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RESEARCH ARTICLE

CHENG Kewu, ZANG Runguo, ZHOU Xiaofang, ZHANG Weiyin, BAI Zhiqiang

Influence of floods on natural riparian forests along the Ergis River, west China

Abstract The riparian forests along the Ergis River, west China, composed mainly of Salicaceae species, play an important role in eco-environment protection and sustainable development of local agriculture, stockbreeding, and social economy of the northern desert region of Xinjiang Uygur Autonomous Region. The study of the influence of floods on the natural riparian forests is imperative for the understanding of the successional process and the acceleration of conservation and restoration of forests. By investigating the relationship between floods and dispersal of seeds, sprouting, natural regeneration, the structure of the forests, and their current distribution, we conclude that: 1) the ripening and dispersal periods of Salicaceae species seeds overlap largely with flood occurrence periods, and the sprouting and natural regeneration of seeds depend greatly on flood events; 2) floods supply soil water and increase groundwater level of riparian land through flood irrigation and horizontal infiltration to maintain the normal growth of the riparian forests; 3) floods have a decisive influence on the structure, composition, and distribution pattern of riparian forests, and any disturbance in the water flow has a profound effect on these characteristics. Given these facts, some management measures for conservation and restoration of the riparian forests are proposed, including the establishment of riparian forest buffer belt, bank stabilization measures, and maintenance of flood protection.

Keywords flood, flooding, regeneration, the Ergis River

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CHENG Kewu (✉), ZHOU Xiaofang
College of Landscape Architecture and Tourism, Agricultural University of Hebei, Baoding 071000, China
E-mail: chengke@163.com

CHENG Kewu, ZANG Runguo, ZHANG Weiyin
Research Institute of Forest Ecology, Environment and Protection, Chinese Academy of Forestry, Beijing 100091, China

BAI Zhiqiang
Institute of Forest Ecology, Xinjiang Academy of Forestry, Urumqi 830000, China

1 Introduction

Riparian forest ecosystems are especially renowned for their high biomass productivity, biodiversity, and ecological benefits of controlling flood and erosion, removing nutrients from agricultural runoff, alleviating pollution, and existing as habitats for birds and mammals (Kozlowski, 2002). Floods have a great influence on the formation, succession, and distribution of riparian vegetation especially in arid and semi-arid areas. Researches on the relationship between floods and riparian vegetation mainly focused on the influence of the vegetation on floods (Zhong and Cheng, 2001; Wang and Zhao, 2003; Sveeney et al., 2004), and the effects of floods on the coverage and productivity of vegetation (Morecroft et al., 2004; Nilsson et al., 2004), soil contaminations and microelements (Nunez-Elisea et al., 1999; Pant et al., 2002), and individual plants (The geographical society of Xinjiang, 1983; Piglucci and Kolodynska, 2002; Voesenekl et al., 2003), whereas studies of flood effects on the vegetation structure, composition, succession, and regeneration are very few.

The riparian forests of the Ergis River, which are composed mainly of Salicaceae species, play a key role in water and soil conservation and desertification prevention on the riverside, and sustainable development of agriculture, stockbreeding, and economy of this region. In the riparian forests, there are many rare and special species, especially Salicaceae. Salicaceae has abundant species centralized in the Ergis River, and is extremely rare in China and even in the world; so it has very high protection value. In the past half century, with the continual growth of population, rapid development of agriculture and stockbreeding, and interception from the upstream of the Ergis River, the riparian forests suffered severe damages, the succession of many arbor species was interrupted—especially *Populus canescens* and some other species were near extinction—and the distribution area of poplar forests decreased rapidly. Therefore, in 1998, the natural riparian forests were listed as part of the State Natural Forests Protection Project.

The Ergis River is located in the desert region of the temperate zone in China and the natural riparian forests belong to intrazonal vegetation. Floods play an important role in the occurrence and succession of the riparian forests in this region. However, the paucity of research on flood functions in the riparian forests has led to the ignorance of management and conservation practices in the natural forests along the Ergis Riverleading to a decline in forests. In this study, we investigated the relationship between floods and the structure, regeneration, and succession of the riparian forest communities of Salicaceae species in the Ergis River to understand the riparian forest ecosystem of the Ergis River and provide effective protection of the natural riparian forests and sustainable development of agriculture and stockbreeding.

