Determination of priority nature conservation areas and human disturbances in the Yangtze River Basin, China

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ABSTRACT

Because of limitation of manpower, funding, and land available in conservation, the problem of how to select essential regions to establish protection systems for biodiversity maintenance has been widely discussed. In an effort to address the problem, this study has aimed to select a set of priority areas and to determine their priority order by quantifying human disturbances for each area in the Yangtze River Basin (YRB). This basin covers 2.143 million km², or more than 20% of China's territory. The habitats of 627 indicator species were predicted as a proxy for biodiversity. A conservation planning tool, MARXAN, was used to determine the optimal set of planning units, and three different target scenarios were generated. In addition, under the assumption that if two areas have equal value for conservation, the one suffering more severe disturbance needs more urgent protection than the other, priority ranking analysis was carried out using a 6-12-1 BP artificial neural network. Then hierarchical cluster analysis was applied to the classifications of human disturbances to formulate more detailed conservation strategies. By integrating the degree of irreplaceability of each unit, expert experience, and mountain boundaries, 17 biodiversity priority areas containing 33,200 units over an area of 0.83 million km² were defined. These areas also protected 56% of 32 types of rare forest ecosystem and 76.4% of six types of rare grassland ecosystem on average. According to the evaluation of human impact, a priority order and five types of human disturbance areas were generated. Some protection gaps were also identified, such as the northern part of the Wuyi Mountains. Moreover, the determination of priority nature conservation areas on a large scale can be used to influence the building of a well-connected protection network in each individual area, so that effective genetic communication can occur between species or groups of species. Conservation decisions focusing on the dominant impact factors that are threatening biodiversity sustainability are required as well.

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Introduction

Biodiversity provides many products and services for humanity; however, in recent years, many species have become increasingly threatened by anthropogenic disturbances (Cardinale et al., 2012). To ensure long-term biodiversity maintenance, conservation actions must be urgently undertaken. These actions involve both *in situ* and *ex situ* conservation (Sarkar et al., 2002). In comparison with *ex situ* conservation, *in situ* conservation is more concerned with conservation in the conventional sense because it concentrates more on the preservation of intrinsic features and the long-term sustainability of biodiversity. A well-balanced *in situ* conservation

system will protect biodiversity from the stresses of human activities (Bruinderink et al., 2003; Wu et al., 2011). Nevertheless, in the real world, funding limitations on land conservation initiatives lead to conflicts between economic development and conservation. This issue forces decision-makers to identify essential regions with low economic potential for conservation investment (Pressey et al., 2007).

Methods for selecting priority conservation areas generally include four aspects: mapping biodiversity richness using remote sensor data (Ranjeet et al., 2008; Rocchini et al., 2010); spatial clustering to identify planning units (Dunstan et al., 2012; Yu et al., 2005); eco-regional identification according to the distribution of rare ecosystems and ecosystem services (Egoh et al., 2007; Rogers et al., 2010); and site-selection algorithms (Lehtomäki & Moilanen, 2013; Possingham et al., 2000). Among these, site-selection algorithms have the unique advantage of being able to determine the mathematically optimal reserve system (Vanderkam et al., 2007).

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Using optimality as the core concept, systematic conservation planning combines many of the principles of conservation planning (e.g., total area, connectivity, spatial patterns, socioeconomic costs) to make explicit, effective, and accountable decisions that result in the reasonable allocation of scarce conservation resources (Margules & Pressey, 2000). Because of its advantage in the trade-off between economic development and nature conservation, this approach is highly compatible with developing areas which are under increasing stress from human populations and land-use dynamics.

The Yangtze River Basin (YRB), the largest drainage basin in China, has experienced a booming economy over the last decade, and therefore human disturbances that negatively affect natural biodiversity have intensified. The YRB, as a globally crucial region for biodiversity conservation, contains a huge number of rare and indigenous species. More than 14,000 higher plants, 280 mammals, 762 birds, 145 amphibians, and 166 reptiles are represented in the YRB (Ouyang & Zhu, 2011). Meanwhile, settlements, roads, mineral-resource extraction, tourism, and many other types of human activity are widely and densely distributed across the basin, causing serious disturbances and threatening biodiversity within the region. Apparently, this has led to conflicts when selecting priority areas that are suitable for conservation status. In an attempt to address this problem in part, Heiner et al. (2011) identified a set of conservation areas for the protection of adequate biodiversity in the upper YRB based on the idea of systematic conservation planning, which represented important progress in conservation planning in this region. By contrast, this research presents the results of explicit conservation plans for the whole basin that focus mainly on terrestrial biodiversity and evaluate human disturbance independently to gather information that can be used to manage and improve conservation in this area, instead of being a component in the algorithm as a proxy of conservation cost.

