Groyne fields – sink and source functions of "flow-reduced zones" for water contents in the River Elbe (Germany) *(Water Science and Technology - issue 7 of volume 48 (2003), pp 17-24*

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ABSTRACT

The role of man-made „flow-reduced zones" as a sink or a source of water contents is unknown for the River Elbe, Germany. We measured and compared a) the concentration of suspended matter at the inflow and the outflow of one special groyne field ("UFZ groyne field") weekly for a period of two years and b) the intensity of oxygen metabolism within several groyne fields and the main stream during a Lagrangian survey. Under discharge conditions near or below mean water, we found a significant reduction of suspended particular matter and particle bound nutrients in the "UFZ groyne field". In contrast, concentrations of most soluble wa-ter contents and chlorophyll*a* did not significantly change between in- and outflow. During the Lagrangian survey, pelagic production and respiration rates developed nearly identically in both the main stream and the adjacent groyne fields but oxygen time curves showed higher amplitudes for the groyne fields compared to the river. This higher net-oxygen production in the groyne fields is due to reduced water depth and reduced stream velocity. It enhances the concentration of oxygen in the main stream. The contrary results show the coexistence of both sink and source functions of "flow-reduced zones" in rivers.

KEYWORDS

Groyne Field, Primary Production, Respiration, River Elbe, Sinks, Sources, Water Quality

INTRODUCTION

Numerous hydraulic engineering structures have been built within large European rivers since the middle of the 16th century for the deflection of flows and the protection of banks against erosion (Sukhodolov et *al.,* 2002). In the middle of the 19th century, the demand of transport capacity had grown and streams dominant functions have been extended by that of navigation ways. The main idea of transverse structures like groynes was and nowadays is the reduction of discharge cross-sections to maintain the profitableness of rivers for shipping during times of low flow. In addition, chains of groynes along the river keep the running waters within their manipulated borders during periods of medium or smaller high runoffs avoiding natural meandering. An often described effect of reduced cross-sections is an enhanced stream velocity in between the groyne heads on both sides of the river compared to natural conditions. This leads to an increasing bed erosion in the main river and a self-deepening of the river bed. On the other hand, the shallow bank areas are subdivided into more or less independent systems with higher retention times, as well as reduced flow velocities and turbulence. Thus, banks have changed their character from typical erosion-zones to areas of enhanced sedimentation (Uijttewaal et *al.,* 2001) for most discharge conditions. In periods of high runoff, groyne fields may be cleaned by overflowing water masses and return sediments to the river with a time delay. These developments must have consequences for chemical and biological processes in the streams and their river-sides. An increasing interest in ecological effects of groynes and navigation began at the end of the 20th century leading to intensive studies on both for the river environments. Since then, several authors have shown a series of impacts related to morphological and hydrological aspects, sometimes including reflections of meadow areas or the ecology of aquatic organisms (Carling et *al.,* 1996, Engelhardt et *al.,* 2001, Uijttewaal et *al.,* 2002).

Our paper deals with the influence of groyne fields on water quality criteria of the main stream of the River Elbe. Related to research programs for one special groyne field and one river survey, we focus on the question whether or not "flow-reduced zones" like groyne fields contemporary function as sinks *and* sources for the amount of contents in the pelagic water of the main stream. Standing stocks and oxygen metabolism were taken into account.

STUDIE SITES AND METHODS

The Elbe is one of the largest European rivers and flows manifold impounded 372 km through the Czech Republic before entering Germany (Fig. 1). 9.9 milliard m^3 of water pass the border between both countries every year (313 m^3 s^{-1}) and follow a dam-free river section for further 586 km in the north-west direction.

