COMPREHENSIVE ASSESSMENT MODEL OF ECOLOGICAL RIPARIAN ZONE

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Abstract: Comprehensive assessment of ecological riparian zone is to analyze and evaluate the status of riparian zone ecosystem. The existing problem of the ecosystem can be found through the assessment. The AHP-FUZZY method used in the assessment is based on the hierarchy model of index, grade model of object, and attribution degree of index. Accordingly, the four models have been discussed and presented from the aspect of the stability, landscape, eco-health and eco-safety of riparian zone.

Keywords: riparian zone, ecological, comprehensive assessment, model

1. INTRODUCTION

Riparian zone encompasses the stream channel between the low and high water marks and that portion of the terrestrial landscape from the high water mark toward the uplands, where vegetation may be influenced by elevated water tables or flooding(ZHANG, J.C., et al., 2003; Naimain, R.J., Decamps, H.,1997). It is the interface between land ecosystem and water ecosystem, which possesses many specific physical and chemical attributes, biotic properties and energy and material flow processes. Namely, riparian zone is the ecotone between water ecosystem and land ecosystem, and the edge effect is the most distinct characteristic. Riparian ecosystem is a complex three-dimensional ecosystem, which is affected by land ecosystem and river ecosystem in longitudinal direction, upstream and downstream in lateral direction, and superficial water and ground water in vertical direction. Because of its biodiversity, biotic sensitivity and biotic corridors, riparian zone is regarded as genetic bank and has great influence on both the land ecosystem and the water ecosystem. So it is important to remain its ecological stability, ecological health, and ecological safety.

Many researches on riparian zone have been done and many good conclusions have been obtained. (Swanson F. J., Gregory S. V., Sedell J. R. et al.,1982; Lowrance R., Leonard R. and Sheridan J., 1985). However, most of these researches are qualitative and most of their results are conceptual. Few of these results can act as standards and criteria for efficiently protecting and managing riparian zone. In order to get reasonable standards and criteria, the comprehensive assessment of ecological riparian zone must be done. The comprehensive assessment includes general assessment, structure stability, landscape suitability, ecological health, and ecological safety assessment. In processing these assessments, it's necessary to use right assessment model. Only on the basis of right models, can reasonable results be obtained. This paper will discuss how to construct

the assessment model of ecological riparian.

2. LOGICAL MODEL

The comprehensive assessment includes general assessment and sub-object assessment. The sub-object assessment includes structure stability assessment, landscape suitability assessment, ecological health assessment, and ecological safety assessment, which can be evaluated by use of right model and indices value. According to the assessed results of sub-object, then the general assessment can be done. So, logical structure of the comprehensive assessment is a hierarchy structure as shown in Fig.1. In Fig.1, logical structure is divided into two layers. In the first layer, structure stability landscape suitability, ecological health, and ecological safety can be analyzed on the basis of all kinds of indices. In the second layer, general status can be evaluated according to the results of first layer.

In the two layers, the AHP-Fuzzy method is used, which integrates Fuzzy Method with AHP. By use of AHP, the weight of each index can be calculated. Fuzzy subsets, fuzzy matrices, and fuzzy attribute degree are given via Fuzzy Method. The concrete steps are shown as follows.

1) Constructing assessment factor sets. Supposing the k-th sub-system has m indices, its factor set is
$u_k=\{u_{k1},u_{k2},\ldots\ldots u_{km}\}(k=1,2,3,4)$;

2) Giving grade sets. Supposing the k-th sub-object has p grades, its grade set is $v_k=\{v_{k1},v_{k2},\ldots\ldots v_{kp}\}$;

3) Constructing fuzzy relation matrix. Fuzzy relation matrix of the k-th sub-system is ${}_kR$ as follows.

$$ {}_kR=({}_kr_{ij})_{m\times p}=\begin{bmatrix} {}_kr_{11} & {}_kr_{12} & \mathrm{K} & {}_kr_{1p} \\ {}_kr_{21} & {}_kr_{22} & \mathrm{K} & {}_kr_{2p} \\ \mathrm{K} & \mathrm{K} & \mathrm{K} & \mathrm{K} \\ {}_kr_{m1} & {}_kr_{m2} & \mathrm{K} & {}_kr_{mp} \end{bmatrix} $$

where ${}_kr_{ij}$ means degree of u_{ki} belonging to v_{ki}. ${}_kr_{ij}$ can be calculated via the attribute function of u_{ki}.