The cost calculations associated with conservation are an important part of any systematic conservation plan. Cost estimation is a very positive and constructive contribution to the cost-benefit tradeoffs that occur during conservation planning. However, in many cases, it is difficult to quantify the economic costs of conservation, not only in monetary terms, but also according to other metrics (Banks & Skilleter, 2007). Therefore, a composite human-disturbance index has been developed by combining various factors, assuming that a planning unit with serious human impact incurs higher costs (Wilson et al., 2005). However, some regions with high conservation value are constantly managing the pressure of dealing with human needs, which forces them to be even more protective of their natural resources. Unless an alternative low-impact habitat is available, these areas are often developed because of their high associated economic potential. To avoid abandoning these high-value areas, threatening human factors should be considered separately rather than as a cost proxy. Some areas with intrinsic vulnerabilities demonstrate various levels of human impact where severe conflict exists between conservation initiatives and human activities. Once biodiversity has been destroyed, however, it is difficult to restore it to these regions due to their fragile nature and unique characteristics (Safont et al., 2012). In addition, analysis of human interference using site-selection algorithms enables decision-makers to make reasonable adjustments for resources, which makes a strong contribution to meeting conservation targets in priority areas. For this purpose, an ANN model was constructed to rank areas in terms of conservation priority, rather than merely by order of habitat irreplaceability. For example, if a unit has both high cost and high conservation values, an optimization procedure tends to abandon it due to fiscal concerns. However, these units require urgent investments that are separate from human pressures and have never been ignored. This is why human impact analysis was not included in the algorithm.

In this study, the first step was to identify indicator species and simulate their habitats to compile a dataset as a surrogate for biodiversity. The criteria for indicator species included the protection level and degree of endemic status according to several Red Lists. Maps of the predicted habitats were determined using several environmental variables that affect species habitat (e.g., altitude, vegetation type, slope, and aspect), which were obtained from the datasets of various historical research reports and field samples. Each variable was converted to a Boolean image that constrained the habitat to specific geographic regions. All these modeling results are required to use MARXAN (Marine Reserve Design using Spatially Explicit Annealing) (Game & Grantham, 2008), a site-selection algorithm developed to identify areas with high conservation value. Here, MARXAN was used to aid in the selection of suitable conservation sites in the YRB. After the sites were determined, human disturbance was estimated using an ANN model to quantify the characteristics and the degree of human impacts in each priority nature-conservation area.

The objectives of this research, therefore, were to obtain a solution for optimal-priority areas in the YRB and to analyze several target scenarios to obtain alternative conservation plans. In addition, quantitative analysis of the human impact in each priority area was performed by integrated estimation that considered several categories of existing threat factors, with the expectation that more specific conservation measures would be generated for priority areas.

Methods

Study area

The YRB and its neighboring regions include 829 counties, cities, and districts in 19 provinces. The total area of this watershed is approximately 1.8 million km², or 18.8% of China's territory. The river can be divided into three sections: (1) from the headwaters to Yichang, also known as the upper reaches (4504 km; 1 million km² drainage area); (2) Yichang to Hukou, or the middle reaches (955 km; 0.68 million km² drainage area); and (3) Hukou to the estuary, or the lower reaches (938 km; 0.12 million km² drainage area). After considering the integrity of the ecosystem and wildlife habitat, the research area was extended to include the Qiangtang Plateau, the Ruo'ergai marshes, the northern slope of the Qinling Mountains, Hunan Province, Jiangxi Province, and the Qiantang River basin in Zhejiang Province. The combined study area is 2.143 million km² in total (Fig. 1).

Indicator species

Species were required to meet at least one of the following selection criteria to be considered as indicators of biodiversity: (1) indigenous to China and endangered; (2) found mainly in China and endangered; (3) indigenous to China and under threat according to the IUCN Red List of Threatened Species (IUCN, 2004) and First Volume of the Red Data List of Chinese Species (Wang & Xie, 2004).