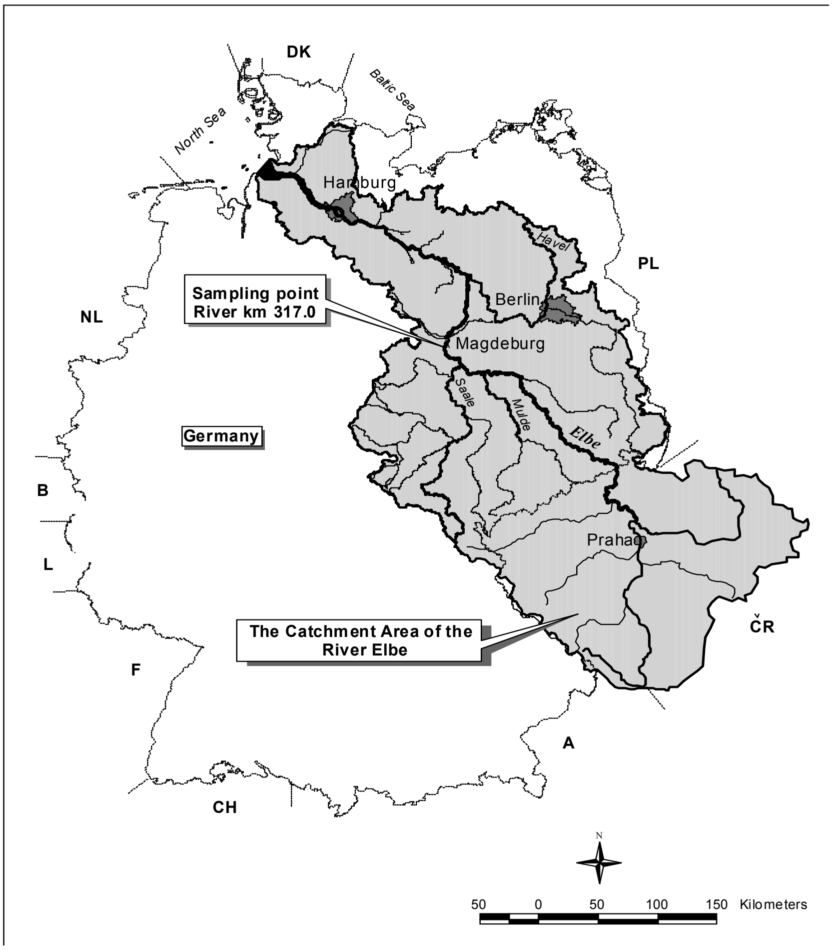


Fig. 1. Germany and the catchment area of the River Elbe. One major area of research is a groyne field at navigation-km 317 ("UFZ groyne field") near Magdeburg (see below) .

The river reaches the North-Sea after 1100 km in total with an annual discharge of 27.7 milliard m^3 (877 m^3 s^{-1}). The Elbe has a catchment area of about 150000 km^2 with nearly 25 Mill. inhabitants (Gruber and Kofalk, 2001). Along the unimpounded stretch in Germany (navigation-kms 0...586), nearly 6000 groynes on both bank sides have been constructed in the past, beginning at navigation-km (N-km) 121 downstreams. More information about morphology, hydrology, land-use or the biochemical history are given in (Guhr et *al.,* 1996, Spott and Guhr, 1996, Gruber and Kofalk, 2001).

