Large Rivers Vol. **15**, No. 1–4
Arch. Hydrobiol. Suppl. 155/1–4, p. 53–61, Mai 2005

Impact of climate change on ecotopes of the rivers Rhine and Meuse

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With 1 figure and 1 table in the text

Abstract: Climate change, resulting in changes in temperature, precipitation, river discharge regime and sea level rise, may affect the ecosystems of the large rivers of the Netherlands in this century. This note discusses the method used to assess the impact of climate change on riparian ecosystems along the large rivers and presents the results of an application for the rivers Rhine and Meuse in the Netherlands. For this purpose, the effects of different climate change and land use scenarios on characteristic ecotopes have been compared with the current situation. The climate change scenarios were derived from the temperature rise estimation of the Intergovernmental Panel on Climate Change (IPCC). These have been translated into a sea level rise and changes in river discharge regime using results from earlier climate studies. Flood durations were derived by combining current contour maps of altitude and future sedimentation loads. For each type of ecotope a transition matrix has been developed to relate changes in flood duration and land use to changes in the types of ecotopes. The results indicate that climate change has a significant impact on several characteristic riverine ecotopes and therefore on the ecological quality of floodplains. However, the effect of natural land use is more dramatic and may therefore compensate for some of the negative effects of climate change.

Key words: climate change, riparian ecosystems, ecotopes, Rhine, Meuse.

Introduction

After the extreme weather-related events, such as the floods in 1993 and 1995 and the dry summer of 1995, the effects of climate change in the Netherlands have been researched in several studies (Kwadijk 1993; Parmet 1995; Grabs 1997; Middelkoop 2001, 2004; Van Asselt 2001). Due to changes in temperature and precipitation surplus the discharges of the rivers Rhine and Meuse will be affected in future in such a way that extremes are accentuated (higher discharges in winter and lower in summer) (e.g. Middelkoop 2004). In addition, sea level rise will

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0945-3784/05/0155-0053 $ 2.25

decrease the possibilities for water to discharge from the rivers and it will increase salt intrusion. These changes in the water systems of the Netherlands will have consequences for water-related functions, like nature. To formulate measures to counteract and mitigate these changes it is necessary to understand these consequences. The objective of this project was to assess the impact of climate change on riparian ecotope distribution in floodplains of the large rivers in the Netherlands, with a focus on low summer flows.

Material and methods

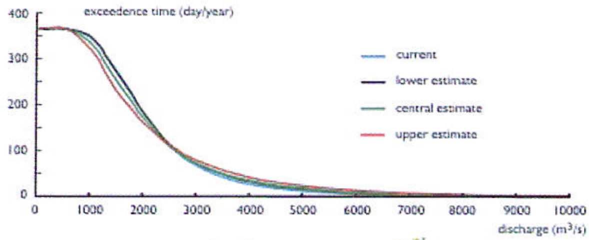
The ecological effects of climate change have been determined by considering the changes in characteristic, natural ecotopes for different climate and land use scenarios for the year 2050 (Fig. 1). The climate scenarios constructed by the Royal Netherlands Meteorological Institute (KNMI) are based on temperature estimations of the Intergovernmental Panel on Climate Change (IPCC) and the empirical relation between precipitation (on wet days) and daily mean temperature, as observed at the Dutch station De Bilt (Van Asselt 2001). We considered the three wet variants, including a lower, central and upper estimation for the year 2050 and a dry variant for the upper estimation in 2050 where temperature and precipitation were uncoupled. Besides climate change, the effects of change in land use were considered. This scenario consisted of a transformation of current agricultural land in the floodplain to more natural grazed areas and is referred to as 'natural land use'. The landscape pattern relates to the physical habitat of the ecosystems (Southwood 1977) and may be seen both as a result of hydromorphological and ecological processes as well as a prerequisite for biological species occurrence (Leuven et al. 2002; Van der Molen et al. 2003). It can be expressed in ecotope composition and is directly affected by the parameters used to express climate change and by measures. Site factors influencing the presence of an ecotope are e.g. flood duration, spring groundwater level, soil texture and land use. The most discriminating factor along large rivers is the flood duration (Dister 1980; Rademakers & Wolfert 1994; Klijn 1998). Therefore, this factor was used to determine the impact of climate change. The climate scenarios have been