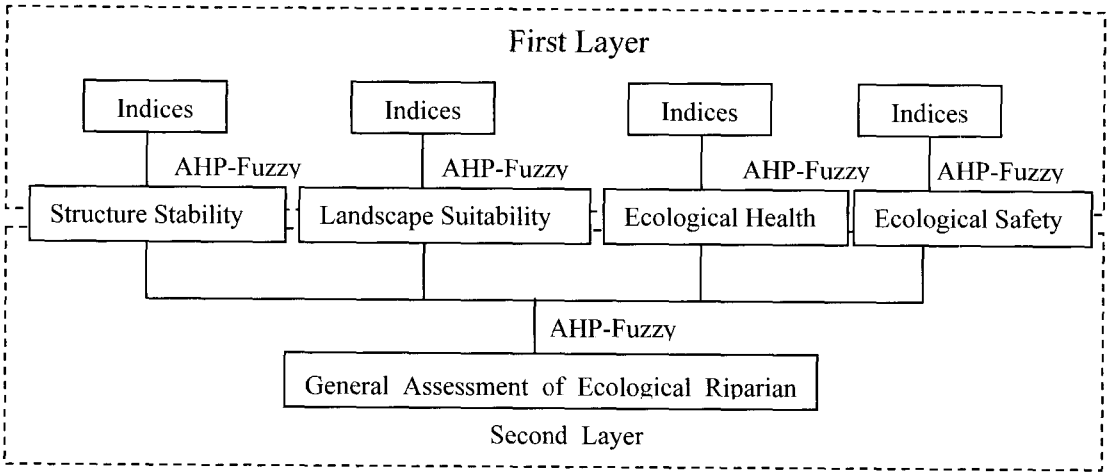

Figure 1. Logical structure of ecological riparian zone assessment

4) Giving weight vector
$_k\varpi = (_k\varpi_j)_m (j = 1,2,...m)$,
where $_k\varpi_j$ is the weight of u_{ki}, which can be got by use of AHP.

5) Fuzzy complex operation.
$_kA =_k R \otimes_k \varpi$, where $\otimes$ is a fuzzy complex operator.

3. BASIC MODEL

3.1 Hierarchy model of indices

In the whole assessment procedure, constructing suitable index system is the basis of the comprehensive assessment. Because logical structure of the comprehensive assessment has two layers, the hierarchy of indices can be divided into two layers. The indices in first index layer include structure stability, landscape suitability, ecological health, and ecological safety. The indices in second index layer are all kinds of classified factors which affect the indexes in first index layer. For example, indexes affecting structure stability include soil classification, slope structure, shear strength, mean rainfall, vegetative covering degree and etc.. The hierarchy of indexes is shown in Table 1(XIA J.H., et al.2004, 2005).

3.2 Assessment grade model

Dividing the grade of assessment object is the premise. The assessment grade of ecological riparian zone includes general object grade and sub-object grade. General object grade has four grades: perfect status, nice status, common status and worse status. "Perfect status" means that riparian zone ecosystem is unspoiled, and its ecological integrity is perfect, and its structure is stable, and landscape is suitable. "Nice status" means that riparian zone has intact ecological function, and its structure and landscape basically remain stable and suitable. "Common status" means that riparian zone can restore its ecological function under less damage, and its structure is not stable. "Worse status" means that riparian zone has no ecological integrity, and its structure and landscape have been destroyed. So the assessment set of general object is {Perfect status, Nice status, Common status, Worse status}. These grades and their meaning are shown in Table 2.

Table 1. Hierarchy model of assessment indexes

First index layer	Second index layer
Structure stability	Soil classification, shear strength, slope structure, slope angle, slope height, degradation degree, earthquake intensity, groundwater depth, mean rainfall, disturbing intensity, percentage of vegetation.
Landscape suitability	Landscape diversity, fractal dimension, landscape evenness, tilth ratio, showplace richness, recreative device richness;
Ecological health	Biocommunity biomass, biocommunity complexity, biology born ratio, biology dead ratio, adventitious species ratio, PH value, intercepting pollution ability, retarding water intensity;
Ecological safety	Invaded frequency, pollution intensity, COD, BOD, flood disaster frequency, flood disaster intensity, regression degree, population, GDP.