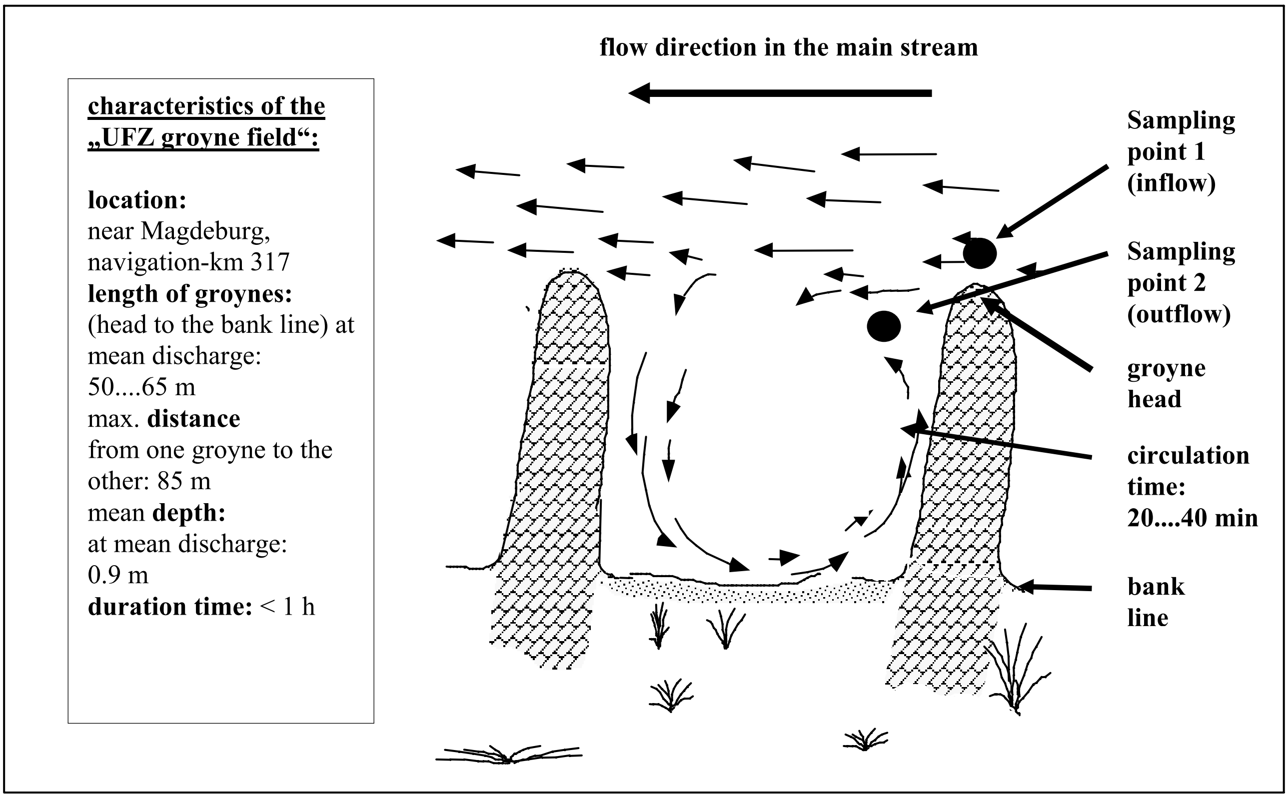
Research programms:

Short time (< 1 h) changes of water contents concentrations during the passage through a groyne field: We measured the concentrations of contents within one water parcel before entering and leaving the groyne field at navigation-km 317 ("UFZ groyne field") weekly in 2000 and 2001. The circle-like water transport through this "flow reduced zone" has regularly been observed for conditions around mean discharge (558 $m^3 s^{-1}$) or below which persists for most of the year. Several tracer measurements have shown a circulation time of 20 to 40 minutes, the whole groyne field water body is exchanged approximately every hour (Kozerski, unpub-lished data). Thus, the daily area specific change of water contents within the groyne fields was calculated by:

$$\frac{dX}{dt} = 21.6 \times (X_{gf} - X_{ms}) \qquad \text{(eq. 1)}$$

dX/dt	area specific change of a specific water content in time ($g\ m^{-2}\ d^{-1}$)
21,6	factor that results from the 24 fold exchange of groyne field water per day multiplied with the water volume of the groyne field (length*width*depth: 85m * 65m *0.9m) divided through the area of the groyne filed (mean water conditions)
X_{gf}	concentration of a specific water content at the outflow of the groyne field ($mg\ l^{-1}$)
X_{ms}	concentration of a specific water content at the inflow of the groyne field ($mg\ l^{-1}$)

For discharge conditions between 600 and 800 $m^3 s^{-1}$ (beginning of groyne´s overflow) or higher runoffs water movements in the groyne field are unknown. So our presented data are selected for conditions < 600 $m^3 s^{-1}$. We regularly used a time distance of half an hour before taking the second (outflow) sample. A scheme of the "UFZ groyne field", the water circulation and our stations of samplings is given in Fig. 2.