Species distributions were modeled using data included in species-location datasets or existing field studies, including (1) China Animal Scientific Database (CAS, 2011a); (2) Scientific Database of China Plant Species (CAS, 2011b); (3) Chinese Biodiversity Information System (CAS, 2005); and (4) Chinese Species Information System (CAS, 2001). The major types of vegetation, altitude, species, and other habitat data (e.g., aspect, slope) were determined from these databases and used in biodiversity richness mapping using the spatial analysis function of geographic information system (GIS) tools. All maps are presented in Boolean format.

Fig. 1. Divisions within the YRB referred to in this study. QTP is the Qinghai-Tibet plateau (the upper reaches); CRP is the Central Region plateau (the middle reaches); and EPHL is the eastern plain and hilly lands (the lower reaches).

Site-selection algorithm

The identification of priority conservation areas was performed using MARXAN (v. 1.8.10) (Game & Grantham, 2008), which is a software program that provides decision support for designing reserve systems within a GIS interface. MARXAN enables the conservation planner to select new conservation areas from a large number of potential sites (or planning units). The degree of irreplaceability of each planning unit was used to facilitate the selection algorithm (Ferrier et al., 2000). This means that areas with higher irreplaceability also have a higher conservation value. A spatially explicit solution that was correlated with the indicator species was also calculated and mapped.

MARXAN requires explicit targets for biodiversity features. An explicit target for habitat proportion defines the extent of species habitat that is sufficient to achieve an acceptable risk level of extinction. However, only a few methods are recognized to translate existing datasets and undocumented data into quantitative targets for indicator species (Justus et al., 2008). To obtain alternative decisions, three target scenarios were simulated. These target scenarios were: (a) to protect 60% of overall habitat for all indicator species; (b) to protect 30% of overall habitat area for all indicator species; and (c) to assign different protection targets (60%, 40%, or 30%) to species with different levels of rarity according to the three grades specified above.

The basin was then divided into 85,694 square planning units (25 km² per unit). Although using sub-catchments as planning units may describe ecological processes better than the more commonly used square or hexagonal planning units (Klein et al., 2009), it is

difficult to map accurately all sub-catchments in a 2.143 million km² region, especially in areas with complex geomorphological and hydrological characteristics. Therefore, square planning units were used. In addition, the YRB runs along three terrain gradients in China that have different climates, ecosystems, and species compositions. For example, there are huge numbers of indicator species in every geographic region (e.g., the Hengduan and Qinling Mountain regions). Some parts of rare habitat for a single indicator species may be neglected by the algorithm because they require higher concentrations in areas with high species richness. This part of a habitat might have several important biological functions, such as acting as a migration corridor or being the habitat of a crucial subpopulation. To ensure that areas with relatively high conservation values were distributed across the whole basin (rather than aggregated into a few large regions), the YRB was further divided into three zones according to average latitude: the Qinghai-Tibet plateau (QTP), the Central Region plateau (CRP), and the eastern plains and hilly lands (EPHL) (Fig. 1). Each zone had its own internal site-selection algorithm. The same cost was applied to all planning units because the overall aim was first to determine the minimum number of planning units needed for the conservation network and to define targets, and then to estimate the level of human disturbance.

Running MARXAN requires a series of parameters, of which some can be given default values and others must be repeatedly checked and debugged using quantifiers such as the Boundary Length Modifier (BLM) or the Species Penalty Factor (SPF). The SPF was set to 500 to ensure that every species would meet its target (Geselbracht et al., 2009). The BLM is a parameter that helps control

Table 1

Index system used to evaluate human impact in the YRB. Human impact factors include six types at the first level (first row) and eleven sub-types at the second level (second row).

Settlements	Transportation infrastructure	Mines	Hydro-electric station	Tourism	Farmland
Urban and rural residents	National, provincial, and county roads	All kinds of mines site		Forest parks, geo-parks, culture and natural heritage sites	Rice paddies, land dry land

Table 2

Characteristics of indicator species and protection levels in YRB and its sub-regions.