2 Study site

The Ergis River (85°30′–90°28′E, 47°31′–48°46′N) originates from the southern slope of the Altai mountain in northern Xinjiang of China, and it passes through Fuyun county, Fuhai county, Aletai city, Buerjin county, and Habahe county from east to west, then enters Kazakstan, and finally via Russia flows into the Arctic Ocean. The entire length in China is about 633 km (The Geographical Society of Xinjiang, 1983; Li and Lei, 2002; Liu and Wang, 2002). There are many inflowing branches in the north forming a “comb” shape, and the total runoff is about 11,900 million m^3. The terrain of the Ergis River region is affected by the interaction of conformation locomotion and exogenic geomorphy force of the southern slope of the Altai Mountain; so there are differences in characteristics of the terrain between the east and the west of the river. The east area from Xibodu is the dry denuded high plain with a well-developed canyon, whereas the west is a low plain with a wide and shallow valley and the development of terrace and flood irrigation area, there is even a meandering river someplace (Xinjiang Integrated Survey Team of Chinese Academy of Science, 1978; Li and Lei, 2002). Under the different terrain backgrounds, different vegetation types were formed: from the Altai mountain to Xibodu (upstream), the valley is “canyon–shaped” and there are no meadow grasslands and riparian forests existing in the bottomland, floodplain, and lower terrace, whereas there is desert vegetation in the higher terrace; from Xibodu to the river’s exit (middle part), the valley becomes wider, the terrace is developed, and from the bank to the high terrace the corresponding vegetation types are swamp meadows, low bottomland meadows, riparian forests and grasslands, sparse forest grasslands, shrubbery grasslands, high-terrace dispersed trees, and sparse shrubbery grasslands (Xinjiang Integrated Survey Team of Chinese Academy of Science, 1978; The Leading Group of the Academic Seminar on ‘1515’ Project of Yili Prefecture, 1999; Li and Lei, 2002). According to our investigations, the middle part of the Ergis River can be divided into two sections based on the distribution of riparian forests: 1) Beitun section: about 150 km from the east of Buerjin to Xibodu, the valley is wide (about several kilometers in some places), the river course influenced by floods is crooked and continuously changing, even divaricated in some parts, many sandbanks and islands are formed, and the riverbed is wide and low. Alongside the river course large areas of natural forest communities composed mainly of Salicaceae arbor species are distributed widely, and this sector is the main distribution site of riparian forests in the Ergis River; 2) Buha section: from the west of Buerjin to the Ergis River, the natural riparian forests are distributed less in this section.

The Ergis River region belongs to the desert and has a semiarid desert climate. The whole year is rainless, winter and spring are freezing, windy, and snowy, summer and autumn are sweltering, and the variation of temperature is great. The annual average temperature is 4.2°C, and average 23.4°C in July in the plain region; the accumulated temperature of $\geqslant 10$°C is 2,986.4°C, the average rainfall is 93.9 mm, the average evaporation is 1,661.4 mm, the dry degree is 5, and the duration of frost-free period is about 120–140 days in the plain region.

The main soil of the riparian terrace is brown soil of semi-desert vegetation with a mass of gravel and a deep soil layer, whereas in the riparian bottomland, it is mostly forest meadow soil where the natural forests grow, and the parent material is composed of silty loam and light loamy soil. In the Beitun section the vegetation types change from the river bottomland meadows to natural riparian forests to desert shrubs in the direction vertical to the river course with the moisture gradient change. The river bottomland meadows are mainly composed of hygrophyte species such as *Carex* ssp., *Phragmites communis*, *Scirpus* ssp., *Chaenerion angustifolium, Equisetum heleocharis*, and so on, and these species form different community types. The natural riparian forest communities are composed of single or several Salicaceae species including *Populus laurifolia* forests, *Populus jrtyschensis* forests, *Populus nigra* forests, *Populus canescens* forests, *Populus alba* forests, *Salix alba* forests, and so on, and the shrub species under the arbor layer are fewer, including *Aletai whitethorn*, *Salix caspica*, *Salix dasyclados*, and *Salix cinerea*. The desert shrubs outside the river include *Tamarix* ssp., *Halimodendron halodendron*, *Rosa acicularis*, *Haloxylon ammodendron*, and so on. The width of the natural riparian forests varies from tens of meters to kilometers as a result of the depth of the river course, the distribution of branches, riparian land use, and human interference.

