areas (43).

In our study we present a restoration project where ongoing succession of a small abandoned wetland (6 ha) should be prevented by low density cattle grazing. The project was launched by the Bund Naturschutz in Bayern. The aim is to protect the biodiversity of open landscapes by extensive farming practices (41).

We studied the influence of cattle grazing on vegetation and on animal populations. Our earlier results showed that the low density cattle grazing favours plant diversity and creates small scale habitat heterogeneity (42), enhances species richness of dung beetles (39), and reproduction success of endangered amphibians (43). The objective of this study are (i) determining the influence of grazing on the relative abundance of epigeic spiders and carabid as well as staphylinid beetles (ii) investigating changes in the species community in relation to grazing, (iii) analysing the long term reaction of grasshopper species on grazing, and (iv) comparing the densities of stem-infesting insects in grazed and abandoned plots.

Study area

The study area is located in South Germany (Oberbayern: 12°22'42" east, 48°10'05" north) and is about 7 ha in size. It includes a damp meadow and small woods (6 ha), which are grazed since 1996 except for a small area of the woodland which was not grazed before 1999. Additionally, an area of about 1 ha remained abandoned where natural succession could take place totally unaffected by grazing or other management activities, In the latter the samples for the ungrazed control were taken.

From April until November between six and nine Galloway cattle (one or two years old) roamed freely in the fenced area. Other management measures such as mowing in autumn were not applied.

Methods

Community of spiders, ground beetles and rove beetles

Spiders (Araneae), ground beetles (Carabidae) and rove beetles (Staphylinidae) were studied in grazed and adjacent abandoned (ungrazed) plots of the same habitat type. Pairs of sample plots (each 100m²) were situated in the following habitats:

1) Open wetland; in the abandoned plot (1a) *Urtica dioica, Phlaris arundinacea* and *Carex* spec. were the dominating plant species, in the grazed plot (1b) these vegetation had been largely replaced by grasses (*Poa* spec), *Mentha longifolia* and *Cirsium* spec. The vegetation at 1a was on average higher and much denser than at 1b, bare ground without vegetation existed only at 1b.

2) Stand of *Alnus glutinosa*. In the ungrazed area (2a) *Urtica dioica* was dominating. The ground at the grazed plot (2b) was sparsely covered with grasses (*Poa* spec), and about 50% of the ground was without vegetation cover.

3) Stand of *Salix caprea* and *Alnus glutinosa*. At the ungrazed plot (3a) as well as at the grazed plot (3b), *Urtica dioica*, *Galium aparine* and *Poa* spec. were dominant, but the vegetation was less dense at 3b because of trampling and grazing by Galloway cattle.

While at the grazed parts of the pairs 1 and 2 grazing started in 1996, plot 3 belonged to the woodland that was included in the grazed area (3b) in 1999.

As an additional sample plot (4) we included an ungrazed reed at the brookside composed of *Phragmites communis* and *Phalaris arundinacea* at the banks of a small stream.

In 1999 and 2000 a set of 5 pitfalls (diameter 7cm) was installed at each plot and activated to catch epigeic invertebrates for 14 days in May, July and September. Trapping fluid was 5% acetic acid and traps were covered with a non-transparent roof to avoid flooding by rain. Additionally, we used a sweeping net to collect spiders from the vegetation. Sampling was done at the end of each pitfall sampling periods and for each sample 100 net strikes were carried out. The arthropods were identified and differences in species number between grazed and ungrazed plots were tested with a t-test for paired samples, the tested combinations being the grazed-ungrazed pairs of each habitat type (1 – 3).

Additionally CANOCO 4.5 (30) was used, to analyse the epigeic arthropod communities among the plots and to separate the influence of grazing from those of habitat characteristics and yearly changing environmental factors. Rare species (represented by less than 20 individuals) that are captured only by chance, were excluded from these analysis. This resulted in 20, 14, and 12 ground beetle, rove beetle and spider species, respectively, which were included in the community analyses. To prevent taxa caught in high numbers from excessively influencing the ordinations, faunal counts were square-root transformed. Correspondence analysis (CA) was used to illustrate the major patterns in the community structure. Canonical correspondence analysis (CCA) and partial ordination was calculated to determine the influence of the grazing in relation to environmental conditions that differed among the habitats and the years by using categorical variables. We analysed Carabidae, Staphylinidae and Araneae separately and, additionally, all arthropod species together. Statistical significances were calculated by Monte Carlo permutation tests and taxa showing positive or negative correlation to grazing were identified by t-value biplots.

The Grasshopper community

Species numbers of grasshoppers were recorded visually on 8 grazed sample plots (each 100m²) from 1996-2004. They were all located in grazed open wetland (1b), except one plot in a stand of *Salix caprea*, (see Zahn et al. 2003, for an overview over the vegetation of these sites). Each plot was searched for grasshoppers for 15 minutes once a year in late August. We did not distinguish between *Chorthippus brunneus* and *Ch. biguttulus* and between *Tetrix undulata* and *T. subulata* because it was difficult to determine single individuals without catching or acoustic methods.

Influence of grazing on insects infesting Cirsium arvense

To study the influence of Galloway grazing on insects infesting stems of plants, we sampled individuals of *Cirsium arvense* in the open wetland at 18 November 2002, in both the ungrazed (1a) and the grazed (1b) part. We distinguished between damaged and undamaged stems. Each sample consisted of 25 steams. As damaged we defined broken branches, open stems and partly browsed parts of the plant. The *Cirsium* - stems were spliced in the lab and searched for hibernating insects or signs of insect infestation (faeces, holes).

Results

Spiders and beetles in grazed and ungrazed areas

Altogether, 65 species of Carabidae were recorded. Of these 9 (14%) are considered as endangered species in the red data book of Bavaria and 6 (9%) in the red data book of Germany (Tab. 2, appendix). On average, numbers of carabid species were higher in plots grazed by Galloway cattle (44 species) compared to the ungrazed ones (38 species) ($p = 0.01$, habitats pooled, $df = 2$, t-test, Fig. 1). Grazed plots were characterized by the occurrence and/or high activity densities of species preferring moist and/or sunny environmental conditions such as *Elaphrus cupreus*, *Dyschirius globosus*, *Acupalpis flavicollis*, *Oodes helopioides* or *Poecilus* spp. (Tab 2, appendix.). The pitfall traps in the reed yielded the highest number of species recorded at one plot, i.e. 39 species (Fig. 1). *Agonum micans*, *A. thoreyi* and several species of the genus *Bembidion*, which are endangered and known for their special adaptations to survive in this type of habitat, were found exclusively at this site.

In total, 111 rove beetles species were recorded including four (4%) endangered species of the Bavarian red data book. Overall species numbers were again higher at the grazed samples plots than on ungrazed ones (73 and 47 species in grazed and ungrazed plots, respectively). However, in one of the three pairs of plots, the *Salix-Alnus* stand (3a/b), we found more species at the abandoned site -(Fig.1). At the brookside (reed) 51 species were captured. Of four red list species one was found in all habitats, one in the reed only, one at grazed plots only and at ungrazed plots only (Tab. 2, appendix).

Altogether, 90 species of spiders were recorded of which 72 and 57 species were found in grazed and ungrazed plots, respectively. Only 27 species were captured in the reed, i.e. the ungrazed reed contributed not as much to spider biodiversity as to beetle diversity (Tab. 2, appendix). Two species (2%) are listed in the red data books of Bavaria and Germany (Tab. 2. appendix); both occurred in ungrazed habitats only, *Donacochara speciosa* in the reed, and *Clubiona stagnatilis* in the reed as well as in the ungrazed open wetland. In all grazed plots the numbers of spider species tended to be higher compared to the abandoned references ($p = 0.06$, habitats pooled, $df = 2$, t-test, Fig. 1). Especially *Pirata*, *Pardosa* and *Oedothorax* species, which are known as hygrophilous and heliophilous showed higher activity densities in the grazed plots.

Twenty-five species of spiders, 10 species of ground beetles and 34 species of rove beetles occurred exclusively on grazed plots (Tab. 2., appendix). For ungrazed plots the respective numbers were 13, 7, and 10 for spiders, ground beetles, and rove beetles, respectively. The ungrazed reed was characterised by 5 species of spiders, 9 species of ground beetles and 28 species of rove beetles, which were found only in this habitat.

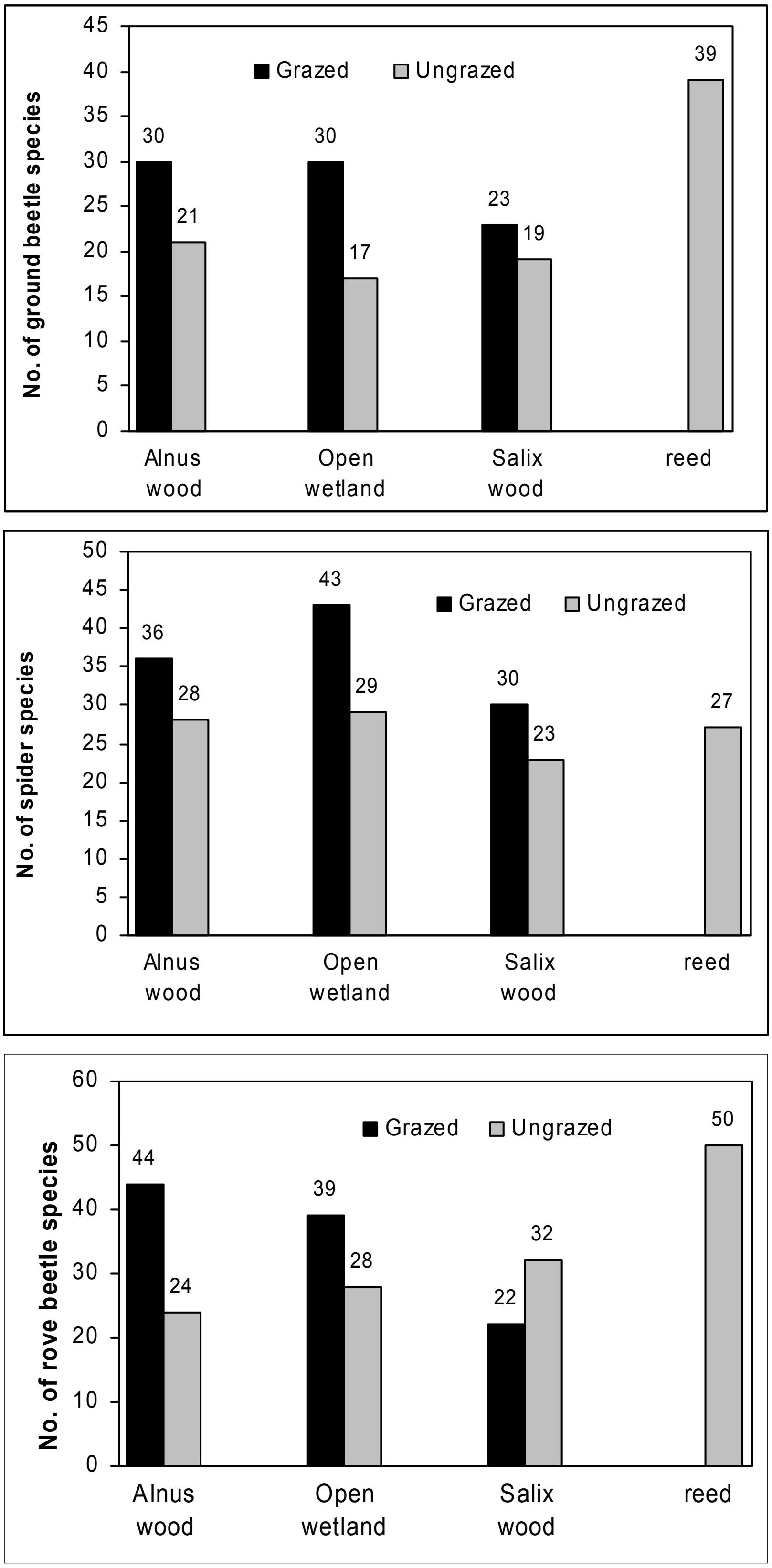

Figure 1. *Impact of grazing on species numbers: Ground beetles, spiders and rove beetles on grazed and ungrazed habitats*

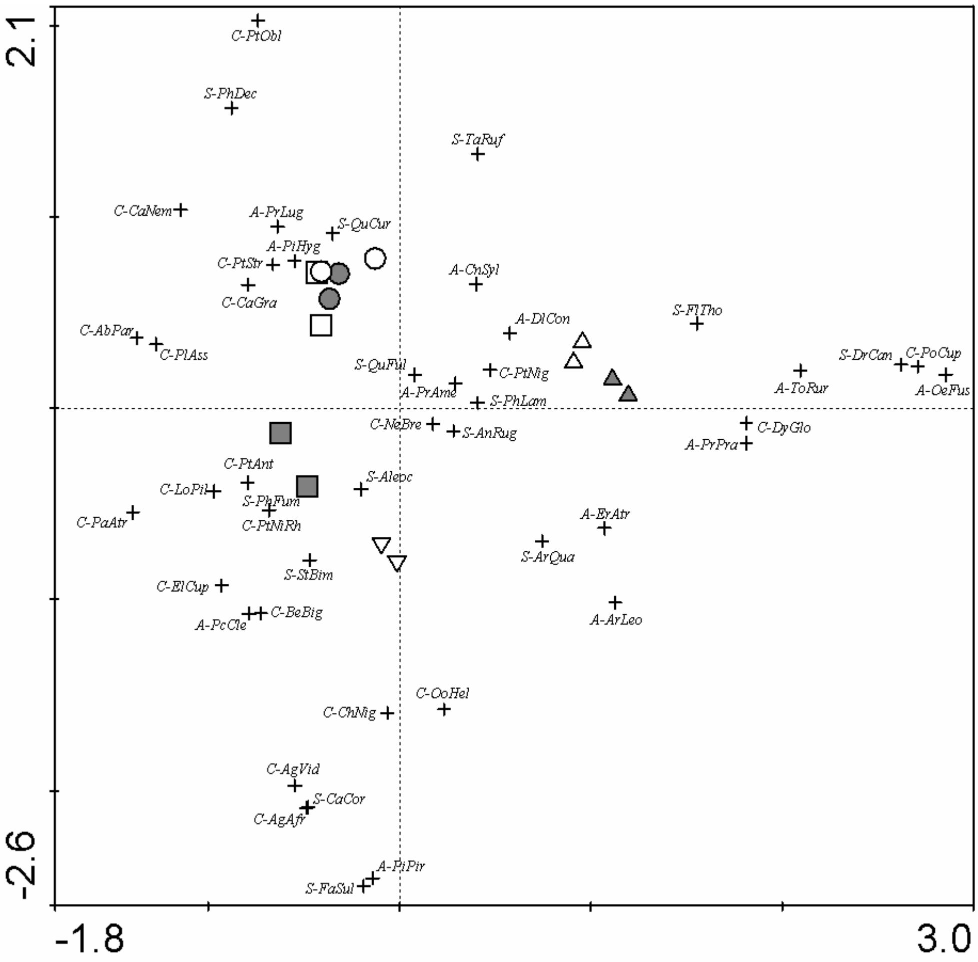

Figure 2. *Fig. 2: Impact of grazing on single species. Given is the ordination of species in relation to the sample plots. Rectangles, circles, upright triangles, and turned round triangles represent stands of Alnus, stands of Salix and Alnus, open wetland, and reed, respectively. Filled symbols indicate grazed plots, while open symbols indicate ungrazed plots. In each case both years are shown. Species names are replaced by abbreviations including C-, S-, or A- for Carabidae, Staphylinidae, or Araneae respectively followed by the first two letters of the genus and the first three letters of the species name. For the total name see Table 2 (Appendix).*

An impact of grazing on the arthropod communities is also indicated by the ordination analyses. 6.3 % of the total variance in the species composition can be explained by grazing (Tab. 1, Fig 2). This effect was more obvious in the ground beetle community (7.6 %) than in spiders (4.0 %) or rove beetles (3.2 %). Not surprisingly, habitat characteristics have been found to be the main factor determining the composition of the soil surface active arthropod community. Differences among the years were marginal (thus are not presented separately). According to a t-values biplot (Fig. 2) several species were significantly influenced by grazing: the ground beetles *Nebria brevicollis*, *Poecilus cupreus*, *Patrobus atrorufus*, *Loricera pilicornis*, *Elaphrus cupreus*, *Pterostichus anthracinus*, and *Pterostichus nigrita/rhaeticus* as well as the spiders *Pardosa amentata*, *Erigone atra*, *Trochosa ruricola*, and *Pachygnatha clercki* (A-PcCle) reacted positively on grazing; The relative abundances of these 11 species

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were higher on grazed plots than on ungrazed ones, irrespective of the influence of other environmental factors, habitat type and year. Negatively influenced by grazing were the rove beetles *Tachinus signatus*, *Aleocharinae spp*., *Quedius fuliginosus*, *Quedius curtipennis*, *Philonthus decorus* and *Falagria thoracica*, the ground beetles *Carabus nemoralis*, and *Abax parallelepipedus,* as well as the spiders *Centromerus sylvaticus* and *Pardosa lugubris*.

Table 1. *Tab 1: Variance decomposition of the effect of grazing and other environmental factors on the epigeic arthropod community. Besides the percentage of total variance that can be explained ("all variables") or not explained ("unexplained") by the studied variables, the uniquely explained percentage of total variance by habitat differences and yearly changing environmental conditions ("habitat&year") and by grazing ("grazing") is listed. "shared" gives the percentage of total variance that is explained by both ("habitat&year" and "grazing")*

	all Arthropods	Ground beetles	Rove beetles	Spiders
all variables	**45.7**	**45.0**	**44.5**	**45.9**
grazing	**6.3**	**7.6**	**3.2**	**4.0**
habitat&year	**39.1**	**37.9**	**40.8**	**40.8**
shared	**0.3**	**-0.6**	**0.5**	**1.2**
unexplained	**54.3**	**55.0**	**55.5**	**54.1**

Grasshoppers in grazed open wetland

Grazing favoured the distribution of grasshopper species. The numbers of species on the sample plots increased during the first years and stayed on a higher level during the last years. (Fig 3). Since the beginning of the study in 1996, new species (*Chorthippus parallelus* and *Chrysochraon dispar*) were found in the area in 2004 only. *Chorthippus albomarginatus* was found sporadically outside the plots in 1996 but continuously on 2 plots during the last years of the study. *Chorthippus brunneus/biguttulus* and *Gomphocerus rufus* were found in increasing numbers until 1998, but slightly decreased again in the subsequent years. No tendency was obvious in *Chorthippus dorsatus, Conocephalus discolor, Metrioptera roeseli, Pholidoptera griseoaptera, Tetrix undulata/subulata and Tettigonia cantan*s. In general, the mean number of single grasshopper species per site increased only in the beginning of the study. However, most species occupied more patches at the end of study indicating that the overall area of suitable habitats had increased.

Stem-infesting insects

We found the highest percentage of infested *Cirsium* plants in damaged stems from the grazed area and the lowest percentage in undamaged ones from the ungrazed plot (Fig. 4). However, the percentage of infested stems was also high in undamaged plants from the grazed area and only slightly lower in damaged plants from the ungrazed plot. The frequencies of infestation differed significantly (Chi-square =11.8, $p < 0.01$, df = 3).

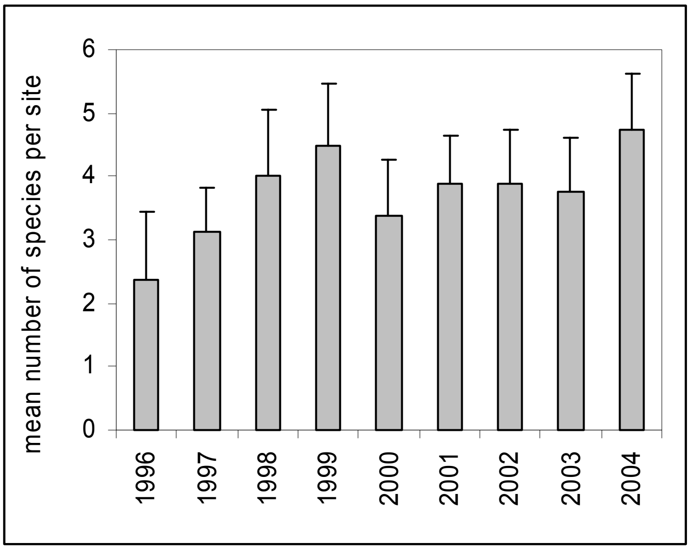

Figure 3. *Number of Saltatoria species per sample plot (1996 – 2004), mean and standard error.*

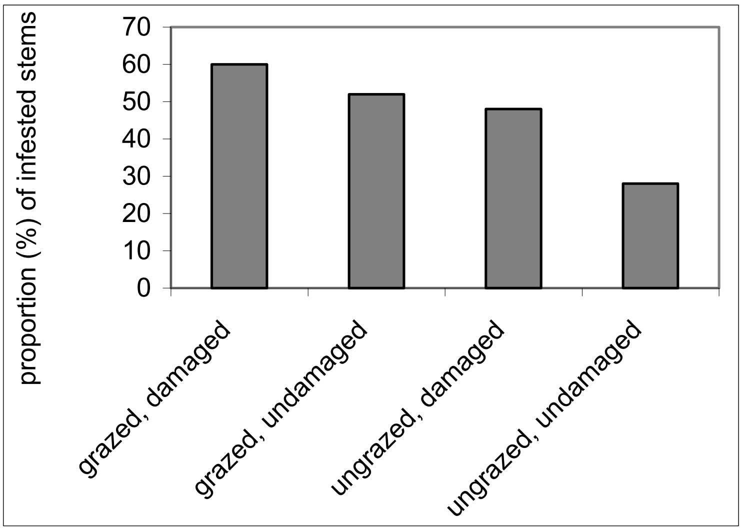

Figure 4. *Percentage of stems infested by insects on neighbouring grazed and ungrazed plots. Each sample consisted of 25 stems. Damaged: Stem or twigs of a stem broken or bitten off.*

Discussion

In general, higher species numbers of arthropods were found on grazed plots. Most likely the habitat mosaic created by the cattle was causing this result (11, 12, 23, 27). While some parts of the area are grazed intensively, other parts are hardly affected through grazing pressure. Some habitat types such as lawn-like, grass-dominated vegetation and bare ground exist only due to the presence of cattle, and are not present in the adjacent abandoned areas. High and low vegetation, bare ground and thick layers of organic material exist in the grazed areas in a low scale mosaic that remains quite stable over years (42). These predictable structural conditions favour species that depend on several habitat types, e.g. during different stages of their life cycle (26).

However, biodiversity increased by grazing must not necessarily result in higher numbers of endangered species. Considering the “red book species” on the paired plots (grazed – abandoned) , we found 9 species of spiders, rove and ground beetles on abandoned and 6 on grazed sites. Perhaps, immigration of endangered species into newly created habitats (the grazed area was abandoned before) is less likely than immigration of common species: many rare species depend on rare habitats (33), and therefore populations from which immigrants can come are scarce, too. Especially highly endangered wetland species can have very special habitat requirements (31), which may not be fulfilled in early restoration projects. And some species may not tolerate grazing at all (14).

Generally grazing favours xerothermophilous species which do not find suitable conditions in dense abandoned stands (34). However, trampling compressed the soil, especially at the woodland sample plots, which reduced drainage loss, thus favouring wet spots, which was reflected by the occurrence of hygrophilous carabids and spiders (*sensu* 20, 21). Wetland species, including some rare and endangered ones, were also typical for the sample plot in the reed, a habitat which could exist only because it was fenced and grazing pressure was excluded. This example demonstrates that low-density grazing does not enhance species richness in every case. Habitats, dominated by plant species such as reed that are preferably eaten by cattle, may even be destroyed, causing the loss of specific plant communities and the associated fauna (42).

In the case of the stem-infesting insects, damaged *Cirsium* individuals probably favour infestation by insects, and therefore the highest infestation rates are found on the grazed areas where plants are more often damaged. Additionally, the extend of damage of most *Cirsium*-plants is higher where the cattle moves. This may explain the difference in the infestation rate of damaged *Cirsium* on grazed an abandoned plots. However, even the undamaged stems are more frequently infested at the grazed plots. An explanation could be that these stems are not partly covered by the surrounding vegetation due to grazing which makes them more obvious as compared to ungrazed plots. In addition, the more open vegetation structure at grazed plots may offer a micro-climate favouring insects.

The example of stem infesting insects illustrates, that grazing acts as a permanent disturbance in the studied ecosystem. Beneath the creation of new habitat types (e.g. bare ground, lawn, broken stems), disturbance generally decreases interspecific competition and may prevent the extinction of inferior competitors (24) which also favours species richness (7).

However, previous studies demonstrated that the intensity of disturbance is a key factor: Very intensively grazed areas show low biodiversity (4, 10, 13, 16, 22). Van Wingerden et al. (36, 37) proposed a model in which moderate grazing intensity favours habitat diversity and species richness. If the grazing pressure is too high, the habitat diversity decreases again which reduces also the species numbers.

This indicates that management methods that reduce habitat diversity in extensively used grazing areas such as sporadic mowing (which is often practiced by farmers to reduce weeds) or short term high grazing pressure (which exists if the cattle is fenced for short periods on small areas e.g. to avoid selective grazing in endangered plant communities (28) have a negative influence on arthropod diversity.

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Appendix: Tab. 2. Araneae, Carabidae and Staphylinidae recorded on grazed, ungrazed plots and in the *reed along the brook. Species listed in the Red Data book of Bavaria and/or Germany are underlined (Lorenz 2003; Trautner et al. 1998; Bussler & Hofmann 2003; Blick & Muster 2003).*

Spiders	ungrazed	grazed	reed	Ground beetles	ungrazed	grazed	reed	Rove beetles	ungrazed	grazed	reed
Achaearanea simulans	x			*Abax parallelepipedus*	x	x	x	*Aleochara brevipennis*		x	x
Aculepeira ceropegia		x		*Acupalpus flavicollis*		x	x	*Aleocharinae sp.*	x	x	x
Antistea elegans			x	*Agonum afrum*		x	x	*Aloconota insecta*		x	
Araeoncus humilis	x	x		*Agonum fuliginosum*	x	x	x	*Anotylus mutator Lohse*	x		
Araneus diadematus	x	x		*Agonum micans*			x	*Anotylus rugosus*	x	x	x
Araneus marmoreus		x		*Agonum muelleri*		x	x	*Anotylus sculpturatus*	x	x	
Araneus quadratus	x			*Agonum sexpunctatum*	x	x	x	*Anotylus tetracarinatus*	x		
Araniella cucurbitina	x			*Agonum thoreyi*			x	*Arpedium quadrum*	x	x	x
Araniella sp.		x	x	*Agonum viduum*		x	x	*Atheta ravilla cf.*		x	
Arctosa leopardus	x	x	x	*Amara aulica*	x	x		*Bledius erraticus*	x		
Argiope bruennichi		x		*Amara communis*	x			*Bledius opacus*		x	
Bathyphantes approximatus		x		*Amara plebeja*		x		*Carpelimus arcuatus*			x
Bathyphantes gracilis		x	x	*Anisodactylus binotatus*	x	x		*Carpelimus corticinus*		x	x
Batyphantes nigrinus		x		*Asaphidion cf. austriacum*		x		*Carpelimus rivularis*			x
Centromerita bicolor		x		*Badister lacertosus*	x	x		*Chilopora longitarsis*		x	
Centromerus sylvaticus	x	x	x	*Badister sodalis*	x	x	x	*Chilopora rubicunda*			x
Cercidia prominens		x		*Bembidion articulatum*	x	x	x	*Deubelia picina*			x
Clubiona lutescens	x	x		*Bembidion biguttatum*			x	*Dexiogya corticina*	x		
Clubiona phragmitis			x	*Bembidion lampros*			x	*Drusilla canaliculata*	x	x	x
Clubiona stagnatilis	x		x	*Bembidion properans*		x		*Falagria sulcatula*			x
Coelotes terrestris	x	x		*Bembidion tetracolum*		x	x	*Falagria thoracica*	x	x	x
Diaea dorsata		x		*Blemus discus*			x	*Falagris sulcatula*		x	
Dicymbium cf. brevisetosum		x		*Carabus cancellatus*	x	x		*Gabrius pennatus*		x	x
Dicymbium tibiale	x	x		*Carabus coriaceus*	x		x	*Gabrius subnigritulus*		x	
Diplocephalus cristatus	x	x		*Carabus granulatus*	x	x	x	*Gabrius trossulus*	x	x	x
Diplocephalus latifrons	x	x		*Carabus hortensis*	x	x		*Geostiba circellaris*		x	
Diplostyla concolor	x	x	x	*Carabus irregularis*	x			*Gyrohypnus scoticus*	x	x	
Dismodicus bifrons		x	x	*Carabus nemoralis*	x			*Hygropora cunctans cf.*	x		x
Donacochara speciosa			x	*Chlaenius nigricornis*	x	x	x	*Hypostenus cicindeloides*		x	
Drapetisca socialis		x		*Chlaenius vestitus*			x	*Ilyobates propinquus*	x	x	

Drassyllus pusillus	x	x		*Clivina collaris*	x		x	*Ilyobates subopacus*		x	
Enoplognatha ovata	x	x		*Clivina fossor*	x	x	x	*Lathrimaeum atrocephalum*	x	x	
Erigone atra		x	x	*Cychrus caraboides*		x		*Lathrobium castaneipenne*	x	x	x
Erigone dentipalpis	x	x		*Dromius quadrimaculatus*	x			*Lathrobium dilutum*			x
Evarcha arcuata		x		*Dyschirius globosus*	x	x	x	*Lathrobium fovulum*	x		x
Evarcha sp.	x	x		*Elaphrus cupreus*	x	x	x	*Lathrobium impressum*	x		
Gnathonarium dentatum			x	*Epaphius secalis*	x		x	*Lathrobium laevipenne*			x
Helophora insignis	x			*Leistus ferrugineus*		x		*Lathrobium pallidum*			x
Larinioides sp.	x	x	x	*Loricera pilicornis*	x	x	x	*Lathrobium terminatum*		x	
Lepthyphantes cristatus	x	x		*Nebria brevicollis*	x	x	x	*Lathrobium volgense*	x	x	
Lepthyphantes pallidus	x	x		*Notiophilus palustris*	x	x	x	*Lesteva longelytrata*		x	
Lepthyphantes tenuis	x			*Oodes helopiodes*	x	x	x	*Lesteva punctata*			x
Leptorhoptrum robustum		x		*Paranchus albipes*			x	*Liogluta microptera*	x	x	x
Leptyphantes sp.	x	x		*Patrobus atrorufus*		x	x	*Liogluta pagana*	x	x	
Linyphia hortensis	x	x		*Platynus assimilis*	x	x	x	*Neobisnius procerulus*			x
Linyphia triangularis	x	x		*Platynus dorsalis*			x	*Neobisnius villosulus*			x
Mangora acalypha	x	x		*Poecilus cupreus*		x		*Nestus boops*			x
Metellina cf. merianae	x			*Poecilus versicolor*		x		*Nestus canaliculatus*		x	
Metellina mengei	x	x		*Pterostichus anthracinus*	x	x	x	*Nestus humilis*		x	
Metellina segmentata	x	x	x	*Pterostichus melanarius*	x	x		*Ocypus fuscatum*		x	
Micrargus herbigradus	x			*Pterostichus minor*			x	*Ocypus melanarius*	x	x	
Misumenops tricuspidatus	x	x		*Pterostichus niger*	x	x	x	*Olophrum fuscum*			x
Neriene clathrata	x	x		*Pterostichus nigrita*		x	x	*Omalium rivulare*		x	
Neriene montana	x			*Pterostichus nigrita/rhaeticus*	x		x	*Omalium rugatum*	x		
Neriene peltata	x			*Pterostichus oblongopunctatus*	x	x		*Ontholestes haroldi*		x	
Oedothorax agrestis		x		*Pterostichus rhaeticus*		x		*Othius myrmecophilus*		x	
Oedothorax fuscus	x	x	x	*Pterostichus strenuus*	x	x	x	*Othius punctulatus*		x	
Ozyptila praticola		x		*Pterostichus vernalis*		x		*Oxypoda lividipennis*	x	x	
Ozyptila trux	x			*Stomis pumicatus*	x			*Oxytelops tetracarinatus*		x	
Pachygnatha clercki	x	x	x	*Synuchus nivalis*	x			*Paederus schönherri*	x		
Pachygnatha listeri	x	x		*Trechus cf. secalis*	x	x		*Philonthus addendus*	x		
Paidiscura pallens	x			*Trechus obtusus*	x	x	x	*Philonthus atratus*		x	
Pardosa amentata	x	x	x	*Trechus pilisensis*	x			*Philonthus carbonarius*		x	
Pardosa lugubris	x	x	x	*Trechus quadristriatus*		x		*Philonthus cognatus*		x	
Pardosa palustris		x						*Philonthus debilis*			x
Pardosa prativaga	x	x	x					*Philonthus decorus*	x	x	x
Pardosa pullata	x	x						*Philonthus fimetarius.*	x		
Pardosa riparia		x						*Philonthus fumarius)*	x	x	x
Pelecopsis parallela		x						*Philonthus laminatus*	x	x	x
Philodromus sp.	x							*Philonthus mannerheimi*	x	x	
Pirata hygrophilus	x	x	x					*Philonthus rubripennis*			x
Pirata latitans		x	x					*Philonthus splendens*		x	
Pirata piraticus		x	x					*Philonthus tenuicornis*	x	x	
Pisaura mirabilis	x	x						*Pseudocypus fuscatus*		x	
Porrhomma convexum		x						*Quedius curtipennis*	x	x	x
Robertus lividus	x	x						*Quedius fuliginosus*	x	x	x
Robertus neglectus		x						*Quedius maurorufus*			x
Singa hamata		x	x					*Quedius molochinus*		x	
Tetragnatha extensa	x	x	x					*Raphirus maurorufus*	x		x
Tetragnatha montana	x	x						*Rugilus erichsoni*		x	
Tetragnatha pinicola	x	x						*Rugilus rufipes*	x	x	
Theridion impressum								*Scopaeus laevigatus*			x
Theridion varians	x							*Sepedophilus marshami*	x		
Trematocephalus cristatus		x						*Staphylinus erythropterus*		x	
Trochosa ruricola	x	x	x					*Stenus biguttatus*		x	

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Trochosa spinipalpis			x					*Stenus bimaculatus*	x	x	x
Trochosa terricola	x	x						*Stenus boops Ljungh*		x	x
Walckenaeria acuminata		x						*Stenus canaliculatus*		x	x
Xerolycosa miniata		x						*Stenus circularis*		x	
Xysticus bifasciatus								*Stenus humilis*	x	x	x
Xysticus cf. cristatus	x	x						*Stenus juno*		x	
Xysticus kochi		x						*Stenus providus*		x	
Xysticus sp.	x	x	x					*Styloxis rugosus*	x	x	x
Xysticus ulmi	x	x						*Tachinus corticinus*	x	x	
Zelotes latreillei		x						*Tachinus laticollis*	x	x	
Zora spinimana		x						*Tachinus signatus*	x	x	x
								Tachyporus abdominalis			x
								Tachyporus chrysomelinus	x	x	
								Tachyporus formosus	x	x	
								Tachyporus nitidulus		x	
								Tachyporus obtusus		x	
								Tachyusa constricta			x
								Tetartopeus fennicum			x
								Tetartopeus terminatum			x
								Trogopgoeus rivularis			x
								Trogophloeus arcuatus			x
								Trogophloeus corticinus			x
								Trogophloeus dilatatus			x
								Trogophloeus rivularis		x	
								Xantholinus laevigatus	x	x	
								Xantholinus longiventris	x	x	

COLONISATION OF POST-MINING RECULTIVATED AREA BY TERRESTRIAL ISOPODS (ISOPODA: ONISCOIDEA) AND CENTIPEDES (CHILOPODA) IN HUNGARY

J.J. PURGER[1]* – S. FARKAS[2] – L. DÁNYI[3]

[1]*Department of Animal Ecology, Institute of Biology, Faculty of Sciences, University of Pécs, H-7624 Pécs, Ifjúság útja 6, Hungary, Tel:++36-72-503-600 Fax:++36-72-503-634*

[2]*Ecological Research Group, Faculty of Animal Science, University of Kaposvár, H-7400 Kaposvár, Guba S. 40, Hungary Tel:++36-82-314-155 Fax:++36-82-320-167*

[3]*Hungarian Academy of Sciences Research Group for Systematic Zoology, Hungarian Natural History Museum, H-1088 Budapest, Baross Str. 13, Hungary Tel:++36-1-267-70-07/135 Fax++36-1-267-58-88*

e-mail: purger@ttk.pte.hu

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Abstract. In the north-eastern outskirts of town Pécs (south Hungary) colonisation by terrestrial isopods and centipedes were studied in a post-mining recultivated area. During 4 months in 2002 a total of 140 pitfall traps that were positioned in the recultivated area, in the adjoining forest and in the forest edge yielded 289 specimens of 5 Isopoda species, and 250 specimens of 15 Chilopoda species. It is primarily the terrstrial isopod (Ligidium germanicum, Protracheoniscus amoenus, Trachelipus rathkii) and centipede (Lithobius erythrocephalus, L. forficatus, L. mutabilis, L. muticus, L. parietum) species living in the neighbouring forest that visited the recultivated area. Nevertheless, in the seventh year after recultivation, these were not valued as stable terrestrial isopod or centiped communities because of the low specimen and species numbers, and due to the irregularity of their occurrence.
Keywords. *colonisation, recultivated area, Isopoda, Oniscoidea, Chilopoda, Hungary.*

Introduction

In Europe, ecosystems on mine-sites represent a rare example of *de novo* ecosystem development. As expected, it has been found that the biocoenosis of ecosystems on mine-sites does not function entirely differently from comparable ecosystems on adjacent unmined sites. Major differences occur on sites with extreme substrate conditions. However, when these extreme sites are ameliorated chemically and rehabilitated with forest trees, pedogenesis and biocoenosis could be viewed as pointing towards normal development that occurs in comparable but unmined forest areas [12]. Soil-dwelling animals have an outstanding role in colonization and succession processes. The effect of feeding by many species of the soil fauna is to accelerate the decomposition processes as a result of comminution (reduction in organic particle size) or predation [11]. Terrestrial isopod species as decomposers and centipedes as carnivorous organisms appear as early as in the initial stage of colonization [3, 4, 22].

We wanted to find out about the chances of terrestrial isopods and centipedes for settling in the recultivated, forest-fringed recultivated area in the initial years after recultivation and tree-planting. Would the first colonizers be forest-dwellers? Would the settlers be stable colonizers, maybe even communities, or just wandering individuals temporarily sallying outside the forest?