Fig. 1. Schematization of the method: Climate change scenarios have been translated into changes in discharge regime. A combination with a GIS map of the elevation gave a flood duration map. Transition matrices were used to derive a GIS map of the ecotopes. An example is given for the ecotopes 'high-water-free forest', 'rich structured floodplain pasture' and 'river dune'. The first row gives the flood durations (colours correspond with given example of flood duration map). If the current ecotope is 'high-water-free forest' and the area changes to a frequently flooded zone, the result ecotope will be 'natural levee forest'. The histogram presents the acreage change of characteristic ecotopes along the Rhine.

climate change scenarios

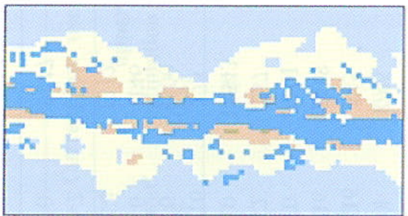
	present	low wet	central wet	upper wet	upper dry
temperature		+ 0.5 °C	+ 1 °C	+ 2 °C	+ 2 °C
yearly precipitation	700 à 900 mm	+ 1.5 %	+ 3 %	+ 6 %	- 10 %
total summer precipitation	350 à 475 mm	+ 0.5 %	+ 1 %	+ 2 %	- 10 %
total winter precipitation	350 à 425 mm	+ 3.0 %	+ 6 %	+ 12 %	- 10 %
evaporation year	620 à 720 mm	+ 2.0 %	+ 4 %	+ 8 %	+ 8 %
evaporation summer	540 à 600 mm	+ 2.0 %	+ 4 %	+ 8 %	+ 8 %
evaporation winter	ca. 100 mm	+ 2.0 %	+ 4 %	+ 8 %	+ 8 %
absolute sea level rise		+ 10.0 cm	+ 25 cm	+ 45 cm	+ 45 cm

change discharge regime and target level



elevation map

flood duration

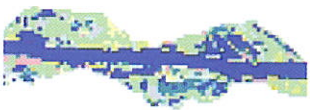


land use map

transition matrix

permanent water > 1.5 m deep	permanent water < 1.5 m deep	wet bank zone > 150 d/yr flooded	frequent flooded zone 50 - 150 d/yr flooded	periodically flooded zone 20 - 50 d/yr flooded	rarely flooded zone 2 - 20 d/yr flooded	never or rarely flooded zone < 20 d/yr flooded
deep riverbed	shallow riverbed	natural river	natural levee softwood forest	natural levee hardwood forest	natural levee hardwood forest	high-water-free forest
lake	floodplain channel	herbaceous swamp	rich structured floodplain pasture	rich structured floodplain pasture	floodplain hayfield	high-water-free hayfield
deep riverbed	shallow riverbed	natural river bank	herbaceous natural levee	herbaceous natural levee	herbaceous river dune	high-water-free herbaceous rough

distribution ecotopes



change total area ecotopes

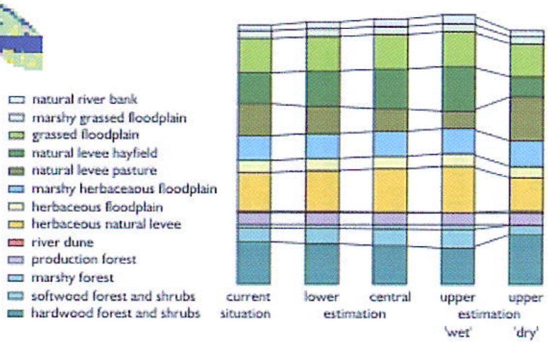


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Table 1. Calculated areas of ecotopes (ha) and area change (%) for the rivers Rhine (top) and Meuse (bottom) in the Netherlands, for the current situation and different climate scenarios for the year 2050. The climate scenario 'central estimate wet' was left out as the changes are approximately between the lower and upper estimate.

