

Development and Application of a River Habitat Assessment Indicator System for the Three Gorges Reservoir (Postprint)

Authors: Chen Miao, Su Xiaolei, Dang Chengqiang, Gao Ting, Huang Huimin, Dong Rong, Tao Jianping

Date: 2018-01-09T00:00:00+00:00

Abstract

After the completion and impoundment of the Three Gorges Reservoir, the tributaries within the reservoir area have experienced drastic changes in river habitat due to water level regulation, and the formation of water-level-fluctuation zones has endowed reservoir rivers with habitats distinctly different from those of natural rivers, making habitat assessment for reservoir rivers under this new situation imperative. Existing evaluation indicator systems and assessment methods, both domestically and internationally, cannot adequately adapt to this special habitat condition, necessitating the establishment or improvement to form new evaluation indicator systems and assessment methods. Based on this, by analyzing numerous domestic and international river habitat assessment methods and according to the ecological and environmental characteristics of reservoir rivers under the influence of large dams, we constructed a reservoir river habitat evaluation indicator system comprising 18 indicators across three aspects: hydrological regime, river morphology, and riparian zone habitat, and calculated the weight of each indicator using the Analytic Hierarchy Process (subjective weighting method) and the entropy method (objective weighting method) combined with a combination weighting method. Using the newly established indicator system and method, and taking the Dongxi River, Huangjin River, and Ruxi River (tributaries in the Three Gorges Reservoir area) as examples, river habitat quality assessment revealed that 52.6% of sampling sites exhibited excellent or good habitat quality; 42.1% were of moderate grade; 5.3% were of poor grade; and no sites were of the worst grade. The results demonstrate that this evaluation indicator system is suitable for the particularity of habitat conditions in reservoir tributaries, the assessment results can intuitively reflect river habitat status, and the method is convenient to operate with readily obtainable data, exhibiting strong scientific validity and operability.

Full Text

Preamble

ACTA ECOLOGICA SINICA ChinaXiv Partner Journal

Vol. 37, No. 24, Dec. 2017

DOI: 10.5846/stxb201610282197

Establishment and Application of a Habitat Assessment Index System for Rivers in the Three Gorges Reservoir Region

Chen Miao, Su Xiaolei, Dang Chengqiang, Gao Ting, Huang Huimin, Dong Rong, Tao Jianping*

Key Laboratory of Eco-environment in the Three Gorges Reservoir Region, Ministry of Education

Chongqing Key Laboratory of Plant Ecology and Resources Research in the Three Gorges Reservoir Region

College of Life Science, Southwest University, Chongqing 400715, China

Abstract

Following the completion and impoundment of the Three Gorges Reservoir, water level regulation has caused drastic changes in the river habitats of tributaries within the reservoir area. The formation of a water-level fluctuation zone has created river habitats that differ fundamentally from natural rivers. Under these new conditions, assessing river habitats in the reservoir area has become essential. However, existing domestic and international assessment index systems and methods cannot adequately adapt to these special habitat conditions, necessitating the establishment or improvement of new assessment index systems and methods.

This study analyzed numerous river habitat assessment methods from China and abroad, considering the ecological and environmental characteristics of reservoir-affected rivers. An evaluation index system comprising 18 indicators related to hydrological regime, river morphology, and riparian zone habitat was constructed. The Analytic Hierarchy Process (AHP) was employed to build this system, and combination weighting was used to calculate indicator weights. Using the new system, habitat quality assessments were conducted for the Dongxi River, Huangjin River, and Ruxi River—three tributaries of the Three Gorges Reservoir. Results showed that 52.6% of sampling sites achieved excellent or good habitat quality grades, 42.1% were average, and 5.3% were poor. No sites received the worst grade. The evaluation results accurately reflect river habitat conditions, and the method is convenient to operate. This index system is suitable for tributaries in reservoir areas, with readily obtainable data, strong scientific validity, and high operability.