Methods

The study was performed in the north-eastern outskirts of town Pécs (south Hungary) in the post-mining recultivated area bordered from the west by the eastern slopes of Misina (535 m height above s.l.), the southernmost summit of Mecsek Hills. The northern part of the Karolina open-cast coal-mine, covering approximately 15 hectares is recultivated (Fig. 1.). Various tree saplings have been planted since 1996, but the covering layer is overgrown by herbaceous vegetation of the initial stage of primary succession [17, 18]. The recultivated area is bordered from the east, north and west by Turkey Oak forests (*Potentillo micranthae-Quercetum daleschampii* Horvát A.O. 1981).

The pitfall traps were laid out along four transect lines, 120 m long each, in a way that the sample plots overlap with forest as well as with the reultivated area as much as possible. In each of the transect lines 7 plots, spaced 20 m apart, were set up, and 5 pitfall traps installed in each (Fig. 1.), yielding a total of 140 pitfall stations. In the individual trap stations, the 300 cm^3 plastic cups (of 8 cm diameter and 11 cm depth) were positioned to form a 0.5 m radius circle, with 4 vessels placed along the perimeter and one in the centre (Fig. 1.). The cups contained a 7:2:1 ratio mixture of water, 20% acetic acid, and ethylene-glycol. Traps were left to function from 7^{th} May to 7^{th} September 2002. During this time they were checked and emptied 8 times, i.e. at 15.12±3.76 (mean±sd) day intervals. Because of the low number of terrestrial isopods and centipedes, data resulting from the four transects were merged (Table 1.).

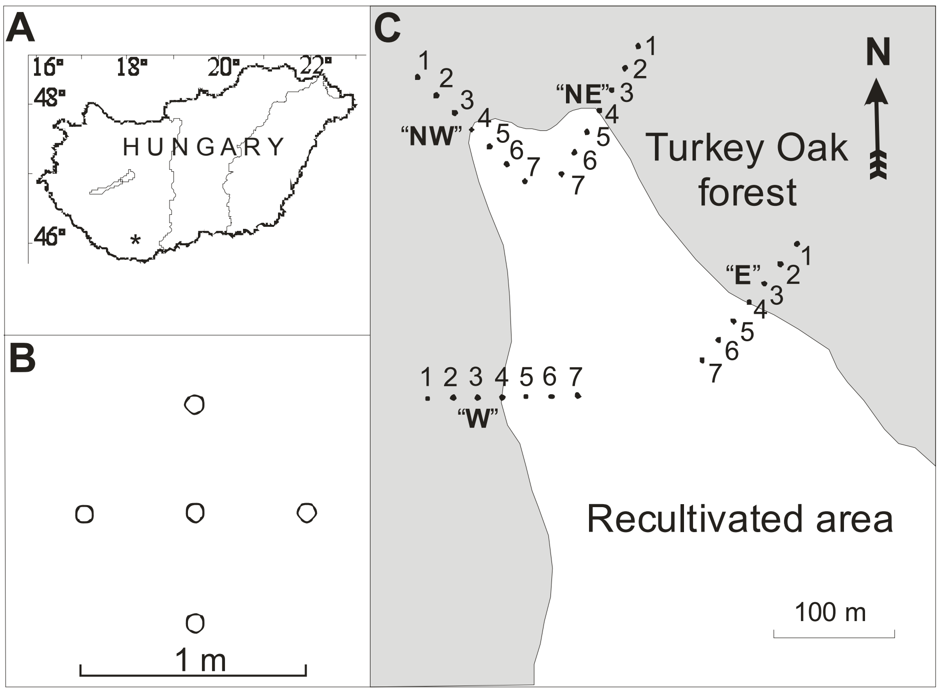

Figure 1. *Location of the study area (*) within Hungary (A); pattern of pitfall traps within trap plots (B); the arrangement of trap plots along the four transect lines (W – western, NW – north-western, NE – north-eastern, E – eastern) (C).*

Table 1. *Capture data in the 7 trapping plots. The naming and listing order of terrestrial isopods and chilopods is according to* SCHMALFUSS *[19] and* DÁNYI *[1].*

Habitat	Turkey Oak forest			Edge	Recultivated area			Total
Trap plots No.	1	2	3	4	5	6	7	7
Isopoda								
Ligidium germanicum	0	1	1	12	1	0	0	15
Lepidoniscus minutus	0	0	1	0	0	0	0	1
Porcellium collicola	0	1	0	0	0	0	0	1
Protracheoniscus politus	34	85	65	23	0	1	0	208
Trachelipus rathkii	16	17	8	21	1	1	0	64
Total	50	104	75	56	2	2	0	289
Chilopoda								
Lithobius agilis	0	0	2	1	0	0	0	3
Lithobius dentatus	2	3	3	0	0	0	0	8
Lithobius erythrocephalus	1	0	1	3	3	2	0	10
Lithobius forficatus	8	10	12	16	1	2	1	50
Lithobius melanops	0	0	0	1	0	0	0	1
Lithobius mutabilis	1	1	1	6	1	1	0	11
Lithobius muticus	20	39	19	27	1	0	0	106
Lithobius nodulipes	0	1	0	0	0	0	0	1
Lithobius parietum	3	2	4	7	1	1	0	18
Lithobius sp.	6	3	1	5	0	0	0	15
Eupolybothrus transsylvanicus	2	2	5	8	0	0	0	17
Eupolybothrus tridentinus	0	0	0	1	0	0	0	1
Cryptops anomalans	1	0	2	3	0	0	0	6
Cryptops parisi	0	0	1	0	0	0	0	1
Strigamia acuminata	1	0	0	0	0	0	0	1
Strigamia transsilvanica	0	0	1	0	0	0	0	1
Total	45	61	52	78	7	6	1	250

Results and Discussion

The number of terrestrial isopod (289) and centipede (250) specimens caught by the 140 traps was similar (χ^2 = 2.82, df = 1, NS) (Table 1.). The low number of the decomposer arthropods was due to the infavourable habitat conditions and the low effectiveness of traps. The relatively high number of carnivorous arthropods, on the other hand, could be caused by the fact that these organisms prey also on other species in addition to terrestrial isopods, and therefore can reach higher species and specimen numbers. The number of centiped species (15) was three times higher than that of terrestrial isopod species (5).

The number of terrestrial isopods caught inside the forest and in the forest edge (1-4) were significantly different (χ^2 = 24.85, df = 3, P < 0.001) (Table 1.). Difference between the effectiveness of traps in various plots may be due to the sloping of the area (descending from plot 1 towards plot 4), and to the uneven distribution of leaf litter on the ground. The comparison of specimen numbers of centipedes in the four plots was, also, different (χ^2 = 10.34, df = 3, P < 0.05) (Table 1.). These carnivorous arthropods seemed to prefer the edge zone. Traps positioned inside the recultivated area (plots 5-7) yielded only 1.4% of total captured terrestrial isopods and only 5.6% of total captured centipedes.

There are 32 terrestrial isopod species known to occur in Mecsek Hills [6, 7, Farkas and Vilisics, unpublished data], of which only 5 (15.6%) were recorded in our study area. In the recultivated area, however, it was possible to capture only those speces that were found to be common inside the forest (*P. politus, T. rathkii*) or in the forest edge (*L. germanicum*). Single specimens of *L. minutus* and *P. collicola*, respectively, were revealed from traps inside the forest.

There are 28 centipede species known to occur in Mecsek Hills [2], of which 15 (53.6%) were recorded in our study area. *Lithobius muticus* was found to be the commonest (42%), yet only one specimen occurred in the recultivated area. Individuals of the second commonest (20%) species (*L. forficatus*), however, made it to even the furthest parts of the recultivated area (Table 1.) Beside these species, only 5 specimens of *L. erythrocephalus*, 2 *L. mutabilis* and 2 *L. parietum* were collected in the recultivated area (Table 1.). Although *Eupolybothrus transsylvanicus* was found only in the forest and the forest edge, this species deserves special attention, because it has not been collected in Mecsek Hills since the studies by Loksa [13] [2].

Our results suggest that the terrestrial isopod *T. rathkii* and the centipede *L. forficatus* may be one of the first colonizer species not only in mine areas [3, 4, 22, 23], but also in recultivated areas. Initial settler species, however, might not come from the nearby forest only. Individuals belonging to species that tolerate less favourable habitat conditions may also appear. This assumption is supported by the fact that in a survey made in 2003 yet another terrestrial isopod (*Trachelipus nodulosus*) was revealed (our unpublished data). *T. nodulosus* occurs primarily in warm and dry habitats; in Mecsek Hills it is a dominant species of south-facing karst shrubby forests [14].

In the recultivation of spoil banks in Visonta (Hungary), plant coverages of up 100 percent were observed by the second year [21]. Similarly, rapid vegetation sucession was observed in the northern recultivated area of Karolina-pit [18], but this was not followed by an immediate colonization by terrestrial isopod and centiped species. Due to their poor quality, low nutritive value and high silicate content, the monocotyledon plants dominating the recultivated area are much less suitable for terrestrial isopods than the high quality food patches of dicotyledonous leaf litter [9, 10] found inside the forest. Moreover, predation pressure (by centipedes, spiders, carabid beetles, amphibians, reptiles, birds and small mammals) is probably stronger in the exposed area with poorer leaf litter cover [16]. Increase in plant-species diversity or structural diversity are often correlated with an increase in species richness of animals [20]. The recultivated area was not favourable for centipedes either. Grgić and Kos [8] investigated the influence of forest development phase on centipede diversity and found the highest species number and abundance in the juvenile phase and the lowest in the deforested area. Also the composition of the centipede community was more sensitive to the successional status of the forest than to the season [8]. In the seventh year after the recultivation of the study area there is no stable terrestrial isopod or centipede community, as concluded from the low species and specimen numbers, and the irregular occurrences. In order for the colonization process to be succesfully followed [5, 15] and for the date of successful completion of recultivation to be estimated, long-term monitoring is essential.

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THE RHIZOSPHERE EFFECT IN TREES OF THE INDIAN CENTRAL HIMALAYA WITH SPECIAL REFERENCE TO ALTITUDE

ANITA PANDEY*[1]-LOK MAN S. PALNI[2]

[1]*Environmental Physiology and Biotechnology, G. B. Pant Institute of Himalayan Environment and Development, Kosi-Katarmal, Almora, 263 643, Uttaranchal, India*

[2] *(Present address): State Biotechnology Programme, Govt. of Uttaranchal, Biotech Bhavan, P.O. Haldi (Pantnagar)- 263 146, U S Nagar. Uttaranchal, India*

**Corresponding author: Anita Pandey: Environmental Physiology and Biotechnology, G. B. Pant Institute of Himalayan Environment and Development, Kosi-Katarmal, Almora, 263 643, Uttaranchal, India*

e-mail: pandeyanita1@rediffmail.com

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Abstract. The present paper deals with the rhizosphere effect exerted on the microbial communities by ten representative and important tree species of the Indian Himalayan region. The study covered a wide altitudinal range (1200 to 3610 m above mean sea level) representing subtropical to subalpine climatic conditions. The rhizosphere to soil (R:S) ratio was found to range from 0.2 to 3.5, 0.3 to 2.9, and 0.3 to 3.4, for bacteria, actinomycetes and fungi, respectively. Barring a few exceptions, generally the tree species of subtropical and temperate regions exerted a slight stimulatory effect on the rhizosphere microorganisms. Coniferous species of the subtropical and temperate locations viz., Cedrus, Pinus and Taxus supported relatively higher microbial population in the rhizosphere in comparison to other species. Abies pindrow (a conifer), Betula utilis, and Rhododendron campanulatum, species of the subalpine region were found to exert a distinct negative rhizosphere effect. The negative rhizosphere effect coincided with lowering of the soil pH in the rhizosphere region.

Keywords: *rhizosphere, R : S ratio, Himalayan trees, soil microbes, soil pH.*

Introduction

Plant roots exert strong influence on the soil microbial populations; the term 'rhizosphere' was introduced by Hiltner in 1904 to denote the region of the soil that is subjected to the influence of plant roots [10]. In general the microbes that inhabit the rhizosphere serve as an intermediary between the plant, which requires soluble inorganic nutrients, and the soil, which contains the necessary nutrients but mostly in complex and inaccessible forms. Rhizosphere microorganisms thus provide a critical link between plant and soil environments. The magnitude of the rhizosphere effect depends mainly on the nature and amount of root exudates which appear to be related to plant age as well as species on one hand and edaphic and climatic factors on the other. The influence of individual plants is reflected in the rhizosphere as the R:S (rhizosphere to non rhizosphere ratio). For bacteria and fungi values commonly range from 5 to 20. Actinomycetes, a somewhat less affected group of microorganisms by the rhizosphere, may reveal R:S ratios between 2 to 12. Literature on various aspects of rhizosphere focusing on plant-microbe interactions or faunal-microbial interactions is extensive [5,8,15,23,28,29,32,34].

The rhizosphere studies conducted so far, including those on rhizosphere effect and root exudation in particular, are largely based on short duration species [9,26,31, 33].

Experiments have also been carried out under artificial conditions or simplified systems, such as hydroponic cultures with single plant species [1,23]. Only a limited number of reports exist on the rhizosphere effect in long duration plants or trees [6,7,11,14,18,24]. The present study was carried out to examine the rhizosphere effect in ten ecologically as well as economically important trees of the Kumaun region of Indian Central Himalaya, covering an altitudinal range from 1200 m to 3610 m amsl (above mean sea level), representing subtropical, temperate and subalpine zones.

Materials and methods

Study site and collection of soil samples

Samples, both from the rhizosphere and non-rhizosphere soils, were collected for all the plant species, from different altitudes in Kumaun Himalaya during the month of October. All the samplings were done in triplicates. Based on the altitude, the regions fall within the subtropical (1200 to 1800 m amsl); temperate (1800 to 2800 m amsl); and subalpine (2800 to 3800 m amsl) zones. The general account of tree species selected for the study, based on Osmaston (1978) [17], is summarized in Table 1. In case of rhizosphere sample, soil adhering to the plant roots was collected after removing the top litter layer (5-10 cm). The soil then was collected aseptically from the next 5-15 cm portion along the length of the root and placed in sterilized bags. For each sampling, the soil was taken at least from three points within the rhizosphere of the same plant and mixed. This represented one sample. Following this method, the soil samples were collected from three different plants (triplicates) for each species, from all the altitudes, separately. Non-rhizosphere soil sample (control), corresponding to each rhizosphere soil sample was collected, well away from roots of the respective plant species. In case of *Betula utilis* and *Rhododendron campanulatum* (3040 m amsl), the soil samples were collected from the mixed forest sites where the two species were growing in close proximity, with their roots intermingled. For all the species under study, soil samples were collected from 2 or 3 different altitudes.

Enumeration of microorganisms

Analyses of three groups of microorganisms, namely bacteria, actinomycetes and fungi were carried out on the basis of serial 10-fold dilutions- pour plate method, in duplicate, using triplicate samples (1g soil) and appropriate dilutions [12]; each value presented here is therefore an average of six individual counts. The method is known to provide valuable information while estimating comparative microbial populations [5]. All petridishes (90 mm dia; 25 ml medium) were incubated at 21 °C in the dark. Colony forming units (CFUs) were recorded ten days after incubation; the average number of CFUs per gram oven dry weight of soil was calculated as: CFU = Counts on the culture

Table 1: *General description of the ten plant species investigated in the present study * Name of the concerned district in the state of Uttaranchal, India is given in the parantheses*

Plant species	**Family**	**Local name**	**Angiosperm/ Gymnosperm**	**Deciduous/ Evergreen**	**Elevation (m)**	**Climate**	**Location***
Abies pindrow Spach.	Pinaceae	Raga	Gymnosperm	Evergreen	2900 3260 3500	subalpine subalpine subalpine	Himtoli (Pithoragarh) Nagling (Pithoragarh) Latakharak (Chamoli)
Aesculus indica Colebr ex Camb.	Hippocastanaceae	Pangar	Angiosperm	Deciduous	2200 2260	temperate temperate	Khati (Bageshwar) Sela (Pithoragarh)
Alnus nepalensis Don	Betulaceae	Utees	Angiosperm	Deciduous	1200 1880	subtropical temperate	Syalidhar (Almora) Tejam Pithoragarh
Betula utilis Don	Betulaceae	Bhojpatra	Angiosperm	Deciduous	3040 3100 3610	subalpine subalpine subalpine	Golphur (Pithoragah) Dugtu (Pithoragarh) Phurkiya (Bageshwar)
Cedrus deodara (Roxb.)	Pinaceae	Deodar	Gymnosperm	Evergreen	1250 1855	subtropical temperate	Hawalbag (Almora) Jageshwar (Almora)
Pinus rouxburghii Sarg.	Pinaceae	Chir	Gymnosperm	Evergreen	1920 2020	temperate temperate	Jageshwar (Almora) Jageshwar (Almora)
P. wallichiana Jackson	Pinaceae	Kail	Gymnosperm	Evergreen	2800	temperate	Chaugla (Pithoragarh)
Quercus semecarpifolia Sm.	Fagaceae	Kharsu	Angiosperm	Evergreen	1800 2100	temperate temperate	Sela (Pithoragarh) Kilbari (Nainital)
Rhododendron campanulatum Don	Ericaceae	Senru	Angiosperm	Evergreen	3040 3190	subalpine subalpine	Golphur (Pithoragarh) Phurkiya (Bageshwar)
Taxus baccata L. sub sp. *wallichiana* (Zucc.) Pilger	Taxaceae	Thuner,	Gymnosperm	Evergreen	1855 2400 2960	temperate temperate subalpine	Jageshwar (Almora) Eskmoru

plate x fresh weight of soil / oven dry weight of soil. A numerical value for the rhizosphere: soil (non-rhizosphere) ratio (R:S ratio) [13] of microbial counts was represented by letters (a-i) to represent p values of <0.001 (a), <0.005 (b), <0.010 (c), <0.025 (d), <0.050 (e), <0.100 (f), <0.200 (g), <0.400 (h), and < 0.500 (i).

The media (Hi Media, Bombay, India) used for microbial analyses were: (1) Nutrient agar for bacteria (5g tryptone, 2.5g yeast extract, 1g dextrose, 15g agar; volume made up to 1litre with distilled water), (2) Caseinate-asparagine agar for actinomycetes (2g sodium caseinate, 0.1g asparagine, 4g sodium propionate, 0.5g dipotassium phosphate, 0.1g magnesium sulphate, 0.001g ferrous sulphate, 15g agar; volume made up to 1litre with distilled water), and (3) potato dextrose agar for fungi (potato infusion from 200g, 20g dextrose, 15g agar; with volume made up to 1litre with distilled water).

Preliminary observations on the microbial isolates

The representative colonies of bacteria, actinomycetes and fungi were isolated and purified from the soil dilution plates by repeated subculturing until pure individual cultures were obtained. The isolates were identified up to the group or genus level using standard morphological, microscopic, cultural, and biochemical methods.

Results

The rhizosphere effect in the ten Himalayan trees examined in this study would seem to vary at the level of the species as well as the altitude. The rhizosphere of plants of the subtropical region was found to exert a stimulatory effect on the soil microbes. In case of *Alnus nepalensis* (1200 m elevation), stimulatory effect was observed on the microbial population, and the same was highly significant in case of bacteria ($P<0.001$). This could be clearly seen in terms of R:S ratio, the values being 3.5, 2.4 and 2.8 for bacteria, actinomycetes and fungi, respectively. The stimulatory effect would appear to decline with the elevation (1880 m); furthermore, an inhibitory effect was seen on the bacterial population ($P <0.500$). While a decline in the populations of actinomycetes and fungi, both for the rhizosphere and non-rhizosphere soils, was recorded, the R:S ratios were close to one (*Fig.1A, Table2*). The microbial population of the rhizosphere soil of *Quercus semecarpifolia* and *Aesculus indica*, representatives of the temperate zone, was quite high. While in case of *Q. semecarpifolia*, the microbial population as well as R:S ratio registered a decline with increasing elevation, a positive rhizosphere effect was, however, seen at both the elevations (*Fig. 1B, Table 2*). The two sampling sites of *Aesculus indica* were fairly close (2200 and 2260 m) and, the R:S ratio was found to range from 1.2 (fungi) to 2.5 (bacteria) (*Fig. 1C; Table 2*).

The microbial population of rhizosphere and bulk soil and the R:S ratio of five coniferous species studied, viz. *Cedrus deodara*, *Pinus roxburghii*, *P. wallichiana, Taxus baccata*, and *Abies pindrow* are presented in *Figures 1D-G*, and *Table 2*. The bacterial population in the rhizosphere soil of *Cedrus deodara* was significantly higher than that of the corresponding non-rhizosphere soil ($P<0.001$) at 1250 m. The rhizospheric stimulation declined for bacteria and actinomycetes at 1855 m elevation.
However, the R:S ratio of fungi increased from 2.2 to 3.4. In case of both *Pinus Table 2:* R:S ratios of three groups of microorganisms and soil pH in respect of selected ten plant species species, a suppressive effect was seen in some instances. *P. wallichiana* exerted

Table 2: *R:S ratios of three groups of microorganisms and soil pH in respect of selected ten plant species*

Plant species	**Elevation (m) amsl**	**Soil pH**		**R:S ratio**		
		Rhizosphere	**Non rhizosphere**	**Bacteria**	***Actinomycetes***	**Fungi**
Abies pindrow	2900	5.7	6.3 (-0.6)	0.7	0.7	1.1
	3260	4.8	5.5 (-0.7)	0.4	0.4	1.3
	3500	4.7	5.6 (-0.9)	0.3	0.4	0.8
Aesculus indica	2200	6.5	6.6 (-0.1)	2.5	2.4	2.0
	2260	6.3	6.5 (-0.2)	1.9	2.3	1.2
Alnus nepalensis	1200	6.4	6.4 (-0.0)	3.5	2.4	2.8
	1880	6.1	6.3 (-0.2)	0.8	1.2	1.1
Betula utilis	3100	4.6	5.5 (-0.9)	0.3	0.5	0.8
	3610	4.7	5.3 (-0.6)	0.4	0.5	0.9
*B. utilis+Rhododendron campanulatum**	3040	4.6	5.4 (-0.8)	0.2	0.3	0.3
Cedrus deodara	1250	6.6	6.7 (-0.1)	2.6	2.3	2.2
	1855	5.9	6.1 (-0.2)	1.3	1.5	3.4
Pinus rouxburghii	1920	5.6	5.9 (-0.3)	1.1	0.9	2.8
	2020	6.1	6.3 (-0.2)	1.1	1.2	1.3
P. wallichiana	2800	5.4	5.5 (-0.1)	0.7	0.9	2.1
Quercus semecarpifolia	1800	6.6	6.3 (+0.3)	1.9	2.2	3.1
	2100	6.3	6.1 (+0.2)	1.3	1.9	1.9
Rhododendron campanulatum	3190	5.6	6.5 (-0.9)	0.4	0.3	0.7
Taxus baccata	1855	6.3	6.4 (-0.1)	3.3	2.9	3.1
	2400	6.3	6.4 (-0.1)	2.2	2.1	2.5
	2960	5.4	5.3 (+0.1)	1.9	1.6	2.0

R = rhizosphere soil; S = non-rhizosphere soil; values within parentheses indicate difference in the pH of rhizosphere soil over non-rhizosphere soil; amsl = above mean sea level

** At this site the roots of these two species were found to be highly intermingled.*

inhibitory influence on the bacterial and actinomycetes populations at 2800 m elevation (*Fig. 1E; Table 2*). However, microbial population of the rhizosphere of *Taxus baccata* was stimulated at all three elevations, and the R:S ratios declined by increasing altitude (*Fig. 1F; Table 2*).

Distinct suppressive effect on the rhizospheric microbial population was seen in *Abies pindrow*, a conifer of the subalpine region; it was particularly pronounced in case of bacteria and actinomycetes as shown by R:S ratios. The suppressive effect increased with elevation; the ratios recorded were: 0.7, 0.4, and 0.3 for bacteria and 0.7, 0.4 and 0.4 for actinomycetes, at 2900, 3260 and 3500 m elevation, respectively (*Fig.1G; Table 2*).

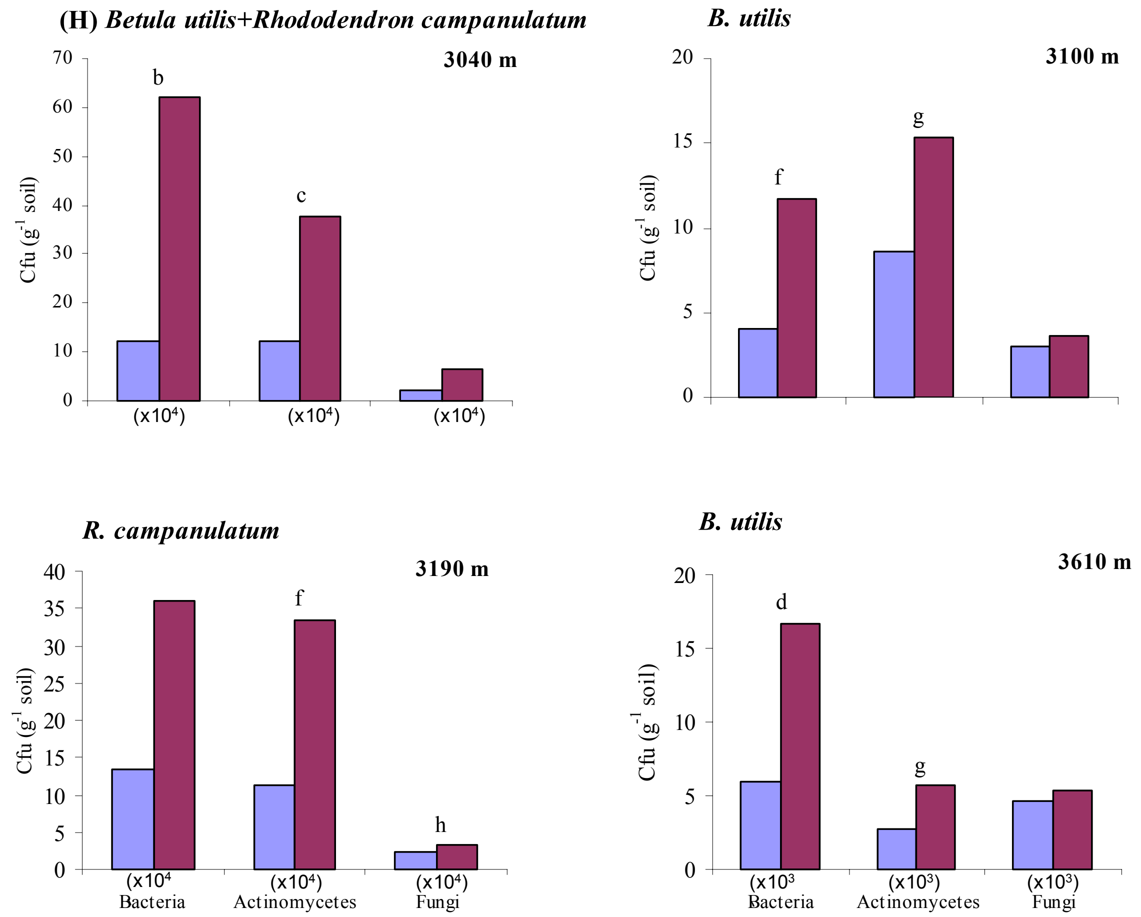

Figure 1. *(A-H). Microbial populations of three groups of microorganisms in the rhizosphere and the corresponding non- rhizosphere soil samples of various trees. Letters a-i represent p values of <0.001 (a), <0.005 (b), <0.010 (c), <0.025 (d), <0.050 (e), <0.100 (f), <0.200 (g), <0.400 (h), and < 0.500 (i).*

Betula utilis and *Rhododendron campanulatum* (both subalpine plants) also exerted a suppressive effect on the microbial communities in the rhizosphere. Significant inhibition of bacteria and actinomycetes was found in *Betula utilis*; R:S ratios did not change much with change in the altitude. A similar trend was observed also in the case of *Rhododendron campanulatum*. Even lower R:S ratios were obtained from regions where the roots of *Betula utilis* and *Rhododendron campanulatum* were found to be entangled (*Fig. 1H; Table 2*).

Lowering in the pH of rhizosphere soil over the corresponding non-rhizosphere soil samples (0.6 to 0.9 units) was recorded in case of *Abies pindrow*, *Betula utilis* and *Rhododendron campanulatum* (*Table 2*).

On the basis of preliminary identification of representative colonies from the rhizosphere as well as non-rhizosphere soil samples in this study, the bacterial population was found to largely comprise species of *Bacillus*, *Flavobacterium*, *Micrococcus, Pseudomonas, Rhodococcus, Serratia, Xanthomonas,* and some other pigmented bacteria (data not presented). Similarly the fungal population was mainly represented by species of *Aspergillus, Cladosporium, Fusarium, Penicillium*, *Paecilomyces*, and *Trichoderma.* Actinomycetes were mainly dominated by species of *Streptomyces*.

Discussion

The classical concept of rhizosphere effect is based on the stimulation of microbial populations, at times fairly intense, in the region adjacent to the roots, as against the bulk soil. This has been based on the results of research conducted largely on short duration plants and only a few tree species. Rhizosphere : soil ratios between 100 and 400 have been reported for genge (*Astragalus sinicus* L.;), a legume where R:S ratios of 24.3, 5.5, 5.9, 3.3, 3.6, and 5.9 for bacteria have been reported for red clover, flax, oats, maize, barley, and wheat, respectively [27]. Ivarson and Katznelson (1960) reported R:S ratios between 8-10 for yellow birch [11]. In this study observations on the rhizosphere effect of ten trees of the Himalayan region have been described. The serial dilution plate count technique has been used throughout this investigation to maintain methodological consistency. The important findings of the present study are: (1) in general, the microbial population and the corresponding R:S ratio in long duration plants, e.g., perennial trees as in this case, are considerably lower in comparison to short duration species, e.g., annual crops, (2) the microbial population and the rhizosphere effect would appear to decrease by increasing the altitude, and (3) under cold and harsh climatic conditions of the subalpines, the tree root exudates tend to become more acidic, and exert a negative influence on the microbial population. It was considered that the rhizoflora of long lived plant species experiencing hard climatic conditions, such as low temperatures, heavy rainfalls and snow falls (e.g., temperate and subalpine climates), might go through various successions due to various biotic and abiotic pressures, resulting in dominance of selected microbial communities or populations. Occurrence of negative rhizosphere effect exerted by the established tea bushes in contrast to the normal stimulatory effect exhibited by the young tea bushes and development of a specialized microflora has been reported [18]. These studies were conducted on tea rhizosphere of young to established (4 to 123 years old) tea bushes, growing in temperate locations representing monsoonal and occasionally experiencing snow falls, of the Indian Himalayan region [21].

The influence of a particular plant species on the rhizospheric microbial population is conveniently illustrated by comparing the values for R:S ratio, which was found to range from 0.2 to 3.5 for bacteria, 0.3 to 2.9 for actinomycetes, and 0.3 to 3.4 in case of fungi, based on a total of ten tree species. Barring a few exceptions, the trees of sub tropical and temperate regions exerted a slight stimulatory effect on the rhizospheric microorganisms. Conifers of the sub tropical and temperate locations, namely *Cedrus*, *Pinus* and *Taxus* supported relatively higher microbial population in the rhizosphere in comparison to non-coniferous species. *Abies pindrow* (a conifer of subalpine region) exerted a distinct negative rhizosphere effect. Similarly two other species of the subalpine region, *Betula* and *Rhododendron,* also exerted suppressive effect on the rhizospheric communities.

The microbial population would appear to decrease with a concomitant increase in the altitude. This is clearly indicated by the values recorded for the population density, in a decreasing order, from 10^6 (subtropical regions) to 10^3 cells g^{-1} soil (alpine regions). The trend was similar for bacteria and actinomycetes, and the values were a little lower, i.e., 10^5 to 10^3 cells g^{-1} in case of fungi. Likewise the rhizosphere effect was also found to be influenced by change in the altitude. The values for R:S ratio in many of the studied plants were found to decrease from sub tropical to temperate location, and in fact negative values were recorded in most samples of the subalpine region. In a recent study from Sikkim Himalaya (1200 m to 1900 m amsl) microbial population was also reported to decrease with increasing altitude [20].

The rhizosphere effect is affected by many factors, like the quantity and quality of root exudates secreted by a particular plant species, in addition to prevailing edaphic and climatic conditions. The effect of root exudates on the soil microflora of the rhizosphere is likely to be more intense, stimulatory or inhibitory, in case of trees, as influenced by the age of the tree. In fact, a tree rhizosphere is likely to develop a microenvironment continuously under the effect of the root exudates, soil characteristics and climatic factors, giving an opportunity for development of a specialized rhizoflora. The inhibitory effect on microbial populations reported in respect of established tea bushes was found to be correlated with the nature of root exudates, greater antagonistic activity, and lowering of the soil pH in the rhizosphere [19,22]. In the present study, interestingly, wherever an inhibitory effect on the rhizosphere microbes was observed, a concomitant decrease in the pH of rhizosphere soil was also recorded. This was particularly prominent in case of *Abies pindrow*, *Betula utilis* and *Rhododendron campanulatum*, important members of the subalpine vegetation. The root exudates in such cases may contain metabolites that might have suppressive effect on the rhizospheric microbial population.

Soil-chemical changes related to the release of organic and inorganic compounds, and the respective products of their microbial metabolism are important factors affecting microbial populations, availability of nutrients, solubility of toxic elements in the rhizosphere, and thereby the ability of plants to cope with adverse soil-chemical conditions. Organic compounds in root exudates are continuously metabolised by root-associated microorganisms and in the rhizosphere. Quantitative and qualitative alterations of the root exudates composition occur due to the degradation of exudate compounds and the release of microbial metabolites. Mobilization of micronutrients or heavy metals in the rhizosphere has been also related to rhizosphere acidification and to complexities with organic acids in root exudates [16,23,32].

Although the focus of the present study was on the rhizosphere effect caused by ten Himalayan tree species on three important free living groups of microorganisms (bacteria, fungi, and actinomycetes) with special reference to the altitude, observations on other related biotic as well as abiotic aspects were also given due importance and are being studied separately. For example, in view of the importance of selection pressures causing the morphological divergence of roots with different types of mycorrhizas [2], detailed studies are being conducted on the mycorrhizal status of these species [3,4]. Similarly amongst the abiotic factors, soil pH as a single factor has been given importance affecting the soil microflora. Observations on other parameters of the soil samples have also been worked out in a separate study. While dominance of sand particles and almost similar moisture content was recorded in all the soil samples, a declining trend in the organic carbon content and no definite trend in nitrogen content were recorded. It was concluded that the soil characteristics were more influenced by the composition of the forest than to the elevation [25].

During the present study, a large number of bacteria, actinomycetes and fungi have been isolated from both the rhizosphere as well as non-rhizosphere soils; further investigations are in progress to understand the microbial diversity of colder regions, including the rhizospheric communities. These long term studies, and characterization of selected microbes will help in screening potentially beneficial microbes, especially the psychrotrophs, for biotechnological applications.

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THE HOURLY DISTRIBUTION OF MOTH SPECIES CAUGHT BY A LIGHT-TRAP

L. NOWINSZKY * [1] - Z. MÉSZÁROS [2] - J. PUSKÁS [1]

[1] *Berzsenyi Dániel College, H-9701 Szombathely, Károlyi Gáspár Square 4, Hungary (phone: +36-94-504-357)*

[2] *Corvinus University of Budapest, Department of Entomology, H-1118 Budapest, Ménesi Str. 44, Hungary*

e-mail: nlaszlo@bdtf.hu

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Abstract. The present study discusses the hourly distributions of Macolepidoptera and Microlepidoptera species caught by a light-trap. The fractional type mercury vapour (125 W) light-trap had been operated by Mészáros, at Julianna-farm of the Plant Protection Institute between 1976 August and 1979 July. This trap was not in operation every night in this period, only periodically. It was in work during 57 nights in total. We summarized all caught specimen of all species hourly. In this way, we examined data of 66 species. We calculated percentages from hourly-totalized specimen number. We made a comparison between nightly distributions in caught species activity and Tshernishev's activity types.
Keywords: *: Lepidoptera, fractional catching, flying activity*

Introduction and survey of literature

The question of the distribution of the catch by light-trap in the course of a night has been a subject of research for several decades. Williams [1] used a fractionating light-trap in four years of examining flight activity as it was changing over the night. A glass-replacing device separated the catch into eight groups. Always adapted to the time of sunset and sunrise, the duration of light trapping varied. Accordingly, the periods of the individual phase of collecting also showed differences, but the fourth period always ended at midnight.

His sum total has revealed that he caught the largest number of insects in the first phase and the smallest in the seventh. Lepidoptera species flew to light in the highest number in the second, fifth and eight phases. However, the time of flight activity of nocturnal insects varies by species (Steward and Lam, [2], Hitchen et al., [3]).

There is significant difference among active flight periods of species even from the same family, according to the results of examinations (Wallner et al., [4]) in the near eastern part of Russia. According to these examinations the highest activity periods of moths are the following: gypsy moth (Lymantria dispar L.) between 11 p.m. and 1 a.m. The black arches (Lymantria monacha L.) between 3 a.m. and 5 a.m. and rosy gypsy moth (Lymantria mathura Moore) between 1 a.m. and 3 a.m. Ambrus and Csóka [5] determined that there is a difference in the light-trap periods of the two sexes of pine moth (Dendrolimus pini L.). The males fly to the light also during late night but females rather in the first part of the night to 22 and 23 hours. There is a relationship between activity and flight to light.

Tshernishev [6] claims that the flight activity of each species follows a special daily rhythm that usually corresponds to the time of flying to light. From this point of view, he establishes four basic types of insects:

- Flight of short duration tied exclusively to twilight, can never be observed by night (most Ephemeroptera, Corixida, Coleoptera, Diptera and Hepialida species),
- Species of a flight of longer duration. They start their flight later, reaching the peak in the evening. Some species fly all night (Trichoptera, Chironomida and a few east-African Ephemeroptera species),
- Intensive flight from sunset to close on sunrise, not letting up during the night (Tripuloidea and Ephemeroptera species),
- Typical night flight with a well discernible nocturnal peak (Ophionina, Lepidoptera, especially the species of Noctuidae and Brown chafer (Serica brunnea L.).

In the same work, the author lays down for a number of insect orders and for some significant species, the values of illumination expressed in lux characterizing the beginning and the peak of the activity. The activity of most Lepidoptera species increases from 0.01 lux to 0.001 lux but decreases by illumination below that value.

Járfás et al. made examinations in Hungary with fractional light-trap to determine the flight to the light of some harmful moths during night. They published the results in different years. We show these published results in Table 1.

In this present study, we show the flight activity of not only the significant harmful moths, but also the flight of those species, which can not be known in any publication in the Hungarian and international literature.