3 Methods

1) Along the river, we investigated the characteristics of the river course (width, flexibility, and branches), riparian terrain, and vegetation in the Beitun section. We studied the water level changes in the river course, frequency, scale and irrigation of flood, and the distribution of riparian vegetation along different parts of the river by analyzing the local hydrology data, visiting, and investigating on the spot.

2) By sample plot investigation, we studied the riparian vegetation types, regeneration and habitat status, and distribution area with the environment gradient change. The

samples were selected by two methods; one was random sampling according to the riparian terrain and vegetation variety status, and the other was fixed sampling in the upright direction of the river course with a 20 m interval. Each arbor sample plot was 20 m × 20 m or 10 m × 10 m; five random herb samples plots were set in arbor plot. We investigated arbor, shrub, and grass species, growth status, habitat condition, human interference, and so on.

3) From the study of blossoms, seed dispersal, germination, and seedling growth of the Salicaceae species and others around the riparian vegetation, and experiments of different enclosures and regeneration measures, we learned the reproductive characteristics of Salicaceae species and its natural renewal demands on habitats.

4 Regeneration ways of the Salicaceae species coupling with water level

4.1 The relationship between floods and seed spread and natural regeneration of Salicaceae species

4.1.1 The coupling relationship between flood period and seed ripening and dispersal periods

The flood period mainly occurs from the last ten days of May to the last ten days of June, and the flood is caused mainly by melting of accumulated snow in winter accompanied by rainfall. When the flood occurs, it submerges the riversides and forms humid habitats in some places, which is suitable for seed germination of Salicaceae species; at the same time, the seeds of Salicaceae species are in their ripening and dispersal periods. Because the seeds are small and light with filiform hairs, after release from the capsule, it is easy to get scattered in the air or drift into the river far away, which helps them get transported. Then, the seeds germinate at suitable sites. The ripening periods of the seeds and the flood period of the Ergis River are shown in Table 1. The periods of seed ripening and dispersal of Salicaceae species are in accordance with flood occurrence.

Table 1 Flood occurrence period and the seeds ripening and dispersal periods of the main species of Salicaceae in the riparian forests of the Ergis River

Species	Seeds scattering periods (month-day)	Flood duration
Populus canescens	05-15–06-01	05-17–06-25 (The interception of water upstream has reduced the flood duration, its frequency, and flooding scope)
Populus alba	06-01–06-15	
Populus laurifolia	06-14–06-25	
Populus jrtyschensis	06-08–06-20	
Populus nigra	06-10–06-19	
Salix alba	06-15–07-20	

4.1.2 Seed sprouting of Salicaceae species

The seeds of Salicaceae species germinate quickly in suitable sites without experiencing dormancy after maturity; otherwise they lose vitality soon (Zhao et al., 1998). Guilloy-Froget et al. (2002) concluded that the germination rates of *P. nigra* seeds are very low, about 28% in natural conditions, and varies greatly among different individuals and over time. Our experiments showed that the five main species of poplar (*P. laurifolia*, *P. jrtyschensis*, *P. nigra*, *P. canescens*, and *P. alba*) along the Ergis riverside had a high germination rate over 90% after maturity in laboratory, and declined to 80% when stored in cool and dry conditions for a month; however, seeds lost vitality completely if stored till the next year. These indicate that the quick germination and growth of the seeds after falling to the ground is vital to the formation of seedlings for Salicaceae species.

