Designing the buffer zone of a nature reserve: a case study in Yancheng Biosphere Reserve, China

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Abstract

The problems existing in design of buffer zones are analyzed, and a procedure for designing the buffer zone of reserves is proposed. The Analytic Hierarchy Process (AHP) is applied to design the width of buffer zone. The different importance of influences in different sections around the reserve leads to different widths of buffer zone being designated around the reserve. The method is illustrated by a case study, designing the buffer zone for the Yancheng Biosphere Reserve, China. © 1999 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The biosphere reserve concept, launched by UNESCO's Man and the Biosphere Program in 1979, provides a useful model and starting point for bioregional management. In the model reserve, a protected "core area" is surrounded by a "buffer zone" and then a "transition area". The core area and buffer zone should each have a definite boundary, and the transition zone as a whole is usually not strictly delineated. The core area excludes all human use except for strictly controlled scientific research. Only activities, such as certain research, education, training, recreation and tourism, that do not conflict with the protection of the core zone are allowed within the buffer zone, while development activities are permitted in the transition area (WRI, IUCN, UNEP, 1992). Establishing a buffer zone can protect the core zone more effectively in biological conservation, and at same time, compensate the local inhabitants for their losses of biological resources within the reserve (Oldfield, 1988). The buffer zone is usually a key aspect for reserve management because it is a link between the

reserve managers and local inhabitants. Experiences in reserve management show that failure in conservation in a reserve often results from poor design of the buffer zone or no buffer zone around a core zone. Hence, a well-justified buffer zone is the key and basis for a reserve existing and developing.

What is a scientific buffer zone? A wider buffer zone will benefit conservation but will occupy more land that may be the only living source for poor local inhabitants. Therefore, the scientific buffer zone should be designed as a compromise between needs of nature conservation and local inhabitants. Because many social, economic, as well as ecological relative factors need to be considered in the design of buffer zone, it is difficult to generate a quantitative relationship between the width of buffer zone and the influential factors. It is suggested that the most unjustifiable aspect of design of the buffer zone for reserves is that its width is usually the same size all around the reserve and does not vary with the importance of the influences in the different sections around the reserve. For example, a distance of 10 km was simply designated as the width for the buffer zone in Amazonian Nature Reserves (Peres and Terborgh, 1995), without consideration of the different influences in the different sections around the reserves. In USA some states (e.g. Massachusetts) even regulate unified

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buffer zones 30.5 m beyond all the delineated wetlands in the reserves (Klein and Freed, 1989; Burke and Gibbons, 1995). In China, the design of a buffer zone has been in confusion. Ma (1992) suggested that the width of buffer zone should be at least 500 m. Obviously, this guideline is too simplistic to be applied in all the reserves.

The design method proposed in this paper is mainly aimed to resolve the above problems with the case study in Yancheng Biosphere Reserve (YBR), P.R. China. The analytic hierarchy process (AHP) is used to generate quantitative relationships between the width of buffer zone and the factors influencing the nature conservation interest of the reserve.

2. Methods

The AHP is a decision analysis method first developed by Saaty (1980), that combines both quantitative and qualitative criteria in decision problems. Although the AHP was a new decision technology, it has become widely used, as evidenced by the significant number of applications published in books, journals, and special issues of different journals (Gholamnezhad, 1981; Arbel, 1983; Cook et al. 1984; Gass, 1986; Haker, 1986; Golden et al., 1989; Vargas, 1990; ACSM/ASPRS, 1997). However published literature describing AHP applications to natural resources is, surprisingly, still limited (Mendoza, 1997). Some of the published applications in natural resources are: forest management planning (Mendoza and Sprouse, 1989; Kuusipalo and Kangas, 1994); integration of biodiversity to forest planning (Kangas and Kuusipalo, 1993); environmental planning processes (Anselin et al., 1989; Varis, 1989); development of resource management plans for national parks (Peterson et al., 1994); and resource inventory and monitoring in national parks (Schmoldt et al., 1994).

