Impact of climate change and anticipating flood management strategy on floodplain ecosystems of the river Rhine, The Netherlands

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ABSTRACT: Due to climate change the discharge of the river Rhine will alter significantly in the near future. To ensure the existing safety levels against flooding, implementation of measures to create more room for the river are inevitable. Therefore, water management authorities in the Netherlands emphasise on the need for new flood risk management strategies based on providing more room for rivers. In addition, those strategies aim for providing oppurtunities for ecological rehabilitation of the river floodplains and riparian wetlands as well. There is a need for information about the possible impact of climate change on flood risk management strategies on the river flooplain ecosystems. WL | Delft Hydraulics has modelled the ecological impact of changes in river discharges including the impact of new flood risk management strategies in several research projects. Based on the modelling results, it can be concluded that the expected changes in the discharge of the river Rhine due to climate change have a relatively small but significant impact on the floodplain ecosystems. Floodplain measures, needed to ensure safety against floods, and land use changes will have a larger impact on the floodplain ecosystems. In addition, floodplain measures may compensate for the negative effects of a changed river discharge for the next 50 years. The modelling results will be presented and discussed in this paper.

1 INTRODUCTION

Extreme events in the last decades have raised questions about the robustness of water management strategies in low-lying densely populated areas. For example, in the Netherlands the floods in 1993 and 1995 have increased the awareness of the vulnerability of living in a delta. As a result of high water levels people along branches of the river Rhine were evacuated. Areas along the Meuse were flooded. Inhabitants and companies experienced inconveniences and substantial damage. Elsewhere Europe the comparable problems occurred with for example the rive Elbe.

Climate change is expected to aggravate these problems by an increase of precipitation surplus in winter and a decrease in summer. Consequently, the discharge regime of the river Rhine will alter significantly in the near future. The inter-annual variation of the river Rhine discharge will change: winter flow increases and summer flow reduces (Middelkoop et al., 2001). Besides a higher probability on flood problems in the wet season, lower discharges may have negative effects on human functions, such as navigation and energy supply.

Because of the flood events and the expected climate change, management authorities in the Netherlands emphasise on the need for new flood risk management strategies based on dealing with the dynamics of the river systems by providing more room for rivers. In addition, these strategies aim of providing opportunities for ecological rehabilitation of the river floodplains and riparian wetlands as well. Climate change, flood risk management strategies and changes in land use due to nature rehabilitation might have an impact on floodplain ecosystems. This paper will describe these possible ecological impact based on modelling results of several projects.

2 METHOD

The ecological effects of climate change have been determined by considering the changes in characteristic ecotopes and fauna for different climate scenarios for the year 2050. The climate scenarios were constructed by the Royal Netherlands Meteorological Institute (KNMI) and are based on temperature estimations of the IPCC and the empirical relationship between precipitation (on wet days) and daily mean temperature, as observed at the Dutch weather station De Bilt (Van Asselt et al., 2001). We considered three climate scenarios: a lower, central and upper estimation for the year 2050. The climate scenarios were translated into an estimation for sea level rise and changes in river discharge regime using results from earlier climate studies (Van Asselt et al., 2001; Asselman, 1999). Ecological relevant flood durations (365, 150, 50, 20 and 2 days/year) were mapped on a grid base of 100 m by combining a contour map of the topography, future sedimentation loads and the discharges corresponding with the relevant exceedance times. This resulted in the mean potential flood duration as the flooding was estimated by extrapolating water levels in the river. Within the upper estimate scenario of climate change a different land use also was considered, which contained a transformation of current agricultural land in the floodplain to more natural grazed areas. This scenario was included in order to evaluate the effects of climate change in combination with nature rehabilitation. For each type of ecotope (van der Molen et al., 2003) a transition matrix has been developed to relate changes in flood duration and land use to an ecotope change. The predicted ecotope maps were used to analyse the availability and quality of habitats with knowledge rules (Duel et.al, 1996) for three species which are representive for different habitattypes in the river basin area: Badger *Meles meles*, Corn crake *Crex crex*, Tree frog *Hyla arborea*. This was carried out with the spatial analysis tool Habitat (Habitat, 2003). Two scenarios were analysed: 1) the upper estimate with current land use and 2) upper estimate with natural grazed areas.