Region	Level	Amphibian	Avian	Reptile	Mammal	Plant	Total
YRB	I	7	2	5	12	133	159
	II	1	7	4	25	49	86
	III	24	28	12	34	284	382
QTP	I	3	0	0	10	49	62
	II	0	2	1	18	18	39
	III	9	20	4	28	188	249
CRP	I	6	2	2	8	93	111
	II	1	2	3	17	29	52
	III	22	18	8	27	188	263
EPHL	I	2	0	4	2	33	41
	II	1	4	2	11	23	41
	III	4	6	5	11	90	116

for spatial compactness in priority areas. By increasing the BLM, the number of planning units was increased to connect isolated units with high conservation values. Therefore, some units with low biodiversity richness could be selected, which would enlarge the total area as a result. To obtain results with moderate clustering, an index (Eq. (1.1)) was used to calculate the effectiveness of the BLM:

$$SI = \frac{0.25L}{\sqrt{A}}, \quad (1.1)$$

where L is the total boundary length and A is the total area. The BLM value at the point of moderate compaction was regarded as the best value from among the different results along the SI curve.

To demonstrate the effectiveness of rare ecosystem conservation using the areas identified, the status of each type of rare ecosystem was analyzed according to the defined priority scheme.

Assessment and classification of human disturbance

According to the selected priority areas, the level of human disturbance in each area was calculated as an indicator for

priority sequencing. This would mean that conservation funds and resources could be reallocated to regions with higher levels of human disturbance. Twelve variables covering six aspects of disturbance (settlement, transportation infrastructure, mines, hydroelectric stations, tourism, and farmland) were selected to assess human disturbance in the priority areas (Table 1). All data were vectorized to GIS format.

The 6-12-1 BP artificial neural network was used to estimate human disturbance. In the authors' experience, other methods of analysis cannot universally weigh and assess all indicators in a distinct ecosystem. All variables were normalized to between 0 and 1 using a normalization function (Eq. (1.2)) to avoid convergent results:

$$x_i^* = \frac{x_i}{\max x_i}, \quad (1.2)$$

where x_i^* is the normalized value of variable i , x_i is the original value of variable i , and $\max x_i$ is the maximum value of this variable in

Fig. 2. Effect of changes in the boundary length modifier (BLM) for each of the three scenarios. Rectangles in the figure indicate the most suitable BLM parameter under all scenarios. SI indicates the degree of spatial compaction of the algorithm results.

Fig. 3. Relationship between conservation areas (expressed as a percentage of protected land) and targets for each of the three scenarios for the YRB as a whole and for each of the three YRB subareas (EPHL, CRP, and QTP).

all priority areas. The logsig activation function (Eq. (1.3)) was used because all values were >1 :

$$f(x) = \frac{1}{1 + e^{-x}}, \quad 0 \leq f(x) \leq 1 \quad (1.3)$$

The learning rate, momentum constant, and convergence error were 0.01, 0.7, and 0.5×10^{-5} respectively. Hierarchical cluster analysis was then used to classify priority areas according to the main types of human impact.

Results

Characteristics of the indicator species

Using the criteria described earlier for defining indicator species, 627 indicator species were identified, including 32 amphibians, 466 higher plants, 71 mammals, 32 birds, and 21 reptiles (Table 2). Zonal statistics show that 350, 426, and 198 indicator species were found in QTP, CRP, and EPHL respectively. The QTP and the CRP apparently contain more rare species than the EPHL. However, the EPHL provides habitats for many globally rare and endangered species, such as the Chinese alligator (*Alligator sinensis*) and Cabot's tragopan (*Tragopan caboti*) that cannot be ignored.

BLM and comparisons of different target scenarios

For each zone and scenario, 10 algorithms were executed under various BLM values between 10^{-5} and 10^4 to identify the most suitable point. As the SI curves show (Fig. 2), areas of moderate compaction were most likely to appear at 10^{-3} . Although the total area was still increasing, the rate of decrease in boundary length was the most severe at this point.

The algorithm generated two kinds of solutions: the single best solution, and the best solution in terms of irreplaceability. For each of the three zones, the single best solution for each scenario completely met the conservation target. Meanwhile, nine priority area

Fig. 4. Spatial distribution of the three districts under three different scenarios according to the site-selection algorithm.

Table 3

Region names, geographic areas, and major ecosystem types of the 17 selected priority areas.

