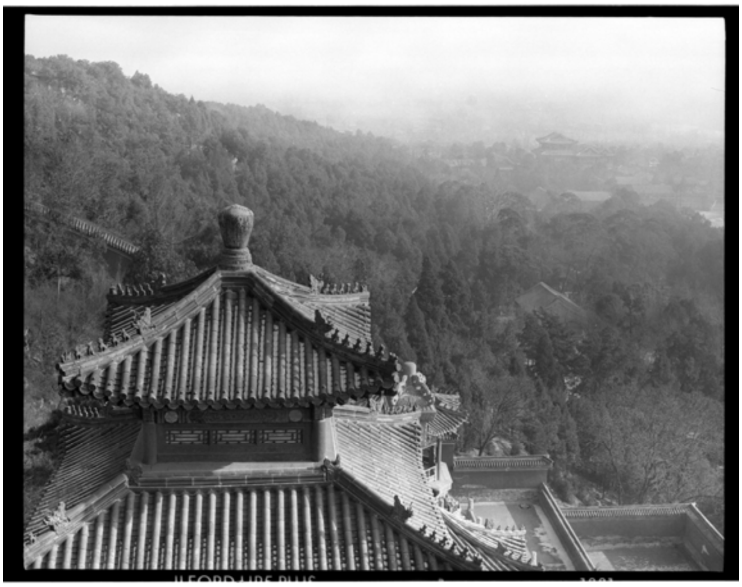
Gordon Brent Ingram, Ph.D.
Assistant Professor, Environmental Planning
LANDSCAPE ECOLOGY GEOGRAPHIC INFORMATION SYSTEMS LABORATORY
The University of British Columbia

1994

Report to the Chinese Academy of Sciences &
the International Development Research Centre (IDRC) of Canada

Geographic information systems for the biosphere reserves of subtropical China: Some methodologies and prototypes



Fanjingshan Biosphere Reserve, Guizhou, China, December 1991 photo by Gordon Brent Ingram

Table of contents

Executive summary

The use of geographic information systems for the better conservation of biological diversity in the biospheres reserves of China could be part of a broader process of "technological empowerment" emphasizing local management. Such new programmes should include appropriate forms of "geographic information systems" (g.i.s). But if the acquisition of g.i.s. technology is not part of a critical effort to link efforts to local sustainable development, much of the resources spent by international aid institutions and foreign universities could be wasted. Without a careful consideration of the linkages between local decision-making, land management and increased public access to information, projects could re-enforce bureaucratic power structures some of which go back to feudal times. This report is on approaches to development of biological diversity geographic information systems in the biosphere reserves of southern China. It explores methodologies that could be employed to build frameworks for conservation planning and land management through the acquisition of an array of computerized technologies.

There are three pressing needs for improved capabilities in the management of biosphere reserves of southern China.

1. As a prerequisite to more effective management, it is necessary to **delineate management zones** based on concepts of biosphere reserve cores, buffers, and transition areas. In most cases, more active protection of habitat is necessary. But at the same time, some forms of expanded, though regulated, land use is inevitable, particularly around protected cores. People are already living in these areas, and traditional land use activities can sometimes even enhance the basis for conservation. More precise and rational delineation of management uints would allow for better possibilities of integration of habitat protection into sustainable regional development. This would improve the effectiveness of various forms of adaptive management and allow for more efficient use of the limited resources of conservation agencies.

2. It is necessary to more effectively integrate protected area zoning and management with **local knowledge** and traditional livelihoods. The peripheries of virtually all of the nature reserves in China continue to be under pressure from peasants needing more land for cultivation and grazing. There are often conflicts between nature reserve administrators and local peasants, some of whom are minorities with distinct and well-developed local knowledge bases. Biodiversity conservation geographic information systems must not only include all relevant information but also reflect the various knowledge bases with their communal (intellectual) property owners.

3. The third imperative for improved conservation capacities is for the better monitoring, conservation and procurement of **genetic resources**, particularly species in crop gene pools and with medicinal values. The use of better monitoring techniques and g.i.s. technology would allow conservation to better contribute to society-wide economic development through providing germplasm for biotechnology ventures and sites for related research. Both of these goals are embodied in the *Convention on Biological Diversity* and this project has originally envisioned as a key prototype for implementation of the Convention both within China and in other biosphere reserves in the international network.