4.1.3 Natural regeneration of Salicaceae species

The natural regeneration of Salicaceae species includes seedling regeneration and stump-sprouting regeneration. When the seedlings form in natural situation, the seeds must be located in humid and bare land to absorb enough water for germination, and the seedlings also need to be kept in a humid environment for their survival. The research of Guilloy-Froget et al. (2002) on *P. nigra* indicated that continuously moist surface is the most beneficial condition for seed germination and seedling growth, and the seedling would die if transferred during the course of a week from a humid environment to a dry condition. Our research indicated that the formation of seedlings from seed germination depends on the humid environment caused by flood irrigation and the duration of flood. Therefore, in the Ergis riverside, the scope of seedlings is limited to the margin of submerged lower land, the brims of trenches, the river islands and humid bare sandy land, whereas in dry places such as natural woodlands, meadows, and deserts, the seedlings struggle to survive, because the surface grass layer (or litter) diminishes the contact between seeds and soil, or the soil moisture cannot satisfy the needs of seeds germination. Subject to the short duration of floods, the humid environment disappears quickly after floods recede, which lead to the shortage of soil water and death of most seedlings; even if some seedlings survive from the water shortage threat, they would not escape from grass cutting or grazing. Therefore, it is difficult for the species of Salicaceae to expand through seedling regeneration in most places of Beitun in the Ergis river region.

Stump-sprouting regeneration is another method for the natural regeneration of Salicaceae species. This kind of seedling mainly generates on the edge and inside of the populations of Salicaceae species, or around the individuals. Our investigation results indicated that the number of stump sproutings has a close relation to species type, stand canopy density, soil moisture, and ground surface shape. The root-sprouting ability of *S. alba*, *P. alba,* and *P. canescens* is the best, followed by *P. laurifolia*, *P. jrtyschensis,* and *P. nigra*. The most suitable canopy density for the seedling formation is 0.5–0.7; in this condition the big trees could reduce the water evaporation from forestland and it is beneficial for the growth of seedlings; when the arbor shade density is too low, the light under the canopy is intensive and disadvantageous for the seedling growth. The stands adjacent to the main river course or the branches could supply moisture through the flood irrigation or horizontal infiltration; for the stands far away from the river course, the horizontal infiltration or flood irrigation becomes difficult, which results in the generation of the seedlings becoming difficult or the seedlings dying during the later growth season or in winter. We also discovered that the fluctuant forest land surface or the land with small gutters are favorable to seedling generation, and the reason is that the uneven surface could change the depth of the lateral roots and promote seedling sprouting in shallow soil layer. Our experiments also confirmed that by ditching in the forestland and eradicating the surface grass layer, the seedling number can be substantially increased. The regeneration patterns are also slightly different among different species of Salicaceae: the seedlings of *S. alba* mainly generate on the edge of the river course, requiring adequate water supply, and the range of the seedlings is less than 5 m to the parent trees; whereas the seedlings of *P. alba* and *P. canescens* usually generate near the river course and the range of it may extend 25 m away, and the seedling range of *P. jrtyschensis*, *P. laurifolia,* and *P. nigra* are less than 25 m.

4.2 The influence of floods on the composition, structure, and distribution pattern of the riparian natural forest

Floods have intense influence on the regeneration of the riparian forests of Salicaceae and the growth, structure, composition, and distribution of the forests in the Ergis River. With the riverbed down-cutting and widening continuously, the water level in dry seasons is lower or horizontal to the terrace underground water level; thus it is difficult for the river to supply water to the riparian forests. In flooding period, the water level increases and is higher than the underground water level of riparian forests, which makes it possible for the river to supply water to the soil of the riverside through infiltration or flood irrigation. Flood influences vegetation mainly through the promotion of the level of watercourse and the increase of the soil water or the groundwater level of the riparian terrace through infiltration or flood irrigation, which meets the water demands for the riparian natural forest growth.

4.2.1 Vegetation differences within and outside the flood irrigation area

We discovered that within and outside flood irrigation area, different vegetation types are formed: in the flood irrigation area, the natural forests grow normally with the canopy density above 0.3, individual trees usually grow as high as 20 m, the herbs under the forest are rich with a high coverage, and the forest communities do not contain *Alhagi sparsifolia*, *H. halodendron*, *Achnatherum splendens,* and other desert shrub species. Outside the flood irrigation area, the vegetation is replaced immediately by desert meadows scattered with sparse low trees and shrubs, the species and number of arbor trees are very few, and the main tree is sparse and low: *P. laurifolia* with height under 6 m. Usually there are only one to two individuals in a 20 m × 20 m sample plot, and the growth of it is abnormal; the shrub plants include one or two species of *Alhagi sparsifolia*, *H. halodendron*, *Tamarix* ssp., *H. ammodendron,* and *Nitraria sibirica*, the coverage of shrub is below 20%, herb plants are composed of sparse *A. splendens* and other xerophil species with coverage lower than 5%, and most of the surface is bare land composed of gravel desert soil.