Region	Geographic area	Major types of ecosystem	Area (km ²)
South Qinghai	Sub-frigid zone, humid plateau regions	Alpine steppe, mountainous steppe	100,677
Yangtze source	Sub-frigid zone, humid plateau regions	Alpine steppe, mountainous steppe	200,020
Minshan	Temperate plateau zone	Mountainous coniferous forest, alpine meadow	35,685
Qionglai	Temperate plateau zone	Mountainous coniferous forest, alpine meadow	27,825
Liangshan-Xiangling	Mid-subtropical zone	Mountainous evergreen, broadleaf forest	36,293
Shennongjia	Northern subtropical zone	Mixed mountainous needle and broadleaf forest	26,577
Wuling mountains	Mid-subtropical zone	Plateau evergreen and broadleaf forest	30,084
Upper Jinsha River	Temperate plateau zone	Mountainous coniferous forest, alpine meadow	68,203
Hengduan mountains	Mid-subtropical zone	Mountainous evergreen broadleaf forest	76,389
Dalou mountains	Mid-subtropical zone	Plateau evergreen and broadleaf forest	24,589
Wannan mountains	Northern subtropical zone	Mixed mountainous needle and broadleaf forest	14,244
Luoxiao mountains	Mid-subtropical zone	Mixed mountainous needle and broadleaf forest	47,562
Daduhe source	Temperate plateau zone	Mountainous coniferous forest, alpine meadow	19,045
Qinling	Northern subtropical zone	Mixed mountainous needle and broadleaf forest	45,785
Northern part of the Wuyi mountains	Mid-subtropical zone	Mountainous evergreen and broadleaf forest	10,807
Nanling mountains	Mid-subtropical zone	Mixed mountainous needle and broadleaf forest	56,111
Dabie mountains	Northern subtropical zone	Mixed mountainous needle and broadleaf forest	10,106

sets were obtained for different scenarios with different targets. The relationship between targets and areas is shown in Fig. 3.

The scenario which aimed to protect only 30% of the habitat needed by all indicator species had significantly smaller conservation areas than the other two target scenarios, which both included all the areas in the first scenario. Moreover, this scenario neglected a large area with high biodiversity richness due to its low target value, and therefore it was not helpful in selecting priority areas. As for the second scenario (60% of total land protected; Fig. 4), which occupies a vast area of the YRB and QTB, it was equally difficult to determine an adequate solution.

By contrast, the third scenario, which assigned different protection targets to species with different levels of rarity, obtained the most reasonable results. This was not only because of its moderate area requirements, but also because of the different conservation values assigned to the different indicator species.

Spatial patterns of the biodiversity conservation system

By integrating the solutions of the third scenario and applying expert experience, a set of priority areas were selected that best represent places where biodiversity should be maintained. Using this procedure, the degree of irreplaceability was used to determine the locations and boundaries of the priority areas. In addition, irreplaceability is important when deciding how to expand existing protected areas (Nel et al., 2009).

After examining the data on irreplaceability and biodiversity, 17 priority areas were selected (Table 3) according to several principles. First, planning units with high irreplaceability were characterized as the major habitats of first-level indicator species that demonstrate very limited distribution ranges within the YRB. Second, important regions that maintain biodiversity richness or special biodiversity processes, such as reproduction or migration, were selected. Third, areas that typically support species in vulnerable ecosystems were selected. Finally, areas with high irreplaceability, but low conservation value were removed.

Conservation of rare ecosystems

Thirty-seven rare forest ecosystems and six grassland types (Table 4) are distributed in the YRB (Li et al., 2003). Intersection analysis indicates that the 17 priority areas enclose 48.4% of the rare forest ecosystems and 76.4% of the rare grassland ecosystems on average. Except for five forest types which do not appear in all the areas, the average percentage of protected rare forest ecosystems can be as high as 56%, which is close

Table 4

Percentages of the area of rare ecosystems within the priority conservation areas identified. The last six types are grassland ecosystems.

