Changing flood pulse dynamics and their impact on fish recruitment in large rivers (Volga, Russia)

Project summary

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1. Introduction

Natural river floodplains are among the biologically most productive and diverse ecosystems on earth. The principal driving force for productivity and biodiversity in these systems is the *flood pulse*, i.e. the temporary flooding of the aquatic-terrestrial transition zones bordering the rivers. This flood pulse is determined by geomorphological and hydrological conditions that control its magnitude, timing, duration and predictability. In many rivers the natural flood pulse is severely altered by river regulation like dams and dykes, or changes in land use. Superimposed on these impacts, even modest climate changes will have major consequences on the flood dynamics of large rivers. Man-induced alterations in hydrological regimes and the reduction of floodplain wetland areas are considered a major

threat for biodiversity and natural resource production, in particular for fish. In the developing world, natural floodplains disappear at an accelerating rate, primarily due to changing hydrology, while in Europe and North-America, about 90% of the floodplains are already considered functionally extinct. Nowadays, there is a rapidly growing appreciation of floodplains for flood protection in combination with river rehabilitation (biodiversity and fish production), especially in view of expected global warming effects.

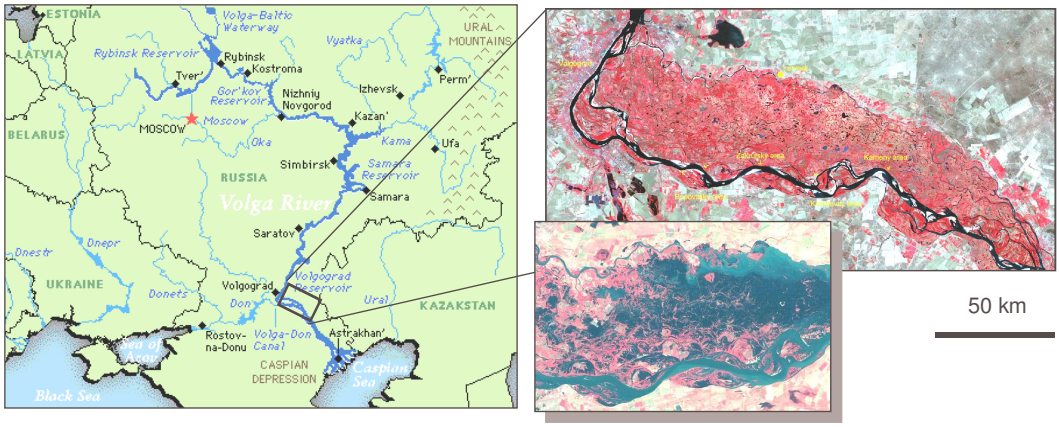
Floodplains play a key-role in the life cycle of many fish species. Life history strategies in the diverse fish faunas of large rivers are highly adapted to the natural hydrological regime, i.e. the timing and duration of inundation. The wide array of different temporal floodplain habitats is crucial for many species, especially in relation to spawning and nursery. In addition to the well-studied species-specific suitability of habitats for different life stages, the actual availability of these habitats - controlling the recruitment success per species - needs to be determined by integrating the flood pulse with local geomorphology. To make rational decisions about the quality and extent of river rehabilitation in relation to fish biodiversity, it is essential to understand the ecological functioning of floodplains and its quantitative relationship with the characteristics of the flood pulse.

Although many theoretical concepts about ecological functioning of rivers in relation to the physical and hydrological environment have been developed, there have been too few rigorous tests of these concepts in real-world floodplains. Until now, little progress has been made in exploring the flood-pulse concept over larger spatial scales and in analysing temporal changes in spatial heterogeneity in response to fluctuating discharge, due to the notorious lack of empirical data. In recent years, advanced models to simulate 2D-hydraulics of water flow over floodplains have become available, but these have mostly been applied to assess flood damage or to study overbank deposition. The challenge still to be undertaken is to quantitatively test existing concepts by linking hydraulic modelling to floodplain ecology.

The objective of the project is to quantitatively test the flood pulse concept, by analysing flood pulse dynamics in response to changes in river flow regime over different temporal and spatial scales, and relating these to the availability of floodplain habitats for recruitment and reproduction of riverine fish species, and thereby on fish population dynamics.

The project will be carried out in the Volga-Akhtuba floodplain, Russian Federation, which is a large and almost intact floodplain system. It provides a unique opportunity to elaborate, quan-

tify and validate ecological concepts associated with the flood pulse, because 1) life history characteristics are already known for most of its fish fauna, 2) the large size of the floodplain and the available long-term time series of its hydrology, fish population and fisheries production allow considering various temporal and spatial scales, and 3) there are excellent local research institutes for co-operation and field data collection.