Keywords: Three Gorges Reservoir Region; reservoir area rivers; habitat assessment; index system

Introduction

River habitat generally refers to the local environment where river life depends for survival, defined by some scholars as the sum of physical, chemical, and biological characteristics within river ecosystems. Following the impoundment of the Three Gorges Reservoir, the reservoir area has exhibited anti-seasonal water level fluctuations (winter storage and summer discharge) distinctly different from pre-impoundment conditions. The reservoir's backwater area experiences prolonged, deep inundation, with maximum water depths reaching 30 m and maximum inundation durations extending up to 10 months. The water-level fluctuation zone at different elevations also faces dual impacts from both natural flood regimes and reservoir water level operations. Consequently, river habitats in the reservoir area demonstrate fundamentally different states compared to natural river habitats.

Due to socio-economic development in tributary watersheds and intensifying hydropower development, the impacts on tributaries are growing. Whether the habitats of Three Gorges tributaries remain intact and whether they continue to play positive and important roles in maintaining ecosystem health and normal functions of the reservoir ecosystem remains unclear. Under these new circumstances, evaluating tributary habitat quality in the Three Gorges Reservoir area and developing suitable assessment index systems and methods for the characteristics of large reservoir fluctuation zones has become extremely urgent.

Since the release of the EU Water Framework Directive, numerous river habitat assessment methods have emerged internationally, including the Swedish Riparian and Channel Environmental Inventory, Australian Index of Stream Condition, U.S. Rapid Bioassessment Protocols, Spanish Hydromorphological Index, and Riparian Quality Index. International research has focused primarily on physical habitat assessment, morphological evaluation, and hydrological regime change assessment. However, these methods are mostly applied to natural rivers and are not suitable for reservoir-affected rivers. Domestic research has also explored river habitat assessment methods, but evaluation objects have primarily been natural rivers, with methods and systems ill-suited for large reservoir-affected habitats. Reservoir-related studies have mainly focused on water quality protection, phytoplankton assessment, ecosystem service function evaluation, ecological management benefit assessment, and ecological vulnerability assessment, with few addressing specific river habitat assessment.

While these studies provide important guidance for Three Gorges Reservoir river habitat assessment, the particularity of habitats affected by large dam impoundment requires a new approach. This study integrates indicators from hydrological regime, river morphology, and riparian zone habitat, adding indicators that reflect water-level operation impacts to construct a new assessment index system that comprehensively captures the inundation characteristics of the Three Gorges Reservoir fluctuation zone. The system establishes evaluation criteria at each level, calculates weights through combination weighting, and

conducts empirical research on reservoir river habitat quality assessment to provide reference and scientific basis for large reservoir river habitat evaluation and management in China.

1. Study Area

The Dongxi River, Huangjin River, and Ruxi River are first-order tributaries of the Yangtze River in the Zhongxian to Wanzhou section of the Three Gorges Reservoir area.

Dongxi River originates in Wanchao Township, Shizhu Tujia Autonomous County, flows through Dongxi Town, and empties into the Yangtze River at Damian Village. The watershed area is 139.9 km², with a reservoir area length of 32.1 km.

Huangjin River originates in Baijia Town, Liangping County, flows through Huangjin Town, and empties into the Yangtze River at Damian Village. The watershed area is 958.0 km², with a reservoir area length of 71.2 km.

Ruxi River originates in Sanjiaodang, FenShui Town, Wanzhou District, flows through Peiwen Town, converges with another tributary in Liangping County, flows through Ruxi Town in Zhongxian County, and finally empties into the Yangtze River at Shibao Town. The watershed area is 720.0 km², with a reservoir area length of 54.5 km. The climate is mid-subtropical humid monsoon, significantly influenced by canyon topography.

2. Sampling Site Setup and Survey Methods

Field surveys were conducted on the three tributaries (Dongxi River, Huangjin River, and Ruxi River) in the Zhongxian-Wanzhou section of the Three Gorges Reservoir area from August 20-28, 2015. Seven sites were selected in Dongxi River (DX1-DX7), five in Huangjin River (HJ1-HJ5), and seven in Ruxi River (RX1-RX7), totaling 19 sites. All data were obtained through field surveys conducted during normal flow periods, avoiding impoundment periods and flood seasons.

Survey methods included field investigation, determination of backwater zone locations, and interviews with local residents. Starting from downstream and walking upstream, measurements and recordings were taken every 500 m for each indicator of river hydrology, river morphology, and riparian zone habitat.