In this report, I explore options for development of geographic information systems expressly for the monitoring of biological diversity and decision-making for more comprehensive and effective

habitat conservation. With the advent of the *Convention on Biological Diversity* (UNEP 1992, African Centre...1993), there also should be capabilities to link better *in situ* conservation of wild species with genetic resources (Ingram 1987) and traditional economic species with procurement of germplasm for the development of biotechnology products. While this report is oriented to the particular context of the CAS, it is applicable to most of the other IDRC biodiversity projects which have components with reliance on spatial data.

The following are the central technical questions that this report begins to explore.
1. What are the necessary components of biodiversity conservation planning g.i.s.?

2. How can simulation and "expert systems" be developed to allow for easy use by reserve managers and local community groups?

3. What should be the data compilation formats in such conditions of high biological richness, extreme forest fragmentation, complex cultural landscapes, and increasingly valuable genetic resources?

4. In this context, how can local knowledge be respected, procured and integrated into such systems?

5. What would be the key aspects of training for not only the use of the computer technology but for imparting personal capabilities for adaptation, redesign, and creative problem-solving for both land management and that of evolving spatial data bases?

This report reviews some of the most relevant literature and considers the progression of phases for creation of biodiversity conservation geography information systems.

■

Problem Statement: The need for biological diversity conservation geographic information systems for the nature reserves of southern China

There is growing recognition of the need for comprehensive programmes of inventorying, monitoring and conservation of "biological diversity" (Wilson 1988, World Resources Institute et al. 1992, Vogel and Ingram 1993, IDRC 1993). Computerized tools[1] for spatial decision-making organized in various architectures (Villa 1992), comprising various types of geographic information systems, are crucial for assisting in making conservation in protected area programmes more effective. Areas with tropical and subtropical rainforest[2] are particularly rich in biological resources

---

[1] The IDRC has an exceptional record for an international aid organization for support computerization and g.i.s. in research related to sustainable development. The two documents on information systems that guided the development of this report were:

IDRC. June 1990. Overview of the geomatics program at IDRC. on file, Ottawa, IDRC Information Sciences Division. and

Benmouffok, D., R. Valantin, G. Cliche. no date. Applied research in geographic information systems in developing countries: IDRC's experience. on file, Ottawa, Information Sciences Division.

and vulnerable to loss from any expanded land use.

The forests and biological diversity of southern China are extraordinarily rich and yet increasingly vulnerable to disappearance. The shift to the "socialist market economy" has compounded many of the problems brought on with expanding rural populations (Smil 1992). Biodiversity conservation geographic information systems can provide a better basis for choosing conservation "tactics" (Soulé 1991) most compatible with local development and therefore more "sustainable. "Developing nations, including China, have been only partially effective at conservation planning and management of local biological diversity. New forms of geographic information systems are necessary to manage areas with high levels of local biological diversity and these must be oriented to integrating habitat conservation into local development. Extensive training, at the post-graduate level, will be necessary if such conservation planning systems are going to have tangible impacts in the coming decade.

Biosphere reserves (Batisse 1992, Vernhes 1989) provide some key opportunities for the monitoring and conservation of biological diversity particularly through its core / buffer / transition zoning concepts (UNESCO 1984, Ingram 1990B, Gregg 1991) and through the international network of exchange of information and training programmes. The Man and the Biosphere Programme National Committee (MAB) of China is committed to developing a new set of programmes to better conserve the biodiversity of its Unesco-affiliated biosphere reserves and its projected system of national biosphere reserves. MAB China has been involved in geographic information system projects for over 5 years though none was of 1993, have been expressly for the monitoring[3], and conservation planning and management for biological diversity. And the use of g.i.s. could assist in the better harmonization of conservation with the development needs of local peasant communities (Wells et al. 1992) has also been an underlying goal of MAB China.

The technical aspects of the development of such biodiversity conservation geographic information are still only in their initial phases even in North America and Europe. There are numerous examples though few have been applied to site-specific decision-making of biosphere reserves. The theoretical, functional, and design aspects of the necessary g.i.s. architecture must be considered carefully for each context. The lack of clarity in theoretical issues and functional requirements have tended to render many geographic information systems outmoded and unworkable after three to five years. And central to developing a "sustainable" g.i.s. must be easy use and training.

I was originally invited to China in 1989, while a Ph.D. candidate at Berkeley, and finally found time to conduct reconnaissances[4] in 1991 under the auspices of The University of British Columbia (UBC), the provincial British Columbia Scholars in China programme, and the Man and the Biosphere Committee (MAB China) of the Chinese Academy of Science (CAS). In 1992, a

---

[2] For a background to the relatively little intact forest remaining in southern China, see Hou et al. (1982), Hou (1983), Murphy (1983), Wang (1990), and Collins et al. 1991.