characteristics of the „UFZ groyne field":

location:
near Magdeburg,
navigation-km 317
length of groynes:
(head to the bank line) at mean discharge:
50....65 m
max. **distance**
from one groyne to the other: 85 m
mean **depth:**
at mean discharge:
0.9 m
duration time: < 1 h

Fig. 2. Scheme of the "UFZ groyne field". Left bank. At discharge conditions < 600 $m^3 s^{-1}$ water from the main stream drifts into the field and leaves it after a circulation time of about half an hour. Groynes in this area are overflown at discharges > 800 $m^3 s^{-1}$, between 600 and 800 $m^3 s^{-1}$ the transport characteristics are unknown.

Chemical parameters have been measured according to German Standard Techniques (Deutsche Einheitsverfahren, 1997), chlorophyll*a* (Chl*a*) was detected using HPLC-methods.

Day-night investigations: Pelagic versus community oxygen metabolism: During one Lagrangian journey (May/June 2002; discharges < mean water) we comparatively measured the vertical distribution of pelagic oxygen production and respiration of both water from the middle of the river and water from the adjacent groyne fields. Samples from 0.2 m depth were divided into 20 - 23 subsamples each and filled into Karlsruher bottles after reduction of oxygen saturation to a level of 50% (bubbling with nitrogen gas). Groups of 3 clean bottles of both sampling sites were exposed *in situ* in 6 to 7 different depths for 4 hours around noon (planktonic primary production), two dark bottles were added to quantify respiration rates. More details of the method are given in Nixdorf et *al.,* 1990, and Nixdorf and Behrendt, 1991. In addition to the bottle method (pelagic metabolism) we took oxygen time curves in the river and the groyne fields over a time period of about 30 hours at each sampling station beginning at 5:00 a.m. These time curves can give information about the net community oxygen metabolism as bulk benthic and pelagic activities (eq. 2). Quantification of oxygen production and respiration rates presume information about the exchange of dissolved oxygen with the atmosphere. K_2-values (coefficient of atmospheric reaeration) could not be calculated during the survey because of lacking information on mean water depth, roughness of the river bed and the distribution of stream velocities along larger parts of the river. The curves were used for half quantitative analyses.

$$\frac{dC}{dt} = K_2 \times (C_s - C) - R + GPP \qquad \text{(eq. 2)}$$

dC/dt	change of O_2-concentration in time (mg l^{-1})
K_2	coefficient of atmospheric reaeration (1 d^{-1})
C_S	O_2-saturation concentration (%)
C	O_2-concentration (mg 1^{-1})
R	O_2-consumption [community respiration (mg O_2 l^{-1} d^{-1})]
GPP	gross-primary production (mg O_2 l^{-1} d^{-1})

Every other day we met the observed water parcel again some ten kilometers down the river and repeated the measurements. Under water light conditions were measured with two sperical quantum sensors (LI-COR) and global radiation was recorded automatically by a planar sensor (LI-COR)

RESULTS

Discharge (Q), temperature (T) and chl*a*-concentrations in the Elbe at N-km 317 (main stream) showed typical patterns for the Elbe in 2000 and 2001 (Fig. 3a). High flows in spring were followed by reduced runoffs during summer, fall and winter. The algal biomass (chl*a*) followed the global radiation (not shown) and temperature trend. For most of the research period, discharges were below or near mean discharge. For these situations ($Q < 600$ m^3 s^{-1}), Figure 3b shows data on the change of suspended particular matter (SPM) concentrations during the half-hour travel of a water parcel through the "UFZ groyne field". It is shown, that with few exceptions, the amount of SPM in the pelagic water was reduced during this passage. In more than 50% of 59 investigations, the SPM-decrease was in a range of 10 to 30% of the concentration in the main river. The "flow-reduced zone" thus works as a sink for non-dissolved water contents, but we could not detect a strong dependence of this reduction on discharge or temperature. Data related to losses of particular matter or particular organic carbon losses indeed show high differences between winter and summer conditions, but the amount of inlet-outlet pairs analyzed for winter conditions were to few. Table 1 gives an overview on calculated losses of those variables, which had shown significant positive correlations ($r^2 > 0.6$, $p < 0.05$) to the decrease behaviour of SPM. This was found for particular nitrogen (PN), particular phosphorus (PP), particular organic carbon (POC) and particular silicate (PSi), but chlorophyll*a* as surrogate para-meter for algal biomass did not show any systematical growth or decrease characteristics. Dissolved fractions of nitrogen (nitrate, nitrite, ammonia), phosphorus (soluble reactive phosphorous), dissolved organic and in-organic carbon or silicate, as well as temperature, conductivity or pH were likewise uneffected by the half an hour journey.