Substrate Survey and Calculation: Along cross-sections or water edges, a metal rod was vertically inserted near the toe of the riverbed every 500 m of forward progress. The length or median diameter of the first rock touched was measured. Sand or silt was recorded without measurement. In areas where substrate could not be accessed due to deep water, the substrate composition near the water surface at the lowest water level was used to represent substrate conditions. Substrate particle size was represented by the length or median diameter

corresponding to the 50th percentile of cumulative particle size distribution.

Substrate Silt Coverage Survey: During substrate surveys, visual estimation determined the silt coverage percentage of particles. The average silt coverage of all surveyed particles represented the cross-section's substrate silt coverage.

Surface Cover Survey: Types, quantities, and coverage area of surface cover materials were recorded. During field scoring, type diversity and coverage area each accounted for 50% of the score.

Geographic Coordinates and Photography: Latitude and longitude coordinates were recorded and photographs taken at each site. Since left and right banks differ in morphology and characteristics, riparian zone indicators were recorded separately for each bank, with final scores averaged.

3. Data Analysis

Excel was used for weight calculation via AHP and entropy methods. MATLAB 7.0 was used for combination weighting calculations. SPSS 22.0 was employed for Pearson correlation analysis and principal component analysis (PCA) to analyze correlations among evaluation indicators, identify dominant factors, and verify indicator rationality.

3.1 Assessment Index System

Changes in hydrological regime are considered valuable predictors of physical living conditions and significantly influence river ecosystems at multiple scales. Three Gorges Reservoir construction directly altered the hydrological regime of tributaries, changing flow velocity and channel structure and severely impacting aquatic organisms. Flow regime changes affect hydraulic conditions and water quality, influencing fish community structure and population diversity. Flow velocity describes river energy variation, dominating nutrient and oxygen transport and exchange, and directly affecting fish reproduction, feeding, and other life processes. The wetting rate (ratio of average width to full water width) reflects cross-sectional topography and water volume variation.

Large reservoir impoundment significantly alters channel structure through river channelization and discontinuity. Reservoirs trap large amounts of sediment, causing substantial deposition and reducing habitat diversity. Riverbed substrate provides habitat for benthic organisms, directly affecting their survival and reproduction. Rich substrate diversity provides varied habitats for river organisms. Surface cover materials (boulders, wood debris, overhanging vegetation) provide habitat for aquatic animals, refuge for fish, and spawning attachment sites, but are often removed by reservoir impoundment, reducing ecological heterogeneity.

Reservoir construction and operation profoundly affect riparian ecosystems,

causing loss of original riparian zones and formation of new ones. Seasonal inundation periodically exposes and submerges riparian zones, damaging vegetation and soil structure and causing new community succession. Bank type determines riparian stability, with different structures showing varying collapse patterns. Riparian width and soil thickness significantly affect ecological functions like pollutant filtration, terrestrial habitat provision, and landscape values. New riparian zones formed by reservoir impoundment require decades to reach equilibrium and initially exhibit low species diversity. Vegetation status and characteristics are the most intuitive, accessible indicators that directly reflect overall ecosystem condition and ecological function strength. Vegetation continuity, integrity, and coverage directly affect river ecosystem health, biodiversity, and ecological functions.

Given the hierarchical nature of factors affecting river habitat, the assessment index system is structured in three levels: target level (river habitat assessment), criterion level (hydrological regime, river morphology, riparian zone habitat), and indicator level (specific metrics).

[Figure 2: see original paper] The River Habitat Assessment Index System

3.2 Indicator Standardization and Assessment Criteria

In multi-indicator comprehensive assessment, indicators have different physical meanings and dimensional units, creating incomparability. Standardization is required to resolve this issue. This study employed a graded scoring method for indicator assignment, with specific criteria presented in Table 1.

3.3 Weight Determination

Weight determination methods include subjective and objective weighting approaches, each with advantages and disadvantages. To balance expert preferences while reducing subjective arbitrariness, combination weighting integrates both approaches based on game theory, yielding more reliable results that avoid both excessive subjectivity and absolute objectivity.

This study used AHP (subjective) and entropy method (objective) to calculate weights separately, then determined final weights through combination weighting.