Name of rare ecosystem	Proportion within the priority areas
<i>Abies forestii</i> C. C. Rogers	68.6%
<i>Picea likiangensis</i> (Franch) Prtitz	77.2%
<i>Abies Faxoniana</i> Rehd. et Wils	54.2%
<i>Picea asperata</i> Mast	33.5%
<i>Picea likiangensis</i> var. <i>Balfouriana</i> (Rehd. Et Wils.) Hiller ex Slavin	55.7%
<i>Picea purpurea</i> Mast	51.6%
<i>Picea brachytyla</i> var. <i>Complanata</i> (Mast) Cheng ex Rehd	59.8%
<i>Larix potaninii</i> Batal	32.1%
<i>Sabina tibetica</i> Kom	60.3%
<i>Sabina saltuaria</i> (Rehd. Et Wils)	70.2%
<i>Sabina przewalskii</i> Kom	0
<i>Pinus babulaeformis</i> Carr	46.3%
<i>Pinus bungeana</i> Zucc	48.3%
<i>Pinus armandii</i> Franch	57.0%
<i>Pinus armandii</i> Franch	69.2%
<i>Pinus taiwanensis</i>	80.1%
<i>Pinus henryi</i> Mast	39.6%
<i>Platycladus Spach</i>	53.8%
<i>Cryptomeria fortunei</i> Hooibrenk	0
<i>Pinus yunnanensis</i>	50.1%
<i>Pinus yunnanensis</i> var. <i>Tenuifolia</i> Cheng et La	93.8%
<i>Pinus yunnanensis</i> var. <i>Langbianensis</i> (A. Chev.) Gausson	0
<i>Keteleeria evelyniana</i> Mast	0
<i>Cathaya argyrophylla</i>	40.7%
<i>Cupressus L.</i>	6.5%
<i>Quercus liaotungensis</i> Koiz	42.1%
<i>Quercus variabilis</i> BL. - <i>Quercus serrata</i> var. <i>Brevipetiolata</i> (DC.) Hakkia-Castanopsis <i>sclerophylla</i> (Lindl.) Schoot. - <i>Cyclybalanopsis glauca</i> (Thunb.) Oerst	49.0%
<i>Quercus acutissima</i>	40.1%
<i>Cyclobalanopsis</i>	76.1%
<i>Fagus longipetiolata</i> Seem. - <i>gravel oak</i>	95.9%
<i>Castanopsis sclerophylla</i> (Lindl.)	36.7%
<i>Castanopsis delavayi</i>	0.6%
<i>Castanopsis fargesii</i>	44.5%
<i>Castanopsis fargesii</i> Franch	65.0%
<i>Castanopsis fabri</i>	58.0%
<i>Quercus aquifolioides</i> Rehd. et Wils	66.5%
<i>Quercus cocciferoides</i> Hand. Mazz	68.2%
<i>Tibetan bellard kobresia meadow</i>	76.7%
<i>Weed meadow dominated by garden burnet and ivyleaf bellard kobresia</i>	100.0%
<i>Stipa purpurea</i>	94.8%
<i>Small bellard kobresia meadow</i>	60.9%
<i>Yunnan gueldenstaedtia</i>	91.4%
<i>Sheep fescue</i>	34.7%

Table 5

Criteria used for assessing human impact in this study (ps means points with *.shp format).

Impact	Hydroelectric plants (ps/100 km ²)	Mines (ps/100 km ²)	Transportation (km/100 km ²)	Settlements (ps/100 km ²)	Tourism (ps/100 km ²)	Farmland (km ² /100 km ²)
Slight	0	0.0137	0.6762	0.1069	0	0
	0	0.1409	3.4509	2.5935	0.0009	0.7469
Moderate	0	0.2599	5.3752	5.2458	0.0081	4.3659
	0.0043	0.2759	6.8067	8.2805	0.0183	11.1690
	0.0053	0.4026	9.1631	11.6472	0.0250	13.6603
	0.0091	0.5724	11.8252	12.7371	0.0280	15.1490
Heavy	0.0141	0.6772	12.8543	14.1302	0.0320	15.6967
	0.0249	0.8263	16.2005	14.8656	0.0412	19.4874
Severe	0.0351	1.4980	17.9077	16.0145	0.0601	26.8119
	0.0431	2.2948	20.5578	16.4342	0.0632	35.4581

to the conservation target for first-level indicator species. These five absent types of ecosystem represent two situations. Some of them are verge habitats with only a small area in the YRB and their main extent in other parts of China, such as *Sabina przewalskii* Kom, *Cryptomeria fortunei* Hooibrenk, *Pinus yunnanensis* var. *Langbianensis* (A. Chev.) Gaussen, and *Keteleeria evelyniana* Mast. Others consist of *Castanopsis delavayi*, which has been well protected (62.7% of total area) by existing conservation networks.

Level of human disturbance in each area

BP artificial neural networks (BP-ANN) can be used to assess complex projects using multiple variables that depict the target system. Table 5 provides a set of evaluation criteria in which every joint at 10% intervals of each maximum factor value were used as training data.

The BP-ANN generated an assessment of levels of human impact for all the selected priority areas, as shown in Fig. 5. Three priority areas included areas with severe human disturbance, including the northern part of the Wuyi Mountains (0.9932), and nine regions included areas with heavy or moderate human disturbance. Only four of the selected priority areas had comparatively slight levels of human disturbance.