Material and method

A fractional type mercury vapour (125 W) light-trap was in work, operated by Mészáros, at Julianna-farm of the Plant Protection Institute between 1976 August and 1979 July. This trap was not in operation every night, but only periodically. It was in work during 57 nights. The working period was 12 hours in spring, summer and the beginning of autumn from 5 p.m. until 5 a.m., but from the second part of October between 4 p.m. and 4 a.m. (UT). Mészáros identified all Macrolepidoptera species and the harmful Microlepidoptera ones from the caught insect material. We used this data in this study.

We summarized hourly all caught specimen of all species. We did not examine later those species which number was 5 or less. In this way, we examined data of 66 species. We calculated percentages from the total hourly specimen number. We made comparison between nightly distributions in caught species activity and Tshernishev's activity types when the specimen number was high.

Results

The percentages of hourly caught specimen number of examined species are shown in Table 2. For each species, the total trapped individual number and the number of those nights when these species were caught by the light-trap is shown.

Discussion

The nightly activity of Macrolepidoptera species, except one, belongs to the 4th Tshernishev type. Types 1 and 2 do not occur. It is striking, although these species fly to the light during all night, light-traps did not catch before 7 p.m. in none of the months. Generally, the swarming peak can be found between 9 p.m. and midnight.

The activity types of Macrolepidoptera species belong to type 2 and 4. The frequency is almost the same in these types. Type 3 is infrequent, and type 1 can not be found as well.

There are differences between Tshernishev's types and type 3 and 4, because we found 2-2 activity peaks in the first part of the night or rather during the whole night (3a and 4a).

Table 2 shows those species, of which more than 5 individuals were caught, but their number was insufficient to determine nightly distribution. We also publish these results, because they prove that these species are active during the period.

Table 1. *The hourly distribution (%) of harmful moth species caught by light-trap according to Járfás et al.*

Species/hours	18-19	19-20	20-21	21-22	22-23	23-24	0-1	1-2	2-3	3-4	References
Hyponomeuta spp.	3,3	6,1	15,0	19,0	14,9	17,2	12,4	8,1	2,4	1,6	Járfás [7]
Pandemis dumetana Tr.	5,5	19,3	23,8	16,4	8,9	6,7	5,3	5,1	6,1	2,9	Járfás [7]
Pandemis heparana Schiff.	19,4	14,4	17,1	14,7	14,5	7,2	5,1	3,5	1,6	2,5	Járfás [7]
Pandemis ribeana Hbn.	8,8	6,0	17,6	23,5	6,0	8,8	14,7	8,8	2,9	2,9	Járfás [7]
Adoxophyes reticulana Hbn	8,1	6,4	7,2	5,2	7,8	15,1	17,7	15,7	12,2	4,6	Járfás [7]
Laspeyresia pomonella L.	5,3	8,9	15,6	14,0	14,5	14,2	11,1	8,2	4,6	3,6	Járfás [9]
Ostrinia nubilalis Hbn.	6,3	8,4	14,6	16,3	14,1	11,0	10,3	9,2	6,2	3,6	Járfás [8]
Loxostege sticticalis L.	4,0	8,6	10,0	15,0	10,9	12,2	12,0	10,3	8,0	9,0	Járfás and Viola [12]
Hyphantria cunea Drury	5,4	7,6	9,1	9,4	10,1	10,0	18,1	16,1	8,7	5,5	Járfás and Viola [11]
Scotia segetum Schiff.	10,1	15,9	12,8	12,0	12,0	11,2	11,5	7,9	4,9	1,7	Járfás [9]
Autographa gamma L.	14,6	15,8	13,5	10,8	12,9	9,7	9,0	7,9	4,4	1,4	Járfás et al. [10]

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Table 2. *Light-trap catch (in %) of the examined species during night (UT)*

Species	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	0-1	1-2	2-3	3-4	4-5	Indi-viduals	Nights
Plutellidae															
Plutella maculipennis Curt. (4)				15,0	18,0	19,0	25,0	5,0	5,0	6,0	1,0			262	24
Gelechiidae															
Recurvaria nanella Hbn.						17,0	34,0		17,0	34,0				6	
Tortricidae															2
Tortrix viridana L. (4)			0,4	4,5	25,6	23,7	21,1	11,7	7,1	4,5	0,8	0,8		266	10
Pandemis heparana Schiff. (4)			2,2	8,9	28,9	33,3	15,6	6,7	2,2	2,2				45	8
Pandemis ribeana Hbn. (3)			14,3	9,5	14,3	14,3	9,5	14,3	9,5	9,5	4,8			21	7
Hedia nubiferana Haw. (4)			0,6	2,5	15,4	14,8	22,2	11,7	14,2	11,7	4,3	1,2	1,2	162	14
Spilonota ocellana F. (4)				14,3	35,7		28,6	7,1	7,1				7,1	14	2
Laspeyresia pomonella L.			16,7	16,7		16,7	16,7	16,7				16,7		6	4
Pyralidae															
Oncocera semirubella Scop.						16,7	33,3	16,7	16,7	16,7				6	5
Sitochroa verticalis L. (4)				6,7	13,3	6,7	40,0			20,0	6,7	6,7		15	7
Microlepidoptera spec. indet.		0,2	1,3	5,3	12,0	14,0	22,1	12,0	13,0	11,6	6,8	1,7	0,2	2802	39
Drepanidae															
Polyploca ridens Hbn. (2)			7,9	26,3	34,2	0,0	7,9	2,6	7,9	5,3	7,9			38	5
Asphalia ruficollis Schiff. (2)		7,1	50,0	19,0	14,3	2,4	4,8				2,4			42	4
Drepana binaria Hfn. (4)				4,8	14,3	42,9	23,8		9,5		4,8			21	8
Geometridae															
Chiasmia clathrata L. (4)					9,1	22,7	31,8	9,1	9,1	9,1	9,1			22	13
Biston stratarius Hfn. (2)		2,4	18,1	32,1	22,1	5,6	8,0	4,8	0,8	4,0	0,8	1,2		249	21
Apocheima hispidaria Schiff. (2)		4,4	40,0	24,4	22,2	4,4	2,2				2,2			45	8
Lycia hirtaria Cl. (4)		8,9	6,7	4,4		2,2	24,4	11,1	8,9	15,6	13,3	4,4		45	10
Lycia zonaria Schiff.		12,5					62,5		12,5	12,5				8	3
Biston betularia L.						14,3	14,3	28,6	14,3	28,6				7	6
Erannis marginaria Bkh.					33,3		33,3	11,1	11,1		11,1			9	5
Bapta temerata Schiff.					42,9	14,3	14,3	14,3		14,3				7	1

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EFFECT OF *LANTANA CAMARA* L. COVER ON LOCAL DEPLETION OF TREE POPULATION IN THE VINDHYAN TROPICAL DRY DECIDUOUS FOREST OF INDIA

GYAN P. SHARMA* AND A.S. RAGHUBANSHI

Department of Botany, Banaras Hindu University, Varanasi-221005, India. Fax: 91–542-2368174. Tel : 91-542-2368399.

e-mail: gyan_in1@rediffmail.com

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Abstract. The dry deciduous forest of northern India is being progressively invaded by an alien invasive woody shrub *Lantana camara* L. (Lantana). The invasion of lantana threatens the survival of many species. This study examines the demographic instability of tree species at different levels of lantana cover. Based on proportion of seedlings of a species in its total population (seedling+sapling+adult), about 39.5% and 60% of total 38 species exhibited local demographic instability at different levels of lantana cover for the first and the second census respectively. This decline in species could be attributed to altered microenvironment (light, pH and temperature) beneath the lantana bushes. The study concludes that the presence of lantana shrub as dense understorey perturbs the seedling recruitment of native tree species in the forest and this leads to differential depletion of native trees.
Key words: *declining species population, demographic instability, invasion, lantana cover*.

Introduction

Invasion of native communities by exotic species has been among the most intractable ecological problems of recent years (Sharma *et al.* 2005a). It is a global scale problem experienced by natural ecosystems and is considered as the second largest threat to global biodiversity (Drake *et al.*, 1989). Despite the recent recognition of the invasion of exotic species as a problem, there are many areas in the world where information on the demographic instability caused by invasion is lacking. In India, especially in the dry deciduous forest region, no information is available on demographic instability caused by lantana (*Lantana camara* L.). Lantana that ranked top in-terms of highest impacting invasive species (Batianoff & Butler 2003), and considered one of the worlds 100 worst invasive alien species (GISP 2003), has spread in almost all the areas in the dry deciduous region (Sharma & Raghubanshi 2006).

Tropical forests occupy 7% of the Earth's land surface (Wilson 1988) and harbour approximately two third of all biological populations (Hughes *et al.* 1997). On global basis, 52% of the total forest are tropical and over 42% of tropical forest have been classified as dry deciduous (Holdridge 1967). In India, tropical forests account for approximately 86% of the total forest land (Singh & Singh 1988) while dry forests are 38.2% of the total forest cover (MoEF, 1999). These forests are under immense pressure due to various human induced activities. Especially in Vindhyan highlands, quarrying for limestone, establishment of cement factory, thermal power stations and the construction of G B Pant Sagar reservoir have resulted in rapid population increase, causing deforestation and conversion of natural forest ecosystem into marginal croplands (Singh *et al.* 1991). In fact, during the past 20-years (1981-2001), human population doubled (1463468) in the Sonebhadra district in the Vindhyan region (Rajya

Niyojan Sansthan, 2000; Anonymous, 2003). Forests around this region are also exposed to illegal sporadic tree felling, wide spread lopping of trees for timber resources and shrubs for fuel wood and leaf for fodder (Singh & Singh 1989; Jha & Singh 1990). This rapid modification of the habitat facilitated the invasion of lantana at an accelerated rate (Sharma *et al.* 2005b), which can subsequently affect species regeneration.

Due to its strong allelopathic properties, Lantana has the potential to interrupt regeneration process of other species by decreasing germination, reducing early growth rates and selectively increasing mortality of other plant species (Sharma *et al.* 2005ab). These result in a reduction of species diversity and decline of species.

The objective of the present study was to identify the declining species population at low, medium and high lantana cover in the tropical dry deciduous forest of Vindhyan plateau, India. If the ratio of various age groups in a population is known, demography can be used to elucidate the current reproductive status and future trends of that population (Odum 1983; Smith 1996). A large population of young individuals indicates a rapidly expanding population, a more even distribution of age classes a stationary population, and a large population of old individuals a declining population (Odum 1983; Sagar & Singh 2004). We use the above demographic concept in identifying the depleting species in the areas of lantana invasion.

Material and Methods

Study area

The study area lies on the Vindhyan plateau in the Sonebhadra district of Uttar Pradesh (24º 13' to 24º19' N; 83º59' to 83º13') (Fig. 1). The elevation above the mean sea level ranges between 315 and 485 m (Singh & Singh 1992). This area has been known as "Sonaghati" (golden valley) due to the richness of its natural resources (Singh *et al*. 2002).

The climate is tropical with three seasons in a year, i.e. summer (March to mid June), rainy (mid June to September) and winter (October to February). October and March constitute the transition months between the rainy and winter seasons, and between winter and summer seasons, respectively. The average rainfall varies between 850 and 1300 mm. About 85% of the annual rainfall occurs during the rainy season from the southwest monsoon. The maximum monthly temperature varies from 20ºC in January to 46ºC in June, and the mean minimum monthly temperature reaches at 12ºC in January and at 31ºC in May.

Red coloured and fine textured sandstone (Dhandraul orthoquartzite) is the most important rock of the area. Sandstone is generally underlain by shale and limestone. The soils derived from these rocks are residual ultisols and are sandy-loam in texture (Raghubanshi 1992). These soils are part of the hyperthermic formation of typical plinthustults with ustorthents according to VII approximation of the USDA soil nomenclature (Singh *et al.* 2002). The potential natural vegetation of the region is tropical dry deciduous forest, which is locally dominated by species such as *Anogeissus latifolia, Boswellia serrata, Buchanania lanzan, Diospyros melanoxylon, Hardwickia binata, Lagerstroemia parviflora, Lannea cormendelica, Madhuca longifolia, Shorea robusta* and *Terminalia tomentosa*.

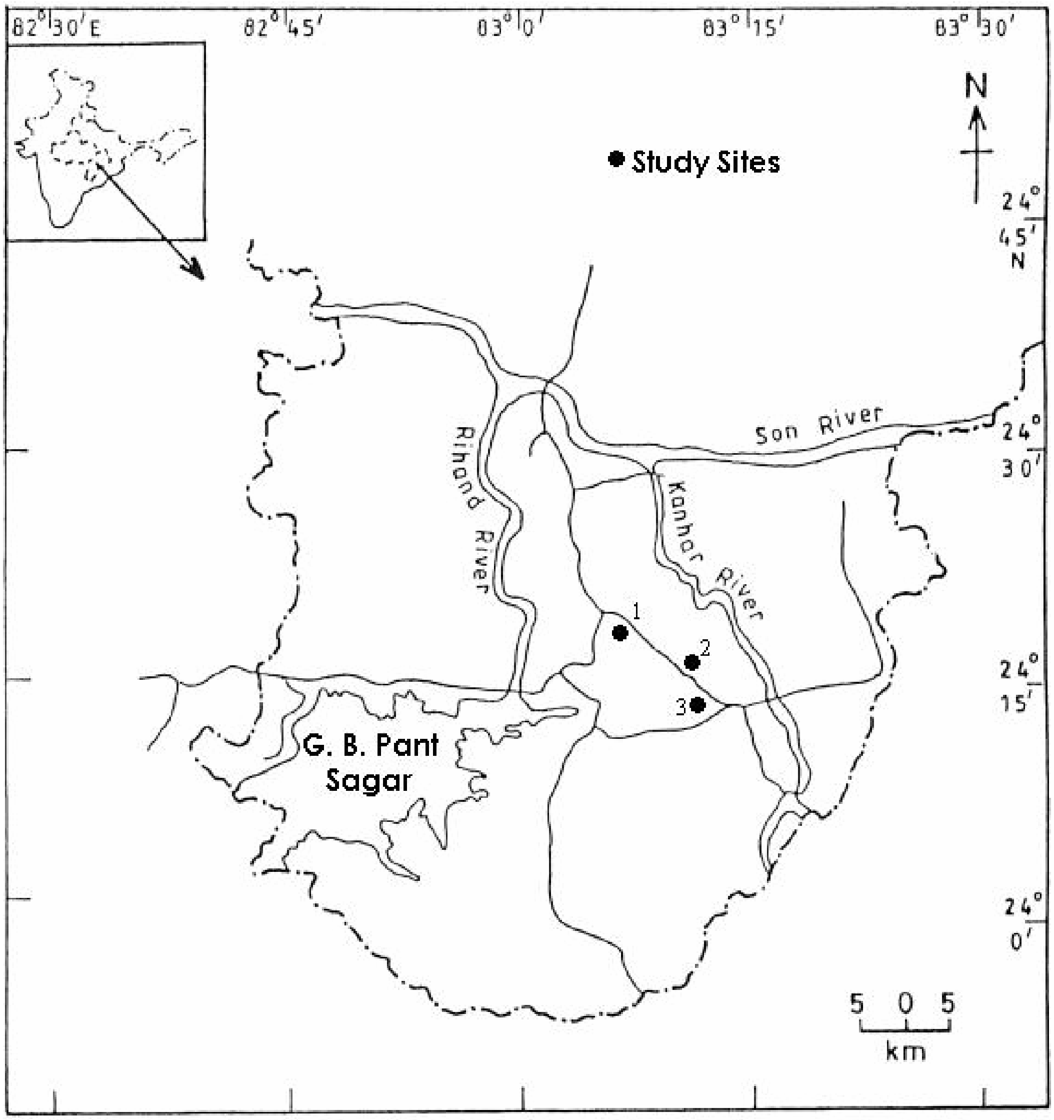

Figure 1. *Location of study sites with low, medium and high lantana cover within Vindhyan highlands, India. 1-Hathinala (low); 2- Bhaheradol (medium); 3- Rajkhar (high).*

Methods

Reconnaissance survey of the entire region was made and three sites (Baheradol, Rajkhar and Hathinala) in the region were selected at random. At these sites, which had visually different levels of lantana invasion sampling was done for the year 2002 and 2003 in the month of October. At each site, 30 quadrates each 10 x 10 m in size, were sampled randomly for vegetation analysis. A total of 90 quadrates, were sampled for vegetation analysis from the entire study area.

Lantana cover was estimated in each quadrate, using the Domin Krajina scale and was transformed into percentage cover for final analysis (Mueller-Dumbois and Ellenberg 1974). Lantana cover was taken as the percentage of the ground surface covered by the shadow of the lantana foliage, estimated as <1, 5, 10, 30, 50, 60, 75, 90, >95%, mean values of lantana cover at each site decided its presence in low, medium and high invaded sites. Later, each site was quantified into low (0%-30%), medium (31%-60%) and high (61%-100%) invasion sites on the basis of percentage cover of lantana. Data on the canopy cover were collected in each sampling unit in 2002 and 2003. Canopy covers were classified into three categories based on visual estimates of the approximate percentage of overstorey canopy cover- low canopy ; 0-30% (high light), medium canopy ; 31-60% (medium light) and high canopy ; 60-100% (low light). The sites varied in topography; the land was relatively gently sloping at Bhaheradol, undulating at Hathinala site and steep sloping at Rajkhar. These sites also differed in the physico-chemical characteristics of soil and were not related to the lantana cover.

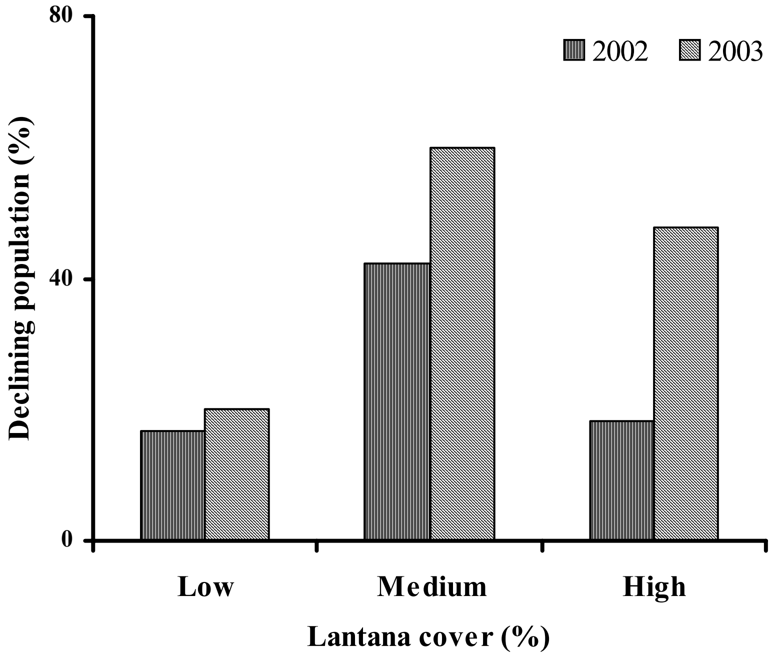

Figure 2. *Proportion of declining species at low, medium and high lantana cover within Vindhyan dry deciduous forest of India for two consecutive census (2002 and 2003).*

The diameter of each adult individual tree (≥9.6 cm diameter at breast height, dbh) was measured in each quadrate. In the centre of each 10 x 10 m quadrate, a 2 x 2 m area was marked for enumeration of saplings (individuals 3.2 cm to <9.6 cm dbh) and established seedlings (individuals <3.2 cm diameter but ≥ 30 cm height) (Sagar and Singh 2004). Seedlings shorter than 30 cm height were considered ephemeral, and the established seedlings category represented 1 to >3 yr old individuals. Stem diameter of adult and sapling individuals was measured at 1.37 m from the ground and for seedlings it was measured at 10 cm above the ground (Sagar and Singh 2004). Thus, all individuals were enumerated and measured by species.

The demographic analysis of species populations on each site was based on the proportion of seedlings of a species in its total population (seedlings + saplings +

adults). We assumed that for normal replacement, the seedling population should at least comprise more than 50% of the total population of a species. Based on this assumption we calculated the ratio of seedling population to the total population of a species. The species on each site were classified into four arbitrary categories on the basis of this ratio: <0.5 for declining species population (i.e. less than 1 established seedling per mature individual), 0.50-0.66 for relatively stable population, 0.67-0.99 for potentially expanding population (i.e. more than 2 seedlings per mature individual) and 1 for newly recruited species from neighbouring areas. A ratio of <0.25 (i.e. less than 1 established seedling per 3 mature individuals) was considered to represent severely depleting species population (Sagar & Singh 2004). Percentage decline at different lantana cover class was obtained by the ratio of number of declining species multiplied by 100 to the total number of species present in different lantana cover classes. However, percentage decline for each year was calculated by the number of declining species in each year multiplied by 100 to the total number of species present in each year.

Relationship between pH, canopy cover, temperature, lantana cover and year of sampling was analyzed by using SPSS software Version 10.0 (SPSS 1997

Result

In total, 38 species, and 28668 stems were recorded in the cumulative sampled area for both the census with 14851 and 13817 stems for the two consecutive censuses respectively (Table 1). A total of 376 adults, 1500 sapling and 12975 established seedlings were recorded in the first census while 368 adults, 2825 saplings and 10625 established seedlings were recorded in the second census. In total, 7 rare species were recorded, 2 in high and 6 in medium lantana invaded plots. *Acacia auriculiformis, Boswellia serrata, Briedelia retusa, Cassia fistula, Elaeodendron glaucum, Eriolena quinquelaris,* and *Miliusa tomentosa,* were recorded as one individual per 0.3 ha sampled area and were distinguished as rare species for both the census. *Acacia auriculiformis* and *Cassia fistula* were represented as one individual in entire 0.9 ha sampled area both the census (Table 1).

A total of 15 and 23 species exhibited demographic instability for the two consecutive censuses (Table 2), in other words, local reduction in population size. Of these, 15 species (*Acacia auriculiformis, Adina cordifolia, Boswellia serrata, Briedelia retusa, Buchanania lanzan, Cassia fistula, Elaeodendron glaucum, Emblica officinalis, Eriolena quinquelaris, Hardwickia binata, Lannea coromandelica, Miliusa tomentosa, Mitragyna parvifolia, Schleichera oleosa, Schrebera swietenioides*) showed relative declining abundances of established seedlings wherever they were present for both the census (Table 2).

Elaeodendron glaucum showed declining population at all the levels of lantana invasion both the census while large number of species with declining population occupied only one or few sites (Table 2). Thus, while 23 species showed declining population at different levels of lantana invasion both the census. The proportion of declining species population was maximum at medium lantana invasion (42 & 60 %), than at high lantana invasion (19 & 48 %) and minimal at low lantana invasion (16 & 20 %) for both the census respectively. However, the total number of species decreased with increasing lantana cover.

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ANOVA revealed that pH and temperature significantly varied with the year of sampling, but the canopy cover did not varied significantly with the year (Table 3). However, pH, canopy cover and temperature varied significantly with lantana cover (Table 3). Tukey's test revealed that pH, canopy cover and temperature showed significant differences in terms of lantana cover and year of sampling (Table 4).

Table 1. *Number of species in different growth categories (A = adult; S = sapling; ES = established seedling) at low, medium and high Lantana camara invasion in a dry tropical forest sites of northern India at temporal scale. Data are number of individuals per 0.3 ha area. Adults were enumerated in 30 quadrats of 10 x 10 m size and saplings and established seedlings were enumerated in 30 quadrats of 2 x 2 m size at each forest sites. The saplings and established seedling individuals were scaled up in same unit as adult.*

Species	**Lantana cover (%)**																	
	2002									**2003**								
	Low			**Medium**			**High**			**Low**			**Medium**			**High**		
	A	S	ES	A	S	ES	A	S	ES	A	S	ES	A	S	ES	A	S	ES
Acacia auriculiformis	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Acacia catechu Willd.	12	25	75	19	75	50	0	0	0	12	25	50	20	100	25	0	0	0
Adina cordifolia Hook.	0	0	75	0	0	0	4	0	0	0	0	75	0	0	0	4	0	0
Azadirachta indica A. Juss.	0	0	25	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0
Antidesma ghaesembilla Gaertn.	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	25
Anogeissus latifolia Wall.	3	25	150	15	25	100	0	50	300	3	25	150	12	25	75	3	100	100
Bauhinia racemosa Lam.	0	0	150	0	0	0	0	0	0	0	0	150	0	0	0	0	0	0
Boswellia serrata Roxb.ex.Colebr.	3	0	400	1	0	0	0	0	0	3	0	350	1	0	0	0	0	0
Briedelia retusa Muell - Arg.	9	100	800	1	0	0	0	0	25	10	75	750	1	0	0	0	0	25
Buchanania lanzan Spreng.	10	0	50	5	25	25	3	0	0	10	0	25	4	25	0	3	0	0
Cassia fistula Linn.	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Carissa spinarum DC.	0	0	0	0	0	0	0	25	75	0	0	0	0	0	0	0	25	75
Casearia elliptica Willet.	0	0	0	0	0	0	0	0	150	0	0	0	0	0	0	0	0	150
Diospyros melanoxylon Roxb.	6	25	625	9	50	1100	2	100	950	7	0	550	10	25	1050	3	225	700
Elaeodendron glaucum Pers.	2	0	0	2	0	0	1	0	0	2	0	0	2	0	0	1	0	0
Emblica officinalis Gaerth.	6	25	50	1	0	0	0	0	25	6	25	50	1	0	0	0	0	0
Eriolaena quinquelocularis Wight.	0	0	125	1	0	0				0	0	125	1	0	0		0	0
Flacourtia indica Murr.	0	0	250	2	0	200	0	0	25	0	0	250	2	0	150	0	0	100
Gardenia latifolia Ait.	1	25	125	1	0	25	0	0	0	1	25	125	1	25	25	0	0	0
Grewia serrulata DC.	0	0	275	0	0	0	0	0	0	0	75	175	0	0	0	0	0	0
Hardwickia binnata Roxb.	5	0	0	3	25	0	0	0	0	5	0	0	3	25	0	0	0	0

Holarrhena antidysenterica DC.	0	0	1050	1	0	150	0	0	200	0	150	875	1	0	150	0	25	75
Hymenodictyon excelsum Wall.	0	0	100	0	0	25	0	0	0	0	0	100	0	0	0	0	0	0
Lagerstroemia parviflora Roxb.	4	0	50	14	25	100	1	50	75	4	0	50	14	25	100	2	50	25
Lannea coromandelica Merr.	17	25	0	3	50	25	17	25	75	17	25	0	3	50	25	17	25	25
Madhuca longifolia MacBr.	0	0	0	0	0	0	12	0	25	0	0	0	0	0	0	10	0	25
Miliusa tomentosa Sincl.	3	25	175	3	100	450	1	0	0	3	50	125	3	200	300	1	0	0
Mitragyna Parvifolia Korth.	0	0	25	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0
Pterocarpus marsupium Roxb.	0	0	25	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0
Schleichera oleosa Oken.	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	25	0
Schrebera swietenioides Roxb.	9	0	0	0	0	25	0	0	0	9	0	0	0	25	0	0	0	50
Semecarpus anacardium Linn.f.	2	25	300	0	25	50	0	0	25	2	75	250	0	50	25	0	0	25
Shorea robusta Gaertn.	52	75	650	39	50	450	31	75	675	48	175	550	34	175	425	28	325	300
Soymida febrifuga A. Juss	4	25	25	1	0	75	0	0	0	4	25	25	1	50	25	0	0	0
Sterculia urens Roxb.	2	50	100	0	0	50	0	0	0	2	50	100	0	25	50	0	0	0
Terminalia tomentosa Wight.	8	25	1075	12	175	275	11	75	200	7	25	1025	12	200	250	12	125	75
Zizyphus nummularia Wight & Arn.	0	0	75	0	0	50	0	0	0	0	25	75	0	0	50	0	0	0
Sikti (unidentified)	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0	75

Table 2: *Species showing local population depletion (*) based on the <0.50 ratio of seedling population to total species population at low, medium and high Lantana camara invasion at temporal scale. Zeroes indicate complete absence of established seedlings. Values are ratios of established seedlings to total population (- = species not present).*

Species	**Family**	**Common names**	**Lantana cover**					
			2002			**2003**		
			Low	**Medium**	**High**	**Low**	**Medium**	**High**
Acacia auriculiformis	Mimosiaceae	Australian babool	-	0.00*	-	-	0.00*	-
Acacia catechu Willd.	Mimosiaceae	Khair	0.67	0.35*	-	0.57	0.17*	-
Adina cordifolia Hook.	Rubiaceae	Haldu/Karam	1.00	-	0.00*	1.00	-	0.00*
Azadirachta indica A. Juss.	Miliaceae	Neem	-	-	1.00	1.00	-	-
Antidesma ghaesembilla Gaertn.	Euphorbiaceae	Sahrauta	1.00	-	-	-	-	1.00
Anogeissus latifolia Wall.	Combrataceae	Dhaura/Dhau	0.84	0.71	0.86	0.84	0.67	0.49*
Bauhinia racemosa Lam.	Caesalpiniaceae	Katahul	1.00	-	-	1.00	-	-
Boswellia serrata Roxb.ex.Colebr.	Burseracaeae	Salai	0.99	0.00*	-	0.99	0.00*	-
Briedelia retusa Muell - Arg.	Euphorbiacae	Khaja	0.88	0.00*	1.00	0.90	0.00*	1.00
Buchanania lanzan Spreng.	Anacardiaceae	Piyar	0.83	0.45*	0.00*	0.71	0.00*	0.00*
Carissa spinarum DC.	Apocynaceae	Karaunda	-	-	0.75	-	-	0.75
Casearia elliptica Willet.	Flacourtiaceae	Bheri	-	-	1.00	-	-	1.00
Cassia fistula Linn.	Caesalpiniaceae	Amaltas	-	0.00*	-	-	0.00*	-
Diospyros melanoxylon Roxb.	Ebenaceae	Tendu	0.95	0.95	0.90	0.99	0.97	0.75
Elaeodendron glaucum Pers.	Celastraceae	Mamar	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*

Emblica officinalis Gaerth.	Euphorbiacae	Aonla	0.62	0.00*	1.00	0.62	0.00*	-
Eriolaena quinquelocularis Wight.	Sterculiaceae	Dheriya	1.00	0.00*	-	1.00	0.00*	-
Flacourtia indica Murr.	Flacourtiaceae	Kantaila	1.00	0.99	1.00	1.00	0.99	1.00
Gardenia latifolia Ait.	Rubiaceae	Papar	0.83	0.96	-	0.83	0.49*	-
Grewia serrulata DC.	Tiliaceae	Bichhula	1.00	-	-	0.70	-	-
Hardwickia binnata Roxb.	Caesalpiniaceae	Parsiddha	0.00*	0.00*	-	0.00*	0.00*	-
Holarrhena antidysenterica DC.	Apocynaceae	Khirana/Koraya	1.00	0.99	1.00	0.85	0.99	0.75
Hymenodictyon excelsum Wall.	Rubiaceae	Bhurkul	1.00	1.00	-	1.00	-	-
Lagerstroemia parviflora Roxb.	Lythraceae	Siddha	0.93	0.72	0.60	0.93	0.72	0.32*
Lannea coromandelica Merr.	Anacardiaceae	Gigan	0.00*	0.32*	0.64	0.00*	0.32*	0.37*
Madhuca longifolia MacBr.	Sapotaceae	Mahua	-	-	0.68			0.71
Miliusa tomentosa Sincl.	Anonaceae	Kari	0.86	0.81	0.00*	0.70	0.60	0.00*
Mitragyna Parvifolia Korth.	Rubiaceae	Gurahi	1.00	-	-	0.00*	-	-
Pterocarpus marsupium Roxb.	Fabaceae	Biya/Vijayasal	1.00	-	-	1.00	-	-
Schleichera oleosa Oken.	Sapindaceae	Kusum	-	-	1.00	-	-	0.00*
Schrebera swietenioides Roxb.	Oleaceae	Ghantha	0.00*	1.00	1.00	0.00*	0.00*	1.00
Semecarpus anacardium Linn.f.	Anacardiaceae	Bhela	0.92	1.00	1.00	0.76	0.33*	1.00
Shorea robusta Gaertn.	Dipterocarpaceae	Sal/Shakhu	0.84	0.67	0.86	0.71	0.67	0.46*
Soymida febrifuga A. Juss	Miliaceae	Rohina	0.46*	0.83	-	0.46*	0.33*	-
Sterculia urens Roxb.	Sterculiaceae	Kuruli	0.66	0.99	-	0.66	0.67	-
Terminalia tomentosa Wight.	Combrataceae	Asan/Saja	0.97	0.60	0.70	0.97	0.54	0.35*
Zizyphus nummularia Wight & Arn.	Rhamnaceae	Ber/Beri	1.00	1.00	-	0.75	1.00	-
Sikti (unidentified)			-	-	1.00	-	-	1.00

Table 3. *Summary of ANOVA for pH, Canopy cover, temperature in response to year and lantana cover.*

Source of variation	**Dependent variable**	**df**	**F**	**P**
Year	pH	1	64.04	0.000
	Canopy cover (%)	1	1.06	0.312
	Temperature (°C)	1	10.46	0.004
Lantana cover (%)	pH	2	24.06	0.000
	Canopy cover (%)	2	180.413	0.000
	Temperature (°C)	2	47.26	0.000
Year× *Lantana* cover (%)	pH	2	0.67	0.51
	Canopy cover (%)	2	0.54	0.58
	Temperature (°C)	2	0.68	0.51
Error		24		
Total		30		

Table 4. *Data on pH, temperature and canopy cover at different lantana cover for the two consecutive years.*

Lantana cover (%)	Year	
	2002	**2003**
	pH	
Low	6.65 ± 0.02[a]	6.86 ± 0.02[d]
Medium	6.52 ± 0.04[b]	6.72 ± 0.05[b]
High	6.38 ± 0.03[c]	6.65 ± 0.03[e]
	Temperature (°C)	
Low	33.22 ± 0.45[a]	32.61 ± 0.36[d]
Medium	30.96 ± 0.35[b]	29.73 ± 0.65[b]
High	29.53 ± 0.34[c]	27.92 ± 0.38[e]
	Canopy cover (%)	
Low	71 ± 1.87[a]	72 ± 2.55[a]
Medium	50 ± 2.24[b]	46 ± 1.87[d]
High	21 ± 3.67[c]	17 ± 3.74[e]

Values affixed with different letters were significantly different from each other at <0.05.

Discussion

Sagar and Singh (2004) reported 12 species (viz. Boswellis serrata, Carrissa spinarum, Cassia fistula, Cassia siamea, Dalbergia sissoo, Ficus benghalensis, Holoptelia integrifolia, Madhuca latifolia, Syzygium heyneanum, Terminalia tomentosa, 2 unidentified species- Papra and Rij) showing a reduction in population size at varied disturbance regimes. Study conducted at various levels of lantana cover revealed that the species with declining population differed, except for Boswellis serrata and Cassia fistula which showed declining populations at various disturbance regimes (Sagar & Singh 2004). Thirteen more species, other than those with declining population due to disturbance, showed a decline at different levels of lantana invasion for both the census. The number of declining species increased when both the phenomena (viz. disturbance and lantana invasion) were taken into consideration. Thus, we may interpret that disturbance and invasion synergistically affect the tree regeneration process in the Vindhyans. Although, Sharma et al. (2005c) emphasized that while studying invasiveness, all the available tenets must be taken into consideration to explain invasions in totality.

Species exhibited as a single individual at different lantana cover included Acacia auriculiformis, Boswellia serrata, Briedelia retusa, Cassia fistula, Emblica officinalis and Eriolena quinquelaris at medium lantana invasion and Elaeodendron glaucum and

Miliusa tomentosa at high lantana invasion (Table 1). It is obvious that the species with only one individual would be highly vulnerable, since a local population composed of only a few individuals can undergo catastrophic decline due to environmental change, genetic problem or simple random events when isolated in a limited geographic range (Cunningham & Saigo 1999). According to Barbault & Sastrapradja (1995), species with small population size are highly vulnerable and severe the environmental change the higher the rate of local loss of species population. A minimum size of population is required for long-term viability of rare and endangered species (Cunningham & Saigo 1999).

The forest supplies approximately 90% of the fuel wood and fodder needs of the local population. Exploitation of single species can cause the entire structure of the plant community to change (Spurr & Barnes 1980). Further, fuel wood collection can be a major contributor to forest degradation. These result in canopy openings, which permit lantana to flourish well and affect the tree regeneration process due to competition. Under such conditions, shading effect and allelopathic activity of lantana cause seedlings of tree species have stunted or no growth. When canopy trees are removed patches of increased light intensity (Rejmanek 1989) and nutrient resources (Davis et al. 2000) are created. Lantana is faster growing than native tree species and it captures the resources efficiently, creating substantial biomass of lantana in the inter-canopy and at the edges of the forest (personal observation). Breshears (2006) also emphasized that canopy opening (in terms of cover) affects ecosystem functioning between canopy and inter-canopy patches in terms of light irradiance. Rodger & Twine (2002) advocated that lantana invasion could be considered as a form of bush encroachment. The dense growth of lantana in the form of understorey mat prevents the light to reach the ground, resulting in marked heterogeneity in terms of irradiance and temperature. Light has long been recognized as an important plant resource (Maximov 1929; Blankenship 2002) that may interact with other plant resources to affect plant performance (Cole 2003). Below certain thresholds, however, light limitation alone can prevent seedling survival regardless of other resource levels (Tilman 1982). It is likely that seedlings of tree species are influenced by the amount of light that reaches the forest floor, and this may be probably one of the mechanisms responsible for the decline of seedlings. Sharma and Raghubanshi 2006 advocated that the growth architecture pattern of lantana is such that it prevents the light penetration to the forest floor, leading to the decline of tree seedlings.

Almost all the species with declining population (Acacia auriculiformis, Adina cordifolia, Boswellia serrata, Briedelia retusa, Buchanania lanzan, Cassia fistula, Elaeodendron glaucum, Emblica officinalis, Eriolena quinquelaris, Hardwickia binata, Miliusa tomentosa, Schrebera swietenioides) require high to moderate light for proper growth (Troup 1921). Lantana canopy certainly lowers sunlight to reach the ground level, which may affect the soil temperature. The dry forest tree species are fairly tolerant to moderately high temperatures at all the life cycle stages (Khurana and Singh 2001a). As increase in temperature triggers germination by changing the internal enzymatic kinetics and thus the biochemistry of seed cells (Khurana and Singh 2001b, Vazquez and Orozeo 1982). However, the decrease in temperature due to lantana canopy might perturb seedling recruitment. This may possibly be one of the reasons that inhibits seedling establishment of the tree species. Further, the change in pH that may be attributed to the allelopathic potential of lantana and this could have important implication for the seedling establishment.