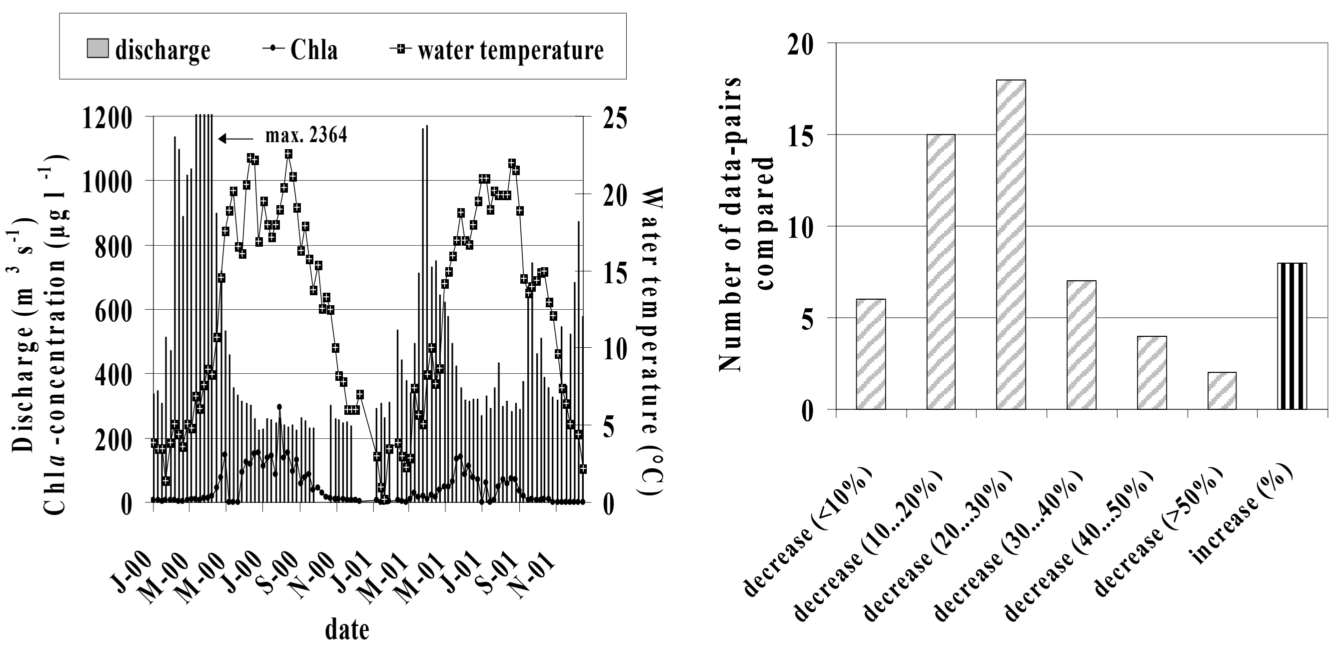

a)
b)

Fig. 3a, b. Annual (2000 and 2001) changes of discharge, water temperature and chlorophyll*a* (chl*a)* concentration in the Elbe at navigation-km 317 (3a); distribution of change of the amount of suspended particular matter (SPM) during the travel of a water parcel through the "UFZ groyne field" at navigation-km 317, left bank (3b).