Spatially, there is a tendency to estimate lower values of human disturbance for priority areas located in the western YRB in comparison with the east. This is largely because people prefer to live in more developed areas.

Following ANN evaluation, the priority areas were further clustered into five classes according to the type of human threat, including slightly disturbed areas, areas affected by hydroelectric plants, mining areas, areas with significant human settlements, and areas characterized by extensive farmland (Fig. 6).

As shown in Fig. 7, the slightly disturbed areas are characterized by relatively few human disturbances and are all located in QTP in areas with low human population densities. Hydroelectric stations and areas with many human settlements are typically single-factor impact areas, which means that there is an obvious main threat present in these areas that is much more significant than other threats; therefore, this factor deserves special attention. Mining and farming-dominated areas demonstrate more complex impact mechanisms that not only depend on the individual impact itself, but are also seriously affected by other factors, such as transportation infrastructure and tourism, that present greater challenges to the protection of local biodiversity.

Local governments should therefore strive to relieve human pressure in highly ranked priority conservation areas and to establish specific conservation measures for all types of areas.

Discussion

Implications for improving the current conservation system

In the YRB, researchers have begun to analyze the spatial patterns of biodiversity using different approaches, such as ecosystem estimation or spatial cluster indexing (Zhang et al., 2008), eco-regional conservation methodology (Wu et al., 2006; Xu et al., 2006), and systematic conservation planning (Heiner et al., 2011; Zhang et al., 2010). These studies successfully identified areas with high conservation value under different biodiversity proxies. According to their results, until 2012, governments had established 828 nature reserves occupying over 31 percent of the YRB, and numerous initiatives have been implemented over the past few decades. However, because of the relatively late start in implementing these initiatives, there are still deficiencies in connectivity and capital allocation in conservation policies, which have weakened the effectiveness of the existing reserve system. In this study, which has focused on spatial patterns of conservation priority areas with explicit conservation goals, a broader region covering 38.7% area of the entire study area was obtained. As can be seen in Fig. 8, existing nature reserves in six regions (the northern part of the Wuyi Mountains, the Dabie Mountains, the Wuling Mountains, the Wannan Mountains, the Luoxiao Mountains, and the Nanling Mountains) occupy less than 10 percent of the territory. Especially in the northern part of the Wuyi Mountains, which provides core habitat for many rare species such as *Tragopan caboti* and *Torreya grandis* var. *jiulongshanensis*, there has been disturbance by complex human activities.

Based on the distribution of the conservation priority areas and their priority ranks in the YRB, these results have two implications for improving the current biodiversity system. First, according to the spatial distribution of priority areas, systematic planning of the conservation network in each individual area should be carried out, and these networks should be determined using spatially explicit boundaries that can be revised or extended to complement any existing reserve system, particularly in areas with poor conservation status. For example, using sub-catchments as the planning unit provides a better fit with both ecological processes and terrain features than using symmetrical shapes. At the same time, to reduce the extinction rate of local meta-populations further and to maintain genetic communication between species or groups of species, connectivity analyses are needed. Shelters and wild training centers for rare species should be arranged in the network according to suitable transit times to ensure that incidents involving injured or orphaned wild animals can be dealt with in good time. Second, as the ranking analysis shows, 7 out of 17 priority areas are suffering from severe human impact, but different influencing factors were identified in each case, which

Fig. 5. Location of the identified conservation priority areas within the YRB (main figure), along with spatial patterns and severity of human disturbance in each area (bar figure in the small frame).

mean that different measures need to be taken to mitigate different threats in different areas. Only one disturbance factor was readily detectable in slightly impacted areas. For example, at the Yangtze source and in South Qinghai, transportation systems play leading roles in habitat fragmentation, which has prompted management departments to set up passages for wild animals. Tougher measures are needed to protect biodiversity in more complex areas, such as reasonable attribution of nature resource royalties,

restrictions on the number of tourists, and balancing ecological immigration.

Limitations and further research

This study has two important limitations. First, simulation of species habitats was limited. The most important input datum required by the algorithm is the species distribution matrix. To

Fig. 6. Result of clustering analysis according to dominant human impact factor in conservation priority areas (PAs).