In this study, we use AHP to design the width of the buffer zone, based on the following steps:

1. Determine the decision alternatives of buffer zone widths
2. Determine the factors that affect the buffer zone widths.
3. Generate the analytic hierarchy, and evaluate the importance of each influential factor and the priority of each decision alternative with respect to each influential factor.
4. Determine the relative priority of each alternative with respect to the buffer zone width, and calculate the buffer zone width.

Step 1 is based on available ecological knowledge, the objectives of the reserve and local land-use planning. In this step, some constraints about the decision alternatives will be determined, such as the upper and the

lower width limits of the buffer zone. The decision alternatives should be located between these limits.

Step 2 refers to the influences of human disturbances, such as the requirement of resources from the reserve and accessibility to the reserve. These factors differ between reserves.

Step 3 is carried out using the principles of AHP. Many factors affect the width of the buffer zone, and the task of AHP is to clarify the hierarchy of priorities by weighting factors in order of impact and to offer management options that can resolve the problems.

After the first three steps have been carried out, in step 4 priorities of the decision alternatives with respect to the width of buffer zone are estimated using a simple linear function, as follows:

$$WD_i = \sum_{j=1}^n W_j P_{ij} \quad (1)$$

where WD_i is the relative priority of decision alternative i with respect to the width of buffer zone; W_j is the weight of the factor j ; n is the number of factors considered; P_{ij} is the relative priority of alternative i with respect to factor j .

Last, the width of buffer zone is calculated as follows:

$$\bar{B} = \sum_{i=1}^n WD_i \times B_i \quad (2)$$

where $\bar{B}$ is the designated width of buffer zone; B_i is the width of buffer zone of the decision alternative i .

3. Design of the buffer zone in YBR

3.1. Study area

YBR was established in 1983 with the major aim of protecting an endangered bird species, the red crown crane (*Grus japonensis*). It was approved as an international biosphere reserve in UNESCO's Man and Biosphere Program in 1992. The reserve is located in Jiangsu Province, east coast of China, and extends 582 km along the coast of the Yellow sea. It is a typical coastal wetland with a total area of 280,000 ha and covers parts of 5 counties in administration.

The original core zone in YBR was simply delineated along the boundary of the area where the cranes were most frequent in 1983, when YBR was first established. The existing boundary of YBR was thus determined based on the original core zone. However, many potential habitats became available as the population of the crane increased recently, and the beach wetland became wider due to marine deposition. Therefore, redesign of a new core and entire boundary became necessary. As the

first task of the reserve design, the design of core zone was completed in the YBR (Li et al., in press), as shown in Fig. 1. The designated core zone covers parts of 3 counties, Sheyang, Dafeng and Dongtai. The designated buffer zone will be placed around this core zone.

3.2. Decision alternatives

The field survey showed that the closest distance, B , to which humans can approach red crown cranes without disturbing them is 600 m (Zhou and Su, 1990). Therefore the minimum width of buffer zone is designated as 600 m. In addition, the greatest distance between the permitted boundary of the reserve and the boundary of the core zone should be 3 km according to the local land-use planning approved by government. Therefore, the largest width of buffer zone should be less than 3 km. The decision alternatives are defined as $1B = 600$ m, $2B = 2 \times 600$ m, $3B = 3 \times 600$ m, $4B = 4 \times 600$ m, and $5B = 5 \times 600$ m.

3.3. Influential factors

The factors affecting the width of buffer zone will vary with different reserves. Even in the same reserve, the importance of each factor varies in different sections around the reserve. In YBR, the local inhabitants partly live on coastal reed and some seashore products like crabs, shellfish etc. On the other hand, the protected species, red crown cranes, attract a lot of tourists and

researchers every year due to their beautiful and elegant appearance and their rarity. The above activities will be not permitted in the core area of the reserve, so the buffer zone should accommodate the functions that supply necessary living resources to local inhabitants, and supply opportunities for tourism and research. Therefore, two direct influential factors should be considered as follows: the local inhabitants' requirement of resources from the reserve (R); the attraction caused by the value of tourism and science research (T). Besides these functions, the buffer zone should also function to mitigate environmental pollution and bar humans from the core. Therefore, two indirect influential factors should be consider as follows: the environmental quality around the reserve (E); and the accessibility to the reserve (A).