River Habitat Assessment Indicators and Criteria

3.3.1 AHP Weight Calculation

The Analytic Hierarchy Process (AHP) hierarchically analyzes multi-indicator systems, modeling decision-makers' cognitive processes for complex systems. A questionnaire for large reservoir river habitat assessment indicator weights was designed and distributed to experts from Beijing Forestry University, Beijing Normal University, Chinese Academy of Environmental Sciences, East China

Normal University, Chongqing Normal University, Southwest University, and other institutions. Experts conducted pairwise comparisons to determine relative importance and construct judgment matrices. After consistency testing, matrices with satisfactory consistency were retained for calculation.

3.3.2 Entropy Method Weight Calculation

The entropy method determines weights based on information content transmitted by each indicator, effectively avoiding human interference and yielding realistic results. Using survey data from 19 river sections across three tributaries, entropy weights were calculated.

Weight Values of River Habitat Assessment Index System (AHP and Entropy Method)

3.3.3 Combination Weighting for Indicator Weights

Combination weighting synthesizes multiple weighting results through specific algorithms to obtain more objective and reasonable weights. For calculation procedures, refer to literature by Shan Chengju and Chen Jialiang. The calculation results are as follows.

Weight Values of River Habitat Assessment Index System (Combination Weighting Method)

3.4 Assessment Method

Each indicator uses a 0-5 scoring system, where higher scores indicate better habitat conditions. Weighted averaging calculates secondary indicator scores, which become primary indicator scores. To differentiate among sites, the total score is multiplied by 10 to obtain the Index of Stream Habitat Quality (ISHQ):

$$ISHQ = \sum (B_n \times w_i) \times 10$$

where B_n is the primary indicator score and w_i is the indicator weight.

Classification Criteria for Stream Habitat Quality

4.1 Correlation Analysis of Assessment Indicators

Pearson correlation analysis revealed significant correlations among river habitat assessment indicators, necessitating principal component analysis to verify indicator selection rationality.

4.2 Principal Component Analysis of Assessment Indicators

PCA results identified five principal components with a cumulative variance contribution rate of 80.417%, indicating these components play a decisive role in river habitat quality and reflect most information. Indicator loadings show:

- PC1 primarily reflects C11, C12, C14, C23, C24, C32, C35
- PC2 primarily reflects C21, C31, C39
- PC3 primarily reflects C13, C38
- PC4 primarily reflects C33, C36, C37
- PC5 primarily reflects C22, C34

The results demonstrate that assessment indicators effectively reflect river habitat characteristics without significant redundancy. Although indicators show correlation because they represent different spatial positions of river ecosystem habitat structures that are closely related, they are not substitutable. For example, larger substrate particles generally correspond to more flow regime types, but the ecological function of flow regime cannot be replaced by substrate. Therefore, any missing indicator would affect the authentic reflection of river habitat conditions, confirming the rationality of indicator selection.

Principal Component Loading Matrix of Assessment Indicators

4.3 River Habitat Quality Assessment

The ISHQ values for 19 sites across the Dongxi, Huangjin, and Ruxi rivers ranged from 15.1 to 41.6. According to the classification criteria, 10 sites (52.6%) exhibited excellent or good habitat quality, 8 sites (42.1%) were average, and 1 site (5.3%) was poor. No sites were classified as very poor.

Sites with excellent or good grades were located in upstream areas unaffected by reservoir impoundment, characterized by diverse substrate types, varied flow regimes, high natural vegetation coverage, and minimal human disturbance. The single poor-grade site (Longtan, RX1) was located downstream near the river mouth, affected by reservoir impoundment, with single flow regime type and substrate dominated by fine sand or silt.

River Habitat Quality Assessment Results for Dongxi River, Huangjin River, and Ruxi River

5. Discussion

Numerous river habitat assessment methods exist internationally, including the Swedish Riparian and Channel Environmental Inventory, Australian Index of Stream Condition, U.S. Rapid Bioassessment Protocols, Spanish Hydromorphological Index, and French River Physical Environment Quality Assessment System. However, these methods have limitations. For instance, the Australian method assesses small rivers in agricultural landscapes through comparison with original conditions, while the U.S. Rapid Assessment of Riparian Condition is

considered suitable for tree-dominated riparian zones. These methods are not applicable to the special habitat conditions created by Three Gorges Reservoir's water level operations (145 m, 175 m), which produce backwater and non-backwater zones.

