# Impact of Ecological Water Conveyance in the Lower Tarim River on the Ecological Resilience of Desert Riparian Forests (Postprint)

**Authors:** Fu Aihong, Cheng Yong

**Date:** 2021-06-17T00:00:00+00:00

## Abstract

Ecological resilience refers to the capacity of an ecosystem to self-regulate and recover to its pre-disturbance state under external interference, and studying ecological resilience can provide a theoretical basis for effectively addressing threats to ecosystems from external disturbances. Based on the analysis of Normalized Difference Vegetation Index (NDVI) and meteorological data of riparian desert forest vegetation over the past 20 years, this study investigated the mean Net Primary Productivity (NPP) and the status of ecosystem resistance, stability, and resilience in different sections of the lower Tarim River during four periods (2001-2005, 2006-2010, 2011-2015, and 2016-2019), and obtained the recovery status of ecosystems in different sections during different periods. The results indicate that: (1) The period of 2016-2019 had the highest mean and maximum NPP values; compared with 2006-2015, ecosystem resilience was greater, but slightly lower than that of 2001-2005. (2) Resilience was highest in the upper section during 2011-2015, and in the middle and lower sections during 2016-2019, while it was lowest across the upper, middle, and lower sections during 2006-2010. (3) After 20 years of water conveyance, the recovery status of the ecosystem in the upper section was better than that in the middle and lower sections. (4) Ecological recovery is relative to a certain state; in the first 10 years after ecological water conveyance, ecological resilience was relatively low, indicating that the ecosystem was not easily restored to a non-degraded state, while in the subsequent 10 years, ecological resilience was greater, suggesting that the ecosystem was increasingly approaching a non-degraded condition, with the overall vegetation growth status improving.

## Full Text

# Effects of Ecological Water Conveyance on Ecological Resilience of Desert Riparian Forests in the Lower Reaches of the Tarim River

**FU Aihong[1], CHENG Yong[2], LI Weihong[1], ZHU Chenggang[1], CHEN Yapeng[1]**

[1]State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, Xinjiang 830011, China
[2]Xinjiang Tarim River Basin Authority, Korla, Xinjiang 841000, China

### Abstract

Ecological resilience refers to the capacity of an ecosystem to self-regulate and recover to its pre-disturbed state under external interference, and studying ecological resilience provides a theoretical foundation for effectively addressing threats to ecosystems. Based on analyses of normalized difference vegetation index (NDVI) and meteorological data for desert riparian forests over the past two decades, this study investigated the ecosystem resistance, stability, and resilience of different river sections in the lower reaches of the Tarim River, and obtained the restoration status of ecosystems in different periods and sections. The results indicate that: (1) During 2016–2019, vegetation net primary production (NPP) exhibited the highest mean and maximum values, showing greater ecosystem recovery capacity compared with 2006–2015, though slightly lower than that of 2001–2005. (2) Ecological restoration is relative to a certain reference state; during the first ten years after water conveyance, ecosystems were less likely to recover to their non-degraded state, whereas during the latter ten years, ecological resilience was greater, indicating that ecosystems are approaching their undegraded condition and overall vegetation growth is improving.

**Keywords:** ecosystem resilience; stability; resistance; desert riparian forests; lower reaches of Tarim River

### Introduction

Desert riparian forests are widely distributed along the banks of inland rivers in arid regions, representing forest ecosystems with relatively simple species composition under desert environmental conditions. These forests play crucial roles in windbreak and sand fixation, as well as in maintaining ecosystem balance and stability in arid areas. The Tarim River is a major inland river in southern Xinjiang, with desert riparian forests composed primarily of *Populus euphratica* trees, shrubs dominated by *Tamarix ramosissima*, and drought-resistant herbaceous plants, featuring simple species composition and nutrient structure. Over the past several decades, increasing population and socioeconomic activities in the Tarim River Basin have led to dramatic increases in water consumption for production and daily life, severely reducing ecological water use and causing river channel drying, as well as the desiccation of Lop Nur and Taitema Lake. Consequently, desert riparian forest vegetation has severely degraded, with diminishing capacity to resist external disturbances and self-repair, exacerbating land degradation, desertification, and pest problems.