Lantana bushes are fire prone and can burn readily altering the fire regime to favour its persistence (Hiremath and Sundaram 2005). These lantana bushes when burned create ample heat, causing seed and seedling mortality in the area (Moore & Wein 1977). Thus, interaction of these factors with biotic pressure might inhibit both seed germination as well as seedling establishment, which may result in population loss.

There are several ways in which lantana could suppress tree recruitment selectively. As lantana forms dense bushes and when such bushes grow nearby each other they form an understorey mat like structure (personal observation). And such mat formation prevents the seeds of tree species to reach the ground; these seeds get entrapped in the lantana mat. For example, the fruit of Schrebera swietenioides is 2-3 inch long (Brandis 1978), which can be easily trapped in lantana mat. Although when few seeds reach the ground there is scarcity of light. At ground level there is accumulation of lantana litter and other broken dry debris of lantana, which could lead to allelopathic suppression for germination of seeds of tree species (Gentle & Duggin 1997).

Conclusion

This study suggests that not only many species of the tropical dry deciduous forest have small local population, but also several of them exhibit declining or even severely depleting population at different levels of lantana invasion. Such invasive species cover may create demographic instability among the tree species and reduce tree diversity and can even change the structure of the forest in the near future. As seedlings of most of the tree species of tropical dry deciduous forest are adapted to grow in relatively open conditions, because of the poor canopy cover and deciduous nature. The presence of lantana shrub as dense understorey perturbs the seedling recruitment of native tree species in the forest and this lead to differential depletion of native trees. This calls for immediate conservation activity. Further this study gives an implication and need for in-depth microcosm study in relation to lantana specific performance of declining species in the tropical dry deciduous forest.

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TOXICITY OF ZINC TO HETEROTROPHIC BACTERIA FROM A TROPICAL RIVER SEDIMENT

C. O. NWEKE [1, *] – C. S. ALISI[2] – J.C. OKOLO[1] – C. E. NWANYANWU[1]

[1] *Department of Microbiology, Federal University of Technology, P.M.B.1526, Owerri, Nigeria.*
[2] *Department of Biochemistry, Federal University of Technology, P.M.B. 1526, Owerri, Nigeria.*

e-mail: xrisokey@yahoo.com

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Abstract. Tolerance to Zn^{2+} by pure cultures of *Bacillus*, *Salmonella* and *Arthrobacter* species isolated from New Calabar River sediment was assessed through dehydrogenase assay. The cultures were exposed to Zn^{2+} concentrations of 0.2 to 2.0 mM in a nutrient broth-glucose-TTC medium. The responses of the bacterial strains varied with Zn^{2+} concentration. In *Salmonella* sp. SED2, Zn^{2+} stimulated dehydrogenase activity at 0.2 mM. In *Bacillus* sp. SED1 and *Arthrobacter* sp. SED4, dehydrogenase activity was progressively inhibited with increasing Zn^{2+} concentration. The IC_{50} ranges from 0.206 ± 0.030 to 0.807 ± 0.066 mM. Total inhibition of dehydrogenase activity was observed at concentrations ranging from 1.199 ± 0.042 to 1.442 ± 0.062. The order of zinc tolerance is: *Salmonella* sp. SED2 > *Arthrobacter* sp. SED4 > *Bacillus* sp. SED1. The result of the in vitro study indicated that Zinc is potentially toxic to sediment bacteria and could pose serious threat to their metabolism in natural environments.
Keywords: *dehydrogenase activity, sediment bacteria, New Calabar River.*

Introduction

Bacteria and other microorganisms densely colonize freshwater and marine sediments. In these environments, bacteria constitute the primary agents of early transformation of organic matter and regeneration of nutrients and also serve as food source for higher trophic level.

Microorganisms are vital for the efficient functioning of any ecosystem, hence factors that affect their metabolism, composition and abundance are of great concern. Monitoring microbial responses has been recommended as an early warning indicator of ecosystem stress as microbes respond promptly to environmental perturbations [12, 29]. Measurement of microbial enzyme activity is used in the assessment of ecotoxicological impacts of environmental substrates. In this regard, dehydrogenase activity has been widely used. The dehydrogenase assay is an effective primary test for assessing the potential toxicity of metals to soil microbial activities [1, 7, 18, 31] and bioavailability of metal in a beach sediment [9].

The pollution of New Calabar River is due to anthropogenic activities along its bank [25, 27, 28]. The heavy metal content, seasonal variations in the population of heavy metal resistant bacteria and toxicity of heavy metals to bacteria isolated from the New Calabar River have been reported [23, 25, 26]. Moreso, Odokuma and Abah reported bioaccumulation of selected heavy metals by bacteria isolated from this river [24]. Although, these works focused on pure cultures of bacterial isolates, they did not consider the inhibition of dehydrogenase enzyme activity in these bacteria. This study was aimed at assessing the effects of zinc on the dehydrogenase activities of *Bacillus*, *Salmonella* and *Arthrobacter* species isolated from New Calabar River sediment.

Materials and methods

Sample collection and analysis

The New Calabar River is a short tidal coastal river of about 150-200 km in length and is situated in the Niger delta of Nigeria. The water is brackish and impacted by effluent discharges from industries sited along its bank. The sampling site have been described elsewhere [26, 27]. Sediment and water samples were collected along the course of the river at Choba. Eckman grab sampler was used for collection of sediment sample. The overlying water sample was collected midstream along the course of the river from a depth of 30 cm. The samples were collected in sterile glass bottles, stored in a cooler and taken to laboratory. All samples were analysed within 6 hours of collection. The pH and zinc content of the samples were determined using pH meter (Jenway 3015) and atomic absorption spectrophotometer (Perkins Elmer 3110) respectively.

Isolation of bacterial strains and culture conditions

Aerobic heterotrophic bacteria in the New Calabar River sediment were isolated and purified on nutrient agar plates. Characterizations were done using standard microbiological methods. Identifications to the generic level followed the schemes of Holt *et al.* [13].

The bacterial strains were grown to mid exponential phase in nutrient broth (Lab M) on a rotary incubator (150 rpm) at room temperature (28 ± 2 ^{o}C). The cells were harvested by centrifugation at 4000 rpm for 10 minutes. Harvested cells were washed twice in deionized distilled water and resuspended in the same water. The resuspended cells were standardized in a spectrophotometer to an optical density of 0.85 at 420nm. The dry weights of the standardized cells were determined by drying 10 ml of cell suspension to constant weight in an oven at 110^{o}C. These standardized cell suspensions were used as inoculum in the dehydrogenase activity assay.

Dehydrogenase activity assay

Dehydrogenase activity was determined using TTC as the artificial electron acceptor, which is reduced to the red-coloured TPF. The assay was done in 3-ml volumes of nutrient broth-glucose-TTC medium supplemented with varying concentrations (0.2 – 1.0 mM) of Zn^{2+} as zinc sulphate in separate 20 ml screw-capped test tubes. Portions (0.3 ml) of the bacterial suspensions were inoculated into triplicate glass tubes containing 2.5 ml of phthalate-buffered (pH 6) nutrient broth-glucose medium amended with Zn^{2+} and preincubated on a rotary incubator (150 rpm) at room temperature (28 ± 2 ^{o}C) for 30 min. Thereafter, 0.2 ml of 0.4 %(w/v) TTC in deionized distilled water was added to each tube to obtain final Zn^{2+} concentrations of 0.2, 0.4, 0.6, 0.8 and 1.0 mM in different test tubes. The final concentrations of nutrient broth, glucose and TTC in the medium were 2, 2 and 0.267 mg/ml respectively. The controls consisted of the isolates and the media without Zn^{2+}. The reaction mixtures were further incubated statically at room temperature (28 ± 2 ^{o}C) for 4 h. The TPF produced were extracted in 4 ml of amyl alcohol and determined spectrophotometrically at 445 nm (λmax). The amount of formazan produced was determined from a standard dose-response curve [0-50 mg/l TPF (Sigma) in amyl alcohol; R^2 = 0.996]. Dehydrogenase activity was expressed as milligrams of TPF formed per mg dry weight of cell biomass per hour.

Zinc inhibition of dehydrogenase activity was calculated relative to the control. The percentage inhibitions for *Bacillus* and *Arthrobacter* species were linearized against the concentrations of Zn^{2+} using gamma parameter (Γ) as shown in the equation below [19]. The toxicity threshold concentrations (IC_{20} and IC_{50}) were then determined from regression plots. The total inhibitory concentrations (IC_{100}) were estimated from the linear regressions of log transformation plots of the dose-response data.

Inhibition of dehydrogenase activities in the sediment bacteria was compared with that of planktonic bacteria isolated from New Calabar River water.

$$\Gamma = \frac{\%\text{Inhibition}}{100 - \%\text{Inhibition}}$$

Statistical analysis

Data generated were subjected to multiple factor analysis of variance (2-Way ANOVA).

Results and discussion

The sediment is slightly acidic (pH 6.62) and has elevated zinc concentrations of 65.8 mg/kg sediment. The pH and zinc content of the overlying river water were 6.4 and 5mg/l (≈76.48 μM) respectively. The higher zinc content in the sediment could be attributed to incorporation of zinc into sediment following it's association with particulate matters. In an undisturbed environment, heavy metals are preferentially transferred from the dissolved phase and thus metal concentrations in sediments are generally much higher than in the overlying water [6]. Previously, zinc levels of 0.01 to 0.71 mg/l [24, 25, 26] in the river water and 31.18 to 32.02 mg/kg [15] in the sediment of New Calabar River was reported. This indicated that zinc was accumulating in the New Calabar River water and sediment over time.

Three predominant bacterial strains comprising one Gram negative (*Salmonella* sp. SED2) and two Gram positive (*Bacillus* sp. SED1 and *Arthrobacter* sp. SED4) organisms were isolated from the river sediment. These isolates were able to reduce TTC to its formazan and so were used to assess toxicity of toxicant through dehydrogenase activity assay. *Bacillus*, *Arthrobacter*, *Salmonella* and *Proteus* species have been isolated from New Calabar River by Odokuma and Ijeomah [24, 25].

The rate of dehydrogenase activity varied among the bacterial strains (*Table 1*). The Gram positive *Bacillus* sp. SED1 had higher rates of dehydrogenase activity than the Gram negative *Salmonella* sp. SED2 and Gram positive *Arthrobacter* sp. SED4. In a similar study with planktonic bacteria of New Calabar River, Gram negative bacteria was reported to have higher rate of dehydrogenase activity than the Gram positive ones [23]. The reason for these differences is not known. However, it may be attributed to the physiology of the bacteria.

The effects of Zn^{2+} on the dehydrogenase activity and its relative inhibition in the bacterial strains are shown in *Figure 1* and *Table 2* respectively. In *Bacillus* sp. SED1 and *Arthrobacter* sp. SED4, dehydrogenase activity decreased with increasing concentration of Zn^{2+}. In *Salmonella* sp. SED2, dehydrogenase activity was slightly stimulated at 0.02 mM Zn^{2+} and progressively inhibited at concentrations greater than 0.2 mM (0.4 – 1.0 mM). The stimulatory effect observed with *Salmonella* sp. SED2

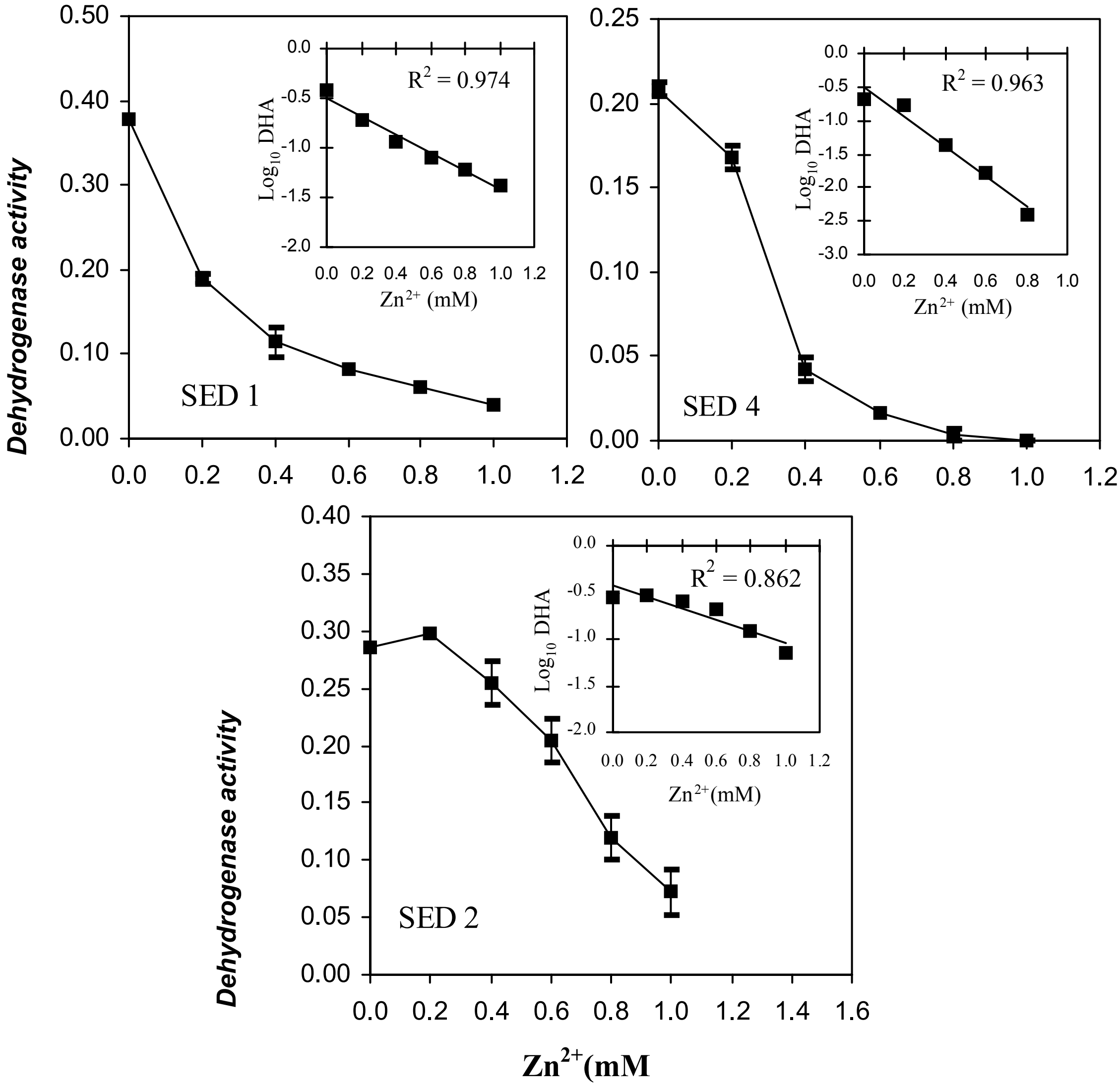

Figure 1. *Dehydrogenase activity in response to various concentrations of zinc ion by Bacillus sp. SED1, Salmonella sp. SED2 and Arthrobacter sp. SED4. The vertical bars indicates mean ± standard deviation (n=3). The figure insets show linear relationships between Zn^{2+} and mean dehydrogenase activity (DHA) in each bacterial strain*

Table 1. *Uninhibited dehydrogenase activities in the isolates*

Strain	Dehydrogenase activity[a] (mg Formazan/mg cell dry wt/h)
Bacillus sp. SED1	0.379 ± 0.038
Salmonella sp. SED2	0.208 ± 0.004
Arthrobacter sp. SED4	0.285 ± 0.002

may be attributed to the use of zinc as trace element by this bacterium. Zinc is associated with a number of processes essential for growth and metabolism in bacteria [8]. The inhibition of dehydrogenase activity observed in this study is consistent with the reported toxic effect of zinc at high concentrations [16]. Although zinc is an essential element, it is an inhibitor of respiratory activities in microorganisms [3,17, 30].

Results presented in *Table 2* showed that the Gram negative *Salmonella* sp. SED2 tolerated zinc more than the Gram positive *Bacillus* sp. SED1 and *Arthrobacter* sp. SED4. *Salmonella* sp. SED2 had lower percentage inhibition of dehydrogenase activity at all concentrations of Zn^{2+}. Better tolerance to heavy metal toxicity by Gram negative bacteria have been reported [20,21]. In comparison, there is no significant difference ($p < 0.05$) between the percentages of inhibition of dehydrogenase activities in sediment and planktonic bacteria of New Calabar River. This did not corroborate reports that organisms isolated from heavy metal polluted habitats are more tolerant to metals than organisms isolated from unpolluted habitats. It could be that the concentration of zinc was not high enough to select for tolerant organisms in the sediment. The effects of zinc on the microbial activity of water and sediment communities have been reported [22, 23, 32]. A suppression of organic decomposition was observed in the heavy metal contaminated sediment of Palestine Lake containing average zinc level of 17840 mg/kg sediment [22]. Likewise, Zn^{2+} inhibited glucose uptake and mineralization by water and sediment microbial communities of a contaminated stream. A 10 % reduction in the maximum rate of glucose uptake was obtained at lower metal concentrations in the water samples than in the sediment ones [32]. This indicates that water microbial community is more sensitive to metal toxicity than sediment community. Hornor and Hilt have made similar observations, where bacteria in polluted site are more tolerant to metal than those in unpolluted sediment [14]. Hornor and Hilt also observed that the presence of Zn-tolerant bacteria correlated with the degree of heavy metal contamination. Numerous other reports also revealed that bacteria isolated from environments with high levels of heavy metal exhibit greater metal tolerance than bacteria isolated from unpolluted habitats [2, 10, 11, 33].

The dehydrogenase activities correlated with Zn^{2+} concentration as shown in *Figure 1* (insets). The high R^2 values ($0.862 \le R^2 \le 0.974$) indicated that Zn^{2+} concentration was a strong determinant of dehydrogenase activities in the organisms. Thus , the organisms are at serious stress at high concentrations of Zn^{2+}.

The gamma parameter model gave good linearization of the dose response data for *Bacillus* sp. SED1 ($0.987 \le R^2 \le 0.994$) and *Arthrobacter* sp. SED4 ($0.976 \le R^2 \le 0.993$). However, for *Salmonella* sp. SED2, the response (percentage inhibition) is linear ($0.970 \le R^2 \le 0.993$) with the concentrations of Zn^{2+} and does not require linearization process (*Figure 2*). *Table 3* shows the toxicity threshold concentrations (IC_{20}, IC_{50} and IC_{100}) of Zn^{2+} estimated from the linear regression models. *Bacillus* sp. SED1 having the least IC_{20} and IC_{50} of 0.071 and 0.206 mM respectively was the most sensitive to Zn^{2+} while *Salmonella* sp. SED1 having the highest IC_{20} and IC_{50} of 0.488 and 0.807 mM respectively was the most tolerant. Using INT-dehydrogenase activity assay, Pérez-Garcia and co-workers reported an IC_{20} and IC_{50} of 0.999 and 2.88 mM of Zn^{2+} against *Pseudomonas fluorescens* [30]. In a MetPLATE ™ assay system (based on β-galactosidase activity), zinc IC_{50} of 0.11 ± 0.001 mg/l (0.002mM) was reported for *Escherichia coli* [5]. In a growth inhibition test assessed via turbidity measurements, 7.15 mg/l Zn^{2+} (0.12mM) inhibited the growth of *Pseudomonas putida* by 50 % [34]. In

Table 2: *Zinc inhibition of dehydrogenase activity in sediment and planktonic bacterial species*

Bacterial strains	Inhibition (%)[a] Zn^{2+} (mM)				
	0.2	0.4	0.6	0.8	1.0
Sediment bacteria					
Bacillus sp. SED1	47.804 ± 1.650	66.883 ± 4.496	75.162 ± 3.240	80.562 ± 1.052	84.881 ± 1.080
Salmonella sp. SED2	-4.000 ± 0.000	10.000 ± 6.000	26.000 ± 6.000	53.333 ± 6.110	68.667 ± 6.429
Arthrobacter sp. SED4	17.981 ± 3.155	74.763 ± 3.155	86.330 ± 1.821	91.588 ± 0.911	93.691 ± 0.000
Planktonic bacteria					
Escherichia sp. PLK 1	44.523 ± 2.845	71.313 ± 4.167	76.292 ± 3.580	83.404 ± 0.822	87.672 ± 0.410
Proteus sp. PLK 2	–7.453 ± 3.000	21.140 ± 3.037	57.588 ± 3.037	76.806 ± 3.037	85.421 ± 3.037
Micrococcus sp. PLK 4	–18.182 ± 3.445	31.034 ± 3.449	37.931 ± 3.448	49.425 ± 1.991	53.448 ± 4.562
Pseudomonas sp. PLK 5	33.244 ± 2.053	62.376 ± 5.393	77.599 ± 4.107	85.573 ± 1.480	89.247 ± 1.344

[a] *Data represent means ± standard deviation of triplicate tests*

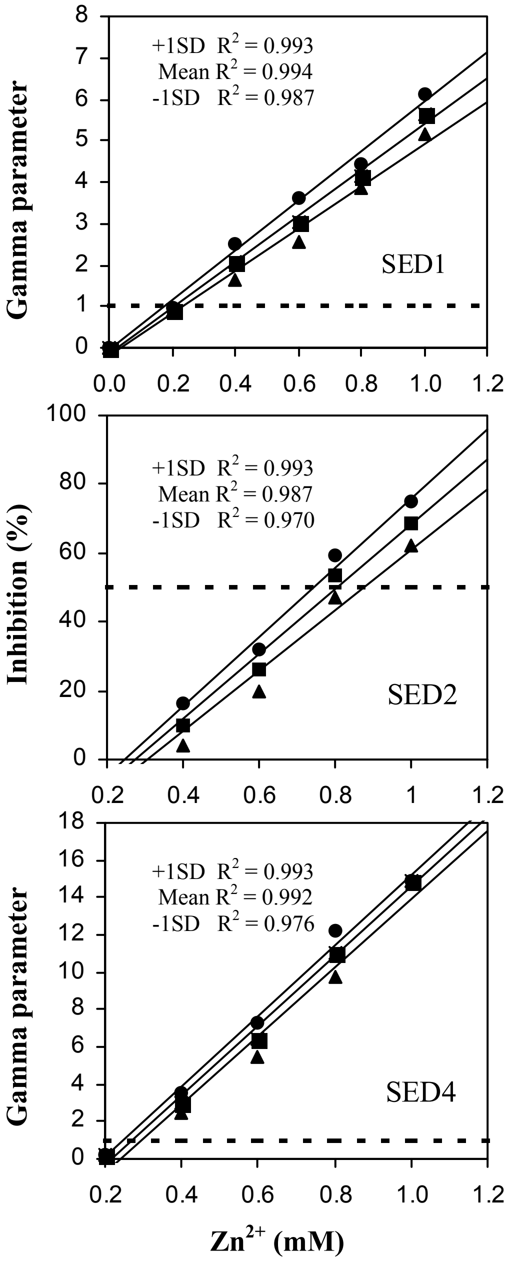

Figure 2. *Relationships between the mean ± standard deviation of gamma parameter and percent inhibition values with zinc ion concentrations for Bacillus sp. SED1, Salmonella sp. SED2 and Arthrobacter sp. SED 4. IC_{50} was calculated as mean ± standard deviation from the linear curves. Symbols: Circle = +1SD, Square = mean, Triangle = -1SD.*

a similar growth inhibition test, 0.1 and 0.5mM of zinc inhibited growth of *Streptococcus faecalis* by 8.77 and 18.42 % respectively [4].

The 2-way ANOVA show that the dehydrogenase activity and its percentage inhibition varied significantly ($p < 0.05$) with bacteria type and the concentrations of zinc.

The result of the *in vitro* study indicated that Zn^{2+} is potentially toxic to the sediment bacteria of New Calaber River. Contamination and accumulation of Zn^{2+} in the sediment would likely impact negatively on carbon metabolism and respiratory activities of the bacterial strains. Since bacteria play important role in detrital breakdown and nutrient cycling, disturbances in their activity would result in general ecosystem stress.

Table 2. *Threshold inhibitory concentrations of zinc against sediment bacterial strains*

Bacteria	Inhibitory concentrations (mM)[a]		
	IC_{20}	IC_{50}	IC_{100}
Bacillus sp. SED1	0.071 ± 0.019	0.206 ± 0.030	1.442 ± 0.062
Samonella sp. SED2	0.488 ± 0.045	0.807 ± 0.066	ND
Arthrobacter sp. SED4	0.233 ± 0.023	0.273 ± 0.024	1.199 ± 0.042

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ECOLOGY OF THE RÁCKEVE-SOROKSÁR DANUBE — A REVIEW

CS. VADADI-FÜLÖP[1,]* — G. MÉSZÁROS[2] — GY. JABLONSZKY[1] — L. HUFNAGEL[3]

[1]*Eötvös Loránd University*
H-1117 Budapest, Pázmány P. sétány 1/c, Hungary
[2]*Szent István University*
H-2100 Gödöllő, Páter K. út 1., Hungary
[3]*Corvinus University of Budapest*
H-1118 Budapest, Villányi út 29-33, Hungary

e-mail: vadfulcsab@gmail.com

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Abstract. Present paper is a review on the Ráckeve-Soroksár Danube in ecological standpoint. The goal of this study is to collect and evaluate all of available publications in that conception, concerning this Danube arm. Phytoplankton, zooplankton, macroinvertebrates, vertebrates, macrophytes and also water chemistry, water management, geographical description are presented. The review comprises the main studies beginning with the earliest faunistic publications up to the recent ecological, multidisciplinary investigations. Spatial and temporal patterns likewise water quality are considered as important. Additionally checklist of aquatic invertebrate and vertebrate fauna are given based on data from literature.

Keywords: *Danube, water quality, eutrophication, composition*

Introduction

The Ráckeve-Soroksár Danube (RSD) is the second largest side arm in the Hungarian section of the river Danube, and is located between the 1642 and 1586 river kilometres (*Fig. 1.*). It is 58 km long from which 11 km belongs to the area of Budapest. It is enclosed by the two estaurine works Kvassay- and Tass sluices, therefore water level is manageable. The water surface is 14 km^2, body of water is around 40 million m^3, it can be replaced within 1,5-2,5 weeks in summer, and within 3-5 weeks in winter [18]. The current velocity is very low, 0,1-0,3 m/s. The shoreline is 120 km long, the shoreline length of the islands and side arms is 60 km, so the whole shoreline is altogether 180 km long, which is equal to that of lake Balaton [44]. The water level fluctuation is between 20-60 cm, the decline of water is between 10-30 cm [94]. The catchment area is around 1800 km^2 [87]. RSD supplied the Danube-Tisza canal, I. Árapasztó canal, Kiskunsági canal with water, moreover Gyáli creek flows into the river arm.

The aim of this work was to collect and evaluate the publications dealing with RSD in ecological conception. We felt it necessary to add some reports performed by VITUKI and KDV-KÖVIZIG and also several Internet references, as these comprise significant pieces of information which should not be ignored. However these sources are not complete. Essentially studies were discussed in chronological order. We focused on aquatic organisms, birds are not considered, on the other hand data of vertebrates, excluding fishes, is scarce. Checklist of invertebrate and vertebrate fauna is given in appendix.

So far any summary has not been written of this river section. Many investigations neglect this river arm and concentrate only on the main arm. Similar comprehensive work has been published in 1987 [19] on the Hungarian river stretch by the Little

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Hungarian Plain. The mentioned section of Danube has become great interest. IAD (International Association for Danube Research) was founded in 1956 with the goal of promoting and coordinating activities in the fields of limnology, water management and water protection in the Danube River basin [93]. Conferences have been organized regularly, special issues are available.

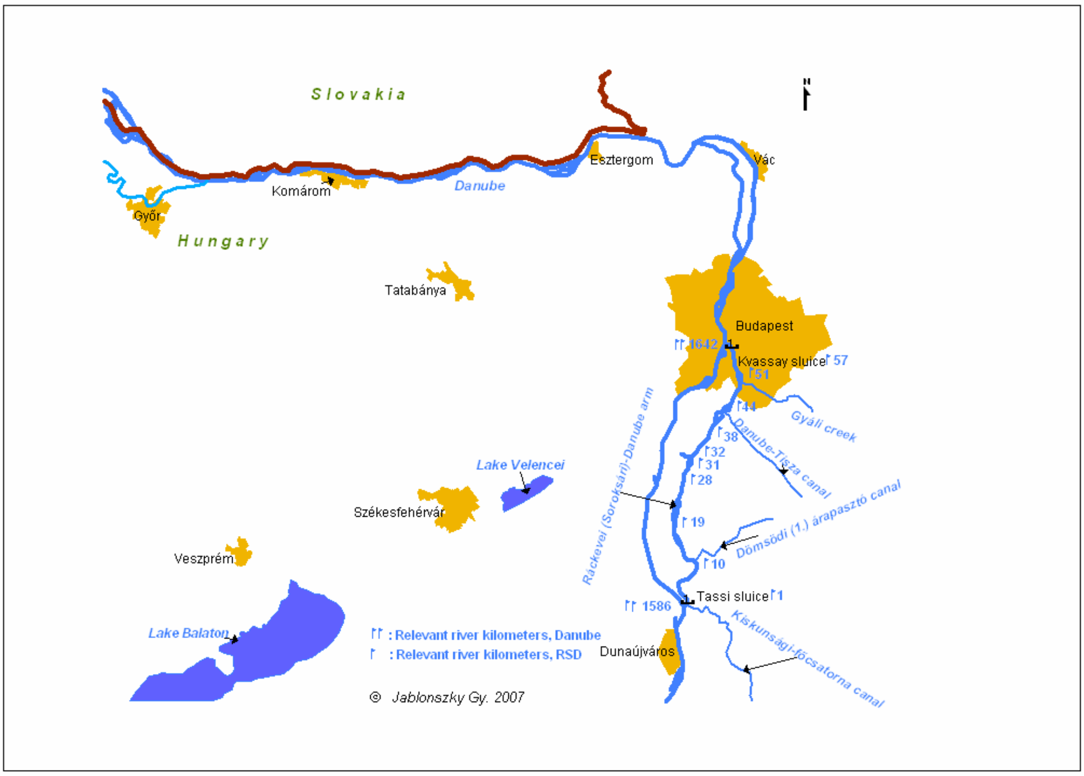

Figure 1. *Location of RSD within river Danube.*

Physical geographical summary of RSD and its area

Ráckevei (Soroksári) Danube arm (hereafter RSD) is located on there the Csepeli-sík, mostly south of Budapest, besides in north at Pesterzsébet, Soroksár and Dunaharaszti smaller segment of the arm assorts with the Pesti hordalékkúp-síkság (alluvium plain of Pest). However surveying the environment of the river arm we should consider the features of the „small-scene" Csepeli-sík.

Csepeli-sík, which is the part of the Dunamenti-síkság (plain inshore the Danube), is a juvenlie formation in geological aspect. Its momentous element is the 10-20 meter gross fluvial pebble stone strata, which had been deposited on Pannonian sediments. This strata which is able to keep huge amount of water constitutes notable pebble stone resources as well, mostly in Szigetszentmiklós, Kiskunlacháza, Bugyi, Délegyháza, Adony, Dunavarsány and Halásztelek [50]. Above the coarse-grained pebble stone and sand strata there are younger sediments of the floodplain: slobby and loamy formations on lower floodplains or rather spillage slob and sand on higher floodplains. In this surface fluvial shifting sand occurs as well [49]. Csepel island had envolved and progressed in late pleistocene and through the whole holocene. The two river arms around the island had came off in river basins determinated tectonically [36].

The elevation in the small-scene is between 95 and 168 meters and the relief parameters are allotted by a gentle north-south directed decrease of altitude, in addition a moderated gradient is noticeable towards the Danube [50]. This area is diversified by numerous abandoned river basins and quondam littoral dunes besides in east surfaces emerge of the floodplain composed by shifting sand [50].

RSD is around 56 kilometers long and its whole catchment area is 1411 square kilometers stand. Gyáli-csatorna, Duna-Tisza csatorna and Északi övcsatorna canals also empty into the RSD, where the fluctuation of water level exists smoothly, modulated artificially by Kvassay and Tassi sluices standing on the two ends [50]. Before the regulation works of RSD, the tierce amount of Danube's runoff had passed through the RSD, but nowdays the extent of runoff is only 30 m^3/s [65]. This is the main reason of continuous and relatively facile depositioning and filling up of river drift's in RSD, where the water is reasonably contaminated, chiefly in view of unclarified sewage inlet [50].

Subsoil waters avarage level is 2-4 m, however the quality of these waters frequently inadequate partly because of settlements deficient sewage systems. Underground waters standing deeper than the mentioned subsoil waters do not jar with the subsoil waters above, and there ate numerouos artesian wells [50].

RSD's area is a temperately warm, dry climated small-scene [50]. The mean annual temperature is fluctuateing between 10,2 and 10,3 ^oC and on the avarage there are 204-208 days a year without frost besides the mean temperature is above 10 ^oC through 192-194 days [50]. The tract belongs to the Hungarian Great Plane's middle (if so dry) climatic sector and the number of sunshine hours exceeds 2000 a year. [3]. The dominant direction of wind is north-western, annual amount of fall exists between 530 and 580 mm and 300-320 mm of this all totality falls on vegetation period besides usually there are 20 days a year when blanket of snow is expected [50].

The soils of Csepeli-sík show so fair variablity. In the aggregate there are 13 types of soils, nevertheless none of them measures up to 20 % of the whole territory in the small-scene. In higher surfaces we can mostly find substantial chernozem soils (frequently effected by water) besides on lower surfaces there are chiefly different types of alluvial meadow soils which graduate into clayey meadow soils in south direction [66]. In south solonchak and solonec soils are prevalent in which partly specific saline associations had come into existence.

The small-scene belongs to the Duna-Tisza közi flora provice, accordingly the following assosiations exist there: *Convallario-Quercetum roboris danubiale, Junipereto-populetum albae, Querco-robori-Carpinetum hungaricum,* besides diverse other associations are also frequent there [49]. In agricultural land corn, fodder corn and alfalfa are the main crops [50] besides in sanded soils viniculture is also occurrent.

History and division for sections

In the 19th century the Danube was split into two arms: Budafok and Soroksár arms. Neither was regarded as the main arm. The flood in 1838 was caused by the unregulated river bed, because packs evolved for the sake of the disordered, shoaly river section. Water level raised and it led to disaster. After the flood, Budafok arm was designated as main arm, Soroksár arm was enclosed with the Gubacsi dam in 1873 (located by the Gubacsi bridge) [70]. Kvassay and Tass sluices were built in the 10s and 20s. Detailed description is available in Bognár's [8] work. Kvassay power plant started up in 1962.

The subdivision began at the 60s and realization of the shoreline and islands. Between the years 1979-1985, the river bed of the upper 10 km long river section was regulated, water current capacity increased up to 50 m^3 s^{-1}. Main functions of Kvassay sluice are providing the water supply and the operational water level, additionally precluding the floods existing on Danube [94].

The Danube arm could be devided into three typical sections. The upper section (38-58 rkm) alters most dinamically that is caused by the large amounts of mud. The river bed is shallow (2-3 m) and narrow (80-200 m), that is why the highest current velocity could be observed here. However this velocity is substantially lower as compared with the Danube, which has several effects. Primarily the floating matter settles here transported from Danube and pollution is intense. Next section (22-38 rkm) is deeper and wider (average bed width 350-400 m, water depth 2,5-3 m), body of water is 16-18 $million^3$. Extended reeds and swamps are characteristic of this stretch that extends between Szigethalom and Ráckeve. The lower section (0-22 rkm), located between Ráckeve and Tass sluice, has a bed width of 300 m, and water depth of 3,5-6 m. Body of water is 20-25 million m^3 that adds up to 50-55 % of the whole water body of RSD [87]. Reeds can be found only in the narrow shore zone. Current velocity is verly low, it can be regarded as a stagnant water. Water quality is most favourable here, mostly suitable for fishing. *Fig. 2.* shows the RSD with the sampling sites, settlements and important works.

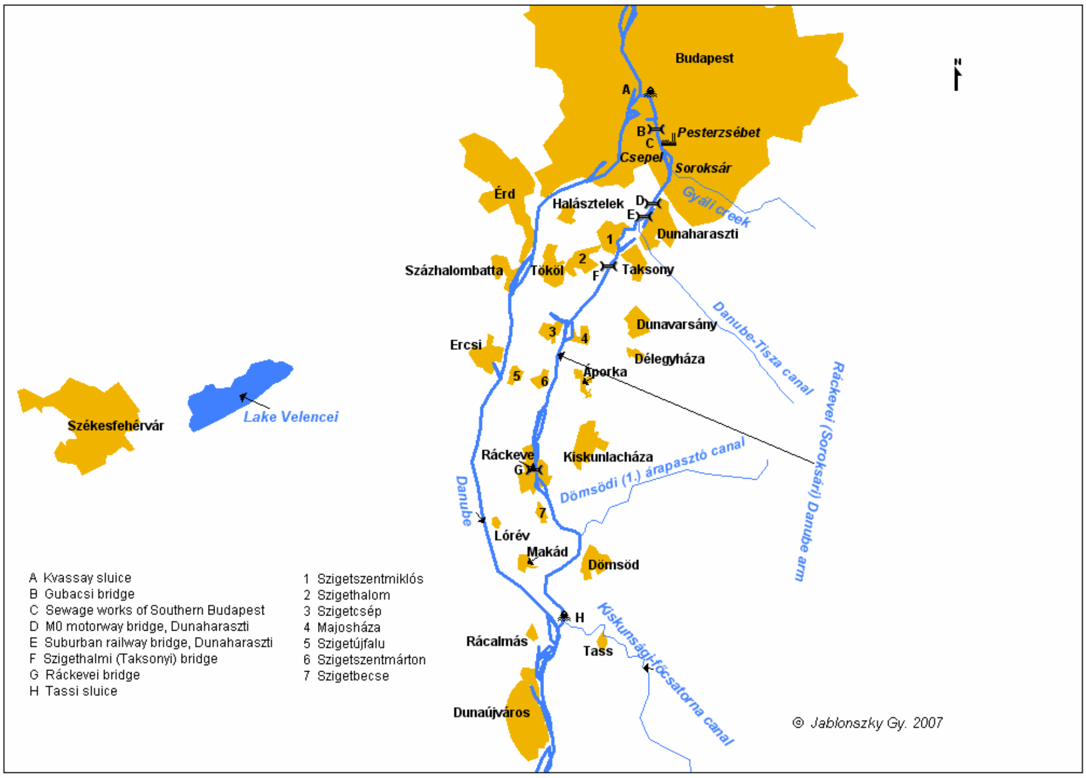

Figure 1. *Map of RSD with sampling sites, settlements, important bridges and works.*

Water management

The close position to the capital and the regulated character of RSD permit of numerous water management utilizations on RSD. Duna-Tisza canal, I. Árapasztó canal and Kiskunsági canal get water from RSD, making it possible to water several agricultural areas. Most amount of water gets the Kiskunsági canal (15 m^3/s) [94]. During the watering season (between 1th April and 30th September) water level is taken higher than during beyond the watering season (between 1th October and 31th March), but it means only few decimetres fluctuation in water level. Average runoff is taken out from Duna-Tisza canal and from I. Árapasztó canal, is 2 m^3/s during watering season. However the former takes water back to the RSD with an average 1 m^3/s runoff in case of inland waters. The side arm as water-way is of little amount in our days, shipping has been ceased. Estuarine works hold up put in and out and also swells are objectionable [89]. The large water surface, long and structured shore line, position, favourable water temperature and rich fauna adapt the Ráckeve-Soroksár Danube for recreation, aquatic sports and fishing. Concerning angling, the side arm has been one of the most significant water in Hungary for a long time [18]. The upper section is suitable for aquatic sports, middle section for fishing and lower section for fishing and bathing [68]. Many demands of exploitation exist, which are the following: watering, industrial water usage, diversion of inland waters, water for fishponds, recreation, aquatic sports, fishing and also shipping earlier [56].