Table 1. Calculated mean daily losses of particular matter within the "UFZ groyne field". The calculations were carried out for data from 2000 to 2001 and discharge condition near and below mean river discharge (< 600 m^3 s^{-1}). Particular matter dry weight (PM); particular nitrogen (PN); particular phosphorus (PP); particular organic carbon (POC); particular silicate (PSi). Temperatures below 10 °C were summarized as "winter-conditions", temperatures of 10 or more °C were called "summer-conditions".

Water content	temperature conditions	mean daily losses of content within the groyne field (g m^{-2} d^{-1})	standard deviation	N
PM	winter	18.3	± 76	17
PM	summer	116.6	± 114	44
PN	winter	0.7	± 3.7	13
PN	summer	1.3	± 4.9	44
PP	winter	0.2	± 0.3	17
PP	summer	0.1	± 0.5	45
POC	winter	4.7	± 4.2	17
POC	summer	7.4	± 11.3	44
PSi	winter	2.7	± 1.8	4
PSi	summer	0.8	± 8.1	24

The vertical distribution of pelagic oxygen production led to nearly identical values for both the main stream and the groyne field waters (Fig. 4 a). Pelagic respiration (dark bottles, not shown) during this investigation reached 0.151 mg O_2 l^{-1} h^{-1} (main stream) and 0.149 mg O_2 l^{-1} h^{-1} (groyne field), respectively. It so was very low compared to the maximum pelagic production (in 0.25 m depth: 1,63 mg O_2 l^{-1} h^{-1}, both compartments). In contrast to the equal pelagic turnover rates in both the main stream and the groyne field waters, oxygen time curves (as a result of community metabolism and physical O_2 exchange) for the groyne fields on both sites of the river and the main stream were different (Fig. 4b). While daily oxygen minimum values in the morning did not show drastic differences between the compartments, maximum values were significantly higher in the groyne fields. These discrepancies between pelagic and community metabolism could be observed for each of the investigated stations. An overview on the results for all sampling points observed during the Lagrangian survey is given in Table 2.