To address this crisis, the Ministry of Water Resources and the People' s Government of Xinjiang Uygur Autonomous Region initiated the "Emergency Ecological Water Conveyance Project in the Lower Reaches of the Tarim River" in May 2000 to rescue the "green corridor" in the lower Tarim River. By the end of 2019, 20 successful water deliveries had been conducted, with a cumulative volume of 84.45$\times10^{8}$ m$^3$, significantly raising groundwater levels within a certain range on both riverbanks and improving groundwater quality. Following water conveyance, wetland and lake areas increased, and riparian plant species and quantities grew, with vegetation condition and coverage recovering to some extent. However, whether and to what extent the ecosystem resilience of near-channel desert riparian forests has improved remains unclear. Therefore, this study analyzes the impact of ecological water conveyance on the ecosystem resilience of desert riparian forests, providing a scientific basis for proposing new ecological management measures and promoting forest restoration.

Ecological resilience refers to the capacity of an ecosystem to maintain its biological composition, structure, and function through self-regulation after being disturbed and deviating from equilibrium. Previous scholars have employed various quantification methods, all selecting one or several key indicators from factors affecting ecosystem resilience or from ecosystem structure and function to comprehensively reflect resilience. Vegetation net primary production (NPP) reflects plant community productivity under natural conditions. This study combines NPP spatiotemporal variations after water conveyance in the lower Tarim River to comprehensively assess ecosystem resilience through changes in mean NPP, resistance, stability, and maximum NPP.

---

## 1. Materials and Methods

**1.1 Study Area** The lower reaches of the Tarim River are located between the Taklamakan and Kumtag deserts in southeastern Xinjiang, spanning 428 km. The region experiences a warm temperate, extremely arid continental climate with mean annual precipitation of only 42.00 mm and mean annual evaporation potential of 3000 mm. Vegetation is dominated by *Populus euphratica* trees, shrubs such as *Tamarix ramosissima* and *Lycium ruthenicum*, and herbaceous plants including *Phragmites communis*, *Apocynum venetum*, and *Alhagi sparsi-*

*folia*. Due to long-term channel drying, vegetation has severely degraded. Since the 2000 water conveyance project implementation, groundwater levels have risen and riparian forest vegetation and ecological conditions have improved to some extent.

**1.2 Data Sources and Processing** NDVI data, monthly mean temperature, precipitation, and photosynthetically active radiation were obtained from the Climate Research Unit (http://www.cru.uea.ac.uk/web/cru/). NPP was calculated using the Carnegie Ames Stanford Approach (CASA) model, which considers external climatic conditions such as temperature, precipitation, and solar radiation. The main input parameters are absorbed photosynthetically active radiation (APAR) and actual light use efficiency ( ). This model is widely applied for regional large-scale vegetation NPP estimation and is considered one of the most accurate models available.

The CASA model calculates NPP as:

$$NPP(x,t) = APAR(x,t) \times \varepsilon(x,t)$$

where $NPP(x,t)$ represents net primary productivity at pixel $x$ in month $t$, $APAR(x,t)$ is photosynthetically active radiation, and $\varepsilon(x,t)$ is actual light use efficiency.

**1.3 Research Methods** Following methods for assessing crop yield resilience, this study proposes comprehensive analysis of vegetation NPP changes, stability, and maximum values to reflect ecosystem resilience. Temporally, based on water resource abundance/drought characteristics and water conveyance status in the Tarim River Basin over the past 20 years, four periods were established: 2001–2005, 2006–2010, 2011–2015, and 2016–2019. Spatially, because channel drying and ecological degradation progressed from lower to upper sections while recovery progressed from upper to lower sections after water conveyance, the lower Tarim River was divided into three segments: upper (Daxihaizi–Yingsu), middle (Yingsu–Alagan), and lower (Alagan–Taitema Lake) to evaluate ecosystem resilience.

**Stability Analysis:** Using SPSS 12.0 software, we analyzed the range, variance, and coefficient of variation (CV) of average NPP for each period. The Finaly-Wilkinson (FW) slope was obtained through linear fitting of detrended NPP against environmental indices. Smaller NPP range, variance, CV, and FW slope in a given period indicate higher ecosystem stability. Overall stability ranking for each period was determined by averaging stability levels across the four indicators.

**Resistance Assessment:** Resistance, a key indicator of ecosystem resilience, reflects the capacity to withstand external stress. We measured resistance using two methods: probability-based frequency distribution analysis and environmental index (EI) prediction. Probability density curves for each period were plotted to calculate the probability of low NPP under unfavorable conditions (minimum NPP). The minimum NPP predicted by EI reflects drought stress intensity.