Continual water input by Kvassay sluice is a deciding factor, because of the loading of wastewater, which should be diluted and mixed. By low water levels, water can not flow gravitationally into RSD, so it must be pumped by Kvassay sluice [94].

Water quality and bacterological investigations

Complex water qualtiy analysis on RSD has been started in the 50s. Lesenyei [47], and Szabó [91] described the then components of wastewaters loaded into RSD. Both chemical and biological examinations were applied to determine the effect of wastewaters. Most cases the water proved to be beta-mesosaprobic. The effect of pollution decreased explicitly at the river km 40, while at the river km 30 no effect was detectable. Most pollution came from Torontal street (at that time there was no sewage farm).

Papp [54] published water quality data concerning Hungarian surface waters based on data series of 10 years. According to the author, RSD can be characterized as follows: oxygen consumption (6,1-10 mg/l; polluted), chloride content (10,1-20 mg/l; medium), sulfate content (20,1-50 mg/l; medium), hardness (8,1-15; moderate), total dissolved solid content (201-500 mg/l; medium), Coli pollution (11-1000 ind/ml; moderately polluted respectively polluted). RSD can be characterized by a little alkaline PH [90].

VITUKI [84] made an assessment between 1963 and 1969 and pointed out, that no change in water quality set in at that period. However the content of ammonium ion and nitrate increased, which refered to the cumulative pollution. Other study performed by VITUKI in 1975 stated [85] that conductivity and toxicity did not change during the survey and are not worrying. Based on calculations, nutrient content of wastewaters in itself, is sufficient for eutrophication in RSD.

Schiefner and Urbányi [64] took samples from the river arm in 1966-67. Dissolved oxygen content was on the average 10,8 mg/l, value of total hardness was14, sulfate content ranged between 20-50 mg/l. After the water quality assessment method of Papp [54], water was moderately polluted up to Majosháza and clean up to Tass based on Coli pollution, whereas moderately polluted based on organic matter content.

In terms of bacterial pollution RSD was devided into two parts after Ulrich et al. [76]: above and below Majosháza. The river stretch above Majosháza is much more polluted. Wastewater creates no effect below Majosháza, the capacity of self-purification is due to the slow current velocity.

Némedi et al. [52] took samples from the river arm in the years 1979-1980. They compared their results with the state existed in 1953 and stated, that the bacterological pollution have not changed substantially between 1953-1980. The decreasing number of wastewaters loaded into RSD have made a temporary improvement in water quality at the beginning the 60s, but data published between 1969-1974 showed that the river arm is overloaded. Bacterological pollution is higher in RSD in the range of the capital, than in the main arm of Danube under Budapest (dilution of wastewater in Danube is 157-fold, while in RSD only 32-fold). Conditions for self-purification of RSD is more unfavourable as compared to the Danube, because of the current velocity, dilution, toxicity and oxygen supply conditions.

Varga et al. [77] published water quality data between 1980-1984. According to the writers, water quality problems occur twice in a year. First in winter, when ice covers the water, self-purification process slows down and oxygen deficiency sets in, secondly in late summer, when algal blooms occur (oft 50 million ind/litre). The ice cover period takes approximately 40-50 days long. Above mentioned problems indicate, that the loadability of the river arm has been reached its limits.

After Dévényi [18], water quality of RSD is determined by the following: water loaded from Danube, wastewaters, loading of inland waters and rainwaters, self-purification process, polluted mud, algal blooms. Water quality of the upper section is influenced primarily by the quality and quantity of water derived from Danube. The author analysed the water quality between 1979-1989 based on chemical and biological measurements performed by VIZIG. Total dissolved solid content was on the average between 300 and 335 mg/l, so it is in keeping with Papp [54]. Water was most polluted between Kvassay sluice and Szigethalom, under Szigethalom water quality improved gradually. Finally he stated, that the biological state of RSD has been declined to a less degree between the years 1979-1989, which manifests in the increasing level of saprobity. Based on bacterological examinations RSD was polluted respectively moderately polluted, similar to Papp's [54] results. Bathing facilities existed only at the lower river section for the sake of bacterological pollution.

In accordance with Haitman [27] self-purification of RSD is satisfying, water quality is generally adequate, excluding the upper section, whereas eutrophication and algal blooms are problematical. Occasionally oxygen deficiency occuring at dawn could be lead to perish of fishes. Diffuse pollution derived from holiday resorts should also not be neglected, furthermore canalization should be carried out. The water quality of RSD has not changed considerably between 1980-1990. Regarding some components, improvements, by others declining could be observed. Compared with the 50s and 60s, notable, favourable tendency became distinct in the case of water quality, however this tendency is not so obvious after 1980. Even so the river arm has been reached its loadability level.

Fekete et al. [21] discussed statistical methods for the analysis of water quality data with examples on the RSD. Trend analysis, autocorrelation, correlation analysis and factor analysis were added. According to the authors hydrometeorological relations, biological processes and effect of civilization should be considered when water quality is evaluated.

The Sewage treatment plant of South-Pest is the greatest source of pollution in the Danube arm, which gives 30% of the nutrient loads. However, it should be mentioned, that the nutrient content, introduced with Danube water is in itself enough to create eutrophic conditions [13]. The eutrophication process is limited by light and temperature, and not by nutrients. Reeds should be protected, the water quality of Danube should be improved and water loading should be provided from main arm to make the river status better, except that pollutants must be stopped [13]. A brief review of the protection of water quality is found in Clement's work [14].

Hollósy [30] performed trend analysis based on data collected between 1968-1993. After the author, wastewater loading is harmful mainly from the great P and N supply, which enhances eutrophication processes. Wastewaters can cause local problems, ammonium content could increase by 10-folds (10-15 mg/l), while dissolved oxygen content decreases below 1-2 mg/l. These values are toxic for fishes and also several perditions have already been. Dissolved oxygen content is higher at the lower river stretch than at the upper section, because of the phytoplankton production. Highest values of total dissolved matter (average value: 321 mg/l) is typical of the sampling site at Szigethalom. Based on data series of 25 years (1968-1993) water quality of RSD is improving, but further arrangements are needed [30].

Heavy oil pollution occured on RSD above the Gubacsi bridge in 11^{th} February 1994 [31]. A new method were developed for determining the time of pollution.

Water quality models were applied by Clement [15] on the example of RSD to describe the changes of water quality. According to Clement trophic status of RSD depends only on the meteorological and hydraulical conditions and not on nutrients. The first model has two variables: the algae phosphorus and the inorganic reactive phosphorus. Second model is constructed for eutrophication effects on dissolved oxygen, since in case of RSD the changes of the dissolved oxygen concentrations have a great importance (temporary depletion of dissolved oxygen level can lead to perishing of fish and mollusc).

Just et al. [35] dealt with comparing and co-ordinating the methods of water quality assessment used in Hungary and in Germany. In part of this study they carried out chemical, microbiological and faunistical examinations on the river Danube and on its side arm RSD. Five sampling sites were designated on RSD (after Kvassay sluice, Dunaharaszti, Majosháza, Ráckeve, Dömsöd). The evaluation of data was performed after the German standard method (DIN 38410) and after the method labored by Csányi (not published). The former method applies indicator organisms and saprobity index, latter ranged between 1-4 (S=1 oligosaprobic and S=4 polysaprobic), taxa are weighted. During the survey, saprobity index ranged between 1,8-2,3, consequently beta-mesosaprobic state existed on the examined stretch of Danube. Csányi's ASPT (average score per taxon) method assignes scores (1-10) for each taxon based on susceptibility of taxa (mainly family) to pollution. After the Hungarian ASPT value researched waters proved to be more polluted, the above-mentioned methods can not be regarded as equal. Authors recommend using of saprobity system on the Danube. Several data were also presented on RSD. Nutrient and nitrate content were similar to the Danube, whereas higher values of ammonia and nitrite could be observed in connection with the stronger wastewater loading. Bacterial pollution was in the upper section up to Dunaharaszti high, higher than in the main arm, which was attributed to the sewage farm of South Pest.

Ráckeve-Soroksár Danube is alpha-beta-mesosaprobic in most cases (S=2,3-2,8), alpha-mesosaprobic state occurs rarely, mainly in winter period at the upper river section, when self-purification processes slow down on the account of the low water temperature. Beta-mesosaprobic state exists mostly at the lower stretch demonstrating the significant self-purification of the water. Based on data series of decades can be stated, that saprobiological state has not changed, only minor spatial and seasonal changes can be observed [90]. Oxygen supply is good, which can be originated mainly in the water movements and mixing, secondly in the oxygen produced by algae. Concentration of dissolved oxygen is prominent throughout the year, but loaded with nitrogen and phosphorus compounds, which occures chiefly in winter [86]. 86% of total organic matter, 70% of total phosphorus and 75% of total nitrogen loading into RSD derive from Danube, whereas 96% of the total water body comes from the Danube at Kvassay sluice [87].

River bed sweeping is important in RSD, mainly in upper section, as silt loading from Danube settles here because of the low current velocity. Total mass of mud can be estimated around 4-17 million m^3 [87]. Mud removed with this process, has a high nutrient content, so the decreased level of nutrients slows down algal blooms and eutrophication. On the other hand deeper bed does not favour algae since light conditions are not advantageous in the deeper regions. Previous conditions are also effectual for macrophytes. Sweeping has a negligible effect on zooplankton, whereas a positive effect may have on fishes [87].

Water quality of RSD has beeing measured since 1969 by KDV KF (Environmental Authority) with a two-week frequency as the part of National Sampling Scheme of Hungary. Examinations inlude both chemical and biological parameters, samples have been taken at four sampling sites: Kvassay sluice, Szigethalom, Ráckeve and Tass. Microbiological investigations have been performed more infrequently [90, 18].

Borsodi et al. [9] carried out bacterological study in RSD (at Taksony) and Lake Velencei. Bacteria have been isolated from *Phragmites australis* to use for molecular taxonomic studies. Authors drew attention to the important role of reeds in self-purification processes and nutrient cyling in waters. On the biofilm of submerged reed surface, representatives of potentially new bacterial taxa adopted to the special environmental conditions were found besides the well-known *Bacillus* species. Submerged reed stems provide habitats for physiologically diverse groups of taxonomically closely related species [9].

Phytoplankton

The algal investigations of RSD started in the 20s [12] with diatoms, but the first detailed research dealing with algae was published in 1936 by Halász [28]. Nine-kilometre-long river section was examined with 57 samples taken from 10 sampling sites between the years 1934-1935. Vegetation was divided into 3 groups in accordance with occurrence: plankton, benthos and reed. Low abundance of planktonic algae could be observed at Kvassay sluice, whereas much more algae occured at the Gubacsi bridge (mainly diatoms). Only diatoms were found during the ice covered period. In March appeared *Oscillatoria*, *Pandorina* and *Eudorina* taxa. Highest abundance occured in summer, especially in August and September, whereas in autumn algae species disappeared gradually in accordance with the descending water temperature. In winter only *Pandorina*, *Eudorina* and *Oscillatoria* were present. Reeds were characterized by *Spirogyra*, *Zygnema*, *Desmidiacea*. Altogether 82 species and varietas have been observed. Present author examined the diatoms of the Soroksár Danube in her next work [29], she felt it necessary to investigate this group because of its high abundance. She stated that diatoms show higher individual numbers at all times as compared to other phytoplankton elements. Several species occured permanently such as *Melosira varians, Diatoma vulgare, Fragilaria crotonensis, Fragilaria capucina, Asterionella formosa, Synedra ulna, Synedra acus*. Algal blooms occured in spring and autumn (the spring abundance is higher). *Asterionella formosa* dominated in spring, while *Melosira granulata* prevailed in summer and autumn.

Next phytoplankton survey was carried out just 30 years later. Palik [53] researched the algae living on concrete stuctures. Schiefner and Urbányi [64] investigated algae within the confines of a complex survey on the Soroksár Danube. They found 157 species of Bacillariophyta, 2 species of Xanthophyta, 5 species of Pyrrhophyta, 9 species of Euglenophyta, 21 species of Cyanophyta, 6 species of Crysophyta and 87 species of Chlorophyta. It is evident that diatoms are presented in the greatest number similarly to Halász's [28, 29] results.

Bothár and Kiss [11] investigated the phytoplankton and zooplankton of RSD. Phytoplankton samples were taken biweekly troughout the year 1983. They compared their results to the achievements of Schiefner and Urbányi [64] and concluded that the individual numbers are much greater in 1983 than were in 1970. The dominance of diatoms could also be observed, especially the Thalassiosiraceae should be mentioned. Frequent species with high abundance were also *Cyclotella* sp., *Sceletonema potamos, Stephanodiscus hantzschii and S. tenuis.* During the winter period algae occured still in high abundance in contrast to Halász's [28] and Schiefner and Urbányi's [64] works. It means that the individual numbers in December (51 million ind./l) were greater than the maximum abundance (46 million ind./l) during the whole survey period observed by Schiefner and Urbányi [64]. Trophic state of RSD was found eu-polytrophic at Ráckeve throughout the year.

According to Kiss [40] the diatom family Thalassiosiraceae has a prominent role in algal blooms. Occurrence and morphological descriptions of this family are provided, extended also to the Soroksár Danube between Dunaharaszti and Ráckeve. Because of the small size of these species using of electron microscope is considered important.

Kiss and Genkal [41] examined phytoplankton blooms in river Danube and in its side-arm. Authors drew the attention to the lack of data on winter populations, because phytoplankton of large eutrophic rivers can be significant even in winter and can be an important factor in primary production. Samples were taken at Dunaharaszti and Ráckeve biweekly or at least monthly. The side-arm was often frozen and the ice was often 15-20 cm thick and was covered with snow in many cases. However ice and snow found not to be limiting factors in the development of blooms. Important factors regulating winter Centrales blooms were nutrient supply, slow water speed and high transparency. During high water periods the current speed is high and the phytoplankton composition is similar to that of the Danube, whereas during low water periods the current speed is low and phytoplankton composition and density change considerably. Characteristic species of the winter diatom blooms proved to be *Stephanodiscus hantzschii* and *S. minutus*, highest trophic values occured at Ráckeve.

Barreto et al. [2] conducted phytoplankton survey on Soroksár Danube covered with ice, in January 1997. They collected samples from the boundary of Dunaharaszti-Taksony. Abundance was much greater (11680 ind./ml) than found in the Danube, which can be originated in the high nutrient supply and transparency as well as in the low amount of suspended matter. Phytoplankton composition developed as the follows: Euglenophyta 1, Chrysophyceae 9, Bacillariophyceae 18, Cryptophyta 4, Chlorophyta 9. According to the writers, Bacteria adhered to the diatoms play an important role in the self-purification of the river.

Just et al. [35] took phytoplankton samples from the Danube and its side arm. Five locations (after Kvassay sluice, Dunaharaszti, Majosháza, Ráckeve, Dömsöd) of RSD were concerned in this survey conducted in 1996. Chlorophyll *a* content was lower in the side arm than in the main arm. A possible explanation for this was given by the writers, namely higher turbidity existed in RSD. The chlorophyll content remained relative constant along the side arm.

Szabó et al. [69] studied periphyton and phytoplankton on RSD. Samples were taken at Taksony in 1996-1997, and at Ráckeve in 1998-1999. Based on the chlorophyll *a* content of the phytoplankton the upper part of the Soroksár Danube at Taksony was oligotrophic in November and July, mesotrophic in January and eutrophic in April. The side arm was eutrophic in April and July, oligotrophic in November and January at Ráckeve. The maximum abundance was 28560 ind./ml at Taksony and 37340 ind./ml at Ráckeve. There was a correlation between periphyton abundance on old and green reed stems that is a higher abundance on the old than the green reed stems was observed. *Eunotia arcus* showed considerable abundance at Ráckeve, which provides a new record for the side arm. This species prefers low nutrient levels, accordingly its occurrence is strange. The authors compared their results with Halász's [28, 29] results and pointed out that while diatoms were present in the highest species number in both cases, Halász found more Zygnematophyceae while they found more Chlorophyceae species. Above-mentioned phenomenon was interpreted by the lower concentration of nutrients and the lower trophic level existed in the 1930s. Additional comparison was given, that is Halász found more oligotrophic diatoms, whereas present authors found many eutrophic-tolerant species among diatoms. It is in accord with the declining water quality.

Seasonal dynamics patterns and other establishments were summarized in the year 2000 [90]. During winter months phytoplankton production is low, other organisms like bacteria, Ciliata, Flagellata can occur in high abundance, however algal blooms can also occur. In spring, with the increasing water temperature rapid algal production can evolve, and under the dominance of Centrales species eutrophic, eu-polytrophic state can be realized, which is composed by few species. Primary production declined at the end of May, phytoplankton composition changes during the summer, green algae occur in high abundance and species number. In autumn, algal abundance increases again with the dominance of Centrales species. By flood algal production decreased because of the suspended matter and lower transparency. Much oft the suspended matter settles at the upper part of RSD, so lower does not effect the phytoplankton considerably. That could be the reason for the higher algal abundance at the lower river section (at Ráckeve and Tass). Further data to the knowledge of algae can be found in other works [1, 42].

Zooplankton

In 1956 the articel of Berinkey and Farkas [5] was published, which expressly deals with plankton Crustaceans, respectively with the nutrition supply disposable for fishes. Notwithstanding that the surveys were carried out at a stretch of 2 kilometres (river km 20-22) and 3 sampling sites were designated, it counts as a fresh ground for RSD research. Present authors described 14 Cladocera species and stated that the river arm as a considerably eutrophicated water deserves top interest.

Berczik [6] reviewed the aquatic fauna of the Hungarian stretch of the Danube on the grounds of data from literature. The Soroksár Danube arm was also mentioned, but no checklist was presented for RSD, simply higher taxa were demonstrated.

Schiefner and Urbányi [64] performed also plankton surveys under complex hygiene examination of the river arm. They pointed out that the abundance of plankton organisms increased gradually from Pesterzsébet up to Tass, highest individual number was found in May. 17 Rotatoria species were identified, the water quality was beta-mesosaprobic based on saprobiological evaluation.

Bothár in her work, published in 1973 [10], analysed the zooplankton samples taken once in a fortnight, for one year, at 3 sampling sites (Soroksár, Dunaharaszti, Ráckeve). At each sampling site occured two peaks: end of May-early June respectively end of August-early September. The author set out that the upper river stretch (Dunaharaszti and Soroksár) has a similar fauna and low individual numbers as compared to the lower stretch, where more species occur and with higher abundance (abundance increased by 30-fold). Previous difference was explained by the pollution of the upper river stretch. The temporal variation of the copepod and cladoceran community was also presented. According to Bothár quantitative and qualitative differences exist among copepod and cladoceran standing stock. During the survey 38 Cladocera and 14 Copepoda species were recorded.

Gulyás and Tyahun [23] similarly investigated the Crustacea plankton of RSD, samplings conducted between May and October 1970 from four sites (Szigethalom, Ráckeve, Dömsöd, Tass). The fauna of reedgrass vegetation was examined both quantitatively and qualitatively, additionally saprobity was estimated. However the authors came to the conclusion that the saprobiological evaluation based on crustacean led to unreal notion in the RSD (oligo-beta-mesosaprobic state). 28 Cladocera, 12 Copepoda and 2 Ostracoda species were identified from samples. In accord with the results of Bothár [10] both the abundance and species number increased around the lower river stretch. In the upper river stretch by Szigethalom, which is more polluted and muddy, are living common species with high level of adaptability. The quantitative and qualitative change of the Entomostraca fauna was identical along the whole section of the river arm. Copepods occur first in the spring, their abundance decreases in summer and increases in autumn again. Contrarily cladocerans peaked in summer and autumn.

Győrbíró [26] dealt partly with cladocerans in his diploma work. Four sampling sites (Soroksár, Szigethalom, Ráckeve, Makád) were included in this research conducted between July and September. Results were compared to Berinkey-Farkas's [5] work. According to Győrbíró the abundance of plankton collected at Soroksár and Szigethalom were constantly decreasing during the survey, while at Ráckeve at first moderate then sharp increasing was followed by a sharp decreasing. It is worth mentioning the low number of Cladocera found by the writer.

Tyahun [72, 73] announced data of Copepoda, Cladocera and Ostracoda from four locations (Szigethalom, Ráckeve, Dömsöd, Tass). In addition to the checklist, seasonal dynamics was also presented, namely copepods are among the first organisms inhabiting the reedgrass, they are characterized by spring and autumn peaks, cladocerans appear later with an abundance maximum in autumn, ostracods could reach the abundance of the order of one hundred thousand in August and September.

Bothár and Kiss [11] conducted phyto-and zooplankton investigations bimonthly at Ráckeve in 1983. They found less species than Bothár in 1970-71, and no other species turned up. The formerly dominant euplanktonic *Bosmina longirostris* occured rarely just as other Cladocera species characteristic previously. Summarized the results they came to the conclusion that the Ráckeve-Soroksár Danube arm has reached the eu-polytrophic state as compared to the meso-eutrophic, eutrophic state existing in 1970-71.

Gulyás [24] examined the Rotatoria and Crustacea plankton of RSD and the main arm for one year. Rotifers were presented in the greatest abundance and also most species occured among Rotatoria. In the initial stretch of the river arm biomass and species composition were similar to the main branch, whereas 20-25 kilometres down increased the biomass notably. In the lower stretch biomass value characteristic for polytrophic stagnant water was measured.

Just et al. [35] dealt with comparing and co-ordinating the methods of water quality assessment used in Hungary and in Germany. In part of this study they carried out chemical, microbiological and faunistical examinations on the river Danube and on its side arm RSD. Five sampling sites were designated on RSD (after Kvassay sluice, Dunaharaszti, Majosháza, Ráckeve, Dömsöd). Greatest zooplankton biomass was found at Ráckeve in June. Most zooplankton species occured among rotifers, 13 species turned up only in the river arm. Difference in species composition between the main brach and branch was interpreted by the different rate of flow (the lower stretch of the RSD has a character of stagnant water).

The qualitative and quantitative changes of Rotatoria and Crustacea plankton in the river Danube was published by Gulyás [25]. In this survey took part 10 researchers from different nations in order to examine the section of Danube between Neu-Ulm and Tulcea incorporating 2581 kilometres. Examinations trended not only to chemical water quality evaluation, but also following the ecological state of the water with attention, in tune with the Water Framework Directive. In the RSD high abundance and low number of species were found during the survey. Rotatoria and Crustacea species characteristic of polytrophic water bodies were presented. Present survey was also published as a summary report „Joint Danube Survey" [48].

Macroinvertebrates

Tyahun [72, 73] described the population dynamics of the mesofauna of RSD. These were the first publications concerning makroinvertebrates in RSD within the confines of a comprehensive approach, giving ecological explanations. Previously were simply fauna descriptions available considering only several taxa. The author appointed that species composition and change in abundance are mainly regulated by spatial inhomogenity, pondweed stand play second fiddle. In the lower river stretch more species were found that was interpreted by the pollution of the upper stretch similarly to Bothár [10]. The dominance of Chironomidae and Oligochaeta could be observed. 123

new species were described to the fauna of RSD, 47 species proved new to the whole section of the river Danube.

Just et al. [35] investigated the macrozoobenthos in the framework of the above-mentioned survey, 25 taxa were only found in RSD thus no occurrence in the main branch of the Danube was observed. The distribution of species among taxa in RSD was similar to the pattern observed in the main branch. The former was characterized by the presence of *Erpobdella octoculata* and the dominance of Chironomidae and Oligochaeta similarly to Tyahun's [72, 73] results. The number of taxa increased southwards.

Csörgits and Hufnagel [17] analysed similarity patterns of Heteroptera communities in the Danube. They illustrated Heteroptera communities of several habitats (also RSD) based on a database of Heteroptera. The similarity of RSD to other freshwaters based on their aquatic bug fauna can be observed.

Csányi et al. [16] summarized the results of three different surveys. From 1995 to 2001 they conducted examinations at 9 locations with sampling sites changing yearly: in the years 1995, 1996, 1998 and 2001 sampling was performed by Kvassay sluice, in 1995, 1996 and 1998 at Dömsöd, however at the backwater by Szigetcsép only in 1998. The taxa of the macroinvertebrate assembly found by the writers, are almost animals with high adaptability, characteristic of stream waters with low flow rate and with high nutrient content. Molluscs proved to be dominant, rheophyl taxa occured only occasionally. Authors drew attention to the dead arms, swamps and fens which could support numerous species new to the fauna of RSD.

Kontschán et al. [43] aimed to giving a key to identify Amphipoda species living in Hungary, concerning 12 species. The Ráckeve-Soroksár Danube arm was not mentioned, only a general description was presented of Danube living amphipods.

Bódis and Oertel [7] examined the mussels of the Hungarian stretch of the Danube included also RSD with four locations. Both faunistical descriptions and ecological conclusions were set out. From the 19 species turned up during the survey, 11 species occured also in RSD. Multivariate analysis was used to examine the connection between mussels and environmental factors. Most species favoured low flow rate.

Finally, we give the faunistical publications concerning RSD. Woynarovics [82] gave an account of the first observation of *Limnomysis benedeni* (in 1950) in RSD. Berczik [6] presented a short review of the macroinvertebrate fauna, nevertheless no checklist was added refer to the RSD. Tyahun [71] described the water mite (Hydracarina) fauna of RSD (samples processed from four sampling sites) as well as a new species to science (*Arrenurus dudichi*). However later previous species proved to be identical with *Arrenurus furciger*.

Additional data to the macroinvertebrate fauna of RSD are presented in the following works: on Heteroptera Hufnagel [34], on Trichoptera Ujhelyi [74, 75], on Mollusca Richnowsky [63], Pintér et al. [57], Pintér and Szigethy [58, 59], Varga and Csányi [78], Varga et al. [79], Bódis and Oertel [7], on Odonata Steinmann [67], Benedek [4], on Chironomida Móra and Dévai [51], on Ephemeroptera Kovács [45], on Decapoda Kovács et al. [46] reported data of occurrences.

Macrophytes, shoreline vegetation

The wood types of Hungarian floodplain area of the Danube can be found in Kárpáti's work [37].

The occurrence of *Urtica kiovensis* in the Danube floodplain has been reported in Kárpáti's study [38]. Fieldwork was carried out in the year 1961. The facies of *Urtica kiovensis* was spread among the bridge at Szigethalom and Majosháza in the coastal zone of 10-30 m, up 70-120 cm water depth. Phragmition and Magnocaricion web constituted swamps, where *Urtica kiovensis* was mostly widespread. Kárpáti pointed out, that the constant water level and low current velocity made for this species possible to colonize the area.

Kárpáti [39] reviewed the vegetation of Danube concerning also RSD. Six associations are discussed concerning RSD: Lemno-Utricularietum, Wolffietum arrhizae, Hydrochari-Stratiotetum, Myriophyllo-Potametum, Nymphaeetum albo-luteae and Trapetum natansis. Wolffietum arrhizae should be emphasized since it occurs very rarely in Hungary. Characteristic species of previous association are *Hydrocharis morsus-ranae, Spirodela polyrrhiza, Riccia fluitans, Lemna trisulca, Lemna minor, Wolffia arrhiza and Ceratophyllum demersum*. Greatest magnitude has on RSD Lemnetosum trisulcae with the species *Lemna minor* and *Lemna trisulca*. Further species which are worth mentioning: *Utricularia vulgaris, Myriophyllum spicatum, Nymphaea alba, Nymphoides peltata, Potamogeton lucens, Nuphar luteum, Trapa natans, Stratiotes aloides*.

Reedgrass borders the riverside almost along the whole river section, especially at shallow parts and dead arms. Most-significant species are *Lemna minor, Spirodela polyrrhiza, Utricularia minor, Utricularia vulgaris, Trapa natans, Hydrocharis morsus-ranae*. More diverse are the associations of reedgrass rooted in water with the species *Ceratophyllum demersum, Myriophyllum spicatum, Myriophyllum verticillatum, Potamogeton pectinatus, Potamogeton perfoliatus, Elodea canadensis, Polygonum amphibium, Chara* sp.. More infrequent are *Nuphar luteum, Nymphoides peltata* and *Nymphaea alba* [90]. Reedgrass plays important role in self-purification processes, as well as it supports nutriment and resource for fishes and macroinvertebrates. However it should be mentioned that native vegetation has been disappeared in several section. Numerous holiday resorts have been built at the expense of wildlife. The shoreline is surrounded with reed (*Phragmites australis*) and bulrush (*Typha angustifolia*) in most sites [90], they have importance by straining pollutants loading from shore.

Among the associations on RSD, swamps deserve greatest attention, namely they count as rareness all over Europe. These growths have peat soil and are constituted from *Phragmites australis, Typha latifolia, Typha angustifolia, Glyceria maxima, Schoenoplectus lacustris Sphagnum* spp. and other plants. Orchids like *Dactylorhiza incarnata* and *Epipactis palustris* and infrequent moss species (*Sphagnum recurvum*, *Sphagnum squarrosum*) are also worth mentioning. Swamps play an important role in water quality, as they take up nutrients from water body and store these as peat for geological periods. This processes set back eutrophication because less nutrients are available, nevertheless they adsorb toxic metals and organic pollutants [90]. Most important swamps can be found at Dunavarsány, Szigetcsép, Szigetszentmiklós and Taksony [88].

Vertebrates

Presentation of the fishing-fish faunistic examination

Beside its role in the industry and transportation RSD is a remarkable fishing area. Consequently all scientific studies of the fish fauna in the RSD have examined the arm in respect of fish production.

In the "prehistoric" time of the RSD fisherman-tenants hired the water and they got other fisherman (paid by fish) to fish in the area. The tenancy was fixed for a certain period and the tenant's only motivation was to make profit. So there was no investment at all. In the 1930s fishing associations took over the water tenancy and from that time the RSD Arm has been a fishing area. Since 1945 the Ráckeve-Soroksár Danube Arm Fishing Associations at Ráckeve has owned the RSD. It is important to mention that there was selective fishing till 1969. In the beginning carnivorous fishes were also caught. Each year 90-120 tons of fishes were caught in the RSD between 1947 and 1950. In the history of the RSD there was a tragic event in 1953. Owing to phenol pollution in winter 90% of the fish population died out. (The Fishery at Makád was created to make up for the loss) Catchings began to grow again till the winter 1962-63 when another disaster struck: approximately 140 tons of fishes died out. They managed to make up for the loss by breeding and the quantity of catching was 60-70 tons per year. Placing pike-fish nests (1000-1500 nests belonged to the Ráckeve-Soroksár Danube Arm Fishing Associations and 250 nests were purchased was remarkable development. From 1949 they were breeding Largemouth bass for several years. In 1962 40,000 Eels and in 1970 309kg of Tenches were introduced – as an experiment – in the RSD. Nothing proves the importance of the RSD better than the fact that the RSD Fishing Association has 24,000 members and it is visited by 15-16,000 guest fishermen every year. With regard to the figures above we can see that the natural breeding – which is rather insignificant because of the present conditions of the bank - considering the great number of the fishermen is insufficient to support the fish population. So new and more fish population is required. The fish production is based on the Fishery at Makád where there are 6 pounds in an area of 91 acres and 200-220 tons of fishes can be produced every year. Most of the fishes are Carp but there are herbivorous and carnivorous species as well. In the last few years the above activity has been done according to new views. Before the 1990s only the quantity was taken into consideration. Now new aspects dominate: as the RSD is natural water we find fishery conditions created by not human but a complex ecological system. The RSD Fishing Association works based upon this fact and pays attention to the natural feautures. The association always does research and makes survey before planning their activity [95, 96]

The number of species – that has been described so far – is 54. Ten of them is very rare or is an "occasional guest" e.g. Brown trout, Rainbow trout, Goldside loach, Razorfish, Burbot. Increase in some species can be observed e.g. Mudminnow. Near the two sluices we can see mainly species that like stream (reophyl species). Eutrophisation is the reason for the dramatic increase in worthless, white fishes and for the decrease in more precious fishes such as Pike perch.

In the following we are giving a summary of the articles associated with fishing and fish fauna in the RSD.

Berinkey and Farkas published the first study of the RSD in 1953 [5]. The objective of their examination was the nutrient that was available for fishes. They analysed the gastric contents of the fishes so that they could determine which of the nutrients the Carp and the Carp bream chose. The authors found out that the nutrients of the two species above mainly came from the animals in the bank zone and the benthos. Tubifex, Chironomus and Entomostraca in the benthos were the most important nutrients of both species. So the Carp bream is the rival of the Carp in the nutrition. Only few pelagic, zooplanktonic organism were found – on average 8/50 liters of water per year. Unfortunately the authors did not show the zooplanktonic species in the samples of surface water so comparison can not be carried out based on this study. Another problem is that they examined the gastric contents of few species and in a small period of the year. So it is difficult to determine the nutrition of the fishes all around the year, especially if we take the seasonal quantity changes of the zooplanktonic and other organism into consideration.

In 1956 Woynarovich published his article [83], "What is happening to the RSD Arm?" This article is a short survey of the conditions and problems at that time in the RSD. The author says that a fish breeding association managed to make up for the loss that had occurred in spring 1954, when lots of fishes died out and owing to this disaster 3000 acres of water area destroyed. The article mentions a problem – that was current at that time – that is the Danube from below at the Tass sluice gate flooded the RSD. In such cases fishes normally move against the stream and when the water is falling, they swim with the water. But at the time of the flood fishes hibernated - were in torpor and inactive - so they were in danger of drifting with the stream. As the flood was stopped by putting stones to the sluice there was no significant loss according to the writer of the article. But he mentions that the number of bream species and other undesirable fishes – that the stream removed from their hibernaculum and drifted away – could increase.

In 1968 Horváth published his study [33] dealing with the question: How to make up for the loss that occurred during the previous decade? The article states that from 1964 each fisherman was allowed to catch 4 Pike-perches per day and had to keep them without limitation on the sizes of the fish. According to the author there was a remarkable increase in the number of carnivorous fishes but carp introduction had to be discussed. The author mentions 150 kg of fish yield per acre so according to his calculations 450,000 kg / 3000 cadastral acres per year is the fishyield (consisting of different fishes) regardless of any loss. The author thinks the half of the yield must be Carp. He adds that introduction of 225-230,000 progeny per year would be needed as practically there is no natural breeding owing to the changes of water level.

The same author studied the composition of the fish fauna [32]. In his opinion Largemouth bass – that was introduced in the '50s – would absolutely needed as it is the killer of undesirable fishes. The author describes the Prussian carp as a relatively new species that came into the RSD through pumps from Dózsa agricultural co-operative. It is important to point out that on Szigethalom island the writer of the article caught Mudminnow, Weather fish and Tubenose goby by net. According to him the Mudminnow is not so rare as it is reflected in the scientific literature.

In 1977 Ribiánszky published his study on the fishfarming features of the RSD Arm [62]. On the basis of 12 years' facts – beginning with the year of 1963 – the author studied the fish production characteristics of the RSD. According to the article – presenting several figures, charts – during 10-12 years fish production became three times and a half bigger than it had been , the catching of Carp went up by 50% and the stock of Pike-perch quadruplicated. The author thinks that that the growing number of Wels is worrying. In his opinion the reason for it is that the bigger the Wels is the more and bigger fish is needed "on the menu". On the basis of the No. 3 chart during 12 years the catchings per fisherman went up to 34.42 kg from 10.05 kg. Based on these figures the author supposes that the yield in natural water also increased. He expects 500 kg/ acre natural yield. (Author Horváth in his study - mentioned above - expected 260 kg/ acre). According to Ribiánszky the ideal composition of carnivorous fishes is the following: 50% of Pike-perch, 10% of Pike, 30% of Asp, 10% of Wels. The author explains that the number of fishermen increased dramatically and meeting higher requirements is unavoidable but it is guaranteed by the water natural supporting character. The Fishery at Makád needs to be improved though.

Veszprémi's article [80, 81] is based on a more than 200 page study. It says that the fishing – biological examination of the RSD was being carried on between the sluices Kvassay and Tass from April 1974 to March 1975. Water samples were taken in 12 regions every month. They examined the water pollution, the supply of mineral substance and organic compounds, the quantity and quality composition of phyto- and zooplankton organism, the supply of oxygen. They examined the mud pollution and the quantity of the living organism in the mud. The article reveals the results of these examinations in details. By giving a summary the article states that the results are mainly reassuring. During the 25 years before the article the water quality in the RSD had improved a lot as regards the fish physiology. The reason for it is that the toxic pollution came to an end. The examinations show that the phyto- and zooplankton quantity is twice as much than it was in the 1950's. The same applies to the quantity of the worms and insect larvae living at the bottom and in the mud. It is mentioned as a fact that because of the decreased but continuous pollution the upper third of the RSD has poorer quality than the lower water area.

Papp and Fábián [55] compare the reservoirs at Pátka and Fehérvárcsurgó, the backwaters at Kákafok, Fadd – Dombori and Alcsi island, the RSD, the lakes at Délegyháza and the Quarry lakes at Csepel. The main objective of this comparitive study was to examine the interaction of water quality, fish introduction and catching results. According to this examination the water quality is unstable and at some places it is unfavourable. During a few years previously the examination the RSD Fishing Association introduced 180-200 tons of fishes and in the authors' opinion it was really great sacrifice. The authors think that a survey of the fish fauna quantity and composition would be needed. The growing pace of different species should be studied as well.

In 1967 Rácz published the request according to which they had begun fish marking as an experiment [61]. The percentage of the marked fishes was the following: 40% Carp, 30% carnivorous – mainly Pike, Pike-perch and the remaining 30% consisted of different species mainly bream. Beside growing they also planned to examine whether fish groups develop in fresh water or not. They planned to mark 3,000 fishes.