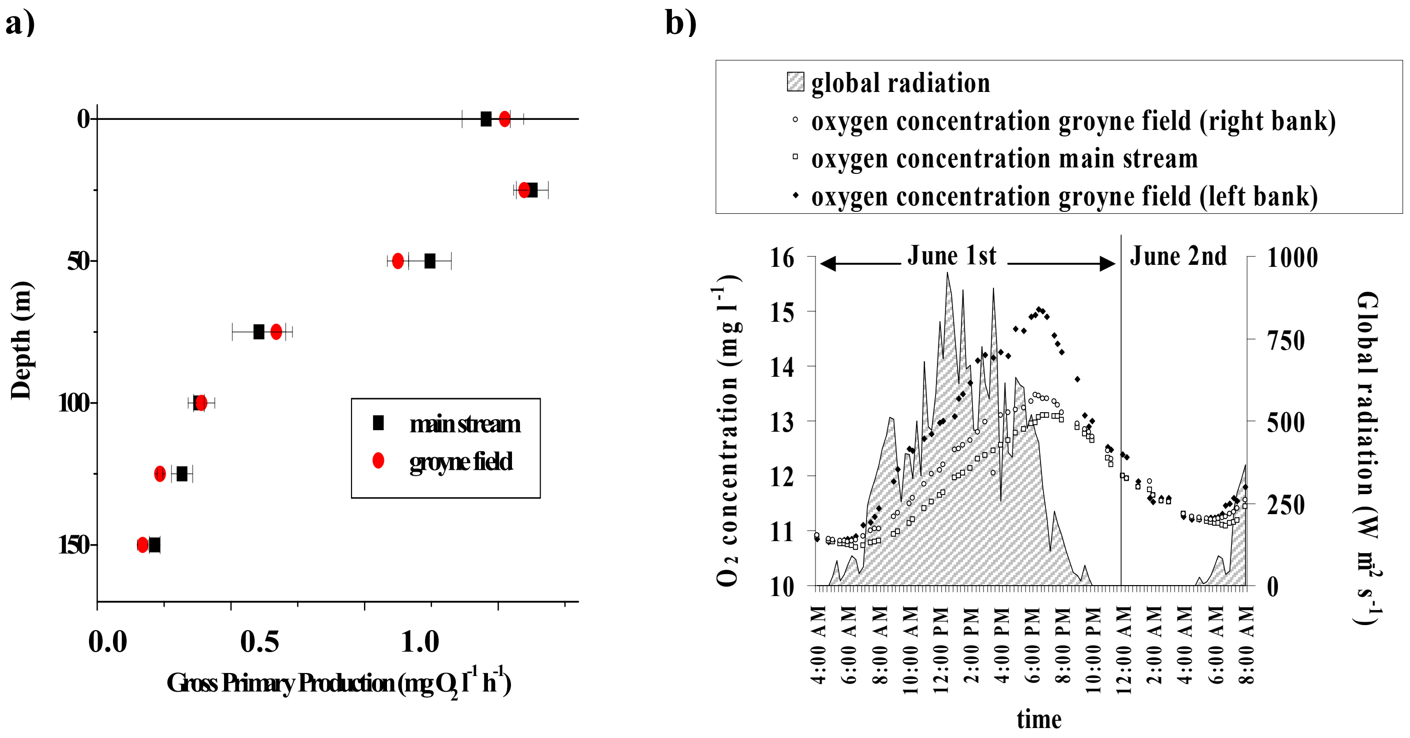


Fig. 4 a, b. Results from a 30 h stay at navigation-km 356.6 on 01.06.2002 during the Lagrangian journey. Depth distribution of pelagic productivity (gross oxygen production ± standard deviation) for both the main stream and the groyne field (left bank) waters (Fig. 4a). Oxygen time curves for the groyne fields (left and right bank) and the main stream (Fig. 4 b). Oxygen saturation was >100% even at night.

Table 2. Results from the Lagrangian survey in 2002. It is shown: the relations between chlorophyll*a* con-centrations (chl*a*) of the main stream (ms) and the corresponding groyne fields (gf); the relations between the depth integrated pelagic oxygen production (DIP) of both compartments and the volume specific pelagic res-piration (VSR) of both compartments; daily oxygen minimum (OMIN) and maximum values (OMAX). At navigation-km 58 (no groynes), we measured O_2 concentrations 2 meters from the banks; *n.d.* = no data.

navigation-km; date	groyne f. river site	$chla_{ms}$/ $chla_{gf}$	DIP_{ms}/ DIP_{gf}	VSR_{ms}/ VSR_{gf}	$OMIN_{ms}$	$OMIN_{gf}$	$OMAX_{ms}$	$OMAX_{gf}$
58; 28.05.02	left, no groynes	0.92	0.95	1.02	8.59	8.4	8.8	9.06
58; 28.05.02	right, no groynes	0,99	*n.d*	*n.d.*		8.28		9.08
205; 30.05.02	left	1.01	0.99	0.98	8.89	9.05	10.69	11.28
205; 30.05.02	right	0,95	*n.d.*	*n.d.*		8.91		11.07
356; 01.06.02	left	0.99	1.03	0.98	10.68	10.8	13.06	15.03
356; 01.06.02	right	1.07	*n.d*	*n.d.*		10.73		13.83
492; 03.06.02	left	0.99	1.04	1.02	12.53	12.43	15.24	15.82
492; 03.06.02	right	0.93	*n.d.*	*n.d.*		12.58		15.56

Similar to the results in the example (Fig. 4a, b), the relations between chl*a* concentrations, the depth integrated oxygen production and the volume specific pelagic respiration rates between both compartments (main stream and groyne field) were always close to one, pelagic metabolic rates were similar. In contrast, oxygen time curves showed higher maximum oxygen values for the groyne field waters..

DISCUSSION AND CONCLUSION

The main object of this paper is to clarify a potential coexistence of both sink and source functions for water contents of groyne fields for the main stream of the River Elbe.