The different width of buffer zone will be designated respectively in the four sections I, II, III and IV (Fig. 1) because the importance of each influential factor is not the same in each section. Sections I, II and III are located in the inland (left side of the reserve in Fig. 1), and belong to three counties respectively. Section IV is located on the eastern seaboard (right side of the reserve in Fig. 1). Using symbol R to represent the requirement of resources, which is evaluated by inhabitants' annual income obtained from reserve. The higher R is, the wider the buffer zone should be. T represents the attraction to people caused by the value of tourism and science research, which is evaluated by the annual number of tourists and researchers entering into the reserve. The higher T is, the wider the buffer zone should be. E stands for the environmental quality outside the reserve, which is a synthetic index reflecting the noise, the water pollution, and other environmental impacts caused by human activities. Water quality monitoring indicated that the rivers entering the reserve were not polluted yet, mainly because the reserve is far beyond human habitations. So in YBR, the influential factor E refers only to the noise caused by walkers, bicycle riders or motor vehicles on the seawall along the west of the reserve. Of course, if the environmental quality is high, the buffer zone need not be so wide; Conversely, if it is low a wider buffer will be necessary. The symbol A stands for the accessibility to the reserve, which is relative to the nature of the terrain outside the reserve and the existing traffic access such as roads or rivers. The more accessible the reserve, the wider the buffer zone should be.

Because section IV is along the sea, all the above influences potentially could be neglected. However, in order to avoid the influence of the human activities from the inshore coast, the width of $1B$ is designated in section IV.

3.4. The AHP solution

A general hierarchy for design of the buffer zone is shown in Fig. 2. The weights for the importance of these

Fig. 1. The location of core zone in YBR, and the sections dividing for design of buffer zone.

influences are determined by means of pairwise comparisons of the importance of the factors, using the eigenvalue technique as presented by Saaty (1980). The pairwise comparisons are made using subjective scale from one to nine, and a reciprocal matrix A of pairwise comparisons is constructed, as follows:

$$A = (a_{ij}) = \begin{bmatrix} 1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & 1 & \dots & w_2/w_n \\ \dots & \dots & \dots & \dots \\ w_n/w_1 & w_n/w_2 & \dots & 1 \end{bmatrix}, \quad (3)$$

where w_i is the importance of the factor i . The value of w_i/w_j is evaluated as follows: w_i/w_j is equal to 1 if w_i and w_j are equally important; equal to 3 if w_i is weakly more important than w_j ; equal to 5 if w_i is strongly more important than w_j ; equal to 7 if w_i is demonstrably or very strongly more important than w_j ; equal to 9 if w_i absolutely more important than w_j . The number 2, 4, 6, 8 are used to facilitate compromise between above slightly differing judgments.

The relative weights of the influential factors are computed based on the matrix of pairwise comparisons using the eigenvalue method, i.e. $A_w = \lambda_{\max} w$. The eigenvector w corresponding to the largest eigenvalue $\lambda_{\max}$ is used in the estimation of relative weights. Using the AHP approach, the eigenvector is scaled to add up to one to obtain the weights.

The priorities of decision alternatives in terms of their relationships with different factors affecting the width of the buffer zone are resolved in the same manner. In the comparisons, it is determined which of the two

alternatives is better with respect to each of the factors, and how much better. After carrying out these comparisons, the matrix of pairwise comparisons is constructed for each factor. On the bases of these matrices, the relative priorities of buffer zone alternatives are calculated with respect to each influence or factor. Priorities are scaled to one to obtain the weights.

Saaty (1977) showed that the largest eigenvalue $\lambda_{\max}$ of a reciprocal matrix A is always greater or equal to n (= number of rows = number of columns). If the pairwise comparisons do not include any inconsistencies, $\lambda_{\max} = n$. The more consistent the comparisons are, the closer the value of computed $\lambda_{\max}$ is to n . A consistency index, CI , measuring the inconsistencies of pairwise comparisons, can be computed as follows:

$$CI = (\lambda_{\max} - n)/(n - 1) \quad (4)$$

A consistency ratio, CR , also measures the coherence of the pairwise comparisons (Eq. 5). CR is a useful measure, because CI , in itself, is difficult to interpret.

$$CR = CI/RI, \quad (5)$$

where RI , called random index, is the consistency index of a randomly generated reciprocal matrix from 1 to 9. RI varies functionally with the size of matrix (Saaty, 1980).