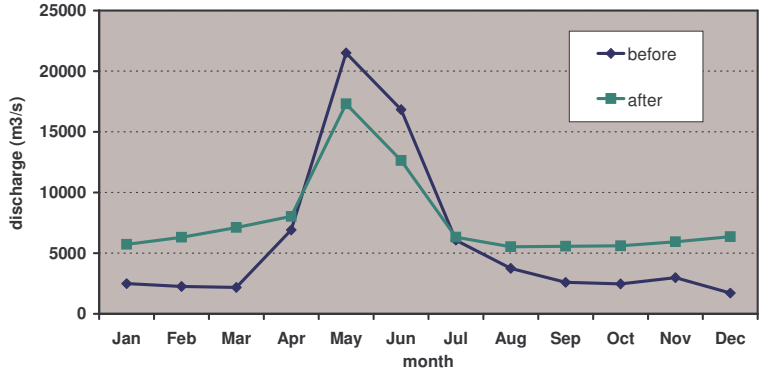
Location of the Volga-Akhtuba floodplain and fragment of the floodplain during initial inundation.

Project outline

The programme consists of three interrelated projects: 1) a PhD study on the hydrological regime of the Lower Volga and the associate flood pulse dynamics in the Volga-Akhtuba floodplain; 2) a PhD study on the ecology and habitat use of a selection of fish species that are dependent on the floodplain for the completion of their life history; and 3) a postdoctoral study linking both PhD studies, resulting in a quantitative model describing recruitment success of fish as a function of flood pulse hydrodynamics and habitat availability.

Project 1: Hydrological regime, flood pulse dynamics and habitat availability in the Volga-Akhtuba floodplain (PhD student, University of Utrecht).

Project 1 studies the hydrodynamics of flow regime and flood pulses in the Volga-Akhtuba floodplain at a range of temporal (intra-seasonal, seasonal, yearly, decadal) and spatial (specific habitat site to whole floodplain) scales. For individual flood pulses a detailed and quantitative analysis will be made of the sequences of hydraulic patterns and habitat characteristics (e.g., area, patchiness, shoreline length, connectivity, flow depth, velocities) that occur during floodplain inundation, depending on flood magnitude and duration. This will be done using remote sensing data showing the extent of floodplain inundation during different flood stages, in combination with a 2D hydraulic model of floodplain inundation (SOBEK-overlandflow) that uses floodplain topography, land cover and river flow as boundary conditions. At the long time scale, year-to-



Annual hydrograph of the Lower Volga at Volgograd, before and after the construction of upstream dams

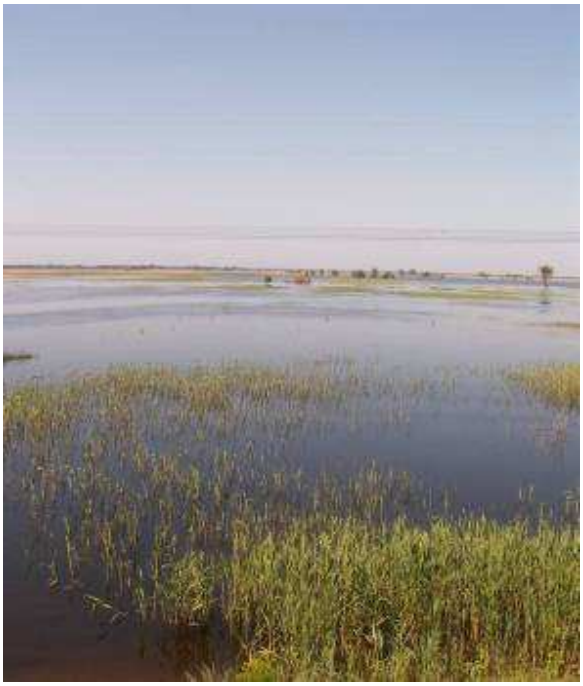
year variations in flood magnitude and duration will be compared for present-day, pre-reservoir (before 1960), and potential future climate conditions.
The following steps will be undertaken:

H1. Analysis of short- and long-term (decennia) time series of discharge and water levels of the Lower Volga River.
H2. Analysis of floodplain 2D inundation patterns using satellite images.
H3. Determination and digitising of the Volga-Akhtuba floodplain morphology and land cover based on topographic maps, RS data and field surveys.
H4. Simulation of the flood dynamics during inundation of the floodplain with a 2D hydrodynamic model (SOBEK-overlandflow), calibrated with remote sensing images and flow measurements over the floodplain.
H5. Identification and quantitative description of habitat types by combining floodplain inundation patterns and analysis of habitat characteristics (such as patch size, connectivity, water depth, shoreline index).
H6. Determination of time series of occurrences of habitat types, resulting from the decennia-scale record of flood pulses in the Lower Volga.
H7. Evaluation of changes in habitat patterns in response to different scenarios in flood pulse timing and magnitude.

This project results in (1) a quantitative description of key characteristics of flood pulses and associated fish habitat dynamics within the floodplain area, and how these depend on variations in river discharge, and (2) a quantification of changes in flood pulse characteristics between the pre-reservoir situation and present, and an estimate of the sensitivity of the flood pulse to climate change. The first result provides essential quantitative information on fish habitat dynamics that together with the results of project 2 is the basis of a quantitative model of the effects of the flood pulse on habitat availability (to be developed in project 3). The second result will be used in combination with long-term data on fish population dynamics in project 3 for evaluating the long-term implications on fish populations.