4.2.2 Influence of floods on the vegetation around the branches, abandoned river courses, and lowland

During the dry season, it is difficult for the river to reach or pass through the branches, abandoned river courses, and lowland far away from the main river course. The river can supply soil water after the flood period, and the accumulated water in the branches and lowland could infiltrate into the ground and delay the quick decline of the underground water level, and satisfy the water requirement of the natural riparian forests away from the main river course. Therefore, the natural forests in these places usually can grow normally. However, influenced by the short period of flood duration, the composition, structure, and distribution pattern of forest communities in these places are different from those of communities in the flood irrigation area, especially the regeneration manner of arbor trees. The main regeneration of the trees away from the main river course is through root sprouting, which often leads to the formation of single species-dominant communities and the communities are often separated from each other with smaller distribution areas. Therefore, the composition and structure of these communities are simple; the arbor layer contains only single species and the average height is about 10–12 m, the growth status is inferior, the shrub species are scarce, and the main species is *R. acicularis*, whereas the herb plants are similar to those in the flood irrigation area.

4.2.3 Influence of floods on the vegetation in islands

Many islands are formed by conditions of flood erosion and river course ramification. Most of the smaller islands are submerged in the flood period; so they have adequate water supply and the vegetation on the islands usually flourish. On the edge of the island, flood plain meadows are usually formed, or shrubs are present from the root sprouting of *S. alba*, *S. caspica,* and *S. cinerea*, and the shrubs grow well with height about 5 m. Inside the islands the stands are composed of several species of Salicaceae with height about 20 m; under the stands, there are many root sprout seedlings and herb plant species with high coverage. With the increases of the island area, the vegetation composition and structure show obvious change from the edge to the center of the islands because the influence of floods on the center area becomes less, followed by the reduction of the species and coverage in the arbor layer and the herb layer. In the center area of large islands, the vegetation types, composition, and structure are similar to those of the desert vegetation outside the main river course.

4.2.4 Influence of water interception and other factors on the riparian vegetation

According to our survey, the frequency of flood was as high as three to four times every year till the end of 1990s, the duration was long enough to maintain the flood irrigation to the riparian vegetation for one month, and the amount of interception upstream was small; even in nonflood period, the water level of the river was sufficiently high to provide enough water to the river course branches and lowland around. However in recent years, with the water interception increasing due to irrigation and dam construction upstream, the peak flow of the flood has become small and the duration reduced, which has reduced the scope, intensity, and duration of the flood irrigation, and many of the lands flooded earlier cannot be flooded anymore, or even if the land can be flooded, the flooding time has been shortened and water supply to the riverside terrace limited. In nonflood period, the runoff amount is small and the water level is low, the branches and lowland are dry and cannot supply water to the forest land of the riverside, and the groundwater level falls constantly. So it is difficult to satisfy the water demand for the entire growing season of the riparian natural forests through one short flood irrigation per year. Because of lack of sufficient water supply, the natural forest has declined rapidly and become sparse at present in Beitun section of the Ergis River, the tree mortality has increased, the plant diseases and pests are serious, the biomass of the surface grass has reduced, the height of the herb has become low and its coverage decreased, and the natural forests are changing rapidly to the desert type of vegetation. In partial surface of the riverside, the gravel is exposed and traveling dunes formed. Other factors influencing the flood irrigation include highway construction, building, and riverbank construction alongside the river, which has changed the original landform characteristics and limited the flood irrigation scope.