In human evaluation processes, some inconsistencies will occur. As a rule of thumb, a CR value of 0.1 or less is considered acceptable (Saaty, 1980; Saaty and

Fig. 2. A general presentation of hierarchy for design of the buffer zone.

Kearns, 1985). Otherwise, all or some of the comparisons have to be made anew. Mathematical methods are available for determining which pairwise comparisons need to be revised in order to improve the consistency ratio.

The hierarchy for design of the buffer zone in YBR is shown in Fig. 3. The optimal width $\bar{B}$ of the buffer zone is the general decision goal at the top level of the decision hierarchy. The second level consists of two groups of influential factors. One group D represents the direct influential factors including R and T , which means the influence is caused by a human entering into the reserve; and the other I represents the indirect influential factors including E and A , which means the influence is from the outside activities of humans. The third level consists of the four influential factors R , T , E and A , and the five decision alternatives 1B, 2B, 3B, 4B and 5B are the fourth level.

The importance of each influential factor and the priority of each decision alternative with respect to each factor is evaluated on the basis of human expertise using AHP principle in the three sections respectively. The weights of factors R , T , P and A are determined using pairwise comparisons based on the survey information and the opinions of relative experts and the reserve managers. Pairwise comparisons for determining the priorities of the five decision alternatives with respect to the four factors are based on the importance of human influence to the reserve caused by the different factors. The consistency ratio appeared to be less than 0.1 for every matrix of pairwise compositions.

In section I, the relative weights of groups D and I with respect to general goal $\bar{B}$ are $(W_D, W_I) = (0.83, 0.17)$; the relative weights of factors R and T with respect to group D are $(W_R, W_T) = (0.88, 0.12)$; the relative weights of factors E and A with respect to group I are $(W_E, W_A) = (0.75, 0.25)$; and the priorities of each decision alternative with respect to each factor R , T , E and A are as follows:

Fig. 3. The decision hierarchy of the case study.

$$(P_{5B-R}, P_{4B-R}, P_{3B-R}, P_{2B-R}, P_{1B-R}) \\ = (0.52, 0.26, 0.13, 0.06, 0.03);$$

$$(P_{5B-T}, P_{4B-T}, P_{3B-T}, P_{2B-T}, P_{1B-T}) \\ = (0.49, 0.27, 0.13, 0.07, 0.04);$$

$$(P_{5B-E}, P_{4B-E}, P_{3B-E}, P_{2B-E}, P_{1B-E}) \\ = (0.42, 0.31, 0.16, 0.07, 0.04);$$

$$(P_{5B-A}, P_{4B-A}, P_{3B-A}, P_{2B-A}, P_{1B-A}) \\ = (0.42, 0.26, 0.16, 0.10, 0.06).$$

The priorities of the decision alternatives with respect to the width of buffer zone in section I are estimated using Eq. 1, as follows:

$$(WD_{5B}, WD_{4B}, WD_{3B}, WD_{2B}, WD_{1B}) \\ = (0.5, 0.27, 0.14, 0.06, 0.03).$$

In the same manner, the priorities of the decision alternatives with respect to the width of buffer zone in section II are estimated as follows:

$$(WD_{5B}, WD_{4B}, WD_{3B}, WD_{2B}, WD_{1B}) \\ = (0.49, 0.26, 0.14, 0.07, 0.04).$$

The priorities of the decision alternatives with respect to the width of buffer zone in section III are as follows:

$$(WD_{5B}, WD_{4B}, WD_{3B}, WD_{2B}, WD_{1B}) \\ = (0.47, 0.27, 0.14, 0.08, 0.04).$$

4. Results

The width of buffer zone in each section is calculated using Eq. 2.

$$\bar{B}_1 = 0.5 \times 5B + 0.27 \times 4B + 0.14 \times 3B + 0.06 \times 2B \\ + 0.03 \times 1B;$$

$$\begin{aligned}\bar{B}_{II} &= 0.49 \times 5B + 0.26 \times 4B + 0.14 \times 3B + 0.07 \times 2B \\ &\quad + 0.04 \times 1B;\end{aligned}$$

$$\begin{aligned}\bar{B}_{III} &= 0.47 \times 5B + 0.27 \times 4B + 0.14 \times 3B + 0.08 \times 2B \\ &\quad + 0.04 \times 1B;\end{aligned}$$

and in section IV, $\bar{B}_{IV} = 1B$.