Rhine	Current land use							Natural land use	
	current situation (ha)	lower estimation 'wet' (ha)	lower estimation 'wet' %	upper estimation 'wet' (ha)	upper estimation 'wet' %	upper estimation 'dry' (ha)	upper estimation 'dry' %	upper estimation 'wet' (ha)	upper estimation 'wet' %
hardwood forest and shrubs	1330	1286	-3	1141	**-14**	1574	18	1334	0
softwood forest and shrubs	451	482	7	592	**31**	291	-35	758	**68**
marshy forest	107	121	13	156	**46**	24	-78	156	**46**
production forest	359	359	0	359	0	360	0	0	-100
river dune	59	50	-15	27	**-54**	78	32	27	**-54**
herbaceous natural levee	1224	1294	6	1460	19	1054	-14	2782	**127**
herbaceous floodplain	372	375	1	391	5	351	-6	381	2
marshy herbaceaous floodplain	782	787	1	795	2	804	3	795	2
natural levee pasture	1012	852	-16	545	**-46**	1391	37	3667	**262**
natural levee hayfield	979	1131	16	1418	**45**	639	-35	11005	**1024**
grassed floodplain	1085	1089	0	1101	1	1041	-4	3621	**234**
marshy grassed floodplain	245	249	2	257	5	228	-7	571	**133**
production grassland	15546	15546	0	15543	0	15471	0	0	-100
natural river bank	183	212	16	273	**49**	190	4	273	**49**
riverbed	8800	8800	0	8800	0	8800	0	8800	0
water	4146	4146	0	4146	0	4146	0	4146	0
agricultural area	1545	1476	-4	1312	-15	1733	12	0	-100
urban area	1222	1192	-2	1131	-7	1272	4	1131	-7
total	39447	39447	0	39447	0	39447	0	39447	0

Table 1 (continued).

Meuse	Current land use							Natural land use	
	current situation (ha)	lower estimation 'wet' (ha)	%	upper estimation 'wet' (ha)	%	upper estimation 'dry' (ha)	%	upper estimation 'wet' (ha)	%
hardwood forest and shrubs	1542	1540	0	1530	-1	1547	0	2736	**77**
softwood forest and shrubs	9	11	22	21	**133**	4	**-56**	29	**222**
marshy forest	0	0	0	0	0	0	0	0	0
production forest	1214	1214	0	1214	0	1214	0	0	-100
river dune	0	0	0	0	0	0	0	0	0
herbaceous natural levee	903	900	0	890	-1	913	1	9236	**923**
herbaceous floodplain	17	21	24	38	**124**	6	**-65**	38	**124**
marshy herbaceous floodplain	17	18	6	20	18	14	-18	20	**18**
natural levee pasture	1218	1214	0	1197	-2	1225	1	5148	**323**
natural levee hayfield	82	85	4	89	9	88	7	6002	**7220**
grassed floodplain	21	22	5	35	**67**	8	**-62**	156	**643**
marshy grassed floodplain	29	29	0	29	0	29	0	30	3
production grassland	9987	9987	0	9986	0	9987	0	0	-100
natural river bank	27	31	15	39	**44**	18	**-33**	39	**44**
riverbed	3828	3828	0	3828	0	3828	0	3828	0
water	3574	3574	0	3574	0	3574	0	3574	0
agricultural area	8357	8355	0	8346	0	8361	0	0	-100
urban area	3149	3145	0	3138	0	3158	0	3138	0
total	33974	33974	0	33974	0	33974	0	33974	0

translated into a sea level rise and changes in river discharge regime using results from earlier climate studies (Van Asselt 2001; Asselman 1999). Ecologically relevant flood durations (364, 150, 50, 20 and 2 d/yr) were derived on a grid base of 100 m by combining a current contour map of the elevation, future sedimentation loads and the discharges corresponding to the relevant exceedance times. This resulted in the mean potential flood duration because the flooding was estimated by extrapolating water levels. The ecotope composition used for the present situation was surveyed in 1997–1998, using true colour aerial photographs on a scale of 1:10,000 (Van der Molen et al. 2003). Ecotope maps for the scenarios were derived by combining the ecotope map from the survey with the future flood durations, land use and expert-based transition matrices describing the ecotope change as a result of a change in flood duration and land use (see Fig. 1 for an example).