In order to provide more room for the rivers the floodplain needs to be excavated and the hydraulic roughness needs to be reduced by for example changing forests into grassland. This will however reduce the biodiversity. One of the new flood risk management strategies in consideration, meeting both flood protection and nature rehabilitation objectives is Cyclic Floodplain Rejuvenation (CFR; Baptist et al., 2004.). This strategy aims at mimicking the effects of channel migration by removal of softwood forests and sand excavation or dredging, in such a way that the conveyance capacity can be maintained and the diversity in floodplain habitats can be increased. The two main measures in CFR are: setting back vegetation to pioneer stages (even bare substrate) to lower hydraulic roughness of floodplains, lowering the floodplains to create more room for the river. In this study hydrological, morphological and ecological processes were modelled in an integrated way (Baptist et al., 2004.). The effects of the CFR measures on water levels were assessed for the next 50 years using the one-dimensional open-channel dynamic numerical modelling system (Verweij, 2001) together with rule-based models for floodplain vegetation and sedimentation (Van der Lee et al., 2001). If the critical water level was exceeded extra measures were taken. In addition, knowledge rules on the habitat suitability for individual species were used to model impact on some characteristic fauna species with the Habitat tool. These knowledge rules give the relationships between the habitat suitablilty, flood duration and vegetation type. This was done for each time step, which allowed us to follow the habitat suitability during time.

3 RESULTS

3.1 *Climate change*

Due to an increase of higher and lower discharges of the Rhine water levels of discharges with an exceedance time of 50, 20 and 2 d/yr increase. On the other hand, water levels for the discharge which is exceeded 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 change 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 river Rhine wetter conditions imply that areas of ecotopes with an intermediate flood duration (20 to 150 d/yr), such as herbaceous swamps and floodplain softwood forest increase. On the other hand, extreme wet and dry ecotopes, like natural levee pasture, river dune and hardwood forest decrease in area. This effect is larger in scenarios with a larger climate change. The changes in the total areas of characteristic ecotopes vary from -46% to +45% (Table 1).

The impact of climate change for the tree representative species is small (Table 2). The breeding habitats for the Corn crake in the river basin are situated in the herbaceous grasslands (haylands), occurring in the ecotopes natural levee pasture, grassed floodplain and herbaceous floodplain. The potential living habitat and the corresponding expected numbers of the Corn crake reduces with approximately 25% as a result of the wetter conditions. Floodplains are an important food habitat for the Badger. Optimal food habitat for this animal are moisty natural grassland, production grassland and hardwood shrubs. Although the increase of suitable habitat the expected numbers of Badgers stays more or less the same as the area change is not large enough to provide more room for badgers. The terrestrial habitats of the Tree frog are situated in hardwood and softwood forest. For reproduction suited habitats are available in shallow isolated river branches, which are assumed not to change in the modelling. Because both the hardwood and softwood forest provide a habitat for the Tree frog the total change in suitable habitat does not significantly change as climate change mainly changes the existing forests into softwood forest. The numbers for the Tree frog and Badger remain more or less the same.

3.2 *Climate change and nature rehabilitation*

A transformation of current land use to natural land use in the upper estimate scenario of climate change shows a change of the production grasslands into natural levee hayfield, grassed or marshy grassed floodplain, depending on the hydrodynamics. The same counts for the agricultural areas, which change in herbaceous natural levee and herbaceous floodplains. Production forests change in natural forest (hardwood, softwood or marshy forest). Consequently, these natural ecotopes increase in area. This effect is larger then the impact of climate change.

In contrary to the effects of the climate scenarios, natural land use has a large impact on the habitat suitability of the researched species (Table 2). The potential number of Corn crakes increases with a factor 3, while the Tree frog and Badger increase with 50%.