As an extension of the previous article Fábián [20] announces the achieved results. In 1968 the catchings of the marked fishes was 11,6%, in 1969 it was 7,7%. The author believes that when fixing the most profitable average weight at the introduction, the monthly increase in weight – till the fish reaches the desired size – and the rate of the loss of the breeding animals -that have different weight- should be taken into consideration. Based on the catching results the author says that the introduction of 20 – 30 decagramme two- summer progeny is the most ideal. He concludes from the approximately 68 –78 decagramme increase in weight per year, that contrary to the introduction of 70 –80 tons at that time, the introduction could be increased to 100 –

120 tons without the danger of decrease in weight. The author believes that the facts of 2 years are not enough to come to the final conclusion.

Fish breeding in Fishery at Makád was presented in Fűrész's work [22]. Between the years 1974 and 1981 data of growth and introducing were given.

In 2003 Szent István University and the RSD Arm Fishing Association took samples upon the Association's call "Opportunities of the Carp Natural Breeding in the RSD" They carried on the examination by electronic fishing machine at Majosháza, at Szigetszentmárton, at Raffás island, in the backwater at Dömsöd, on two spots at Szigetcsép and between the 5 – 6 river kilometre mark. They examined the length and weight, analysed scale samples in laboratory. They showed 24 species in the RSD. Two species, Tubenose goby and Bitterling are protected by nature conservation. Eight species: Pike, Asp, Carp, Grass Carp, Wels, Pike-perch, Largemouth bass, Volga pikeperch were protected by size limitation. Beside protection they classified the species according to danger, ecology, life history, reproductive strategy, population in the habitat. The objective of the examination was mainly to survey the natural breeding opportunities not a comprehensive fauna study [92].

Samples were not taken at the upper section of the RSD. Consequently the described species are only for information. Nevertheless it has been the most remarkable examination in the recent years.

Amphibia, Reptilia

Besides fishes, sources on vertebrates in RSD is very scarce. Herpetological atlas of Hungary [60] contains the species living in this river arm and also gives further information of the species in question. The data base of this atlas contains altogether 16627 data distributed among 1020 10 km x 10 km UTM squares. Nine methods were used for detecting amphibian and reptile species. For the species see *Appendix*. RSD deserves increased attention because of the reptiles and amphibians living and reproducing here [90]. We have not found any publications besides the above-mentioned works.

Illustrating the publications

Fig. 3. shows the investigations carried out on RSD in temporal aspect. Only publications were included, reports were not considered. Number of studies has been increased up to the 70s, then was a small decline in the 80s. The earliest studies were algal investigations, whereas in the 60-70s most important fish, zooplankton and macroinvertebrates studies were published. In the 90-00s mainly water chemistry, phytoplankton and macroinvertebrates were favoured.

Looking at *Fig. 4.* it is conspicuous that macroinvertebrates have main interest, but it should be mentioned, that many of these macroinvertebrate surveys are only faunistic publications with data of occurrence also refer to other waters. Interestingly phytoplankton and zooplankton studies contribute 15-15%, fishes have also great magnitude in investigations.

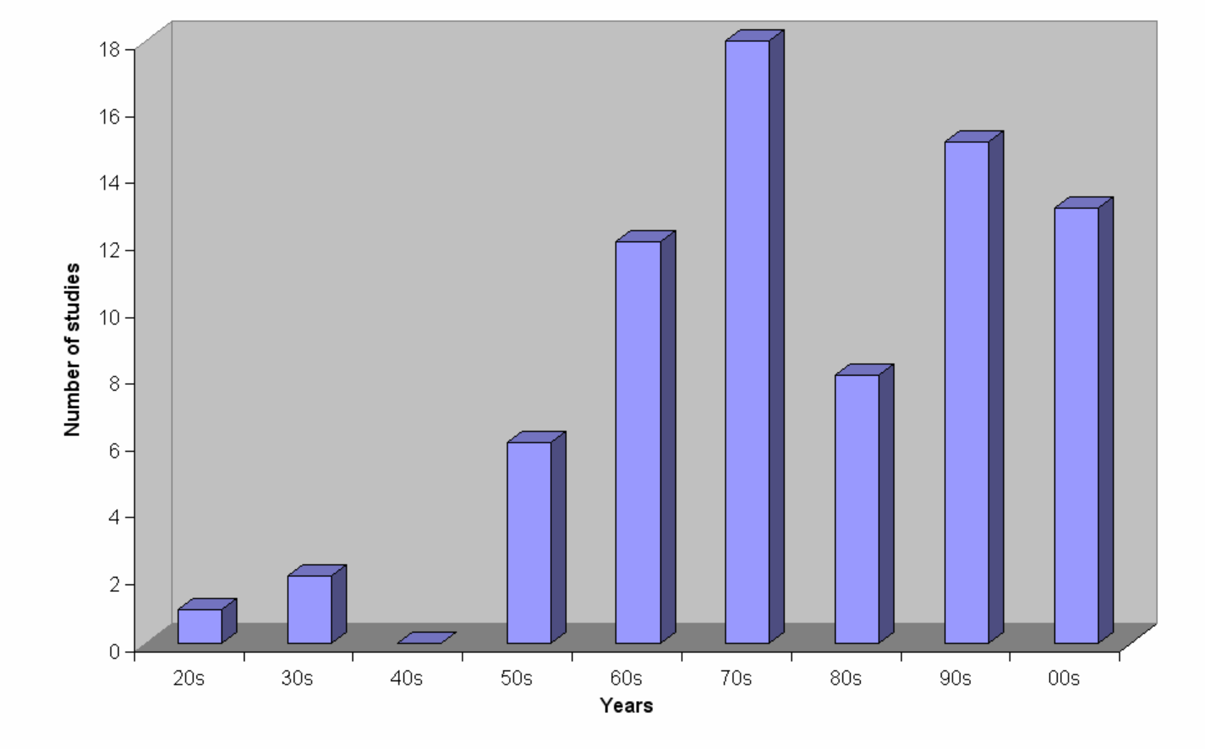

Figure 2. *Distribution of studies carried out in RSD among decades.*

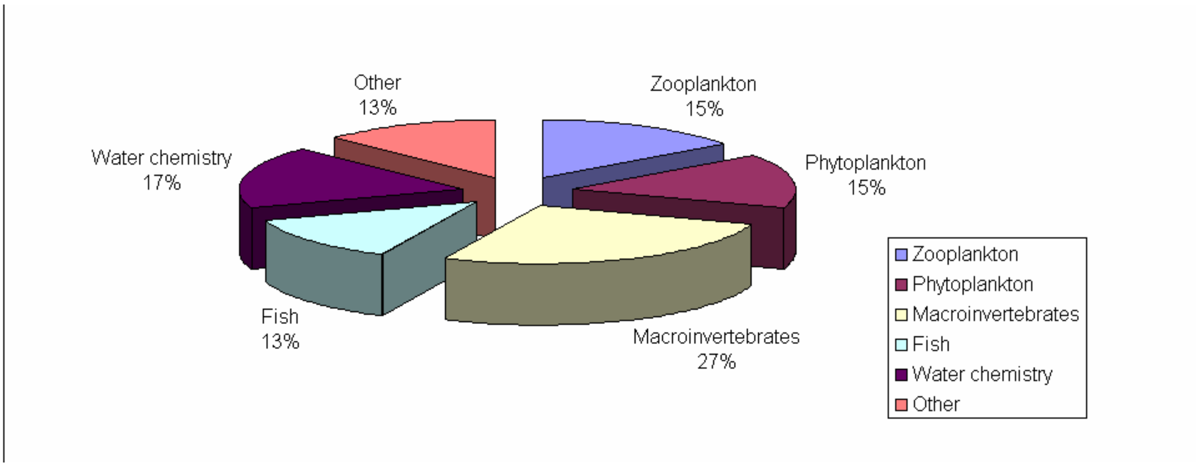

Figure 3. *Distribution of objects among studies carried out in RSD.*

Summary and future tasks

We have seen the RSD in many aspects, which from water quality is one of the most crucial. The saprobic state of RSD proved to be beta-mesosaprobic and alpha-beta mesosaprobic in most cases, alpha-mesosaprobic state occurs rarely. However spatial differences existed, namely the upper section is characterized by higher pollution due to the wastewater loading. Based on bacterological pollution only the lower section is susceptible for bathing, but not recommended at all times. The upper section is polluted, the effects of wastewaters are sensible unequivocally, however as from the lower stretch this effect ceased. Self-purification processes play an important role in the water quality. Many problems should be taken into consideration, such as eutrophication, occasional oxygen depletion, algal blooms, wastewater overloading, bacterological pollution, diffuse pollution, siltation. Long-term change in the water quality is not easy to interpret, but has been improving since the 70s, notwithstanding the situation is not so simple and requires attention.

Reeds and swamps should be protected as they play an important role in self-purification processes, whereas swamps are worthy for additional research as they are speciality of RSD.

Algal investigations pointed out that not only spring and autumn, but also winter peaks can occur and the abundance can reach the number of 50 million ind./litre. Diatoms proved to be the most important group with highest abundance. Current velocity, water level fluctuation, nutrient content and transparency found to be crucial factors affecting algal production. Trophic state was estimated in some cases (from oligotrophic to eu-polytrophic states have been observed).

Notwithstanding that more publications have been published concerning macroinvertebrates than zooplankton, the latter has been researched more detailed. The reason for this is that zooplankton surveys have been begun earlier, on the other hand many macroinvertebrate investigations have been focused on faunistic description. Several taxa of macroinvertebrates have been researched purly in RSD, expectedly new species will be described.

More research are needed from ecological point of view, spatial and temporal changes should be taken into consideration and evaluated, nevertheless comparisons should be handled watchfully. Furthermore the modelling approach lacks. Wastewater loading, diffuse pollutants should be kept in check and continuous measuring of chemical and biological components of water quality are needed. RSD deserves more attention not only for the sake of its location, recreation possibilities, manageable water level, fishery, but for the specific habitat and reach fauna and flora.

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APPENDIX

THE FAUNA OF THE RÁCKEVE-SOROKSÁG DANUBE

ROTATORIA

Ascomorpha ecaudis Perty, 1850
Asplanchna priodonta Gosse, 1850

Brachionus angularis *Gosse, 1851*
Brachionus budapestinensis Daday, 1885

Brachionus calyciflorus calyciflorus *Pallas, 1766*

Brachionus calyciflorus amphiceros *Ehrenberg, 1838*

Brachionus calyciflorus anuraeiformis *Brehm, 1909*
Brachionus calyciformis spinosus Rousselet, 1901
Brachionus diversicornis (Daday, 1883)
Brachionus leydigi tridentatus (Sernov, 1901)
Brachionus forficula Wierzejsky, 1891
Brachionus falcatus Zacharias, 1898
Brachionus quadridentatus quadridentatus Hermann, 1783
Brachionus quadridentatus brevispinus Ehrenberg, 1832
Brachionus quadridentatus cluniorbicularis Skorikov, 1894
Brachionus urceolaris (O. F. Müller, 1773)
Euchlanis dilatata (Ehrenberg, 1832)
Filinia longiseta (Ehrenberg, 1834)
Filinia terminalis (Plate, 1886)
Kelikottia longispina (Kellicott, 1879)
Keratella cochlearis cochlearis (Gosse, 1851)
Keratella cochlearis tecta (Gosse, 1851)
Keratella quadrata (O. F. Müller, 1786)
Keratella serrulata (Ehrenberg, 1838)
Lecane bulla (Gosse, 1886)
Lecane luna (O. F. Müller, 1776)
Lecane lunaris (Ehrenberg, 1832)
Lecane quadridentata (Ehrenberg, 1832)
Lophocharis salpina (Ehrenberg, 1834)
Mytilina mucronata (O. F. Müller, 1773)
Mytilina ventralis (Ehrenberg, 1832)
Notholca acuminata (Ehrenberg, 1832)
Notholca squamula (O. F. Müller, 1786)
Platyas quadricornis (Ehrenberg, 1832)
Pompholyx complanata Gosse, 1851
Polyarthra vulgaris Carlin, 1943
Synchaeta pectinata Ehrenberg, 1832
Testudinella patina (Hermann, 1783)
Trichocerca pusilla (Lauterborn, 1898)

CNIDARIA

Hydra vulgaris Pallas, 1766

TURBELLARIA

Planaria (Dugesia) lugubris (O. Schmidt, 1861)

ANNELIDA

Alboglossiphonia heteroclita (Linnaeus, 1761)
Criodrilus lacuum Hoffmeister, 1845

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Dina apathyi Gedroyc, 1916
Dina lineata (O. F. Müller, 1774)
Erpobdella nigricollis (Brandes, 1900)
Erpobdella octoculata (Linnaeus, 1758)
Glossiphonia complanata (Linnaeus, 1758)
Glossiphonia paludosa (Carena, 1824)
Glossiphonia heteroclita (Linnaeus, 1785)
Haemopis sanguisuga (Linnaeus, 1758)
Helobdella stagnalis (Linnaeus, 1758)
Hemiclepsis marginata (O. F. Müller, 1774)
Piscicola geometra (Linnaeus, 1761)
Theromyzon tessulatum (O. F. Müller, 1774)
Chaetogaster diaphanus (Gruithuisen, 1828)
Stylaria lacustris (Linnaeus, 1767)
Nais obtusa (Gervias, 1838)
Nais pardalis Piguet, 1906
Ophidonais serpentina (O. F. Müller, 1773)
Dero dorsalis Ferronniere, 1899

MOLLUSCA

GASTROPODA

Acroloxus lacustris (Linnaeus, 1758)
Ancylus fluviatilis (O.F. Müller, 1774)
Anisus vortex (Linnaeus, 1758)
Anisus vorticulus (Troschel, 1834)
Anisus septemgyratus (Rossmassler, 1835)
Aplexa hypnorum (Linnaeus, 1758)
Armiger crista (Linnaeus, 1758)
Bathyomphalus contortus (Linnaeus, 1758)
Bithynia tentaculata (Linnaeus, 1758)
Bithynia leachi (Sheppard, 1823)
Fagotia esperi (Ferussac, 1823)
Ferrissia wautieri Mirolli, 1960
Gyraulus albus (O. F. Müller, 1774)
Galba palustris O. F. Müller, 1774
HIPPEUTIS COMPLANATUS (LINNAEUS, 1758)

Lithoglyphus naticoides (Pfeiffer, 1828)
Lymnaea stagnalis (Linnaeus, 1758)
Lymnaea palustris (O. F. Müller, 1774)
Lymnaea peregra (O. F. Müller, 1774)
Physa fontinalis (Linnaeus, 1758)
Physella acuta (Draparnaud, 1805)
Planorbarius corneus (Linnaeus, 1758)
Planorbis carinatus O. F. Müller, 1774
Planorbis planorbis (Linnaeus, 1758)
Potamopyrgus jenkinsi (Smith, 1889)
Radix auricularia (Linnaeus, 1758)
Radix ovata (Draparnaud, 1805)
Radix peregra ovata O. F. Müller, 1774
Segmentina nitida (O. F. Müller, 1774)
Stagnicola turricula (Held, 1836)
Theodoxus transversalis (Pfeiffer, 1828)
Valvata cristata O. F. Müller, 1774
Valvata piscinalis (O. F. Müller, 1774)
Valvata natacina (Menke, 1854)
Viviparus acerosus (Bourguignat, 1862)
Viviparus contectus (Millet, 1813)

BIVALVIA
Unio crassus Retzius, 1788
Unio pictorum (Linné, 1758)
Unio tumidus (Retzius, 1788)
Sinanodonta woodiana (Lea, 1834)
Sphaerium corneum (Linnaeus, 1758)
Pseudanodonta complanata (Rossmassler, 1835)
Pisidium supinum (Schmidt, 1851)
Pisidium amnicum (O.F. Müller, 1774)
Pisidium henslowanum (Sheppard, 1823)
Pisidium moitessierianum (Paladilhe, 1866)
Pisidium nitidum (Jenyns, 1832)
Pisidium subtruncatum (Malm, 1855)
Dreissena polymorpha (Pallas, 1771)
Anodonta anatina (Linnaeus, 1758)
Anodonta cygnea (Linnaeus, 1758)
Musculium lacustre (O. F. Müller, 1774)

CRUSTACEA

COPEPODA

Attheyella trispinosa (Brady, 1880)
Canthocamptus staphylinus (Jurine, 1820)
Macrocyclops albidus (Jurine, 1820)
Macrocyclops fuscus (Jurine, 1820)
Eucyclops serrulatus (Fischer, 1851)
Eucyclops macruroides (Lilljeborg, 1901)
Eucyclops macrurus (Sars 1863)
Paracyclops fimbriatus (Fischer, 1853)
Cyclops strenuus Fischer, 1851
Cyclops vicinus Uljanin, 1875
Cyclops unisetiger (Graeter, 1908)
Megacyclops viridis (Jurine, 1820)
Acanthocyclops vernalis (Fischer, 1853)
Acanthocyclops robustus (Sars, 1863)
Diacyclops bicuspidatus (Claus, 1857)
Microcyclops bicolor (Sars, 1863)
Mesocyclops leuckarti (Claus, 1857)
Thermocyclops crassus (Fischer, 1853)
Thermocyclops oithonoides (Sars, 1863)
Eudiaptomus gracilis (Sars, 1863)
Eurytemora velox (Lilljeborg, 1853)
Ectocyclops phaleratus (Koch, 1838)

CLADOCERA

Alona tenuicaudis Sars, 1862
Alonella nana (Baird, 1850)
Anchistropus emarginatus Sars, 1862
Bosmina longirostris (O. F. Müller, 1785)
Bosmina coregoni Baird, 1857
Camptocercus rectirostris Schoedler, 1862
Leptodora kindti (Focke, 1844)
Sida crystallina (O. F. Müller, 1776)
Diaphanosoma brachyurum (Lievin, 1848)
Daphnia cucullata Sars, 1862
Daphnia hyalina Leydig, 1860
Daphnia longispina O. F. Müller, 1785
Disparalona rostrata (Koch, 1841)
Eurycercus lamellatus (O. F. Müller, 1785)

Graptoleberis testudinaria (Fischer, 1848)
Simocephalus serrulatus (Koch, 1841)
Simocephalus vetulus (O. F. Müller, 1776)
Moina macrocopa (Straus, 1820)
Moina micrura Kurz, 1874
Moina rectirostris Leydig, 1860
Monospilus dispar Sars, 1862
Ceriodaphnia quadrangula (O. F. Müller, 1785)
Ceriodaphnia dubia Richard, 1894
Ceriodaphnia laticaudata (P .E. Müller, 1867)
Ceriodaphnia pulchella Sars, 1862
Scapholeberis mucronata (O. F. Müller, 1785)
Macrothrix laticornis (Fischer, 1848)
Macrothrix hirsuticornis Norman & Brady, 1867
Iliocryptus sordidus (Lievin, 1848)
Iliocryptus agilis Kurz, 1878
Acroperus harpae (Baird, 1834)
Peracantha truncata (O. F. Müller, 1758)
Leydigia leydigi (Schoedler, 1863)
Chydorus sphaericus (O. F. Müller, 1776)
Pleuroxus trigonellus (O. F. Müller, 1785)
Pleuroxus uncinatus Baird, 1850
Pleuroxus aduncus (Jurine, 1820)
Pseudochydorus globosus (Baird, 1843)
Alona quadrangularis (O. F. Müller, 1785)
Alona affinis (Leydig, 1860)
Alona intermedia Sars, 1862
Alona guttata Sars, 1862
Alona rectangula Sars, 1862

OSTRACODA

Cypridopsis vidua (O. F. Müller, 1776)
Cypria ophthalmica (Jurine, 1820)

AMPHIPODA

Dikerogammarus villosus (Sovinski, 1894)
Niphargus hrabei Karaman, 1932
Orconectes limosus (Rafinesque, 1817)

BRANCHIURA

Argulus foliaceus Linnaeus, 1758

ISOPODA

Asellus aquaticus (Linnaeus, 1758)

MYSIDA

Limnomysis benedeni Czerniavsky, 1882

HETEROPTERA

Plea minutissima minutissima Leach, 1817
Micronecta scholtzi (Fieber, 1860)
Micronecta meridionalis (Costa, 1862)
Micronecta pusilla (Horváth, 1895)
Ilyocoris cimicoides (Linnaeus, 1758)
Callicorixa praeusta praeusta (Fieber, 1848)
Callicorixa concinna (Fieber, 1848)
Cymatia coleoptrata (Fabricius, 1777)
Cymatia rogenhoferi (Fieber, 1864)
Sigara falleni (Fieber, 1848)
Sigara striata (Linnaeus, 1758)
Ranatra linearis (Linnaeus, 1758)

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Gerris argentatus Schummel, 1832
Microvelia reticulata (Burmeister, 1835)
Hebrus pusillus (Fallén, 1807)
Hesperocorixa linnaei (Fieber, 1848)
Nepa cinerea Linnaeus, 1758

MEGALOPTERA

Sialis fuliginosa Pictet, 1836

ODONATA

Platycnemis pennipes (Pallas, 1771)
(Coen)Agrion puella (Linnaeus, 1758)
Crocothemis erythraea erythraea Brullé, 1832
Erythromma najas (Hansemann, 1823)
Enallagma cyathigerum Charpentier, 1840
Ischnura pumilio (Charpentier, 1825)
Ischnura elegans (Van der Linden, 1820)
Anax imperator Leach, 1815
Sympetrum striolatum striolatum (Charpentier, 1840)
Orthetrum cancellatum cancellatum (Linnaeus, 1758)

EPHEMEROPTERA

Cloeon dipterum (Linnaeus, 1761)
Caenis horaria (Linnaeus, 1758)
Caenis macrura Stephens, 1835
Caenis robusta Eaton, 1884
Potamanthus luteus (Linnaeus, 1767)

ACARI

Georgella koenikei Maglio, 1906
Hydrodroma despiciens (O. F. Müller, 1776)
Hydrachna globosa (De Geer, 1778)
Oxus strigatus (O. F. Müller, 1776)
Limnesia undulata (O. F. Müller, 1776)
Limnesia fulgida Koch, 1836
Unionicola aculeata (Koenike, 1890)
Unionicola crassipes (O. F. Müller, 1776)
Mideopsis obricularis (O. F. Müller, 1776)
Neumania deltoides (Piersig, 1894)
Neumania limosa (Koch, 1836)
Neumania vernalis (O. F. Müller, 1776)
Piona coccinea (Koch, 1836)
Piona conglobata (Koch, 1836)
Piona longipalpis (Krendowskij, 1878)
Piona pusilla Neuman, 1875
Piona variabilis (Koch, 1836)
Arrenurus abbreviator (Berlese, 1888)
Arrenurus bruzelii Koenike, 1885
Arrenurus crassicaudatus Kramer, 1875
Arrenurus globator (O. F. Müller, 1776)
Arrenurus integrator (O. F. Müller, 1776)
Arrenurus cuspidifer Piersig, 1896
Arrenurus sinuator (O. F. Müller, 1776)
Arrenurus tricuspidator (O. F. Müller, 1776)
Arrenurus furciger Viets, 1935
Eylais extendens (O. F. Müller, 1776)
Hydrozetes parisiensis Grandjean, 1948
Hydrozetes lemnae (Coggi, 1899)

TRICHOPTERA

Mystacides nigra (Linnaeus, 1758)
Stactobia eatoniella McLachlan, 1880
Cyrnus flavidus McLauchlan, 1864
Ecnomus tenellus (Rambur, 1842)
Setodes tineiformis Curtis, 1834

ARANEIDEA

Argyroneta aquatica (Clerck, 1757)

CHIRONOMIDAE

Endochironomus albipennis (Meigen, 1830)
Dicrotendipes nervosus (Staeger, 1839)
Tanypus punctipennis Meigen, 1818
Procladius choreus (Meigen, 1804)
Procladius rufovittatus (van der Wulp, 1874)
Procladius ferrugineus Kieffer, 1919
Chironomus nudiventris Ryser, Scholl et Wülker, 1983
Chironomus obtusidens Goetghebuer, 1921
Chironomus plumosus (Linnaeus, 1758)
Cryptochironomus defectus (Kieffer, 1913)
Microchironomus tener (Kieffer, 1918)
Parachironomus frequens (Johannsen, 1905)
Tanytarsus huesdensis Goetghebuer, 1923
Polypedilum sordens (van der Wulp, 1874)
Cricotopus sylvestris (Fabricius, 1794)

COLEOPTERA

Acilius sulcatus (Linnaeus, 1758)
Haliplus fluviatilis Aubé, 1836
Laccophilus hyalinus (De Geer, 1774)
Noterus crassicornis (O. F. Müller, 1776)
Noterus clavicornis (De Geer, 1774)
Hydroglyphus geminus (Fabricius, 1792)
Laccobius minutus (Linnaeus, 1758)
Limnebius nitidus (Marsham, 1802)

VERTEBRATA

PISCES

Eudontomyzon mariae Berg, 1931
Acipenser ruthenus Linnaeus, 1758
Salmo trutta m. fario Linnaeus, 1758
Oncorhinchus mykiss (Walbaum, 1792)
Esox lucius Linnaeus, 1758
Rutilus rutilus (Linnaeus, 1758)
Ctenopharyngodon idelle (Valenciennes, 1844)
Scardinius erythrophthalmus Linnaeus, 1758
Leuciscus leuciscus (Linnaeus, 1758)
Leuciscus cephalus (Linnaeus, 1758)
Leuciscus idus Linnaeus, 1758
Aspius aspius (Linnaeus, 1758)
Leucaspius delineatus Heckel, 1843
Blicca bjoerkna (Linnaeus, 1758)
Abramis brama (Linnaeus, 1758)
Abramis ballerus (Linnaeus, 1758)
Abramis sapa (Pallas, 1811)
Vimba vimba (Linnaeus, 1758)
Pelecus cultratus (Linnaeus, 1758)

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Tinca tinca (Linnaeus, 1758)
Chondrostoma nasus (Linnaeus, 1758)
Barbus barbus (Linnaeus, 1758)
Gobio gobio (Linnaeus, 1758)
Gobio albipinnatus Lukasch, 1933
Pseudorasbora parva (Temminck & Schlegel, 1846)
Rhodeus sericeus amarus (Bloch, 1782)
Carassius carassius Linnaeus, 1758
Carassius auratus (Linnaeus, 1758)
Cyprinus carpio Linnaeus, 1758
Hypophtalmichthys molitrix (Valenciennes, 1844)
Aristichthys nobilis (Richardson, 1845)
Noemacheilus barbatulus (Linnaeus, 1758)
Misgurnus fossilis (Linnaeus, 1758)
Alburnus alburnus (Linnaeus, 1758)
Cobitis taenia Linnaeus, 1758
Sabanejewia aurata Filippi, 1865
Silurus glanis Linnaeus, 1758
Ictalurus nebulosus (LeSueur, 1819)
Anguilla anguilla (Linnaeus, 1758)
Lota lota (Linnaeus, 1758)
Gasterosteus aculeatus Linnaeus, 1758
Lepomis gibbosus (Linnaeus, 1758)
Perca fluviatilis Linnaeus, 1758
Gymnocephalus cernuus (Linnaeus, 1758)
Gymnocephalus schraetzer (Linnaeus, 1758)
Gymnocephalus baloni Holcik & Hensel, 1974
Stizostedion lucioperca (Linnaeus, 1758)
Stizostedion volgense (Gmelin, 1788)
Zingel zingel (Linnaeus, 1766)
Zingel streber (Siebold, 1863)
Proterorhinus marmoratus (Pallas, 1814)
Neogobius kessleri Günther, 1861
Neogobius fluviatilis (Pallas, 1814)
Umbra krameri Walbaum, 1792

AMPHIBIA

Triturus dobrogicus Kiritzescu, 1903
Triturus vulgaris Linnaeus, 1758
Bombina bombina Linnaeus, 1761
Pelobates fuscus Laurenti, 1768
Bufo bufo Linnaeus, 1758
Bufo viridis Laurenti, 1768
Hyla arborea Linnaeus, 1758
Rana arvalis Nilsson, 1842
Rana dalmatina Bonaparte, 1840
Rana ridibunda Pallas, 1771
Rana esculenta Linnaeus, 1758

REPTILIA

Emys orbicularis Linnaeus, 1758
Trachemys scripta elegans Seidel, 2002
Natrix natrix Linnaeus, 1758
Natrix tessellata Laurenti, 1768

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APPLICATION OF AIRBORNE HYPERSPECTRAL AND THERMAL IMAGES TO ANALYSE URBAN MICROCLIMATE

ANDRÁS JUNG[1] - LÁSZLÓ TŐKEI[1] - PÉTER KARDEVÁN[2 *]

[1] *Corvinus University of Budapest, H-1118 Budapest, Villányi út 29–43. Hungary*
(Phone: +36-1-482-6272 Fax: +36-1-482-6336)

[2]*Geological Institute of Hungary, H-1143 Budapest, Stefánia út 14. Hungary*
(Phone: +36-1-251-0999 Fax: +36-1-251-0703)

e-mail: andras.jung@uni-corvinus.hu

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Abstract. Urbanisation is a long standing problem and phenomenon all around the world. It means more and more challenges for scientists. Remote sensing techniques with high spectral and spatial resolution open novel approaches which enable the analysis of vegetated and non-vegetated urban surfaces with high heterogeneity. In this paper it is demonstrated how hyperspectral images and thermal maps can be used for detecting vegetated and built-in areas in a city. Methods were collected and developed that can describe different features of urban climate and ecological state. The most important vegetation indices and urban climate parameters were calculated: red-edge position values for green places, different NDVIs, defining the role of vegetation in surface temperature carried out by masking method, urban heat island intensity, horizontal surface temperature gradient by means of Fourier-transformation and classified thermal maps.
Keywords: *urban climate, hyperspectral remote sensing, thermal images, red-edge, urban vegetation*

Introduction

The UNO [20] Report 2005 projects that 50% of the world's population, and 75% of Europe's will be living in cities by 2010. The social, environmental and economic problems caused by urbanisation will present more and more challenges for scientists.

Recent advances in remote sensing have allowed applied disciplines to bring aerial and satellite imaging to provide a helpful tool in scientific problems. There are very different materials with very different energy budgets within only a few square meters in a city.

Our main research aim was to analyse a remote-sensing database with high spectral and spatial resolution, using both published methodologies and techniques developed by us, in order to be able to help experts who are dealing with cities or urban air quality projects [13], [16], [22].

Our database gave us two directions of investigation, using both short and long wavelengths that contained at least 10 bands in the spectral region of 600–800 nm to investigate the urban environment. We therefore needed to construct a vegetation index that can consider 10 or more bands. We further needed to consider thermal bands to study differences in surface temperature within the city [1], [9], [10]. Beyond these general aims our specific goals were to determine indices that could characterize built-up urban areas on the basis of a hyperspectral data cube and thermal sensor data as follows:

- Determine urban heat-island intensity;

- Determine the horizontal urban surface temperature gradient and the "oasis-effect" of urban green spaces;
- Determine the contribution of the whole vegetated area to the temperature distribution of a city surface;
- Establish remote sensing methods (red-edge method) that can suitably characterize vegetation with a positive effect on the urban environment, and set up the statistical tests needed to confirm the relationship.

There are well-known methods to define red-edge position [2],[3];[5],[8],[15]. In our work we have carried out numerical derivation (calculating with the second derivative) on the reflectance curve at the red and infrared end of the spectrum, where the red-edge position would be determined. We did not prefer to use the linear method because of the 10 spectral sampling points [12]. Results were compared with other vegetation indices (NDVI) and surface temperature values. Questions were formed as follows:

- Is there a statistically significant relationship between red-edge position and traditional vegetation indices?
- Is there a statistically significant relationship between vegetation surface-temperature differences and traditional vegetation indices?
- Is there a statistically significant relationship between vegetation surface-temperature differences and red-edge position?

Materials and Methods

Study area

The first Hungarian aerial hyperspectral imaging programme took place within the framework of the 2002 HYSENS project. The images were taken on the afternoon of the 18th of August 2002. The images included complete coverage of the town of Gyöngyös (GPS coordinates: N 47°48.9', E 19°58.7'). This provided a suitable basis for our investigations. As the images were taken on a summer day, the longwave radiative properties of the urban surface could be observed with good results (soil temperature at a depth of 2 cm: 07:00h – 19 oC; 13:00h – 31.4 oC; 19:00h – 24.2 oC, measurements taken at the Károly Róbert College meteorologic station).

Data collection and analysis

The effectiveness of urban climate research by remote sensing depends on the properties of the camera equipment. Our images were taken using a DAIS 7915 airborne imaging spectrometer equipped with an additional thermal sensor. Its spatial resolution was 5 m. Our data base also contained topographic maps, true-colour airborne images and field surveys.

With the collaboration of the Geological Institute of Hungary (MÁFI) we were able to obtain true-colour airborne images (spatial resolution of 0,65 m) produced by Légiproject 2000 (taken in July that year) from the Institute of Geodesy, Cartography and Remote Sensing (FÖMI). We had access to EOTR topographic maps covering Gyöngyös in 1:10000 scale in two cuts (76–244 and 76–422) [11];[21].

Table 1. *Most important built-in methods used during the investigation.*

Origin of the method	**Name of the method applied**	**Database requirements**	**Explanation of application**
I. ENVI built-in function	Masking	After supervised classification of resampled NDVI images, merging the classes into two groups with values 0 and 1	To separate vegetated and non-vegetated areas
	MNF transformation	Hyperspectral image	To reduce noise-component of hyperspectral data cube
	Fourier transformation	Original thermal image	To decrease spatial variability of the original thermal image because of gradient calculation
	Image fusion	Airborne true-colour and hyperspectral image	To merge the benefits of an image with good spatial resolution and another image with good spectral resolution

Table 1 and *2* list the methods used and implemented in our work [7],[17],[18]. We have grouped procedures according to whether they were built in into the ENVI software or whether they had to be worked out to suit our aims. Descriptions and explanations are provided in column 4.

Methods with tangential bearing on our work, such as mosaic composition to join separate topographic cuts into one, are not included. Supervised classification was also applied as preparation for image masking. In Table 2 we have listed several vegetation indices that were defined in our work, each of which brought us closer to comparing the benefits of the red-edge method with various traditional vegetation indices. For our calculations we used the built-in functions of ENVI 3.6, or wrote programs in IDL where it was necessary (for instance calculating of red-edge position).

Table 2. *Most important developed methods used during the investigation*

Origin of the method	Name of the method applied	Database requirements	Explanation of application
II. Methods developed during the investigation	Vegetation index based on curve analysis: determination of red-edge position	Hyperspectral image in spectral region 600–800 nm (with 10 bands) reduced by MNF transformation	To work out a vegetation index for hyperspectral images to replace traditional, multispectral NDVI
	Traditional vegetation indices: NDVI, SAVI, NDVI(11/16), SAVI(11/16)	Hyperspectral image in spectral region 600–800 nm, reduced by MNF transformation	For comparison of new and traditional vegetation indices
	Horizontal temperature gradient	Thermal image filtered by Fourier transformation	To calculate 1 m surface temperature rate in the vegetation, at the border between vegetation and built-up area and on built-up areas
	"Heat-island" phenomenon	Original thermal image	To determine the temperature difference between the centre and the suburban area
	"Oasis" phenomenon	Thermal image filtered by Fourier-transformation	To determine how vegetation can moderate the temperature extremes on built-up areas
	Role of vegetation in surface temperature	Original thermal image, but masked	To determine how the distribution of surface temperature changes depending on plant coverage

The methods we have developed and the results obtained relate to data from a single date, because airborne images were taken on one summer day. We could investigate the spatial features of an urban environment and not its temporary changes. It is important to emphasize that the dynamic properties of cities are important as well and our methods – with some changes – could also be applied for urban change detection.

Results

Distribution of vegetation surface temperature

On the basis of field observations and true-colour airborne images, it was established that areas with large biomass like trees (height: 15–20, diameter: 10–15 m), other wooded districts with good water conditions (brook-sides) or cultivated areas with large biomass (orchards) were found to be on areas with a temperature interval of 17–19 oC in the thermal image. Areas with a temperature interval of 19–21 oC were characteristic for one-layered vegetation like football pitches, grassy parks, meadows or other grass-covered areas. Surfaces with temperatures of 21–23 oC are transition zones that are next to the vegetation but close to bare soil or built-up areas.

Intensity of surface heat island

On the basis of our calculations the built-up areas had an average surface temperature of 26 oC, the garden-city had 23 oC, and the suburb had 21 oC. From those values the heat island intensity in Gyöngyös on the 18th August 2002 was found to be 5 oC.

Horizontal temperature gradient and 'oasis-effect'

In cities it is easy to observe the "oasis-effect". Especially on hot summer days, green areas have a very valuable microclimatic effect on the artificial surfaces (concrete, asphalt) nearby. The value of the horizontal temperature gradient was an order of magnitude greater on built-up urban surfaces than on vegetated or transitional zones. For the whole analysed territory the mean surface temperature gradient was 0.015 oC·m-1.

The horizontal surface temperature gradient can be used to determine the cooling effect of vegetation as opposed to the urban effect on vegetation. We found a 0.7 oC temperature difference between vegetated and transitional zones, and a 3.1 oC temperature difference between vegetated and built-up areas. It was concluded that the gradient over the sample range (0–120 m, 121–240 m, 241–360 m) declined with increasing proximity to vegetated surface. The "oasis-effect" lowers the surface temperature values around a vegetated surface, especially on hot summer days, and the temperature distribution will be more balanced.

Temperature of urban surfaces with and without vegetation

It was observed (as illustrated on *Fig. 1*) that when an urban area was covered with vegetation and with other artificial surfaces too then 50 % of these areas were in the 19–23 oC temperature interval, but when vegetation was masked this fell to 34.3% of the classified pixels.

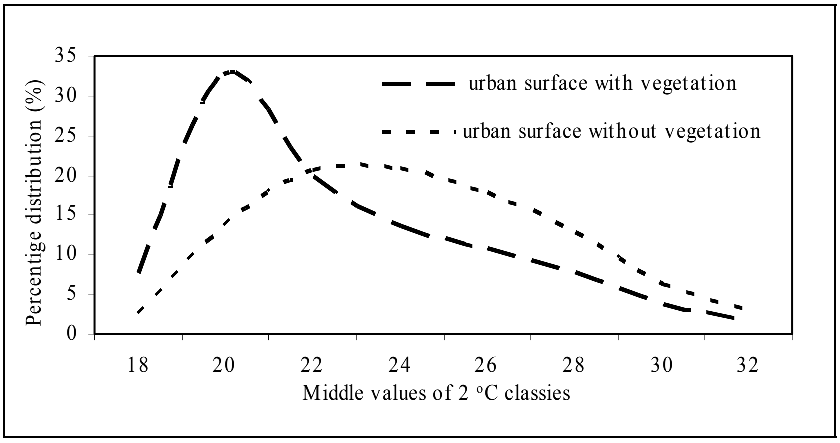

***Figure 1.** Role of vegetation in urban surface temperature distribution.*

Before masking, 7.5% of the pixels were in the 17–19 oC interval; after masking only 2.4 %. 32.8% of pixels fell into the 19–21 oC interval; masking reduced this to

13.6%. So it can be concluded that without vegetation the temperature of urban surfaces will be higher, and masking effectively demonstrates the role of vegetated areas in cities.