Our data for the "UFZ groyne field" show, that it functions as a sink for particulate matter during times of mean or low flow. Changes in the concentration of dissolved contents could not be detected during the short time investigation. This observation goes conform with the results of other research groups (Westrich, 1977, Przedwojski, 1995, Uijttewaal et *al.*, 2001) and the decrease of particular matter seems to occur generally in protected areas under low flow. Often, coarse mineral particles disappear from the pelagic zone but will be replaced by finer organic material (Sukhodolov et *al.,* 2002). This may be the reason for a strong reduction of particular matter during the circle through our "UFZ groyne field" but a like-wise small decrease of particle bound nutrient fractions or an indifferent behavior of chl*a* concentrations.

The Lagrangian journey in 2002 had shown, that changes of the oxygen concentration as one dissolved water content can be observed during longer investigation times. Enhanced daily dynamics of oxygen occur in groyne fields under low flow conditions compared to the main stream. This is, although Chl*a* concentrations, depth integrated pelagic primary production, volume specific respiration in the pelagic and compensation depths (depth layer, were net O_2 production is zero; data not shown) are equal for both compartments. According to eq. 2, several literature models describe the dependence of O_2-dynamics on physical conditions, as well as community production and respiration (Langbein, 1967, Thyssen and Erlandsen, 1987, Uehlinger *et al.,* 2000). The pelagic parts of production and volume specific respiration (Fig. 4a, Table 2) are equal, thus, the differences in the oxygen time curves must be mainly a function of different physical conditions (turbulence, depth, stream velocity) and/or benthic activity in both compartments. First, the volume below 1 m² of water surface is smaller in the groyne fields because of reduced water depth. Although both compart-ments show identical compensation depths, the unproductive zone (below the compensation depth) is higher in the main stream. That means, that identical pelagic volume specific respiration rates lead to enhanced area specific pelagic O_2 consumption in the main stream compared to the fields and so lower the net production during day light. This is true for both groyne field and non-groyne field areas, and so we found differences in the O_2-time curves at N-km 58 (no groynes), too. A second point is, that reduced turbulence in the groyne fields will lower the O_2 losses from the water to the air under conditions of O_2 oversaturation. This factor will enhance the discrepancies between main stream and near bank waters during daylight, the main stream will have given up more oxygen than the flow reduced groyne fields. Interestingly, one could imagine the opposite for the night. That means, that under conditions of O_2-undersaturation in darkness, the input of oxygen into the water will be more intensive in the highly turbulent main river than in the fields. This would explain reduced daily oxygen minimum values in the main stream compared to the fields. As the Elbe mostly was oversaturated during our research (N-km 0....270: low oxygen deficiencies at night; down-streams: per-manent oversaturation of 110-180%), the potential input under unsaturated conditions is not a clear argument for sometimes identical, sometimes indifferent oxygen minimum values at both compartments. Instead, benthic oxygen consumption activities seem to play a dominant role in this respect. Since the water volume above an area of sediment is lower in the fields, potential equally distributed benthic respiration will effect these areas more than in the stream. In addition, benthic respiration per area may be strongly enhanced in the fields because of the enrichment of deposited organic matter. So, the manipulated physical conditions within the groyne fields enhance both the net production of oxygen during day light and the volume specific con-sumption of oxygen at night. As the oxygen maximum values are regularly higher in the groyne fields, but the daily minimum values are not very different between the groyne fields and the main stream, these zones of reduced flow work as sources for oxygen and of course other primary products for the main stream. The effects are certainly not measurable in short time experiments or standing stock comparisons, because of the manifold water exchange between groyne fields and the main stream during a day.

Our two different research programs have shown, that groyne fields can contemporary work as sinks and sources for the main stream of the Elbe. A closer quantification of these effects demands more detail knowledge on the morphological and physical structure of the river bed, as well as examinations especially about the gas exchanges with the atmosphere under different discharge conditions. This will be one main point of our future work.

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