Results

Due to an increase of higher and lower discharges of the Rhine in the wet variants of the scenarios, water levels of discharges with an exceedance time of 50, 20 and 2 d/yr increased, while the lower discharges occurred more than 150 d/yr decrease. These changes in water levels have implications for the width of different environmental zones, which are distinguished by different flood durations. The area affected depends on the relief in the floodplains. If the water level shifts to areas with a steep slope the area diminishes and vice versa. For the Rhine wetter conditions imply that areas of ecotopes with an intermediate flood duration (20 to 150 d/yr), such as herbaceous natural levee, natural levee hayfield and floodplain softwood forest increase (Table 1). Extreme wet and dry ecotopes, like natural levee pasture, river dune and hardwood forest decrease in area. This effect is greater in scenarios with a larger climate change. The variation in the total areas of ecotopes ranges from –54 % to +49 %. In the river basin of the Meuse areas with different flooding duration shift to higher places (Table 1). The acreage with a flood duration higher than 2 d/yr increases, while rarely flooded areas become smaller because they cannot shift as a result of natural elevations or embankments. The area with ecotopes softwood forest, (marshy) herbaceous and grassed floodplain increase in the wet variants of the climate scenarios. The relative changes vary from –2 % to +133 % for the upper estimation, but the absolute differences are small. The results from both rivers show contrasting changes for the dry variant of the upper estimation of climate change. Hardwood forest, river dune and natural levee hayfield increase at the cost of softwood and marshy forest and herbaceous floodplain. Changes range from –78 % to +37 % for the Rhine and –65 % to +7 % for the Meuse. The results of the natural land use scenarios show a transition of the production grasslands into natural levee hayfield, grassed or marshy grassed floodplain, depending on the hydrodynamics. The same occurs with for the agricultural areas, which changes into herbaceous natural levee and herbaceous floodplains. Production forests change into natural forest (hardwood, softwood or marshy forest). Consequently, these natural ecotopes increase in area. The effect of natural land use scenarios is larger then the impact of climate change.

Discussion

Improvements of the results could be derived by using a sophisticated three-dimensional hydrodynamic model instead of extrapolating the water levels and taking into account small elevations through a more detailed elevation grid. Although flood duration is the most important factor influencing the riparian vegetation, groundwater levels could be of importance, too (especially during summer). This was already explored in the Netherlands in other studies (e.g. VERMULST et al. 1998; HAASNOOT et al. 1999; VAN WALSUM et al. 2002). HAASNOOT et al. (1999) modelled a significant impact on wet **terrestrial** ecosystems. VAN WALSUM et al. (2002) concluded that groundwater changes were not large enough to create a situation with significant moisture stress for **riverine grasslands along brook valleys**. For examining the potential impact we focused on the indirect effects of climate change through hydrology. Direct effects, through a change in temperature and CO_2 concentration, on the germination, growth, flowering and fruiting of plant species were not taken into account. This will probably mainly affect the quality of the ecotopes (considered as biodiversity) and not the distribution as explored in this study. In spite of these critical notes we think that the method we used is good enough to estimate the potential impact on riverine ecotopes along large rivers.

Conclusions

The results indicate that climate change has a significant impact on several characteristic riverine ecotopes and therefore on the ecological quality of floodplains. This is mainly shown by an increase in the area of ecotopes such as softwood and marshy forest, river banks and herbaceous swamps. Conversely, there is less space for higher-lying ecotopes like hardwood forest and river dune. The dry variant of the climate scenarios shows an opposite effect. Summer drought due to climate change has almost no impact on riverine ecotopes as it does not change the mean flood duration significantly. Changes in land use may have more impact compared to climate change, so a shift in management practice in the floodplains may compensate for the adverse effects of climate change on the ecological quality of the floodplains. The focus of river rehabilitation and management practice should be on the typical riverine habitats that decrease, which is largely dependent on the actual climate change.

References

Asselman, N. (1999): The impacts of change in climate and land use on transport and deposition of suspended sediment in the river Rhine. – Inst. for Inland Water Management and Waste Water Treatment (RIZA), Lelystad, 182 pp.