Table 2. Grades and meaning of general object

Grade	Meaning
Perfect Status	Riparian zone ecosystem is unspoiled, and its ecological integrity is perfect, and its structure is stable, and landscape is suitable.
Nice Status	Riparian zone has intact ecological function, and its structure and landscape basically remain stable and suitable.
Common Status	Riparian zone can restore its ecological function under less damage, and its structure is not stable.
Worse Status	Riparian zone has no ecological integrity, and its structure and landscape have been destroyed.

According to the characteristics of structure stability, the grades of structure stability have four levels: rather stable, stable, unstable, and rather unstable. "Rather stable" riparian zone recently has no distortion and is not damaged. Riparian zone whose structure has some looseness but no distortion is called "Stable". "Unstable" riparian zone has many expanding crannies which will result in serious distortion and landslip. "Rather unstable" riparian zone has serious distortion and landslides at any time. The different grade and its meaning are shown in Table 3. So the assessment set of structure stability is {Rather stable, Stable, Unstable, Rather unstable}.

Landscape suitability of riparian zone is focused on different emphasis in different area. The landscape suitability of area where the population is very dense has an emphasis on whether the landscape is suitable for the demand of recreation and living. In the area where population is sparse, the landscape has an emphasis on whether it is suitable for the nature. According to these features, the landscape suitability of riparian zone has four levels: high suitability, middle suitability, low suitability, and unfit suitability. "High suitability" riparian can fully satisfy residents' recreative desire and is in harmony with landscape of neighboring ecosystem. "Middle suitability" riparian can remain its basic functions which can basically satisfy residents' need. "Low suitability" riparian can only satisfy a part of the desire of residents. "Unfit suitability" riparian can not satisfy the desire of people and is not in harmony with the surrounding landscape. To some extent, it may destroy the surrounding landscape. The four levels and meaning are shown in table 4. So the assessment set of landscape suitability is: {High suitability, Middle suitability, Low suitability, Unfit suitability}.

Table 3. Grades and meaning of stability

Grades	Meaning
Rather Stable	Riparian zone recently has no distortion and is not damaged.
Stable	Riparian zone has some looseness but no distortion.
Unstable	Riparian zone has many expanding crannies which will result in serious distortion and landslip.
Rather Unstable	There is serious distortion in riparian and riparian landslides at any time, which most easily happen and most possibly to lead to serious disaster in raining season.

Table 4. Grades and meaning of landscape suitability

Grades	Meaning
High Suitability	Riparian can fully satisfy residents' recreative desire and is in harmony with landscape of neighboring ecosystem.
Middle Suitability	Riparian can remain its basic functions which can basically satisfy residents' recreative need.
Low Suitability	Riparian can only satisfy a part of the desire of residents.
Unfit Suitability	Riparian can not satisfy the desire of people and is not harmonized with surrounding landscape. To some extent, it may destroy the surrounding landscape.

The grades of the ecological health can be divided into four levels: rather healthy, healthy, less healthy, sick, while the assessment set of ecological health is: {Rather healthy, Healthy, Less healthy, Sick}. "Rather healthy" riparian has strong self-regulation ability, in which the cycles of material and energy are benign. "Healthy" riparian has common self-regulation ability which can remain the basic cycles of material and energy in the riparian ecosystem. "Less healthy" riparian has weak self-regulation ability which results in the cycles of material and energy in the riparian ecosystem are abnormal. "Sick" riparian almost loses its self-regulation ability so that the cycles of material and energy cannot do in the ecosystem. These four levels and their meanings are shown in Table 5.

The grades of ecological safety can be divided into four levels: rather safe, less safe, less dangerous, dangerous, while elements of assessment set of ecological safety are rather safe, less safe, less dangerous, and dangerous. "Rather safe" riparian has no disturbance from outside and can provide good service for residents. "Less safe" riparian has little disturbance from outside, but depending on its restoration ability and it can keep its good structure and functions. "Less dangerous" riparian is suffered with much disturbance which makes some functions not restored. "Dangerous" riparian is suffered with serious disturbance and the ecosystem is degrading. These grades and their meanings are shown in Table 6.

4. MEMBERSHIP FUNCTION MODEL

4.1 Membership function model of structure stability

It is a basic way of Fuzzy math to use degree of membership to describe the different fuzzy boundary things. Membership functions of struc-

Table 5. Grades and meaning of ecological health

Grades	Meaning
Rather Healthy	Riparian has strong self-regulation ability, in which the cycles of material and energy are benign.
Healthy	Riparian has common self-regulation ability which can remain the basic cycles of material and energy in the riparian ecosystem.
Less Healthy	Riparian has weak self-regulation ability which results in the cycles of material and energy in the riparian ecosystem are abnormal.
Sick	Riparian almost loses its self-regulation ability so that the cycles of material and energy cannot do in the ecosystem.