**Maximum NPP:** The maximum NPP for each period was assessed to reflect management differences under favorable growth conditions.

---

## 2. Results

**2.1 NPP Variation** Since implementing ecological water conveyance in 2000, NPP of desert riparian forests within 10 km of the lower Tarim River channel has shown a significant increasing trend at a rate of 3.16 g $C \cdot m^{-2} \cdot yr^{-1}$ ($R^2 = 0.8064$, Sig. $< 0.001$), particularly in the middle and lower sections. Mean NPP values for the entire lower reach were 16.63, 18.26, 19.72, and 20.86 g $C \cdot m^{-2}$ for the four periods, respectively, with significant differences between periods (F = 2,5342, Sig. $< 0.001$). The slight decrease in 2006–2010 may relate to reduced water delivery during basin drought years, while the 2019 decrease may result from autumn water delivery missing the peak growing season.

Spatial analysis revealed that areas with NPP of 16.15–29.57 g $C \cdot m^{-2}$ significantly decreased by 26.25% in 2016–2019 compared with 2001–2005 (F = 2,2517, Sig. = 0.10). Conversely, areas with NPP of 29.57–55.26 g $C \cdot m^{-2}$ increased by 162.40% (F = 2,2836, Sig. $< 0.001$), and areas with NPP of 55.26–100.53 g $C \cdot m^{-2}$ increased by 195.63% (F = 2,409, Sig. $< 0.001$). Areas with NPP $>$ 100.53 g $C \cdot m^{-2}$ increased by 98.55% (F = 666.08, Sig. $< 0.001$). These changes primarily occurred along the middle and lower river sections.

[Figure 1: see original paper] Annual variations of net primary production (NPP) on desert riparian forests in the lower reaches of Tarim River

[Figure 2: see original paper] Spatial variations of net primary production (NPP) on desert riparian forests in the different periods in the lower reaches of Tarim River

**2.2 Stability Changes** Stability analysis revealed that for the Daxihaizi-Yingsu section, stability in 2001–2005 and 2011–2015 was equivalent and relatively high, while other periods showed poor stability, particularly 2006–2010 with the largest NPP range, variance, and CV. For the Yingsu-Alagan section, 2016–2019 showed the best stability, while 2006–2010 exhibited the largest NPP range, CV, and variance, indicating the poorest stability. For the Alagan-Taitema Lake section, 2011–2015 showed the best stability, while 2006–2010 again showed the poorest stability.

NPP stability parameters and ranking of desert riparian forests in the lower reaches of Tarim River in different periods

**2.3 Resistance Changes** With water conveyance implementation, the probability of low NPP significantly decreased from 3.10% in 2001-2005 to 2.00% in 2016-2019, while the probability of high NPP increased from 4.38% to 6.20%. The minimum NPP was highest in 2001-2005, then decreased, particularly in 2006-2010 when water delivery was lowest (0.08$\times10^{8}$ m$^3$ average), subjecting vegetation to severe drought stress. Since 2011, intermittent moderate-to-large water deliveries have reduced drought stress, with 2016-2019 showing the lowest resistance (strongest ecosystem). Maximum NPP was highest in 2016-2019, increasing by 20.27 g C · $m^{-2}$ compared with 2001-2005, indicating improved vegetation growth conditions.

Probability of high and low NPP, minimum and maximum NPP of desert riparian forests in different periods in the lower reaches of Tarim River

**2.4 Resilience Changes** Synthesizing mean NPP, stability, resistance, and maximum NPP indicators, we calculated ratios relative to maximum values to assess ecosystem resilience. For the entire lower Tarim River, 2016-2019 showed the greatest mean and maximum NPP, with ecosystem resilience larger than 2006-2015 but slightly smaller than 2001-2005. The upper section showed greatest resilience in 2011-2015, while middle and lower sections peaked in 2016-2019. The lowest resilience across all sections occurred in 2006-2010, likely related to persistently low water delivery. Ecological restoration is relative to a reference state: the first ten years post-conveyance showed lower resilience, indicating difficulty recovering to the non-degraded state, while the latter ten years showed higher resilience, suggesting ecosystems are approaching undegraded conditions with improving overall vegetation growth.