Table 1. Areas of ecotops (ha) the characteristic ecotopes for the river Rhine in the current situation, upper estimate for climate change in 2050 with current land use, upper estimate for climate change in 2050 with natural land use. The lower part of the table presents the vegetation development with CFR over 50 years for the Waal, branche of the river Rhine. Differences in the total amount of ha are caused by differences in the boundary of the study area and different clustering of ecotope types. In spite of these differences, the results show that nature rehabilitation (by a change of arable to natural land use) and the flood risk management strategy CFR have a larger impact on ecotopes than climate change.

Ecotope	current situation	climate change	climate & land use change
hardwood forest and shrubs	1330	1141	1334
softwood forest and shrubs	558	748	914
marshland	1027	1052	1366
herbaceous natural levee[1]	1224	1460	2782
herbaceous floodplain [2]	372	391	381
natural levee pasture [3]	1012	545	3667
natural levee hayfield [4]	979	1418	11005
grassed floodplain [2]	1085	1101	3621
production grassland	15546	15543	0

Ecotope	after x years of implementation CFR					
	0 y	10 y	20 y	30 y	40 y	50 y
hardwood forest and shrubs	0	0	0	0	0	0
softwood forest and shrubs	600	1000	1000	1100	1600	1800
marshland	200	<100	<100	<100	<100	<100
dry grasslands	400	3100	3900	3600	3100	3200
wet grasslands	400	1400	1300	1200	1200	1100
dry herbaceous vegetation	200	400	400	500	400	500
wet herbaceous vegetation	100	300	200	300	200	200
production grassland	0	0	0	0	0	0

3.3 *Flood risk management strategy: CFR*

After implementation of CFR the area of bare substrate decreased significantly as these areas are overgrown with vegetation. Over time the initial floodplain ecotopes develop into softwood forest (Figure 1). In the first decades, the floodplain mainly consists of herbaceous vegetation and grasses with sparse patches of trees. After 30 years the forest cover increases to 10 – 25%. The area of hardwood forest increased most, which is explained by the relatively high-lying parts in this floodplain area. After 10, 25 and 35 years of vegetation development CFR measures needed to be applied again as the critical water level were exceeded. Each time CFR measures were implemented, areas with softwood forest regenerated to pioneer vegetation with an intermediate stage of herbaceous vegetation.

Immediately after implementation of the CFR measures the surface area of the breeding habitat of the Corn crake increases, resulting in an initial increase of the habitat suitability and consequently the expected numbers. As the forest area increases with time, the habitat suitability decreases. The habitat suitability for the Tree frog shows first a decrease and increasing with the higher density of forest. The amount of suitable habitat for the badger increases when the bare soil is overgrown by grass. After 20 years the amount of forest increases resulting in an decrease of suitable habitat.

A species which may feel some negative effects from the CFR measures, because it needs productive grasslands, is the White fronted geese. This birds was however not included in the modelling. White-fronted Geese will also profit slightly from the initial effects of the clearings carried out by CFR, although the longer winter inundation times might hamper with their feeding opportunities.

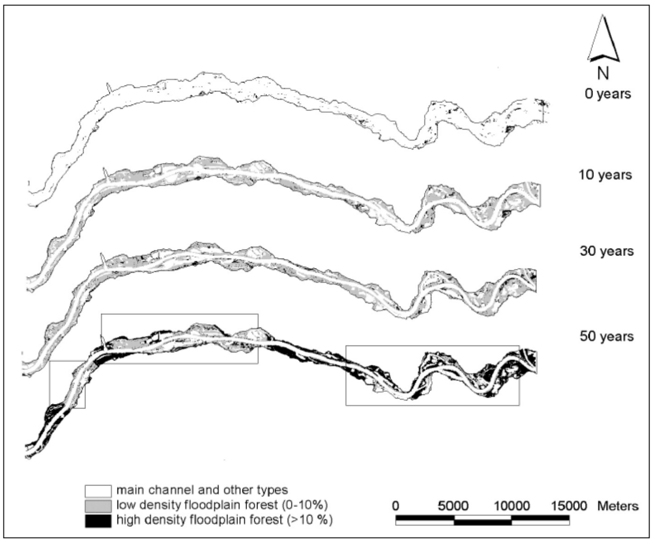

Figure 1. Increase in Floodplain forests along the River Waal over a period of 50 years. The sections indicated with square boxes are areas where floodplain forest had to bee removed to remain within the safety standards for flooding (Baptist et al., 2004 reprinted with permission).