Table 6. Grades and meanings of ecological safety

Grade	Meanings
Rather Safe	Riparian has no disturbance from outside and can provide good service for residents.
Less Safe	Riparian has little disturbance from outside, but depending on its restoration ability and it can keep its good structure and functions.
Less Dangerous	Riparian is suffered with much disturbance which makes some functions not restored.
Dangerous	Riparian is suffered with serious disturbance and the ecosystem is degrading.

ture stability are given in two ways. One is expert giving grades, and another is formula way. For discrete indices, the membership functions are given in expert-giving-marks way, while the membership functions are given in formula way for continuous indices. According to the characteristics of continuous indices, the degree is measured by use of descend-semi-trapezoid distribution as formula(1) to formula (4).

$$U_I(x)=\begin{cases}1 & x\le S_1\\ -\dfrac{S_2-x}{S_2-S_1} & S_1<x\le S_2\\ 0 & x>S_2\end{cases} \quad (1)$$

$$U_{II}(x)=\begin{cases}0 & x<S_1, x>S_3\\ -\dfrac{S_1-x}{S_2-S_1} & S_1<x\le S_2\\ \dfrac{S_3-x}{S_3-S_2} & S_2<x\le S_3\end{cases} \quad (2)$$

$$U_{III}(x)=\begin{cases}0 & x<S_2, x>S_4\\ -\dfrac{S_2-x}{S_3-S_2} & S_2<x\le S_3\\ \dfrac{S_4-x}{S_4-S_3} & S_3<x\le S_4\end{cases} \quad (3)$$

$$U_{IV}(x)=\begin{cases}0 & x<S_3\\ -\dfrac{S_3-x}{S_4-S_3} & S_3<x\le S_4\\ 1 & x\ge S_4\end{cases} \quad (4)$$

where U_I, U_{II}, U_{III}, U_{IV} are membership degree which one index subordinates different grades; S_1, S_2, S_3, S_4 are different criteria value of different grades ; x is real value of index.

4.2 Membership function model of landscape suitability

According to the characteristics of the factors affecting landscape, normal distribution is used as the membership function when the study results of assessment of land suitability are used for reference. It is expressed as formula (5).

$$\mu(x)=e^{[-\frac{(x-m)^2}{c}]} \quad (5)$$

where $\mu(x)$ is membership degree; m is mean value; c is constant; x is real value of index.

When x equals to m, the value of $\mu(m)$ is 1. That is to say. When x equals to m, the value of $\mu(m)$ will reach maximum. So m is the average of upper limit and down limit of one grade, which can be expressed as $m=(x_{up}+x_{down})/2$.

The boundary value is between two neighboring grades, the degree subordinating to one grade equals to the degree subordinating to next grade. So the membership degree is 0.5. It can be written as expression (6).

$$\mu(x_{up}) = e^{-(\frac{x_{up}-m}{c})^2} \approx 0.5 \qquad (6)$$

Substituting $m=(x_{up}+x_{down})/2$ into expression (6), and expression (7) will be attained.

$$e^{-(\frac{x_{up}-x_{down}}{2c})^2} \approx 0.5 \qquad (7)$$

Logarithm conversion is done for expression (7), and then c can be given as expression (8).

$$c = \sqrt{-(x_{up} - x_{down})/4\ln 0.5} \qquad (8)$$

When m and c are known, the membership degree can be reaches.

4.3 Membership function model of ecological health and ecological safety

These two kinds of indices have influence on ecological health and ecological safety. One is positive index while another is a negative one. The positive index has greater influence when these values become more. The membership functions of this kind of index are described by use of ascend-semi-trapezoid distribution as expressions (9) ~ (12). On the other hand, the membership functions are expressed by use of descend-semi-trapezoid distribution as expressions (1) ~ (4).