Based on 20-year averages of NPP, stability, resistance, and maximum NPP ratios, the Daxihaizi-Yingsu section showed the best restoration status (average ratio 0.73), while the Alagan-Taitema Lake section showed the poorest (average ratio 0.58). These differences among sections likely relate to water conveyance volume and delivery methods.

[Figure 3: see original paper] Ecosystem resilience in the lower reaches of Tarim River in 2001-2019

---

## 3. Discussion

Our analysis of post-conveyance NPP changes, stability, resistance, and resilience reveals gradual ecosystem recovery, consistent with previous findings of significant ecological benefits from water conveyance. Is vegetation recovery related to increased channel flow and rising groundwater depth? Analysis shows significant positive correlation between NPP and water conveyance volume (correlation coefficient = 0.85, Sig. $< 0.001$), with NPP increasing as conveyance frequency and cumulative volume grow. Under water conveyance disturbance, ecosystem recovery improved yearly, potentially reaching new states with enhanced vegetation coverage.

For different river sections, Liao et al. found significant NPP increases near Daxihaizi Reservoir and Taitema Lake, possibly due to longer inundation periods in upper and lower sections. Our results differ slightly, showing higher NPP in the upper section than middle and lower sections, with better restoration status in the upper section, likely because the upper section receives water for longer durations. Studies have found that *Populus euphratica* twig length and leaf number increased more significantly in the upper section than in middle and lower sections after water conveyance, supporting our findings.

To help desert riparian forests reach new stable states and maintain health, long-term water conveyance is needed to raise riparian groundwater levels and promote surface vegetation recovery. Future water delivery could enhance ecological benefits by using braided channels to expand the inundation area of desert riparian forests.

---

## 4. Conclusions

1. Following ecological water conveyance, areas within 10 km of the middle and lower Tarim River channels with NPP of 29.57-55.26 g $C \cdot m^{-2}$ and 55.26-100.53 g $C \cdot m^{-2}$ showed significant increasing trends, while areas with NPP of 16.15-29.57 g $C \cdot m^{-2}$ decreased.

2. For the Daxihaizi-Yingsu section, stability in 2001-2005 and 2011-2015 was equivalent and relatively good, while 2006-2010 showed the poorest stability. For the Yingsu-Alagan section, 2016-2019 showed the best stability and 2006-2010 the worst. For the Alagan-Taitema Lake section, 2011-2015 showed the best stability and 2006-2010 the worst.

3. Ecosystem resistance was strongest in 2001-2005 and weakest in 2016-2019. The 2006-2010 period, with the lowest water delivery, experienced the strongest drought stress.

4. Based on comprehensive analysis of mean NPP, stability, resistance, and maximum NPP, ecosystem resilience in 2016-2019 was greater than in 2006-2015 but slightly less than in 2001-2005. The upper section showed greatest resilience in 2011-2015, while middle and lower sections peaked in 2016-2019. All sections showed lowest resilience in 2006-2010, likely due to persistently low water delivery.

5. Ecological restoration is relative to a reference state. The first ten years post-conveyance showed lower resilience, indicating difficulty recovering to the non-degraded state, while the latter ten years showed higher resilience, suggesting ecosystems are approaching undegraded conditions with improving vegetation growth.

## References

[1] Li Weihong, Chen Yongjin, Chen Yapeng, et al. Effects of ecological stream water transfusion on groundwater level and quality in the lower reaches of the Tarim River[J]. Resources Science, 2006, 28(5): 157-163.

[2] Chen Y N, Zilliacus H, Li W H, et al. Ground water level affects plant species diversity along the lower reaches of the Tarim River, western China[J]. Journal of Arid Environments, 2006, 66: 231-246.

[3] Liu Bin, Zhao Yali, Bai Jie, et al. Study on ecological effect evaluation of water conveyance project in the lower reaches of the Tarim River[J]. Geospatial Information, 2020, 18(3): 112-117.

[4] Li Junli, Xiao Hao, Shen Zhanfeng, et al. Vegetation changes during the 2013–2018 period and its response to ecological water transport in the lower reaches of the Tarim River[J]. Arid Zone Research, 2020, 37(4): 985-992.

[5] Yan H M, Zhan J Y, Zhang T. Resilience of forest ecosystems and its influencing factors[J]. Procedia Environmental Sciences, 2011, 10: 2201-2206.