Key indicators are decisive for river habitat health assessment. The major difference between reservoir and natural rivers lies in altered hydrological regimes. To scientifically assess reservoir river habitat quality, this study incorporated hydrological regime naturalness into the assessment system. Riparian zone indicators in backwater areas reflect the fluctuation zone condition—a special habitat vulnerable to soil erosion, geological hazards, and severely damaged plant diversity due to water level fluctuations. Considering this complexity, riparian habitat was included as a criterion level with specific indicators that effectively reflect large reservoir fluctuation zone characteristics.

The established index system effectively corresponds to the special habitat conditions of Three Gorges tributaries, intuitively reflecting habitat status and distinguishing quality differences under varying reservoir influences. The assessment method, based on field surveys, requires no precise measurements or complex calculations, produces consistent results across surveyors, and requires only basic training rather than advanced ecological or hydrological knowledge. This makes it highly operational for large reservoir river habitat investigation.

While this study broadens the approach to river habitat research and provides practical tools for reservoir ecosystem protection and management, improvements are needed. Some indicators show high correlation, and the ecological significance of certain indicators like “river surface cover” requires further research. This exploration of large reservoir river habitat assessment provides reference for deeper ecological studies and ideas for developing habitat assessment models tailored to different river characteristics.

References

- [1] Habitat quality assessment of the Naoli River basin. *Acta Ecologica Sinica*, 2010, 20(2): 481-486.
- [2] Jowett I G. Instream flow methods: a comparison of approaches. *Regulated Rivers: Research & Management*, 1997, 13(2): 115-127.
- [3] EU Water Framework Directive and its implementation. *Environmental Protection*, 2005, (22): 65-66, 52.
- [4] Belletti B, Rinaldi M, Buijse A D, Gurnell A M, Mosselman E. A review of assessment methods for river hydromorphology. *Environmental Earth Sciences*, 2015, 73(5): 2079-2100.
- [5] Szoszkiewicz K, Buffagni A, Davy-Bowker J, et al. Occurrence and variability of River Habitat Survey features across Europe and the consequences for data collection and evaluation. *Hydrobiologia*, 2006, 566(1): 267-280.
- [6] Effects of mountain river habitat on river biodiversity. PhD dissertation, 2011.
- [7] Ecot J R, Dice J L, Celeste L A A, et al. Riparian zone analysis using riparian, channel and environmental (RCE) inventory and water testing analysis in Lun Padidu river, Philippines. *Advances in Environmental Sciences*, 2014, 6(3): 276-283.
- [8] Ladson A R, White L J,