$$U_I = \begin{cases} 1 & x \geq S_1 \\ \dfrac{x-S_2}{S_1-S_2} & S_2 < x < S_1 \\ 0 & 0 \leq x \leq S_2 \end{cases} \qquad (9)$$

$$U_{II} = \begin{cases} 0 & x \geq S_1 \text{ or } x \leq S_3 \\ \dfrac{S_1-x}{S_1-S_2} & S_2 < x < S_1 \\ 1 & x = S_2 \\ \dfrac{x-S_3}{S_2-S_3} & S_3 < x < S_2 \end{cases} \qquad (10)$$

$$U_{III} = \begin{cases} 0 & x \geq S_2 \text{ or } x \leq S_4 \\ \dfrac{S_2-x}{S_2-S_3} & S_3 < x < S_2 \\ 1 & x = S_3 \\ \dfrac{x-S_4}{S_3-S_4} & S_4 < x < S_3 \end{cases} \qquad (11)$$

$$U_{IV} = \begin{cases} 0 & x \geq S_3 \\ \dfrac{S_3-x}{S_3-S_4} & S_4 < x < S_3 \\ 1 & 0 \leq x \leq S_4 \end{cases} \qquad (12)$$

where U_I, U_{II}, U_{III}, U_{IV} are membership degree which one index subordinates different grades; S_1, S_2, S_3, S_4 are different criteria value of different grades ; x is real value of index.

5. CASE STUDY

5.1 Study area

Rujiangshuidao river lies in downstream of Huaihe watershed, which is from Sanhe to Sanjianying and then flows into Yangtze River. Be-

cause of jamming, Ecosystem of Rujiangshuidao river has had little regression. In order to stop the regression, the ecological assessment should be done. Left riparian zone of Rujiangshuidao river has been chosen as the case study, which is 2km long.

5.2 Comprehensive assessment

Soil classification, shear strength, slope structure, slope angle, slope height, mean rainfall, scouring depth, scouring width, disturbing intensity, percentage of vegetation and erosion are used for structure stability assessment. Weight of each index are obtained by use of AHP and judgment matrix is given as follows.

$$\begin{bmatrix} 1 & 2 & 1/7 & 1 & 1/2 & 1/4 & 1/6 & 1/9 & 1 & 1/7 \\ 1/2 & 1 & 1/8 & 3 & 1/3 & 1/3 & 1/7 & 1/8 & 1/3 & 1/6 \\ 7 & 8 & 1 & 6 & 5 & 3 & 1 & 1/2 & 5 & 3 \\ 1 & 1/3 & 1/6 & 1 & 1/3 & 1/5 & 1/7 & 1/8 & 1/3 & 1/4 \\ 2 & 3 & 1/5 & 3 & 1 & 1/2 & 1/3 & 1/5 & 1 & 1/2 \\ 4 & 3 & 1/3 & 5 & 2 & 1 & 1/3 & 1/5 & 2 & 1 \\ 6 & 7 & 1 & 7 & 3 & 3 & 1 & 1/2 & 1 & 1 \\ 9 & 8 & 2 & 8 & 5 & 5 & 2 & 1 & 6 & 7 \\ 1 & 3 & 1/5 & 3 & 1 & 1/2 & 1 & 1/6 & 1 & 1/5 \\ 7 & 6 & 1/3 & 4 & 2 & 1 & 1 & 1/7 & 5 & 1 \end{bmatrix}$$

This matrix is consistent because value of CR is 0.58. So weight vector is eigenvector of this matrix., which is (0.027, 0.023, 0.197, 0.02, 0.052, 0.102,0.142,0.25,0.071,0.116).

The real value of each index is shown in Table 7.

By use of expression (1)~(4), the attribution degree of each index is calculated and the fuzzy relationship matrix is formed as follows.

$$\begin{bmatrix} 0 & 0 & 0.25 & 0.75 \\ 0 & 0.05 & 0.30 & 0.65 \\ 0 & 0 & 0.14 & 0.86 \\ 0.9 & 0.1 & 0 & 0 \\ 0.93 & 0.07 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 0.85 & 0.15 & 0 & 0 \\ 0 & 0 & 0.5 & 0.5 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

Then, using fuzzy complex operator, and B1 which stands for status value of structure stability may be assessed.

$$B_1 = \begin{bmatrix} 0.027 \\ 0.023 \\ 0.197 \\ 0.02 \\ 0.052 \\ 0.102 \\ 0.142 \\ 0.25 \\ 0.071 \\ 0.116 \end{bmatrix}^T \begin{bmatrix} 0 & 0 & 0.25 & 0.75 \\ 0 & 0.05 & 0.30 & 0.65 \\ 0 & 0 & 0.14 & 0.86 \\ 0.9 & 0.1 & 0 & 0 \\ 0.93 & 0.07 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 0.85 & 0.15 & 0 & 0 \\ 0 & 0 & 0.5 & 0.5 \\ 1 & 0 & 0 & 0 \end{bmatrix} = [0.395 \; 0.044 \; 0.077 \; 0.484]$$

The attribution degree to "Rather unstable" is 0.484 which is maximum. According to maximum degree principle, the structure stability of this zone belongs to "Rather unstable".