Grabs, W.K., Daamen, K., Gellens, D., Kwadijk, J.C.J., Lang, H., Middelkoop, H., Parmet, B.W.A.H., Schädler, B., Schulla, J. & Wilke, K. (1997): Impact of climate change on hydrological regimes and water resources management in the Rhine basin. – CHR-report 1-16. Internat. Commission for the Hydrology of the Rhine basin (CHR), Lelystad, 172 pp.

Haasnoot, M., Vermulst, J.A.P.H. & Middelkoop, H. (1999): Impact of climate change and land subsidence on the water systems in the Netherlands. Terrestrial areas. – Report 99.049x. Inst. for Inland Water Management and Waste Water Treatment (RIZA), Lelystad, 67 pp.

Kwadijk, J.C.J. (1993): The impact of climate change on the discharge of the river Rhine. – KNAG/Netherlands Geograph. Studies publ. **171**. PhD-thesis, Utrecht Univ., Dept. of Phys. Geography, Utrecht, 208 pp.

Leuven, R.S.E.W., Gerig, Y., Poudevigne, I., Geerling, G.W., Kooistra, L. & Aarts, B.G.W. (2002): Cumulative impact assessment of ecological rehabilitation and infrastructure facilities in floodplains along the middle reach of the river Waal. – In: Leuven, R.S.E.W., Poudevigne, I. & Teeuw, R.M. (eds.): Application of Geographic Information Systems and Remote Sensing in River Studies: 201–216. Backhuys Publ., Leiden.

Middelkoop, H. (ed.) (2001): The impact of climate change on the river Rhine and the implications for water management in the Netherlands. – Summary report of the NRP project 952210. Inst. for Inland Water Management and Waste Water Treatment (RIZA), Lelystad.

Middelkoop, H., Van Asselt, M.B.A., Van 't Klooster, S.A., Van Deursen, W.P.A., Kwadijk, J.C.J. & Buiteveld, H. (2004): Perspectives on flood management in the Rhine and Meuse rivers. – River Research and Applications **20**: 327–342.

Parmet, B.W.A.H., Kwadijk, J.C.J. & Raak, M. (1995): Impact of climate change in the discharge of the river Rhine. – In: Zwerver, S., Van Rompaey, R.S.A.R., Kok, M.T.J. & Berk, M.M. (eds.): Climate change research. Evaluations and polocy implications. Proc. Internat. Climate Change Conf., December 1995, Maastricht, The Netherlands. Studies in Envirionmental Science **65B**: 911–918. Amsterdam, Elsevier.

Southwood, T.R.E. (1977): Habitat, the template for ecological strategies. – J. Animal Ecol. **46**: 337–365.

Van Asselt, M.B.A., Middelkoop, H., Van 't Klooster, S., Van Deursen, W.P.A., Haasnoot, M., Kwadijk, J.C.J., Buiteveld, H., Können, G.P., Rotmans, J., Van Gemert, N. & Valkering, P. (2001): Integrating water management strategies for the Rhine and Meuse basin in a changing environment. – Final report of the National Research Program on climate change project O/959273/01. Univ. Utrecht, Utrecht.

Van der Molen, D.T., Geilen, N., Backx, J.J.G.M., Jansen, B.J.M. & Wolfert, H.P. (2003): Water Ecotope Classification for integrated water management in the Netherlands. – Europ. Water Management Online 2003/03.

Van Walsum, P.E.V., Verdonschot, P.E.M. & Runhaar, J. (eds.) (2002): Effects of climate and land-use change on lowland stream ecosystems. – Alterra report 523, ISSN 1566-7197. Alterra Green World Research, Wageningen, 200 pp.

Vermulst, J.A.P.H., Haasnoot, M. & Middelkoop, H. (1998): Effects of climate change and land subsidence on the regional hydrology and water management of the Netherlands. – In: Lemmelä, R. & Helenius, N. (eds.): Proc. Second Internat. Conf. on Climate and Water, Espoo, Finland, August 1998, Helsinki Unive. of Technology, Helsinki, **2**: 1435–1449.

Received: 29 September 2003; revised: 1 June 2004; accepted: 9 July 2004.