Fig. 7. Percentage of each specific human impact (e.g., hydroelectric plants, mining, etc.) contributing to overall human disturbance in each conservation priority area.

generate this matrix, a huge dataset of empirical data was compiled from previous studies on every indicator species over the last 30 years. During this period, as climates and landscapes changed, some species departed from their original habitats or even went extinct (Rands et al., 2010). Some ecological models, such as MAXENT and ENFA, which are based on ecological niche theory were not used in the simulations because these models require species appearance data that often come from field sampling. Most appearance data for specific species are accumulated from many different projects in different areas and seasons. Any one of these issues could lead to inaccurate habitat modeling. To maintain accuracy, each of the habitat maps was sent to experts and repeatedly modified based on feedback. The second limitation of this study is the lack of consideration of rare ecosystems as conservation targets in the algorithm. Rare ecosystems demonstrate the characteristics of the local tax on and maintain certain vital ecological processes. Actually, in deciding on the habitat for each species, “suitable ecosystems” were used as an overlap variable to ensure that rare ecosystems containing

rare species could be selected into the priority areas. In addition, to demonstrate the effectiveness of the results for ecosystems protection, the percentage of rare ecosystems in the YRB was examined, and the statistical results were acceptable. However, developing a smarter method which designates both rare ecosystems and rare species in the algorithm as conservation targets would be worthwhile and should form a part of future conservation planning.

The problem of calculating conservation costs has long been discussed, but without any consensus among researchers. One well-recognized idea is that cost can be determined either monetarily or non-monetarily (Naidoo & Iwamura, 2007). Monetary cost can be estimated using the current price of land or available opportunities, such as agricultural, forestry projects, auction cost of species, or land managers’ willingness to sell (Knight et al., 2011; Naidoo & Adamowicz, 2006; Smith et al., 2008), which act as a substitute for actual spending on conservation. Obviously, monetary cost simulation is preferred over the non-monetary method because it enables decision-makers to prepare financial reports and demonstrate

1. Northern part of Wuyi Mountains; 2. Dabie Mountains; 3. Wuling Mountains; 4. Wannan Mountains; 5. Nanling Mountains; 6. Luoxiao Mountains; 7. Liangshan-xiangling; 8. Upper Jinsha River; 9. Dalou Mountains; 10. Qinling; 11. Shennongjia; 12. Hengduan Mountains; 13. Qionglai; 14. Source of Daduhe; 15. South Qinghai; 16. Minshan; 17. Yangtze Source.

Fig. 8. Conservation gaps identified by comparing the percentages of existing protection networks and human impact values in each of the 17 nature-conservation priority areas.

budgetary control over the reconstruction of the conservation network. Therefore, many researchers have tried to quantify the economic cost of conservation in monetary terms (Bryan et al., 2011), but there is no general model because various difficulties are encountered depending on where the model is used. For example, in China, land is nationally owned, which means that planners must focus on opportunity costs instead of acquisition costs when performing their calculations. Therefore, an important route for future studies is determining and estimating monetary cost in the YRB.

In systematic conservation planning, an explicit protection target is required by the algorithm, which is a major difference from expert-driven planning. However, setting a rational target depends greatly on the experience of experts (Cowling et al., 2003) and will unavoidably result in bias due to poor knowledge of the area and taxa. Previous studies tended to have identical goals for all biodiversity features (Ban et al., 2009) or graduated goals depending on the proximity to extinction of the species in the area (Leroux et al., 2007; Pearce et al., 2008). In this study, both methods were used to generate different results. This approach seems to be a more effective method for maximizing the conservation target level given a certain cost because it is harder to determine a fixed target than a financial expectation if an accurate cost map can be obtained. Another problem encountered when selecting targets is the specific content of the protected natural features. Pressey et al. (2003) regarded biodiversity features as individual broad habitat units, species, types of interface, discrete corridors, and gradients. This classification will be of great theoretical and practical importance in future studies. Ultimately, determining whether it is possible to use ecosystem services or vulnerability as the target in conservation planning is worthy of further study.

This paper has provided the results of priority-area mapping and large-scale evaluation of trends in these areas. Although only a relatively coarse map could be provided and some issues warrant further debate, it is crucial to develop further networks on a finer scale. The results indicate the locations, in priority rank order, that are suffering increasingly serious conflicts between human activities and biodiversity initiatives. A truly efficient conservation system that understood the relationships between ecosystems and human activities would be able to adjust for the mechanisms responsible for the environment's ecological characteristics; however, this is beyond the scope of this research. Future studies

should not only include the static habitats of the included species, but should also consider species dynamics in terms of space and time.

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