Project 2: Recruitment dynamics of riverine fish in floodplain systems in relation to flood pulses (PhD student preferably Russian University, Wageningen University).

The PhD student on fish ecology will focus on unravelling the mechanisms underlying temporal and spatial match-mismatch phenomena (see 7a) of differential floodplain habitat use in consecutive life stages. Four types of floodplain habitat use will be distinguished among species with different life history strategies: (1) resident (depending on permanent water bodies), (2) spawning and nursery (later life stages in the mainstream), (3) nursery only (in flowing floodplain waters with spawning sites further upstream), and (4) no significant role of floodplains (mainly species of the mainstream of the river). There is already an extensive amount of knowledge on general habitat requirements and life history strategies of most fish species that occur in the Volga floodplain, but not with respect to match-mismatch phenomena related to variation in flood pulse characteristics. The PhD will particularly focus on the response of year-class strength variation (as a proxy for recruitment) to changes in the temporal availability of crucial habitats. Fieldwork will focus on the timing of spawning (migration)



and early life stages around the flood pulse in different floodplain water bodies. Detailed analyses of seasonal match-mismatch patterns will be carried out for representative species for each of the different groups (in particular residents (1) and the temporal floodplain habitat users of groups (2) and (3)) with different seasonal time windows, such as early and late spawners. Candidate species for this matrix of habitat use and seasonal timing have been selected already, but the final selection of the species for detailed analyses will depend on results from field observations in the first year.

In addition to the fieldwork the PhD will analyse data of the long-term time series of fish survey data (presence of young fish / larvae) and fisheries data and relate these to the flood-pulse time series to find empirical relationships between hydrodynamics and fish population dynamics. The match-mismatch models are an essential input for project 3 in which habitat suitability models are combined with the 2D flood-pulse dynamics (developed in project 1) to produce a quantitative model of the effects of the flood pulse on habitat availability. The empirical relationships between flood pulse data and the survey and fisheries data are to be used as an independent calibration of the model from project 3.

The fisheries data are used to investigate the effects of the hydrological regime on fish production. Since fish production is not only dependent on reproductive success, but also on habitat use, mortality and growth after the recruitment phase, there will be lag period between hydrological events and the effects in the fish production. The length of that lag period will vary between fish species because, to a large extent, it depends on the time scale of the life history of the fish species.

The fish ecology PhD student will undertake the following steps:

E1. Arrange information on available fish sampling data of the Volga-Akhtuba floodplain and select sampling sites for fieldwork.

E2. Establish timing of influx of spawning adult fish from the river's mainstream to floodplain habitats using passive fishing gears (gillnets and fykenets) at selected sites during spring flood events.

E3. Perform field surveys on young fish habitat use during spring and early summer using active fishing gear (towed nets).

E4. Identify key parameters (such as water table, water temperature, flood pulse characteristics) that determine match-mismatch phenomena in successive early life stages for fish species representative for the matrix of seasonal timing and floodplain habitat use.

E5. Upgrade information on seasonal habitat use to input for quantitative habitat suitability models (see project 3).

E6. Test match-mismatch hypotheses from existing databases (1950s-present) of year-class strength variation and flood pulse characteristics.

Project 3: Predicting fish reproduction dynamics in response to short- and long-term changes of the flood pulse and associated fish-habitat availability in large floodplains (postdoctoral researcher, Wageningen University).

The postdoctoral researcher will combine the hydrological and ecological results obtained in projects 1 and 2 to establish a model that predicts the potential reproductive success of selected fish species from flood pulse characteristics and the related floodplain habitat characteristics and availability. In particular, the postdoctoral researcher will work on upscaling fish habitat suitability (derived from seasonal match-mismatch mechanisms of project 2) and habitat availability models (project 1) to large spatial scales to identify large-scale population responses of the fish community to flood pulse dynamics, with a particular focus on species-specific bottlenecks ('carrying capacity' of floodplain areas). The following steps will be undertaken:

I1. Empirical relationships will be determined between characteristics of peak flows in the Lower Volga and fish population, as documented in the available long-term records.

I2. Modelling results of the 2D-hydraulic model obtained in project 1 for flood pulses of various magnitudes will be linked to the specific seasonal habitat suitability models determined in project 2. From these a quantitative relation between flood pulse characteristics and fish reproduction success will be established.

I3. By comparing the frequency of occurrence of habitat availability over a period of decades to time scales of fish life cycles (e.g., required spawning frequency), a recruitment model will be established that predicts the long-term success of fish reproduction depending on the river flow regime. The results will be calibrated and validated using the time series of fish survey data that were analysed in project 2.

I4. The calibrated and validated model of habitat availability and reproductive success will be used to carry out sensitivity analyses of fish recruitment success and fishery production for anticipated future changes in climate, as well as possible changes in reservoir regulation of the flow regime of the Lower Volga over the forthcoming century.

I5. The model finally will be converted to a more generic model that allows to quantify the relations between flood pulse, habitat availability and fish population dynamics on large river systems, and which can be used to analyse scenarios of impacts of changes in flood pulse and floodplain habitat on fish population dynamics.