Water interception upstream has not only influenced directly the growth of the stands, but also the structure and composition of the vegetation by changing soil salinity of the forestlands. The Ergis riverside is located in the inland dry desert area, the surface soil water evaporates intensively, which has led to the groundwater rise through soil capillarity and the salt ions contained in the water accumulate on the surface layer, resulting in the density of salt ions being augmented continually. Through the dilution of flood irrigation, the salt content in the surface layer can be reduced effectively to avoid soil salinification. However, because the scope and the intensity of the flood irrigation has reduced in recent years, soil salinification is increased, the survival and regeneration of the riparian species of Salicaceae face new difficulties, and the salt shrub and grass is gradually replacing the original neutral and wet species.

5 Discussion

The natural vegetation in desert oasis area depends mainly on the supply of ground water, and the depth of the groundwater level is the key factor for the natural vegetation growth. Flood irrigation and infiltration from river with high water level are important to supply and maintain the groundwater level in semiarid desert areas. Li and Wang (2003) concluded that the surface runoff and the groundwater runoff often change uniformly. Other researchers (Zhang et al., 1999; Liu et al., 2000) suggested that: when the groundwater depth is less than four meters, the influence on *P. euphratica* forests is not obvious; when the groundwater depth is between four and six meters, the *P. euphratica* forests do not grow well and the symptoms are bald tip, leaf wilting, a few plant deaths, and desertification of forest; when the groundwater depth touches six to ten meters, most individuals of the *P. euphratica* forest die and the land undergoes moderate desertification; when the depth is over ten meters, the *P. euphratica* forests die out completely and the land desertifies intensely. The study results of Wang et al. (2004) showed that the surface runoff and the groundwater level correlated closely with the lower Tarim River, the groundwater level descended significantly following the decrease of the surface runoff, and only with the increase in surface runoff, the relatively stable and suitable groundwater level could be maintained and the harmonious ecological environment could be ensured. At present, research on the relationship between poplar forest and the groundwater level of the riverside is still unclear in the Ergis River, but it is certain that the decrease in groundwater level has a significant influence on the growth and renewal of the riparian vegetation.

6 Conclusions

1) The seed-ripening periods of the Salicaceae species overlapped highly with the flood occurrence period, and the seed germination and seedling growth greatly depended on the floods in the Ergis River.

2) Floods could supply soil water effectively and keep the groundwater level stable of the riparian lands and maintain the normal growth of the riparian natural forests through flood irrigation and infiltration.

3) The flood had a decisive influence on the structure, composition, and distribution patterns of the riparian vegetations in the Ergis River, and any change on the flood mechanism would bring remarkable changes in the structure, composition, regeneration, and succession of the riparian natural forest.

7 Suggestions

1) The riparian natural forests along the Ergis River play a crucial role in the conservation of the local environment and promotion of the development of agriculture and stockbreeding; also, it is the habitat of many precious and domestic wildlife species. Therefore, protection and restoration of the riparian natural forests of the Ergis River should be paid due attention.

2) Floods play a decisive role on the structure, composition, and succession of the riparian natural forests; therefore, protection and restoration of the riparian natural forest should focus on maintaining the flood irrigation mechanism by reducing the influence of damming, intercepting, road constructing, and other factors, avoiding major changes of the natural configuration of river, and taking into account the potential influence of water usage on the riparian forests. Only if the original integrated riparian ecosystem is protected, the normal succession of the riparian forests can be maintained (Zhang et al., 2004).

3) The width and depth of the main river course affects the height of the river water level, flooding scope, and intensity. At present, the natural forests of the Ergis River have become sparse and the herb vegetation suffers from grazing and trampling by livestock, and all this leads to the riverside protection reducing, the stability dropping, erosion increasing, the river course continuously widening and deepening, water level descending, and the duration of dry season prolonging in the anabranch and disused river course. This has affected the water supply to the riversides and led to further degradation of the riparian vegetation. So the management of the river course should be strengthened to ensure its stability and slow down the down-cutting and broadening. According to relevant research and management experiences (Sweeney, 2004), riparian forest-buffering belts with width of tens of meters should be established alongside the river. Inside the belts, destruction from humans and livestock should be forbidden, and the renewal and restoration of the natural forest should be protected, especially the seedlings of *S. alba* and other Salicaceae species which sprout on both riversides in autumn each year.

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