Therefore, the width of buffer zone corresponding to each section is 2490 m in section I, 2450 m in section II, 2430 m in section III, and 600 m in section IV. The results of designated buffer zone are shown in Fig. 4.

5. Discussion

The sections in which the different width of buffer zone will be designated are formed mainly according to the importance of the influential factors. YBR has a coastal margin, so the importance of factors on the inland side is obviously different from the seaboard. For the inland side, the sections I, II and III corresponding administratively to three counties are formed because their social and economic status are relatively different according to the statistical information, such as the income obtained from resources in the reserve, the numbers of tourists and researchers, and so forth. Furthermore, it is convenient to utilize the statistical data if the sections are determined corresponding to the

administrative counties. It is noted that differences of the buffer zone widths between sections I, II, and III are not very great. However, this does not mean there is no significant difference between the influential factors in the sections I, II, and III. The buffer zone widths change with the combined influences of many factors, not only one factor. Therefore it is not strange when one factor's positive influence balances another one's negative influence. The other important reason for the slight differences between the buffer zone widths in the three sections is the upper limit of 3000 m, which is consistent with the new entire planning of YBR in 1997. That means the new planning boundary should not exceed the original in the west by 3000 m.

The facility for estimating priorities depends on the success in structuring and decomposing the decision problem in question: pairwise comparisons have to be meaningful and easy to understand. In the case study, the four factors are incorporated into two groups: directly influential factors and indirectly influential factors, since the former is more important than the latter. As in the section I, the relative weight of group D is 0.83 while the weight of group I is 0.17. In addition, the relative importance of each factor will be easy for comparison when grouped into different classes according to their attribution.

The scale 1–9 as applied in the standard version of the AHP (Saaty, 1977, 1980) is quite rough when there is only a slight difference in importance or preference between the elements to be compared. The smallest ratio differing from equal weights, using that scale, is 2:1. Intuitively, the ratio 2:1 describes a rather strong preference of one element over another. On the other hand, the largest possible ratio, 9:1, is not always large enough. Graphics have been recommended for use instead of subjective comparisons, especially when only slight differences occur or only two or three decision elements are to be compared (Kuusipalo and Kangas, 1994). Furthermore, each person has his or her own scale when comparing elements subjectively. For example, saying that “objective A is much more important than objective B” does not represent the same numerical ratio for everybody. Therefore it is suggested that the pairwise comparisons should be made based on the opinions of relative experts or public. In this case study, because the survey data are relative complete, such as the annual number of tourists and researchers entering into the reserve in different sections, the inhabitants' annual income obtained from the reserve, etc., the participants supplying the comparisons mainly included experts from planning departments of government, the reserve managers, and the local inhabitants taking part in the reserve management, but did not include extensively the wider public. This is also consistent with Saaty's suggestions (1980) about participants: shared goals; intimate long term contact; work in a climate of social

Fig. 4. The designated buffer zone in YBR.

acceptance; and have equal status when participating.

The result shown in Fig. 4 is only a theoretical design of the buffer zone in YBR. There are still some places needed to be improved in practice. For example, some buffer zones dent into core zone, and this will be unfavorable to conservation of the reserve. Therefore some complementary programme should be undertook in practical operation.

6. Conclusions

Using AHP method, the quantitative relationship between buffer zone width and influential factors is established although some influential factors are qualitative. Under the consideration of the importance of the influences in the different sections around the reserve, the different width of the buffer zone is designated around the reserve. The entire procedure is illustrated by a case study in Yancheng Biosphere Reserve, and the buffer zone width corresponding to different section around the core zone is 2490 m in section I, 2450 m in section II, 2430 m in section III, and 600 m in section IV.

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