[1] Corresponds with dry herbaceous vegetation
[2] Corresponds with wet herbaceous vegetation
[3] Corresponds with dry grasslands
[4] Corresponds with wet grasslands

Table 2. Changes in area with habitat suitability larger than 0.8 as a result of climate change, land use change of arable land to natural grassed land for the river Rhine and CFR after x years of implementation along the river branch Waal. Optimal habitat is 1 and marginal habitat is 0.1. Result have to be Differences between the climate and

	current situation	climate change	climate & land change	x years after implementation of CFR 0 y	10 y	20 y	30 y	40 y	50 y
Corn crake	1318	703	4128	729	6766	5984	5656	2178	1748
Badger	996	1138	3344	859	1615	579	274	267	283
Tree frog	1781	1733	2094	257	374	319	511	508	536

The management of the floodplains will, however, turn out to be even more important for this species. Whenever productive grassland areas are converted to rougher, more natural vegetation types, their function as feeding areas for the geese will diminish. As the forest area increases with time, the numbers decrease. In next studies on flood management strategies it is important to include this kind of species.

Due to the CFR measures the ecotopes show not only spatial changes but also temporal changes. Therefore, the habitat suitability also changes during time, resulting in a higher biodiversity than other flood management strategies which don not allow the growth of forest. However, the total habitat suitability of the river basin has to be taken in consideration as the habitat suitability might sometimes decrease more than wanted (see Figure 2 for an example).

4 DISCUSSION & CONCLUSIONS

The results indicate that climate change has a significant impact on several characteristic riverine ecotopes. Considering different climate scenarios learned us that the final effect of climate change is highly depended on the actual future climate change. The impact of climate change on tree representative species (Corn crake, Badger, Tree frog) is small. Changes in land use from arable to natural grassland may have more impact compared to climate change, so a shift in management practice in floodplains may be very beneficial for the ecological quality of the floodplains.

Moreover, the results show that flood-reducing measures have a much larger impact on ecology than climate change and show larger temporal changes. Therefore, when studying the impact of climate change on floodplain ecology, not only the changes in river discharges should be considered but also the measures that management authorities plan to implement to reduces flood risk. When implementing the flood risk measures the habitat diversity of the river system has to be taken into account as the results show a high temparal variability of for instance the Corn crake, with sometimes very low habitat suitability in the whole river system.

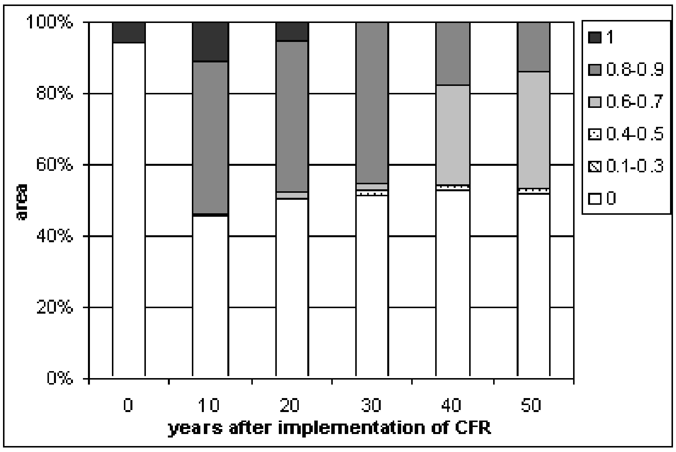

Figure 2. Example of the change in habitat suitability through time. This example shows the model results of the Corn crake. The total amount of potential habitat increases but optimal habitat (suitability of 1) decreases.

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