Doolan J A, et al. Development and testing of an Index of Stream Condition for waterway management in Australia. *Freshwater Biology*, 1999, 41(2): 453-468. [9] Brierley G J, Cohen T, Fryirs K, Brooks A. Post-European changes to the fluvial geomorphology of Bega catchment, Australia: implications for river ecology. *Freshwater Biology*, 1999, 41(4): 839-848. [10] Barbour M T, Gerritsen J, Snyder B D, Stribling J B. *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish*. 2nd ed. Washington, DC: U.S. Environmental Protection Agency, 1999. [11] Ollero A, Ibisate A, Gonzalo L E, et al. The IHG index for hydromorphological quality assessment of rivers and streams: updated version. *Limnetica*, 2011, 30(2): 255-261. [12] Barquín J, Fernández D, Álvarez-Cabria M, Peñas F. Riparian quality and habitat heterogeneity assessment in Cantabrian rivers. *Limnetica*, 2011, 30(2): 329-346. [13] Study on river habitat assessment indicators and methods in the Liao River basin. *Acta Scientiae Circumstantiae*, 2007, 27(6): 928-936. [14] Study on comprehensive evaluation index system for riparian zone ecosystems. *Advances in Water Science*, 2005, 16(3): 345-348. [15] Naturalness evaluation index system for riparian zones in Beijing suburbs. *Bulletin of Soil and Water Conservation*, 2010, 30(1): 161-165. [16] River habitat assessment of the Dong River based on habitat survey. *Acta Ecologica Sinica*, 2014, 34(6): 1548-1558. [17] Comprehensive evaluation of Suzhou River riparian zone at reach scale. *Acta Ecologica Sinica*, 2010, 30(13): 3501-3510. [18] Construction and application of urban river health assessment index system. *Chinese Journal of Ecology*, 2014, 34(4): 993-1001. [19] Preliminary study on urban river ecosystem health assessment. *Advances in Water Science*, 2005, 16(3): 349-355. [20] River habitat quality assessment in Yixing section of Taihu Basin. *Chinese Journal of Ecology*, 2012, 31(5): 1288-1295. [21] River ecosystem health assessment in the Tumen River basin. *Acta Ecologica Sinica*, 2014, 34(14): 3969-3977. [22] Comprehensive water quality safety assessment in Chongqing section of Three Gorges Reservoir area. *Water Resources Protection*, 2014, 45(18): 10-14. [23] Phytoplankton survey and water quality assessment in Xiangxi River. *Journal of Wuhan Botanical Research*, 2004, 22(6): 507-513. [24] River ecosystem service function assessment in Xiangxi River. *Acta Ecologica Sinica*, 2006, 26(9): 2971-2978. [25] Ecosystem service function importance assessment in Three Gorges Reservoir area. *Acta Ecologica Sinica*, 2013, 33(1): 168-178. [26] Comprehensive assessment of ecological management benefits in Xiangxi River basin. *Soil and Water Conservation in China*, 2012, (6): 57-58. [27] Ecological vulnerability assessment in Three Gorges Reservoir area. *Acta Ecologica Sinica*, 2015, 35(21): 7117-7129. [28] Bunn S E, Arthington A H. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management*, 2002, 30(4): 492-507. [29] Poff N L, Allan J D, Bain M B, et al. The natural flow regime: a paradigm for river conservation and restoration. *BioScience*, 1997, 47(11): 769-784. [30] Fish habitat simulation in Heishui River, a backwater tributary of Baihetan Reservoir. PhD dissertation, 2013. [31] River morphology diversity and biological community diversity. *Geographical Research*, 2003, 34(11): 1-6. [32] Hauer C, Unfer G, Trithart M, Habersack H. Effects of stream channel morphology, transport processes and effective

discharge on salmonid spawning habitats. *Earth Surface Processes and Landforms*, 2011, 36(5): 672-685. [33] Nilsson C, Berggren K. Alterations of riparian ecosystems caused by river regulation. *BioScience*, 2000, 50(9): 783-792. [34] Evaluation of weighting methods in multi-indicator comprehensive assessment. *Statistics and Decision*, 2007, 26(3): 220-226. [35] Comprehensive evaluation of ecological landscape in Dongfeng Port riparian zone of Suzhou River. *Journal of Hydroelectric Engineering*, 2006, 37(3): 253-258. [36] Evaluation indicators and standards for healthy rivers. *Water Resources Protection*, 2006, (13): 17-19. [37] Fuzzy assessment of river health based on combination weighting. *Water Resources and Hydropower Engineering*, 2013, 44(2): 28-31. [38] Application of combination weighting method in river health assessment. *Journal of Hohai University (Natural Sciences)*, 2012, 40(6): 622-628. [39] Combination weighting method based on decision-maker preferences and weighting method consistency. *Systems Engineering and Electronics*, 2003, 19(9): 15-16. [40] Study on river health assessment index system and weighting model. PhD dissertation, 2008. [41] Research on combination weighting evaluation method based on game theory. *Systems Engineering and Electronics*, 2004, 26(9): 1226-1230, 1290. [42] An K G, Park S S, Shin J Y. An evaluation of river health using the index of biological integrity along with relations to chemical and habitat conditions. *Environment International*, 2002, 28(5): 411-420. [43] International river health assessment technologies. *Water Resources and Hydropower Engineering*, 2005, 36(11): 15-19. [44] Review of three foreign river health assessment methods. *Bulletin of Soil and Water Conservation*, 2009, 29(3): 40-44. [45] River biological habitat investigation and assessment methods. *Chinese Journal of Applied Ecology*, 2008, 19(9): 2081-2086. [46] Research progress on water-level fluctuation zones. *Journal of Lake Sciences*, 2010, 46(4): 111-119.

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

Source: ChinaXiv – Machine translation. Verify with original.