The statistical relationship between red-edge position and NDVI

NDVI was calculated from the red and near-infrared spectral range (600–700 nm). The relationship between NDVI values and red-edge position (hereafter: REP) was analysed (as illustrated by *Fig. 2*). It was determined that an exponential curve provides the best fit to the data. The equation given in formula (*Eq. 1*), the independent variables of which were in a bounded interval of 0.56 ≤ NDVI ≤ 0.96, and dependent variables in a bounded interval of 714 nm ≤ REP ≤ 726 nm. The equation shows that the rate of change in the NDVI index eventually outpaces that of the REP index. The indices differ to a greater extent at higher values.

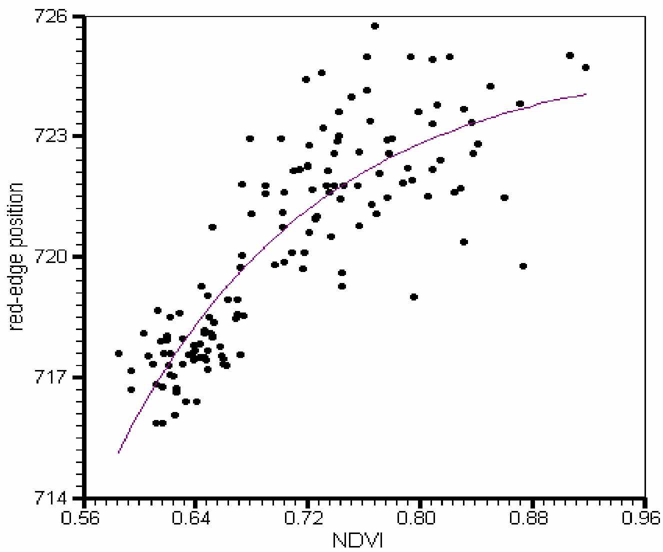

***Figure 2**. The fitted curve for the relation of NDVI and REP.*

The higher are the values of NDVI and REP, the higher is the observed variation. With NDVI values below 0.72 a linear relationship between independent and dependent variables is obtained. This relates to an area covered with one-layer vegetation such as grassy meadow, football field (NDVI < 0.76). In this case the two indices have very similar features.

$$REP = A + B \cdot EXP(-C \cdot NDVI), \quad \text{(nm)} \qquad \text{(Eq.1)}$$

where *REP*= red-edge position,
A = 725.008, *B* =-593.062, *C* =6.999,
NDVI = NDVI calculated over a broad interval.

We concluded that REP provides a better indicator for changes in vegetation properties where there are more than two spectral bands in the reflectance spectrum in the red and near infrared region. An exponential relationship [6] was also observed with other vegetation indices (NDVI(11/16), SAVI, SAVI(11/16)). (11/16) referring to bands 11 and 16 of DAIS 7915.

The statistical relation between NDVI(11/16) and the surface temperature of vegetation

During the investigation it was established that NDVI (11/16) values increase in inverse proportion to the surface temperature of vegetated areas (as illustrated on *Fig. 3*). To interpret and explain temperature changes on the surface, a variable ΔTs was introduced. This expresses the temperature difference of a given vegetated surface as compared with a reference area. In water management, it is good practice to take a cultivated grassy field as a reference. For this study a football pitch was chosen. When more transpirative and photosynthetically active layers are above each other within a canopy then the energy absorbed by plants can moderate the surface temperature of the canopy due to transpiration. While the whole canopy is involved in this process, the result can only be observed on the surface because the remote sensor measures only the surface temperature.

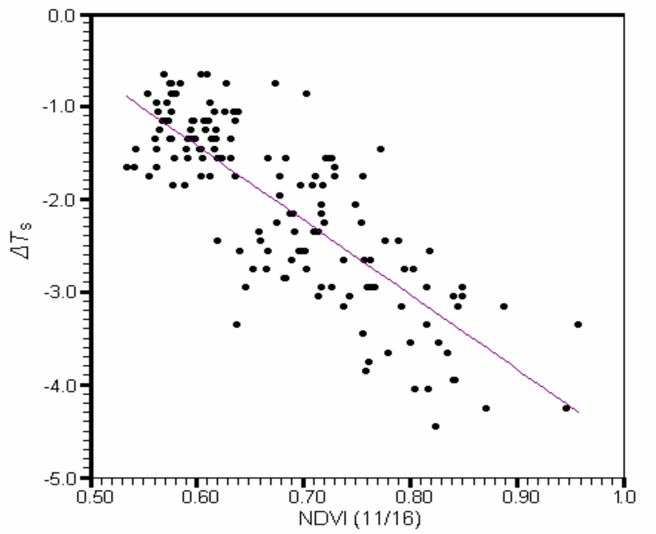

Figure 3. *The fitted curve for the relation of NDVI(11/16) and ΔT_s.*

According to the statistical results the NDVI(11/16) values determine on (R) 81 % the values of surface temperature of vegetation with a confidence level of 95 %. The best fitting curve was a linear function. The equation given in formula (2) has independent variables in a bounded interval of $0.5 \leq$ NDVI(11/16) ≤ 1.0, and dependent variables in a bounded interval of $-5.0 \leq \Delta Ts \leq 0.0$ K. Values of NDVI(11/16) are valid for the time of investigation and for a given phenological state.

$$\Delta T_S = A \cdot \mathrm{NDVI}(11/16) + B\,, \qquad \text{(Eq. 2)}$$

where ΔT_s = temperature changes compared to reference,
$A = -8.036$, $B = 3.400$,
NDVI(11/16) =NDVI calculated from bands 11 and 16 of the DAIS 7915.

The statistical relationship between REP and the surface temperature of vegetation

We have investigated the relationship of REP to ΔTs. The surface temperature of the canopy is influenced by transpiration on all the leaf cover, while vegetation indices are determined by the water and chlorophyll content detected in the canopy surface at a macroscopic (canopy geometry) and microscopic (cellular) level. It is important to remember that only the surface and its physiological features can be observed by remote sensors.

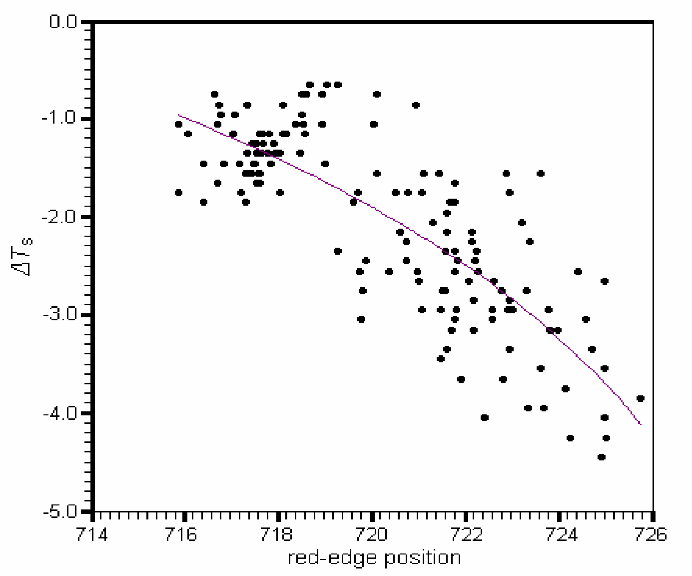

Figure 4. *The fitted curve for relation of REP and ΔT_s.*

According to our results, one- and multi-layer canopies can be distinguished on the basis of REP values. REP values of less than 720 nm are characteristic of homogenous, one-layered vegetation (grassy fields) and REP values greater than 720 nm are typical for multi-layered wooded canopies (height: 15–20 m, diameter: 10–15 m) on the area investigated. One of our most important results was the exploration of the relationship between REP and canopy surface temperature changes (as illustrated on Fig. 4). The comparison can be qualified by the kappa-index and error matrix widely used in remote sensing. The question was whether the spatial clusters of the REP values can be successfully fitted to spatial clusters of surface temperature changes.

It must be mentioned that grassy and homogenous, one-layer vegetation (height < 10–15 cm) can be separated with high probability from tree-canopies (height 15–20 m, diameter: 10–15 m) on the basis of REP and ΔTs maps. With these two classes we have calculated the error matrix and kappa index. The reference was the ΔTs map, as such a detailed and spatially accurate thermal map can be established by remote sensors only. The overall accuracy was found to be 91.24% and the kappa index was 0.81. We found these values encouraging. The implication is that an REP map can be used to deduce surface temperature changes at the same pixel with a probability of 91 %. The curve of best fit for the relationship between REP and ΔTs is a logarithmic function.

The equation given in formula (3) has independent variables in a bounded interval of $714 \leq REP \leq 726$ nm, and dependent variables in a bounded interval of $-5.0 \leq \Delta Ts \leq 0.0$ K. The correlation coefficient (R2) was 0.65.

$$\Delta T_s = A + B \cdot \ln((C - REP)/D) \,, \qquad \text{(Eq. 3)}$$

where ΔT_s = temperature changes compared to reference,
A = -2.559, B = 2.861, C = 730.706, D =8.500 ,
REP= red-edge position.

With higher REP values (REP> 720 nm) the surface temperature changes (ΔTs) were larger than changes in REP values since the whole surface of a tree canopy is always larger than the outward surface of the same canopy as compared to grassy fields. The cooling effect is correspondingly greater for trees than for grassy land.

Discussion

Experts dealing with urban and landscape planning should make use of new remote-sensing and environmental monitoring technologies to make better, faster and more effective decisions. End-users need easy-to-use graphical solutions. We conclude that REP provides a better index than NDVI, when we have more than two spectral bands in the red and near-infrared fragment. Developments in remote sensing will allow us to introduce new methods for analysing urban vegetation.

It can be assumed that REP is a better indicator than NDVI if there are more than two bands to analyse. We have two recommendations that can help experts dealing with canopy climate or biophysics.

- If a thermal map covering a vegetated area is available, but its spatial resolution is insufficient, then the spatial resolution can be enhanced using a high-resolution vegetation index map derived from the red and near-infrared spectrum. The thermal image may be sharpened using image fusion.
- As discussed above, if thermal image data is not available, temperature changes can be estimated by calculating REP values for the area in question. Several ecological and biophysical models take the surface temperature of the canopy into consideration, yet detailed thermal information is not always available. This problem can be alleviated by this method.

Remote sensing and GIS form part of an involved decision-making process [4];[14],[19]. Of course, whether stakeholders and decision-makers want to benefit from their use is another question. On the basis of our results, we would like to deliver spatial decision-making systems that can be deployed in urban climate planning and urban green-space design to optimise human comfort, and resolve special and general problems of urban ecology and urban green area systems.

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SUITABILITY ASSESSMENT OF SHALLOW GROUNDWATER FOR AGRICULTURE IN SAND DUNE AREA OF NORTHWEST HONSHU ISLAND, JAPAN

B.K. MITRA[1*] – C. SASAKI[2] – K. ENARI[3] – N. MATSUYAMA[2] – M. FUJITA[3]

[1]*The United Graduate School of Agricultural Sciences, Iwate University, Morioka, 020-8550, Japan*

[2]*Faculty of Agriculture and Life Science, Hirosaki University, Hirosaki, 036-8560, Japan.*

[3]*Tohoku Institute of Technology, Sendai, Japan*

e-mail: bijonmitra75@yahoo.com

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Abstract. Groundwater quality is an inevitable factor for sustainable agriculture as a source of irrigation water. Therefore, the study was conducted in an irrigated sand dune area of northwest Honshu island in Japan to evaluate the groundwater quality for irrigation. Three observation wells were installed in the investigated field made of polyvinyl chloride (PVC) pipe with three plastic tubes to collect groundwater of 2.0 m, 2.5 m and 3.0 m. The sampling was performed every month from January to November, 2005. Assessment of groundwater quality was performed on the basis of total dissolved solids (TDS), concentration of sodium (Na), calcium (Ca) and magnesium (Mg), sodium absorption ratio (SAR), total hardness (H_T) and concentration of phosphate phosphorus (PO_4-P). Total dissolved solids in groundwater was ranged between 145.5-249.4 mg l^{-1} during the investigation period, revealed that irrigation using groundwater of the study area would not cause salinity hazards. Concentrations of Na, Ca, and Mg were decreased with depth throughout the investigation period. The average concentration of Na and SAR value were 18.8 mg l^{-1} and 0.81, respectively. Since groundwater of the study area contained low concentration of Na with low SAR values, there would not be any possibility of sodium hazards from irrigation using groundwater. On average groundwater of the study area contained 27.5 mg l^{-1} Ca and 9.35 mg l^{-1} Mg, which might contribute to moderate hardness of groundwater in the study area.
Keywords: *Groundwater quality, irrigation, sand dune area, Honshu island.*

Introduction

Groundwater is globally important for human consumption, crop production and industrial usages. The natural state of groundwater is generally of excellent quality, although harmful concentrations of certain ions such as iron and sodium, which can occur naturally and lead to problems [6].Groundwater quality is the physical and chemical characterization of groundwater, which measures its suitability for human and animal consumption, irrigation and other purposes. The quality of groundwater reflects inputs from the atmosphere, from soil and water-rock weathering, as well as from pollutant sources such as mining, land clearance, agriculture, acid precipitation, domestic and industrial wastes. As a source of irrigation water, it influences crops yield, physical and chemical properties of soil, development of the best management practices.

Groundwater contains a varying amount of different kinds of ions. Among them, the major cations are Ca, Mg and Na, which influence the suitability of groundwater for human consumption, agricultural irrigation and other purposes. Some of these cations are beneficial to crop production at expected concentration, otherwise cause toxicity to plants, affect properties of soil and management practices. Bohn *et al.* reported that the concentrations of ions in irrigation water are particularly important because some crops are susceptible to these elements at high concentrations [4]. In a previous study Prunty *et al.* reported that soil properties, crop yield and quality will be deteriorate if low quality water is used for irrigation [12]. Irrigation water with high total dissolved solids (TDS) value results in salinity hazard which cause loss of crop production. Salinity causes the plant to loose energy for extracting pure water from saline water and lack of energy results in reduced crop growth and yield. On the other hand, high sodium absorption ratio (SAR) of irrigation water associated with sodium hazard [13]. Salts from the irrigation water accumulated in the soil profile may deteriorate properties of soil [1].

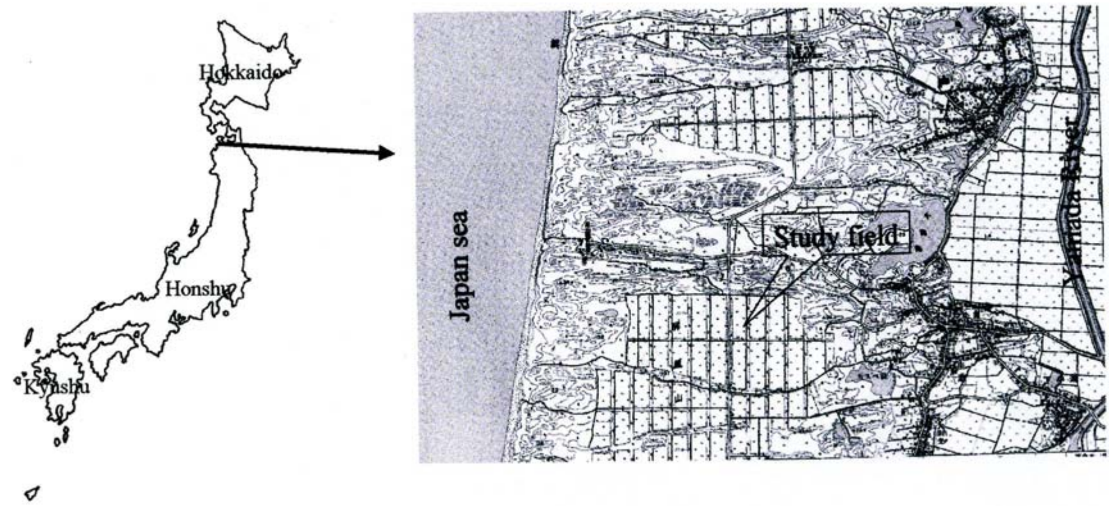
Phosphorus is of environmental concern because excess amount in water bodies may cause eutrophication. On the basis of diffusion studies, Olsen and Watanabe reported that there was an eight times greater risk of phosphate pollution of ground water from sands than from clay [10].

Shallow groundwater quality of sand dune area in Aomori prefecture of Japan is an inevitable factor not only for crop production but also conservation of water bodies and surrounding environment. Mitra *et al.* studied the groundwater quality of this area in various aspects such as pH, electrical conductivity (EC), dissolved oxygen (DO), concentration of iron (Fe), potassium and nitrate nitrogen (NO_3-N) and the results indicated that values for all parameters would not have any threat to agricultural management practices and surrounding environment except high Fe concentration [9]. As the soil characterized with light textured, the sand dune area of Aomori has the greatest risk of contamination in groundwater from anthropogenic activities which may deteriorate groundwater quality and also contribute to eutrophication of Japan Sea. In order to develop the best management practices for sand dune area, well designed detail data are needed on groundwater quality. Therefore this study was initiated to assess the suitability of groundwater as irrigation in sand dune area of northwest Honshu island.

Materials and Methods

Study area

An agricultural field was selected in Tsugaru city of Aomori Prefecture (northwest Honshu island) for the purpose of this study which is located approximately at 40055′ N latitude and 140019′ E longitude with an elevation of 29 m above sea level and about 2.1 kilometers away from Japan sea (*Fig. 1*). Geology of the study area is shown in *Fig. 2* [5]. Usually the farmers of the study area cultivate the crops from April to November. Because of heavy snowfall in winter most of the fields become fallow. Wheat, radish, melon, shallot, Chinese yam, watermelon, burdock, potato, tobacco, garlic, asparagus, pumpkin, leek, and carrot are main cultivated crops of the study area. Percentage of total cultivated areas covered by different cultivated crops are shown in *Table 1*. Crop fields are irrigated by overhead sprinkler irrigation system using water of Yamada river in the study area except melon field where drip irrigation system is used. Irrigation water quality of the study area is shown in *Table 2*. The recommended fertilizer doses for this sand dune area are shown in *Table 3*. Monthly total precipitation and average temperature of the study area are shown in *Fig. 3*. The soil of this area is characterized by sand. Some physico-chemical properties of soil of the investigation field are shown in *Table 4*.



Map of Japan

Figure 1. *Location of the study area in northwest Honshu Island.*

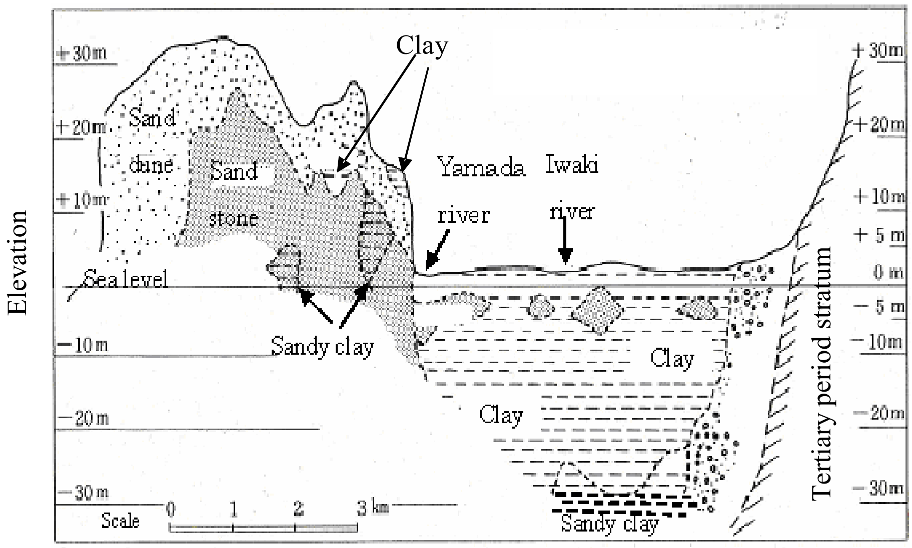


Figure 2. *Cross section of the study area showing geology [5]*

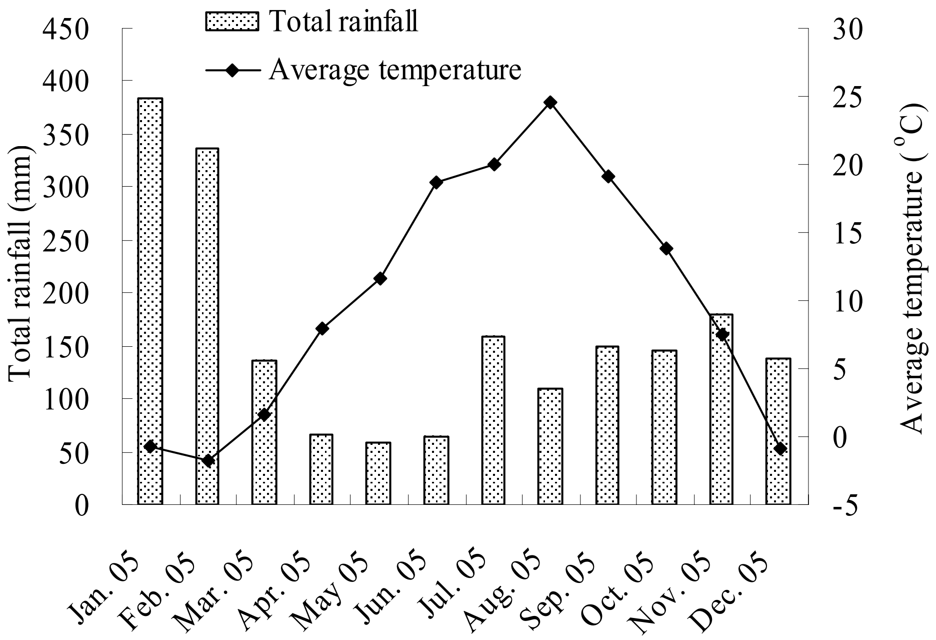


Figure 3. *Monthly total precipitation and average temperature of the study area.*

Sample collection

Three observation wells were installed in the investigated field made of polyvinyl chloride (PVC) pipe to collect the groundwater samples. In every well three plastic tubes with 5 mm diameter were installed to collect the groundwater sample from 2.0 m, 2.5 m and 3.0 m depth. The sampling was performed every month from January to November, 2005. First groundwater was pumped by syringe to rinse the pipe and syringe, and thereafter samples were collected in plastic containers. The samples were then immediately transported to the laboratory of Hirosaki University, Japan, and kept refrigerated until chemical analysis was carried out.

Table 1. *Percentage of total cultivated area covered by different crops in the study area, 1996-2005*

Crop	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
	%									
Wheat	26.1	26.3	24.9	23.3	17.8	18.0	20.0	19.3	13.9	15.7
Radish	26.2	21.1	21.4	22.0	21.2	19.5	17.6	18.7	11.1	11.1
Melon	11.3	10.4	9.1	8.2	7.8	6.4	6.3	4.6	5.7	5.0
Shallot	0.1	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Chinese yam	7.6	10.2	12.0	12.3	8.7	11.9	13.9	16.0	18.4	18.8
Water melon	3.2	2.7	2.1	2.3	2.5	2.7	2.4	2.3	2.3	2.2
Burdock	5.9	5.2	5.0	6.2	5.5	5.3	5.8	7.2	7.9	8.0
Tobacco	1.9	1.7	2.1	2.2	7.9	2.1	2.6	2.5	3.0	3.2
Potato	2.4	4.0	2.6	2.6	3.2	3.9	4.2	3.0	2.7	2.9
Garlic	0.1	0.6	0.4	0.7	1.3	2.2	1.7	1.9	2.6	3.5

Asparagus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.8
Pumpkin	1.3	1.8	2.6	2.5	2.3	2.6	2.8	4.9	4.8	3.1
Leek	7.7	7.8	9.3	9.4	9.7	7.3	7.7	7.7	7.5	7.1
Carrot	1.4	0.5	0.5	0.8	1.2	1.1	1.0	1.6	1.7	1.9
Others	4.8	7.4	7.9	7.3	10.9	17.1	14.1	10.3	18.2	16.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Groundwater quality analyses

The water samples were analyzed for total dissolved solids (TDS), sodium (Na), calcium (Ca), magnesium (Mg) and phosphate phosphorus (PO_4-P). TDS was measured according to Atekwana et al. [2]. The concentrations of Na, Ca, and Mg were determined by using atomic absorption spectrophotometer (Z8200 Hitachi, Tokyo,

Table 2. *Irrigation water quality of the study area,2005*

Month	pH	EC ($dS\ m^{-1}$)	DO	Fe	Na	K	Ca	Mg	SAR	Ca:Mg
			$mg\ l^{-1}$							
July,05	7.25	0.37	3.90	1.20	41.40	15.00	12.95	5.25	2.44	2.47
August,05	7.24	0.22	5.50	2.20	40.90	9.40	14.00	5.25	2.36	2.67
September,05	7.08	0.26	4.50	1.30	34.30	7.70	10.78	4.90	2.17	2.20
October,05	7.44	0.34	6.00	1.00	50.80	10.40	12.47	6.79	2.86	1.84

Table 3. *Recommended fertilizer rate for some agricultural crops in study area.*

Crops	N	P_2O_5	K2O
	$kg\ ha^{-1}$		
Wheat	140	120	100
Radish	200	220	200
Burdock	250	250	250
Melon	130	200	120
Water melon	130	200	120
Potato	170	233	170
Chinese yam	330	238	330
Leek	300	300	300

Table 4. *Physico-chemical properties of soils in study field.*

Texture	Porosity (%)	ρ_b[1] ($Mg\ m^{-3}$)	ρ_p[2] ($Mg\ m^{-3}$)	pH	Exchangeable Cations (meq. $100g^{-1}$ soil)			
					Na	Ca	Mg	K
Sand	44.86	1.48	2.68	6.36	0.36	3.06	0.43	0.32

[1]*Bulk density;* [2]*Particle density.*

Japan). PO_4-P was measured by using NP autoanalyzer in every month. Sodium absorption ratio (SAR) and total hardness (HT) values were computed from the estimated values of Na, Ca and Mg ion concentrations using the following formulae of Todd [15] and Sawyer and McCarty [14], respectively:

$$SAR= [Na^{+}] /\{([Ca^{2+}]+[Mg^{2+}])\}^{1/2} \quad \text{(Eq. 1)}$$

$$HT = Ca^{2+}\times 2.5+Mg^{2+}\times 4.1 \quad \text{(Eq. 2)}$$

Results and Discussion

Total dissolved solids

Total dissolved solids is the concentration of a solution as the total weight of dissolved solids which express the degree of salainity in a medium. TDS of groundwater was differed with depth (*Fig. 4*). On average the highest TDS value 215.27 mg l^{-1} was observed at 2.0 m depth followed by 2.5 m depth and the lowest value was observed 184.93 mg l^{-1} at 3.0 m depth. The value for TDS of groundwater was decreased with soil depth might be due to slow rate of vertical diffusion of solutes in groundwater. The results indicated that groundwater of the study area was fresh water since water with 0-1000 mg l^{-1} TDS values is classified as fresh water [7].

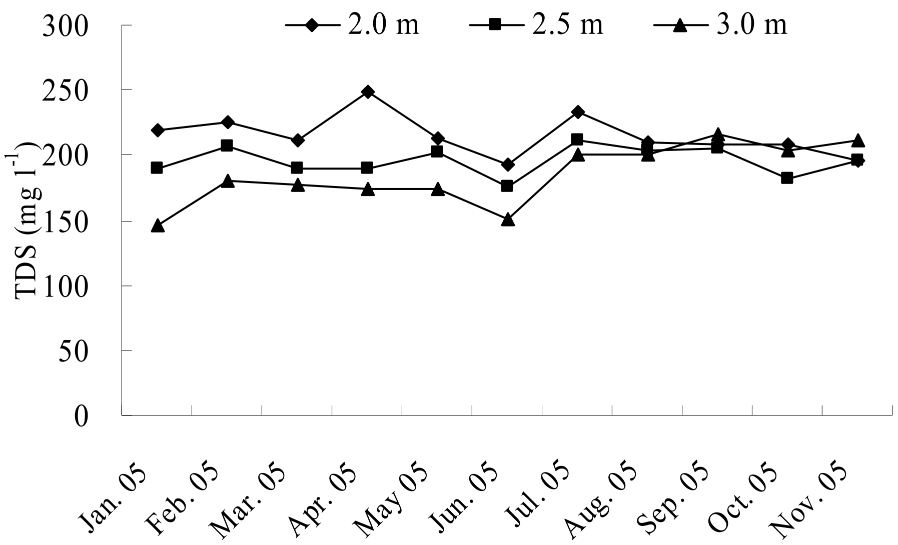


Figure 4. *Total dissolved solids in groundwater at different depth.*

Sodium

Sodium in irrigation water is of concern due to it can deteriorate soil properties and induce leaf burn in sensitive plants at high concentration [3]. Sodium concentration in

groundwater was decreasing with increasing the depth throughout the investigation period (*Fig. 5*). On average the highest sodium concentration (23.15 mg l^{-1}) was observed at 2.0 m followed by 2.5 m and the lowest (14.43 mg l^{-1}) was observed at 3.0 m. The groundwater of the study area is suitable for sprinkler irrigation since, water with <3 me l^{-1} Na has no restriction to use for sprinkler irrigation [3]. Water of Yamada river was used as a source of irrigation which contained 41.85 mg l^{-1}Na, whereas Na concentration in river water of Japan range from 6.70 to 10.60 mg l^{-1}[16]. So it can be assumed that irrigation water from Yamada River might play a vital role as a source of Na in groundwater.

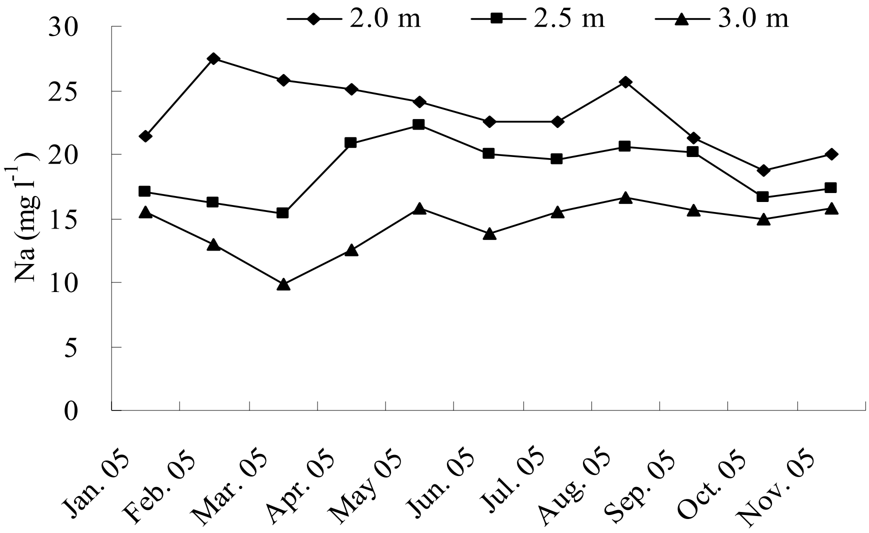


Figure 5. *Sodium concentration in groundwater at different depth.*

Calcium

Irrigation water containing a high proportion of soluble calcium may form scale inside the irrigation component [11] and form scale like deposits on plant parts when overhead sprinkler irrigation system is used [8]. Calcium concentration was varied in groundwater with depth. The highest Ca concentration was observed at 2.0 m depth and the lowest was at 3.0 m depth throughout the investigation (*Fig. 6*). On average the highest Ca concentration (43.91 mg l^{-1}) was observed at 2.0 m whereas the lowest (15.82 mg l^{-1}) was observed at 3.0 m. Groundwater of the study area is suitable for irrigation since usual range of Ca in irrigation water is 0-20 me l^{-1} [3].

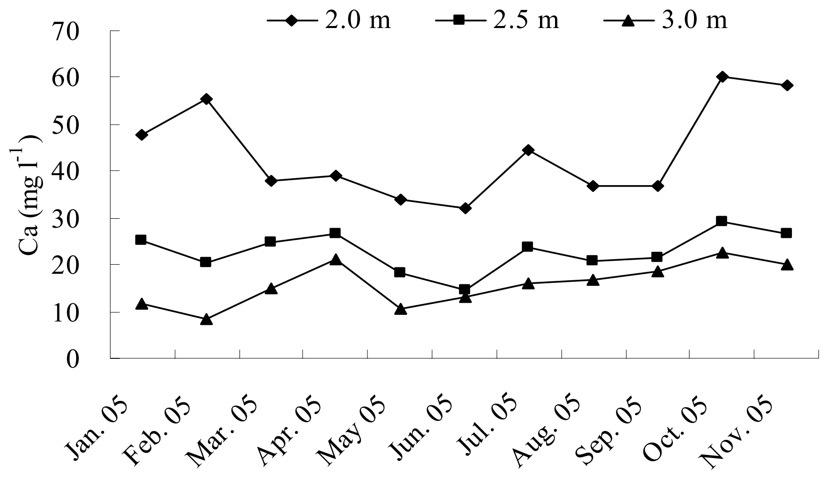


***Figure 6**. Calcium concentration in groundwater at different depth.*

Magnesium

Magnesium is a important element in groundwater which may reduce the crop yield by inducing Ca deficiency at high concentration of Mg [3]. Magnesium concentration in groundwater was varied at different depth (*Fig. 7*). The highest Mg concentration values were observed at 2.0 m depth followed by 2.5 m depth and the lowest values were observed at 3.0 m throughout the investigation period. On avergae the highest Mg concentration (11.56 mg l^{-1}) was obseved at 2.0 m and the lowest (6.83 mg l^{-1}) was obseved at 3.0 m. The usual range of Mg in irrigation water is 0-5 me l^{-1} [3]. So, It can be assumed that groundwater of the study area would be suitable for irrigation.

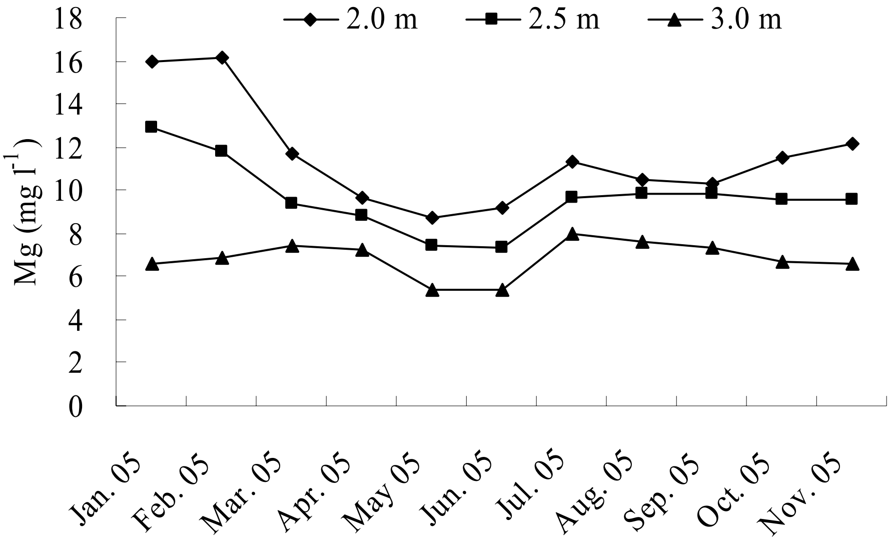


***Figure 7.** Magnesium concentration in groundwater at different depth.*

Sodium absorption ratio

Sodium absorption ratio is the measurement of sodium content relative to calcium and magnesium in soil-water medium which influences soil properties and plant growth. Sodium absorption ratio of groundwater in the study area was observed with in a range of 0.52 to 1.10 (*Fig. 8*). Therefore, the groundwater of the study area is excellent for irrigation since irrigation water with <10 SAR is classified as excellent quality [15]. On average comparatively high SAR values were observed during irrigation period (April-August) than fallow period of land. Yamada River was used as a source of irrigation which contained averagely 41.85 mg l^{-1} Na [9] whereas, Na concentration in river water of Japan range from 6.70 to 10.60 mg l^{-1} [16] and on the other hand comparatively low Ca concentration was observed during that period (*Fig. 6*). On average the highest SAR (0.84) was observed at 2.5 m depth followed 2.0 m and the lowest (0.77) was observed at 3.0 m.

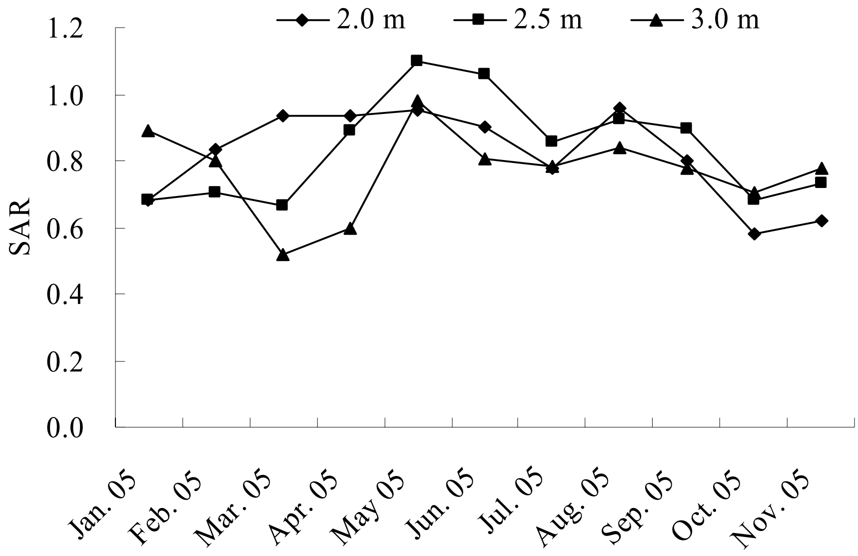


Figure 8. *Sodium absorption ratio of groundwater at different depth.*

Total hardness

Total hardness of water is a measure of dissolved Ca and Mg in water expressed as $CaCO_3$. Total hardness of groundwater in the study area was differed with depth. The highest values of total hardness were observed at 2.0 m depth followed by 2.5 m depth and the lowest values were observed at 3.0 m depth during the investigation period (*Fig. 9*). It might be due to that the highest concentrations of Ca and Mg were at 2.0 m followed by 2.5 m and the lowest were at 3.0 m (*Fig. 6* and *Fig. 7*). On average the highest HT (157.22 mg l^{-1}) was observed at 2.0 m and the lowest (67.61 mg l^{-1}) was observed at 3.0 m. Average HT of groundwater in the study area was observed 107.20 mg l^{-1}. Results indicated that groundwater of the study area can be classified as moderately hard since water with hardness of 75-150 mg $l^{-1}$is moderately hard water [14].