Using the same way, and landscape suitability and ecological health and ecological safety of this zone can be assessed. Landscape suitability is "High suitability", and ecological health is

Table 7. Real value of each index

Soil classification	Silt	Scouring depth	0.54
Slope structure	Loosing	Scouring width	0.9
Shear strength	0.25	Percentage of vegetation	75
Slope height	6	Disturbing intensity	30
Slope angle	16	Erosion	400
Mean rainfall	1000		

"Healthy", and ecological safety is "Less safe" so that the marks of them can be given, which are respective 1, 5, 3 and 3. Then, the general status can be assessed by use of Fuzzy Method, in which the judgment matrix is constructed.

$$\begin{bmatrix} 1 & 3 & 2 & 2 \\ 1/3 & 1 & 1/2 & 1/2 \\ 1/2 & 2 & 1 & 1 \\ 1/2 & 2 & 1 & 1 \end{bmatrix}$$

Because this matrix is consistent, eigenvector is weight vector and its value is (0.423, 0.123, 0.227, 0.227). Then using weighted way, and general status index will calculated.

$A=0.423 \times 1+0.123 \times 5+0.227 \times 3+0.227 \times 3=2.4$

So general status index is 2.4 which belongs to "Nice status".

6. CONCLUSIONS

It is most important to construct fuzzy relation matrices and weight vectors in APH-Fuzzy assessment method used in comprehensive assessment of ecological riparian zone. When the fuzzy relation matrices and weight vectors have been formed, the structure stability, landscape suitability, ecological health, and ecological safety can be analyzed and assessed by use of complex fuzzy operation, then general ecological status of riparian zone can be obtained. In the whole procedure, the hierarchy model, the grade model, and the membership function are the basis, among of which the membership function is the most important model. The membership functions of different kinds of indices are different. For the indices of structure stability, the membership function is drop-semi-trapezoid distribution. For the indices of landscape suitability, the membership function is normal distribution. For the indices of ecological health and safety, both the descend-semi-trapezoid distribution and ascend-semi-trapezoid distribution are used as the membership function. Rujiangshuidao river as a case has been reasonably assessed, of which ecological status belongs to "Nice status"

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REFERENCES

Lowrance, R., Leonard, R. and Sheridan, J.(1985). Managing riparian ecosystems to control non-point pollution. *Journal of Soil and Water Conservation*, Vol. 40, no.1, pp.87-91.

Naiman R. J., H. Decamps and M. Pollock, 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications*, 3(2):209-212 .

Meeban, W.R.,Swanson, F.J., Sedell, J.R.(1977). Influences of riparian vegetation on aquatic ecosystems with particular references to salmonoid fishes and their food supplies. In:Johnson RR, Jones DA eds, Importance, Preservation and Management of Floodplain Wetlands and other Riparian Ecosystems. *USDA Forest Service General Technical Report RM*, no.43, pp.137-145.

Swanson, F.J., Gregory, S.V., Sedell, J.R., et al.(1982). Land-water interactions: the riparian zone. In: Edmonds RL. Analysis of Coniferous Forest Ecosystems in the Western United States. *US/IBP Synthesis Series*

No. 14. Hutchinson Ross Publishing. Stroudsburg. Pennsylvania , USA, pp. 267-291.

XIA,J.H., YAN, Z.M., JIANG, C.F. (2005). Comprehensive assessment index system of ecological riparian zone. *Advances in Water Science*, Vol. 16, no. 3, pp. 345-348.

XIA, J.H., YAN, Z.M.(2003).Advances in research of ecological riparian zones and its trend of development. *Journal of Hohai University(Natural Sciences),* Vol. 32, no.3, pp. 254-257.

ZHANG, J.C., PENG B.Z.(2003). Study on riparian zone and the restoration and rebuilding of its degraded ecosystem. *ACTA Ecological SINICA*, Vol. 23, no. 1, pp. 56-63.

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