[6] Chethika A C, Mikami Y, Matsuda Y, et al. Ecosystem service based composite indicator for assessing community resilience to floods[J]. Environmental Development, 2018, 27: 34-46.

[7] Frazier A E, Renschler C S, Miles S B. Evaluating post disaster ecosystem resilience using MODIS GPP data[J]. International Journal of Applied Earth Observation and Geoinformation, 2013, 21: 258-269.

[8] Han Lu, Chen Jiali, Wang Jiaqiang, et al. Species composition, community structure, and floristic characteristics of desert riparian forest community along the mainstream of the Tarim River[J]. Plant Science Journal, 2019, 37(3): 324-336.

[9] Ponce C G E, Susan M M, Huete A, et al. Ecosystem resilience despite large scale altered hydroclimatic conditions[J]. Nature, 2013, 494: 349-352.

[10] Chen Yaning, Li Weihong, Chen Yapeng, et al. Water use process of constructive plants in desert riparian forest[J]. Arid Zone Research, 2018, 35(1): 130-136.

[11] Song J, Ru J Y, Zheng M M, et al. A global database of plant production and carbon exchange from global change manipulative experiments[J]. Scientific Data, 2020, 7: 323, doi: 10.1038/s41597-020-00630-8.

[12] Li Weihong, Hao Xingming, Qin Xinwen, et al. Ecological process of desert riparian forest communities and its hydrological mechanism of inland river basin in arid area[J]. Journal of Desert Research, 2008, 28(6): 1113-1117.

[13] Yuan Maoning, Liu Yanxu, Wang Man, et al. Ecosystem health assessment based on the framework of vigor, organization, resilience and contribution in Guangzhou City[J]. Chinese Journal of Ecology, 2019, 38(4): 1249-1257.

[14] Gu Kangkang. Concepts and assessment methods of ecological carrying capacity[J]. Ecology and Environmental Sciences, 2012, 12(2): 389-396.

[15] Chen Yongjin, Li Weihong, Chen Yaning, et al. Ecological effect of synthesized governing in Tarim River valley[J]. China Environmental Science, 2007, 27(1): 24-28.

[16] Li M, Peterson C A, Tautges N E, et al. Yields and resilience outcomes of organic, cover crop, and conventional practices in a Mediterranean climate[J]. Scientific Reports, 2019, 9: 12283, doi: 10.1038/s41598-019-48747-4.

[17] Liao Shumin, Xue Lianqing, Chen Jiacheng, et al. Cumulative ecological response of ecological water transmission in the Tarim River[J]. Water Resources Protection, 2019, 35(5): 120-126.

[18] Li Jing, Guan Wenwen. The dialectical relationship between the stability of ecosystem resistance and the stability of resilience[J]. Biology Teaching in Secondary Schools, 2014(5): 47-49.

[19] Zhu Chenggang, Aikeremu Abula, Li Weihong, et al. Ecosystem restoration of *Populus euphratica* forest under the ecological water conveyance in the lower reaches of Tarim River[J/OL]. Arid Land Geography. [2021-03-29]. https://kns.cnki.net/kcms/detail/65.1103.X.20210328.1831.008.html.

[20] Li Yupeng, Chen Yaning, Ye Zhaoxia, et al. Ecological responses of ecological water conveyance in the lower reaches of Tarim River for the 20 years[J/OL]. Arid Land Geography. [2021-03-29]. https://kns.cnki.net/kcms/detail/65.1103.X.20210328.1831.010.html.

[21] Li Lijun, Zhang Xiaoqing, Chen Changqing, et al. Ecological effects of water conveyance on the lower reaches of the Tarim River in recent twenty years[J]. Arid Land Geography, 2018, 41(3): 238-247.

[22] Yang Geng, Cao Yingui, Luo Gubai, et al. Research progress of ecosystem resilience assessment[J]. Zhejiang Agricultural Science, 2019, 60(3): 508-513.

[23] Zhang Pengfei, Guli Jiapaer, Bao Anming, et al. Ecological effects evaluation for short term planning of the Tarim River[J]. Arid Land Geography, 2017, 40(1): 156-164.

[24] Li Weihong, Zhou H H, Fu A H, et al. Ecological response and hydrological mechanism of desert riparian forest in inland river, northwest of China[J]. Ecohydrology, 2013, 6(6): 949-955.

*Note: Figure translations are in progress. See original paper for figures.*