Ratio of calcium and magnesium

Ratio of Ca and Mg in groundwater of the study area was varied with depth. The highest values for Ca and Mg ratios were observed at 2.0 m depth during the investigation period (*Fig. 10*). On average the highest Ca and Mg ratio (3.83) was observed at 2.0 m and the lowest (2.32) was at 3.0 m. Magnesium dominated irrigation water (ratio of Ca/Mg < 1.0) may increase the potential effect of sodium and induce the Ca deficiency [3]. So the results indicated that groundwater of the study area would be suitable for irrigation since ratio of Ca and Mg in groundwater was always >1.0.

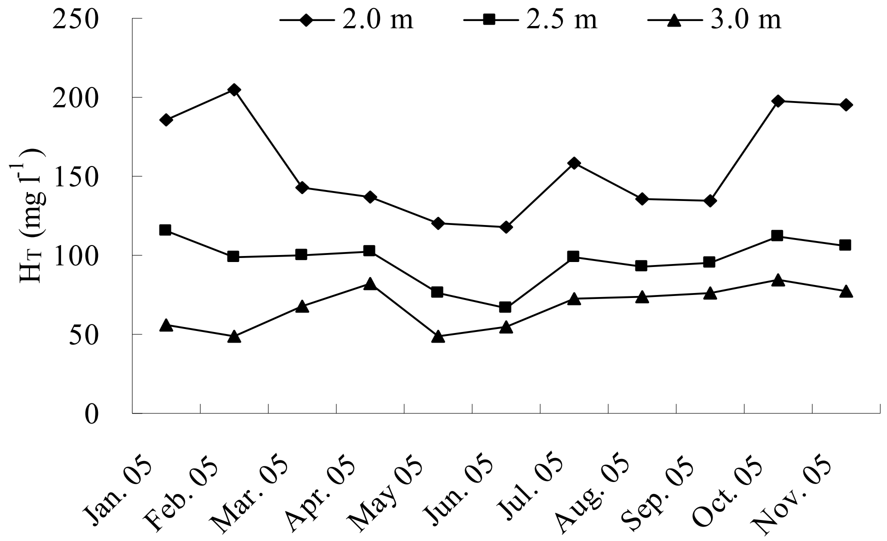


Figure 9. *Total hardness of groundwater at different depth.*

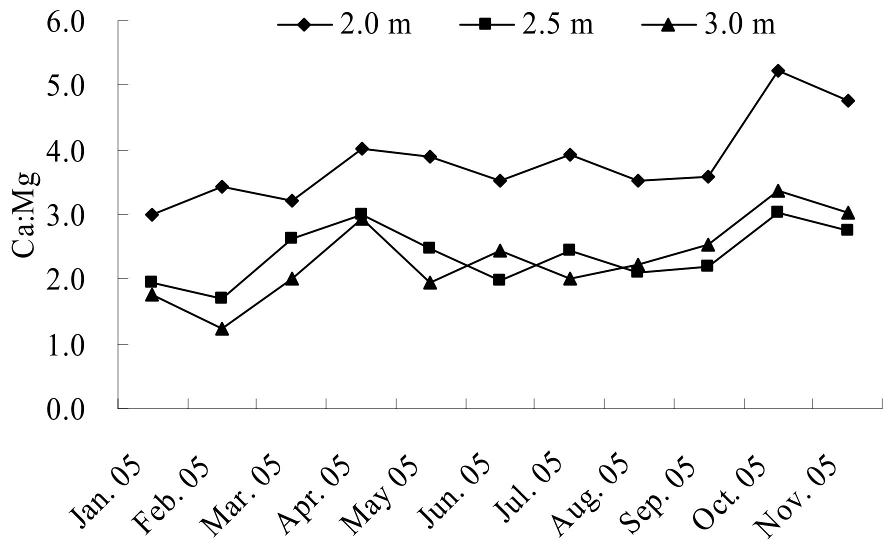


Figure 10. *Ratio of Ca and Mg in groundwater at different depth.*

Phosphate phosphorus

Phosphorus is a soluble agricultural chemical that may be moved from point of application by surface run off or move out of the soil surface layer with percolation. Phosphate phosphorus concentration in ground water of the study area was varied with depth (*Fig. 11*). In average the highest PO_4-P concentration (0.058 mg l^{-1}) was observed at 3.0 m followed by 2.5 m and the lowest (0.042 mg l^{-1}) was at 2.0 m. Our findings indicated that groundwater of the study area would be suitable for irrigation as usual range of PO_4-P concentration in irrigation water is 0-2 mg l^{-1} [3].

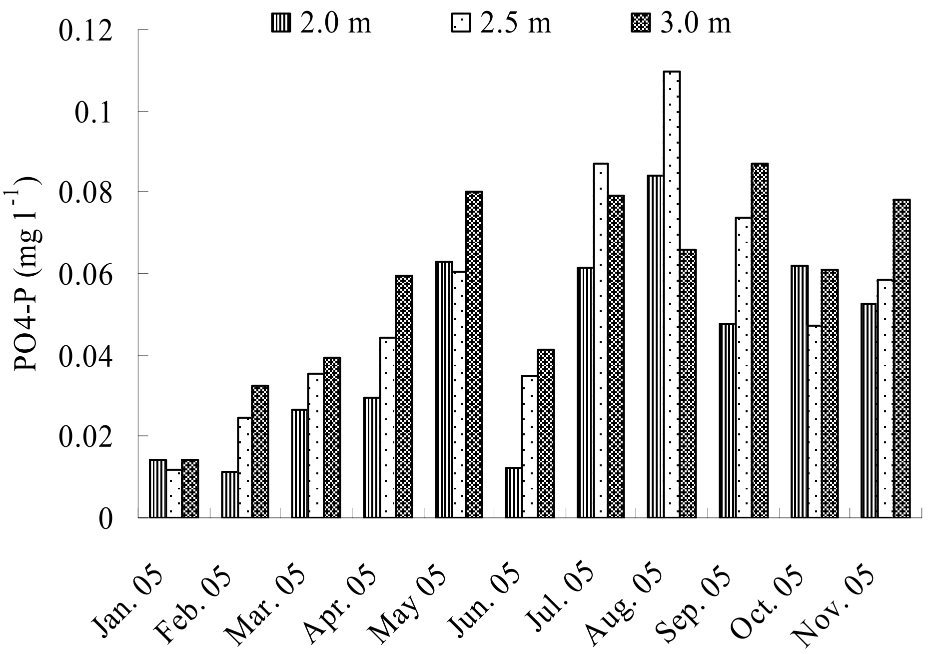


Figure 11. *Phosphate phosphorus concentration in groundwater at different depth.*

Conclusions

According to the findings of this study, TDS, concentrations of Na, Ca, and Mg and total hardness in groundwater of the study area were decreasing with depth, revealed that anthropogenic activities might play a vital role for high values at upper groundwater. Groundwater of the study area contained desirable level of TDS, Na, Ca, Mg, PO_4-P and SAR value for irrigation, indicated that there would not be any possibility of salinity and sodicity hazards from irrigation using groundwater. However, groundwater of the study area was moderately hard. Since concentration of PO_4-P was very low in groundwater, there would not be any threat to eutrophication of surrounding water bodies such as Japan Sea due to PO_4-P in groundwater.

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RESOURCE OPTIMIZATION BY SIMULATION TECHNIQUE IN FOOD LOGISTICS

É. HAJNAL[1]* - G. ALMÁSY[2] – K. Kollár-Hunek[3] – G. Kollár[1]

[1]*Postharvest Department, Corvinus University of Budapest.*
H-1118 Budapest, Ménesi út 45, Hungary
(Phone:+36/20/466-5541)
[2]*Department of Process Engineering, University of Veszprém.*
H-8200 Veszprém, Egyetem u. 10, Hungary
(Phone:+36/88/624-000)
[3]*Department of General and Analytical Chemistry, Budapest University of Technology and Economics. H-1114 Budapest, Szt. Gellért tér 4. Hungary*
(Phone:+36/1/463-3174)

**Corresponding author*
e-mail: hajnal.eva@axing.hu

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Abstract. Any activity that receives inputs and convert them to outputs can be considered as a process. Essentially the same model equations are used in the theory of chemical, biochemical, nuclear, mechanical, or other process engineering. The goal of our researcher group has been to identify the processes, a network of processes, process variables and process equations in food logistics. In our paper we introduce how process building, simulation run and optimization can be carried out in a Food Distribution Centre with a message-based discrete event simulation software. We identify the parameters of the general equations of the discrete event models, with two corresponding examples. We also introduce how simulation can work as a decision supporting tool in the hand of company management, and how can a wrong decision affect the extent of air pollution coming out from cooling vehicles.
Keywords: *Food logistics; discrete event models; simulation technique; queuing, air pollution.*

Introduction

Distribution centres (DC) are important elements of the food supply chain. In a DC there are core processes which are essential for the success of an organization and additional processes. These processes together form a process network.

In business, a common goal is to optimize a system with respect to the highest amount of products using the least amount of resources and time. To find the processes to be optimized, we should do process mapping ranging over the whole organization to define and document all processes necessary for the normal operation. Connections of processes only after this mapping can be defined, as well as the process network described.

After the process network is known, the whole process can be decomposed into subprocesses, where the output of one subprocess is the input of one or more other subprocesses. It is important that every subprocess's contribution to the whole service should be measurable. This forms a distribution chain, where time-based approach is dominating. Delivery times of subprocesses related to the whole process sum up. [1]

Review of literature

We can simplify and define the core process in a DC, which shows *Figure 1.*

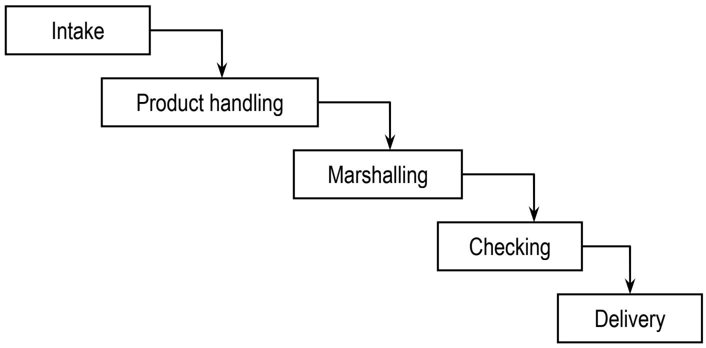

Figure 1. *Core process in a DC [2]*

The efficiency of processes can be measured with the process specific Key Performance Indicators. These indicators are very important in the case of the initial state examination and during process change monitoring. [3] Processes - defined during process mapping - should be recorded and modelled.

Modelling and simulation

In a qualified sense we can call *modelling* mathematical model building. Models are simplified versions of real life processes or systems, which enhance their relevant features. This definition shows that models can never entirely substitute real life processes. In many models, we are interested in the time required for an item to move from one end of the model to the other. Examining processes as a whole unit, one of the most important performance indicator is cycle time, which is necessary to transform inputs to outputs.

Series of experiments carried out on the constructed model is *simulation*. During simulation we simulate real life events by experimental methods. We examine the effect of different inputs, the disturbing signs upon the formed state variables, and also the outputs generally while we are seeking optimal solutions. [4]

Continuous time models can be described by functions that are continuous in their time variable. Values reflect the state of the modelled system at any particular time, and simulated time can advance evenly from one time step to the next.

Discrete event models track individual and unique entities, known as items. These items change state as event occurs in the simulation. The state of the model changes only when those events occur; the mere passing of time has no direct effect. For a discrete event model, simulated time advances from one event to the next and it is unlikely that the time between events will be equal. [5]

It is important that a system can be modelled in any number of different ways, depending on what you want to accomplish. In general, how you model the system depends on the purpose of the model: what type, level, and accuracy of the information you want to gather.

It's advisable to use such a simulation tool whose model-descriptive language can be fitted to the modeller's needs, while model running is managed by an executive system which fits the computer representation. [6]

To model a warehouse operation, we used message-based discrete event simulation software (Extend), and our own programs written for Matlab in C language, or for MS Excel in Visual Basic for Excel (VBA).

The architecture of Extend based on a messaging system. Instead of a centrally located simulation program executing subroutines based on simulation data, this architecture sends messages from one simulation block to another. The central simulation engine performs only event scheduling and selection. The bulk of the simulation execution is performed by blocks sending messages to one another. [7]

Almásy's postulates and equations of discrete process models

According to Almásy's postulates [8], processes may be described by operation models, composed processes by operation models of the subprocesses and transfer models between the subprocesses. We consider all processes possible subprocesses of a more general process, what means, it is enough to discuss process models since they include subprocess models, as well.

In general, to simulate both the operation and transfer models, the knowledge of a lot of state–property functions is needed. These functions are generally called *constitutive equations*.

Considering the food logistics processes we deal with in our paper, we restrict the following statements to the description of discrete time-process that is having discrete variables.

According to Postulate 1, actual properties of a process depending on material quality, are depending only on their actual entity content.

According to Postulate 2, actual changes of processes are depending only on the actual state of the given process.

As a corollary of Postulate 3, the sum of streams is given by the sum of connected streams in any arbitrary point of the process space, regardless of the direction of the streams.

It is necessary to take into account Postulate 6 for the model of process decomposition; it means the process should be decomposed into subprocesses of the same independent variables and those of the same time variable.

The operation model has to fulfil Postulate 9. (E.g. the operation model should be dimensionally correct.)

The solution of the composed models will be given by the time sum of the simultaneous equation system of each operation model and of each stream model, including their initial and boundary conditions. (It requires the fulfilment of ***Postulates 7 and 8***)

The operation model – of course – depends on the material properties, too, but they are considered as properties of the functions describing the model, so we don't discuss it in details. But we assume – according to ***Postulates 4 and 5*** – that the functions that connect potentials and entity contents are known one–to–one (invertible) functions.

To simulate a process, the model has to solve the following problem:

It is necessary to determine the potentials and driving forces between the connected environmental points, based on the entity content of the process and its environmental points, and then to determine the entity content corresponding to a Δt time step, using the sum of the potentials and driving forces with respect to the process variables.

Describing an operation model by its equations in a discrete process space, we have to determine the $h_j(\boldsymbol{e}_i,t)$ potentials for each $\boldsymbol{i}$ subprocess toward or from the $\boldsymbol{j}$ subprocesses and the stream rates of each $\boldsymbol{i}$ subprocess toward or from the environment denoted by $\mathbf{v}_i(t)$. Using the notation above, we get equation (1), the $\Delta\mathbf{e}_i(t)$ entity change for the Δt time step:

$$\Delta\mathbf{e}_i(t)=\left(\sum_{j\in I}\mathbf{L}_{i,j}\left(\mathrm{h}_j\left(\mathbf{e}_i(t)\right)\right)+\mathbf{v}_i(t)\right)\cdot\Delta t \quad \forall\boldsymbol{i}\in I \quad t\in T \tag{1}$$

The first term on the right side (a sum regarding all subprocesses) is defined so that the stream is zero between subprocesses having no contact, or in the case $\boldsymbol{i}$=$\boldsymbol{j}$. The entity increase of each entity component in any process space element $\boldsymbol{i}$ must be the sum of all entering–leaving streams $\boldsymbol{j}$ connected to it.

Equation (2) defines the velocity of entity-transfer between the subprocesses $\boldsymbol{i}$ and $\boldsymbol{j}$ in case of discrete-time processes having discrete process variables:

$$\mathbf{r}_{i,j}(t)=\left(\frac{\Delta\mathbf{e}_j(t)}{\Delta t}\right)_{i=const}=\left(\frac{\left(\mathbf{e}_j(t+\Delta t)-\mathbf{e}_j(t)\right)}{\Delta t}\right)_{i=const}\equiv-\left(\frac{\left(\mathbf{e}_i(t+\Delta t)-\mathbf{e}_i(t)\right)}{\Delta t}\right)_{j=const}=-\left(\frac{\Delta\mathbf{e}_i(t)}{\Delta t}\right)_{j=const}=-\mathbf{r}_{j,i}(t) \tag{2}$$

$$\forall\boldsymbol{i},\boldsymbol{j}\in I$$

As one can see, the velocity in Equation 2 is defined by the partial difference quotients of $\boldsymbol{e_i}$ or $\boldsymbol{e_j}$ with respect to the time; according to this, the dimension of **r** is entity/time. This definition contains also the fulfilling of ***Postulate 3***.

Definitions

QM	Quality Management
DC	Distribution Centre
KPI	Key Performance Indicator
AMB	Ambient
CHL	Chilled
FRZ	Frozen
WH	Warehouse
QL model	Queue length model
FIFO	First In First Out
HR model	Human Resource model
WHK	Warehouse Keeper
RTD	Reach Truck Driver
PPTD	Pedestrian Pallet Truck Driver
IPP	Income per Pallet
InPalNum	Number of pallets processed
cWHK	Cost of one WHK
WHKnum	Number of WHKs
cRTD	Cost of one RTD
RTDnum	Number of RTDs
cPPTD	Cost of one PPTD
PPTDnum	Number of PPTDs
$\mathrm{e}_i(t)$	time dependent distribution of an entity
$\mathrm{h}(\mathbf{e}_i(t))$	potential in a discrete process
$\boldsymbol{i}$ or $\boldsymbol{j}$	a discrete process variable vector
I	the set of discrete proc. variable vectors
M	the set of entities

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$\mathbf{L}_{i,j}$	entity transfer coefficient for discrete process variables
$\mathbf{r}_{i,j}(t)$	velocity of entity transfer
t	time
T	the set of time values
$\mathbf{v}_i(t)$	environmental stream vector (discr. pr.)

Materials and Methods

We modelled processes of a food distribution centre in which there are chambers for products at three different temperature ranges: ambient (AMB), chilled (CHL) and frozen (FRZ). We modelled the inbound delivery of products, transported by trucks. All products are stored on full pallets, and each chamber has the same number of docks. Warehouse (WH) operations are quite complex, hence during building process models we applied simplifications to make models more transparent, and also to shorten running times. These simplifications are not affecting the correctness of the results because the eliminated information does not bear upon high importance to the original questions of our case studies.

Queue length (QL) study

Extend model

In the first study, with Almásy's model and also with the help of Extend simulation software, we examined inbound delivery in a warehouse with the initial data detailed below. A valid question in WH daily operation is whether there is any effect on truck waiting times and queue length if ambient foodstuff can be unloaded also at possibly free chilled docks or not. We studied these two options parallel.
Incoming items:
Trucks carrying food in 3 temperature ranges (ambient, chilled, frozen), arriving in exponential distribution with the mean of 5 minutes (interarrival time);
WH/food type distribution:
50% ambient, 30% chilled, 20% frozen in random distribution;
Priority rule:
version1 QL model's trucks can dock only at the same temperature docks;
version2 QL model's AMB trucks can dock also at CHL docks when there is no CHL truck waiting in the CHL queue, while FRZ trucks can dock only at FRZ docks;

Number of docks:	5 /each WH type;
Resources:	unlimited;
Unloading time:	50 min/truck;
Run length:	24 hours;
Number of runs:	4.

Almásy's model

Entities: trucks (AMB, CHL, FRZ)
Subprocesses: waiting (1), docking (2), intake (3)
Environmental stream: arriving, leaving

- the entity-stream of leaving has no effect on the process
- the sum of entity streams from "arriving" environment is given by the exponential distribution; the individual entity streams are given by random

distribution, dividing the sum of streams into AMB, CHL, FRZ streams toward Subprocess (1)
- the Subprocesses (2) and (3) have no (direct) contact with the "arriving" environment.

The entity streams from Subprocess (1) toward Subprocess (2) are given by the FIFO queueing and in version 2 also by the special bounds for AMB.
Subprocess (3) can also be integrated into Subprocess (2) by a 40 min processing time

Human Resource (HR) study

Extend model

In our second study we examined the human resource question of inbound delivery in an ambient warehouse, and we would like to find out what is the optimal number of Warehouse-keepers (WHK), Reach truck drivers (RTD) and Pedestrian pallet truck drivers (PPTD) to reach the maximum profit.
Incoming items:
Trucks carrying ambient foodstuffs, arriving just like in the QL model (exponential distribution, mean: 5 minutes, 50% random AMB);
Priority rule:
Every worker can do his own tasks plus tasks that require less skills (high – PC knowledge, medium – RT driving license, low – PPT driving license). Administration can do only WHK, pallet intake can do RTD and WHK, and pallet unloading can do PPTD, RTD and WHK. From the resource pools, the model always chooses workers with higher skills to do valuable jobs with higher priority;
Number of docks: 5 /each WH type;
Unloading time: 90 min/(truck/worker); Administration time: 15 min/(truck/worker);
Intake time: 3 min/pallet (30pallets/truck) = 90 min/(truck/worker).
Run length: 24 hours;
Number of runs: For Almásy's model it is discussed at the corresponding model specification. For Extend model checks convergence after 50 cases and terminate if best and worst are within 0.95 level;
Objective function: Our model has parameters that are specified and shouldn't vary, while some parameters could vary and change the efficiency of the model. Because none of the parameters can be varied in our simplified model except the number of WHKs, RTDs and PPTDs, our objective function is given as follows in equation (3):

$$MaxProfit = IPP*InPalNum-cWHK*WHKnum-cRTD*RTDnum-csPPTD*PPTDnum \quad (3)$$

During optimization we varied the number of WHKs between 1 and 5, RTDs and PPTDs between 5 and 15;
Simplifications:
- Doing the same job takes the same time for any workers;
- Workers are doing their jobs only at AMB WH and only inbound delivery;
- The 24–hour run time is divided into 8–hour or 4–hour shifts with respect to the workers.

Almásy's model

Entities: trucks (AMB), Human resources (WHK, RTD, PPTD)
Subprocesses: waiting(1), docking(2), unloading(3), administration(4), intake(5)

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Environmental stream: arriving, leaving (for trucks)

- the entity-stream of leaving has no effect on the process
- the sum of entity streams from "arriving" environment is given by the exponential (mean=10 min) interarrival time, toward Subprocess (1)
- the other Subprocesses have no (direct) contact with the "arriving" environment.

The entity streams from Subprocess (1) toward Subprocess (2) are given by the FIFO queueing, and by scheduling of human resources.
The entity streams between the Subprocesses (2) → (3), (3) → (4) and (4) → (5) are given by the scheduling of human resources.

Results

Queue length (QL) study

The cooling vehicles are waiting for their turn at the parking place with working engine. Each of them acts as an individual air pollutant. With simulation experiments we would like to know how truck waiting times change in case version 1 and version 2 and whether can it cause serious overdose of air pollutants, coming from cooling vehicles or not. In this study we considered unlimited resources that can satisfy the condition keeping 50 min/truck unloading time. This unloading time value is a quite good industrial average. We investigated the effect of scheduling human resources in our second study.

Almásy's model

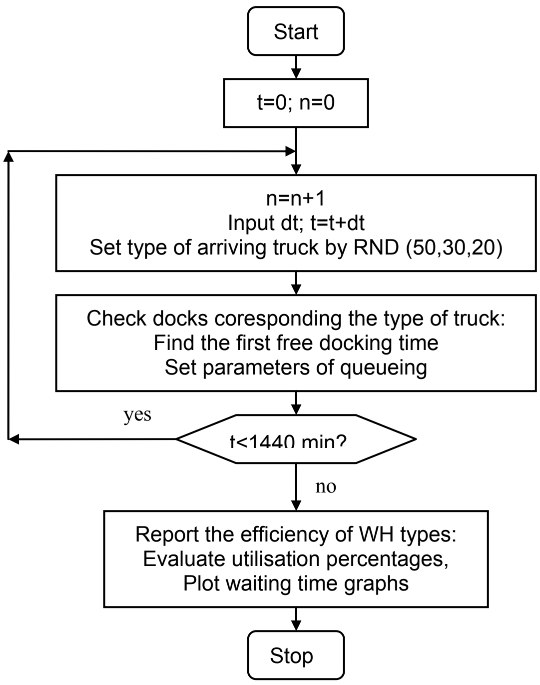

Figure 2. *Block diagram of QL model*

The block diagram for the solution of the process equations is given in *Figure 2;* some of the results are shown in *Figure 3*. Results are numerically detailed in *Table 1*

If we want to simulate more than one 24–hour–shift by this model, at the beginning of the k^{th} shift (k>1), after setting back the time variable to t=0, we have to initialise the n variable taking into account the remained trucks from the previous shift. This can be made by giving up the condition that "arriving" environment is given only by the exponential and random distribution. There is also an initial condition to each shift, namely, there are given the remained trucks to each dock together with their waiting–time vectors.

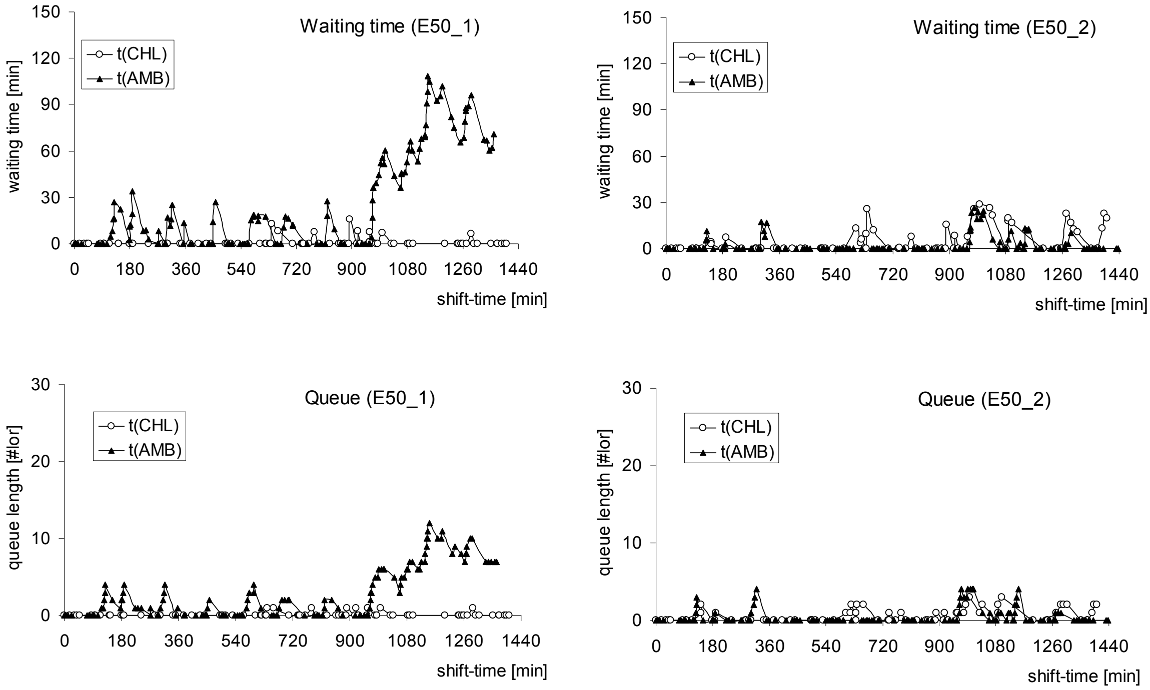

Figure 3. *Queue length and waiting time of Intake version 1 (E50_1) and version 2 (E50_2) by Almásy's model and Extend (run 1)*

Extend model

Figure 4 shows the QL model set up from blocks. The processing itself goes on at docks. *Figure 5* shows the details of the main model's *Intake version 1* and *Intake version 2 blocks*, which are hierarchic blocks in the system. The only difference between two subprocesses is: version2 allows ambient trucks – with lower priority – to dock in at possibly free chilled docks.

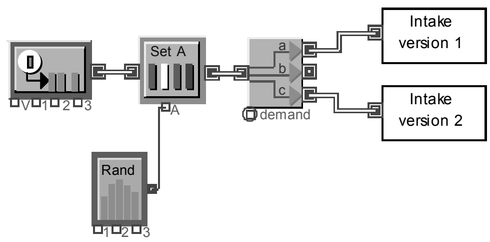

Figure 4. *QL model [Extend simulation software]*

The generator block generates items with an interarrival time according to an exponential distribution, and then we set the warehouse type as an attribute of the generated items. We analysed version1 and version2 parallel; to do this we should equally divide every incoming item (with all of their attributes), and derive them to the next sub-processes. We work with FIFO queueing discipline for ambient, chilled and frozen operations. The model calculates the average queue–length, average wait–time, and utilization of the queue, and counts trucks leaving the docks.

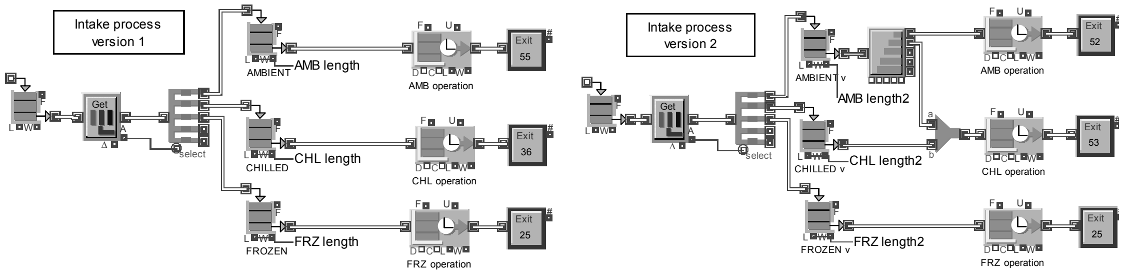

Figure 5. *QL model Version1 and Version2 subprocesses [Extend simulation software]*

Although theoretically it seems to be not trivial to reach better result in case version2 model, there are major differences on truck waiting times and queue length if ambient foodstuffs can be unloaded also at chilled docks. When the ambient trucks can dock only at AMB docks, the queue length and the truck waiting time will start to increase in the last third of the simulation time, and after the 24-hour shift, there will remain trucks stuck in the queue. The utilisation of docks is equalized in case version2; the average wait and the maximum wait have also decreased. The graphs and the numerical results are same as it was in case of Almásy's model (see *Figure 3* and *Table 1*).

Table 1. *Numerical results of Intake versions 1 and 2 by Almásy and Extend (1-4 runs)*

Run	Truck	AMB	CHL	FRZ	Sum	Util(AC)%
1	arrived	136	84	44	264	
	Intake v1	125	82	44	251	94%
	Intake v2	132	81	44	257	97%
2	arrived	143	89	48	280	
	Intake v1	137	88	47	272	97%
	Intake v2	138	87	47	272	97%
3	arrived	147	93	48	288	
	Intake v1	138	92	48	278	96%
	Intake v2	143	92	48	283	98%
4	arrived	156	94	53	303	
	Intake v1	137	93	50	280	92%
	Intake v2	150	93	50	293	97%

Human Resource (HR) study

In this study our goal was to investigate whether a reasonable schedule of human resources could solve the queuing problem of AMB trucks without any changeover to the CHL docks. The individual WHK, RTD and PPTD workers work in flexible shifts. During the 24 hour simulation time – after the transient period – the number of workers can vary between wide ranges.

Almásy's model

A good schedule of human resources made it possible to serve all the incoming AMB trucks at the AMB docks. The average of inbound delivery time was 44.7 min in the case of 135 arrived trucks. *Figure 6* shows the transient part of HR schedule, and in *Figure 7* one can see the number of active RTD workers at the moment.

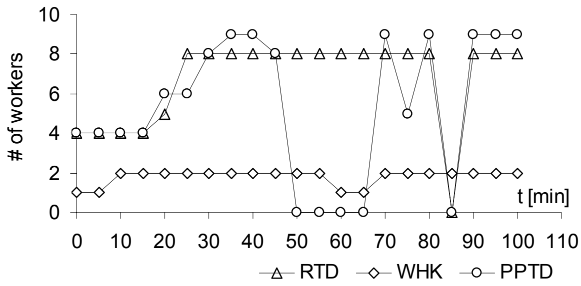

Figure 6. Transient part of HR schedule

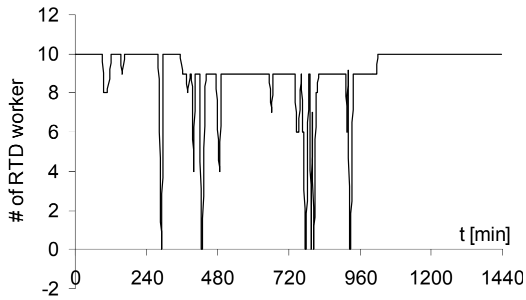

Figure 7. Occupied RTD workers

In *Table 2* we compare the results of the models discussed. The highest Max-Profit belongs to Almásy's model–version.

Table 2. *Results of Almásy's and Extend models*

	arrived	intake	WHK	RTD	PPTD	MaxProfit
Almásy	135	135	2	9	9,5	858 340 Ft
Extend	135	133	2	11	11	819 500 Ft

Extend model

Figure 8 shows HR model, which contains four hierarchical blocks: Docking, Pal.unloading, Administration and Pal.intake. These blocks are shown in *Figure 9* and in *Figure 10*.

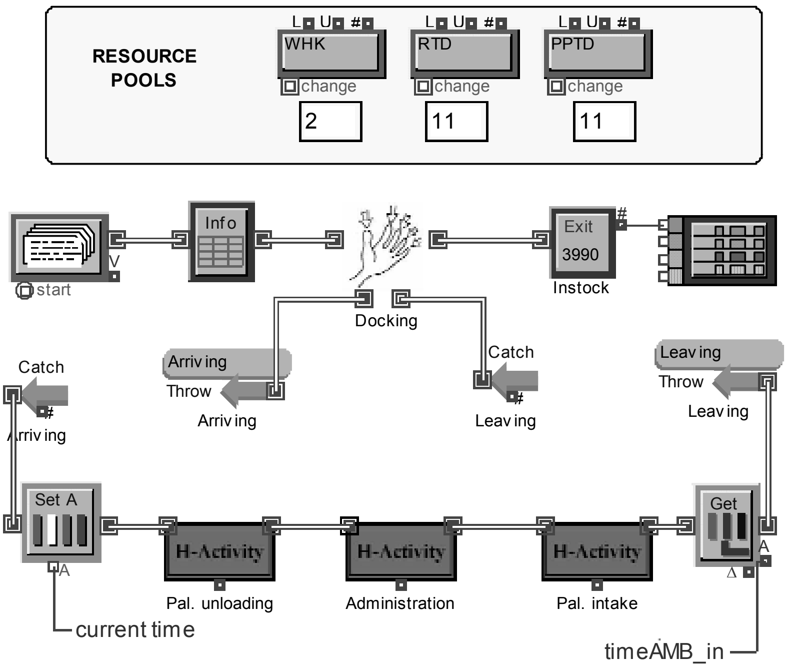

Figure 8. *HR model [Extend simulation software]*

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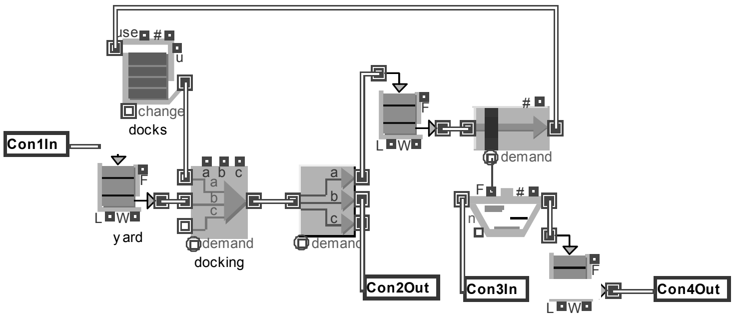

Figure 9. *HR model -Docking subprocess [Extend simulation software]*

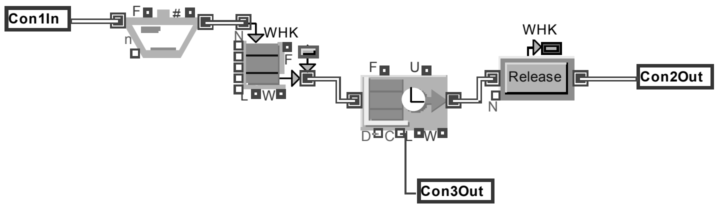

Figure 10. *HR model -Activity multiple subprocess [Extend simulation software]*

In most cases the optimizer would like to minimize the cost or maximize the profit to get a benefit from optimization.

We found the optimum at WHKnum=2, RTDnum=11 and PPTDnum=11 with the convergence of 99%. The max Profit and Convergence plot is shown in *Figure 11*.

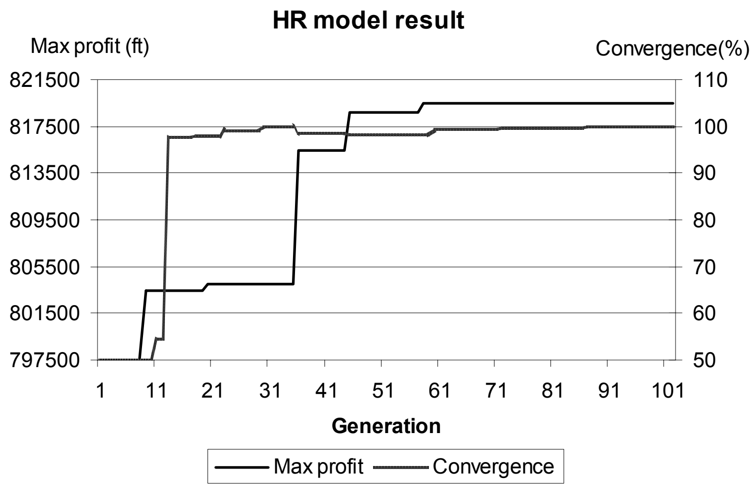

Figure 11. *HR model result by Extend*

Discussion

Any activity that receives inputs and converts them to outputs can be considered as a process – this is a highlighted concept in Quality Management (QM) standards. From the point of view of an efficient QM, the previous statement means that every industrial company is a network (system) of processes.

The basis of process simulation is a very detailed process mapping. Processes should be well defined, documented, up to date, and the key performance indicators, which describe the process, also should be known. During simulation these indicators will show the differences of each setup. Building a model allows us to optimise logistics processes by using computer experiments rather than costly plant time.

In this paper we have examined normal daily warehouse operational problems like directing trucks to docks or optimising human resources. As the cooling vehicles are waiting for their turn at the parking place with working engine, they act as an individual air pollutant. From environmental point of view we found, that to reach the same result (intake all pallets) optimising human resources seems better, than optimizing truck routes. In this case none of CHL trucks should wait at the CHL docks, because previously AMB trucks were directed there.

In our paper we demonstrated how computer simulation works as a decision-supporting tool in the hand of company management. With simulation experiments we verified that a wrong operational decision can cause serious overdose of air pollutants, because of increased truck waiting times.

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