[3] The international MAB network has had its greatest achievements in developing monitoring frameworks for biological diversity. See the following discussions of examples of the objectives and sampling formats for monitoring biological diversity within the context of regional environmental change: di Castri et al. (1992) and Dallmeier et al. (1992).

[4] The 1991 visit involved meetings with the CAS in Beijing plus reconnaissances of Fanjingshan and Dinghushan Biosphere Reserves in the southern part of the country.

collaboration was proposed by IDRC Singapore between the CAS and UBC with the partial funding support of the IDRC.[5] However, it became evident by 1993, that there were a number of other biodiversity conservation initiatives at CAS Beijing and that any Canadian involvement would also need to be in contact with these other units.[6] With the internal politics of MAB China problematic and the lack of funding for UBC involvement in the collaboration, the project was deferred and then cancelled. This report is one of several has been written to satisfy the demands of IDRC Singapore. It was written for the benefit of the CAS, IDRC and other agencies involved with biodiversity conservation and the related used of geographic information systems in China.

Goals for development of a spatial data base for biodiversity conservation

The following are the concerns that emerged the most often in discussions with Chinese officials and scientists.

1. The data base should be expressly oriented to biodiversity and genetic resource conservation planning with highly complex architecture for very different populations, ecosystems and scales. However, such a g.i.s. would be "nested" and used in conjunction with a broader data base on monitoring environmental change and there must be relative compatibility.

2. There should be capacities for simulation, "expert systems,"[7] and the generation of alternatives for conservation and land use.

---

[5] There was slightly over $20,000. provided by the IDRC in 1992 and 1993 for UBC to service the CAS. However, it became evident, by late 1993, that there were insufficient funds from the IDRC to fund UBC participation on an ongoing basis. In addition, it became evident that there were problems with the unit within CAS, the China Man and Biosphere Program (MAB China). After a Unesco-IDRC visit to UBC, from five individuals associated with that unit of CAS in the summer of 1992, it became evident that there were major discrepancies in the goals and practices of CAS personnel. Considerable animosity was exhibited between the personnel from the south China reserves and the administrators from Beijing. Those individuals were:

1. Zhao Xianying, Secretary-General of the China MAB (Man and the Biosphere Programme) National Committee (Chinese Academy of Sciences, 52 Sanlihe, 100864 Beijing China, fax +86 1 80 11 095)

2.Zhao Yong, China MAB National Committee (Chinese Academy of Sciences, 52 Sanlihe, 100864 Beijing China, fax +86 1 80 11 095)

3.Sun Dunyuan, Research Director, Fanjingshan Biosphere Reserve
(Fanjingshan Nature Reserve, China Department of Forests, Jiankon County, Guizhou Province 554400 China, telephone: +86 851 177)

4.Xie Zhi Xin, Director, Wuyishan Biosphere Reserve Fujian Wuyi Mountain National Nature Reserve (Sangang, Wuyishan, 354315 Fujian, China, telephone: +86 32382)

5.Zhang Quanyi, Director, Shennongjia Biosphere Reserve (Shennongjia Nature Reserve, Muyu Town, Shennongjia, Hubei 442421, China)

[6] For example, there had been virtually no contact between MAB China and the recently formed Biodiversity Committee of the Chinese Academy of Sciences nor the CAS Laboratory of Quantitative Vegetation Ecology headed by Professor Chang Hsin-Shih. Both offices are blocks away from those of MAB China in Beijing.

[7] For some examples of relevant expert systems, see Leary (1989), Shakya and Leuschner (1990), Biggins (1991), and Hamilton and Flaxman (1992).

3. There should be capacities for integration of complex data on cultural landscapes, social factors, and trends for assessment of various conservation / land use trade-offs and the social implications of possible interventions.

Precedents in China

The most advanced g.i.s. system for management of a protected areas in China is at the Institute of Botany's Quantitative Ecology Laboratory and is called the **Scientific Information System of Qomolangma Nature Preserve**. This spatial data base is for large area in southern Tibet on the northern slopes of Mt. Everest (Laboratory of Quantitative Vegetation Ecology 1993).

The first involvement of MAB China in a g.i.s. project was with Federal Republic of German-supported project for Changbaishan Biosphere Reserve, in the northeast. The project was part of the Cooperative Ecological Research Project (CERP) which involved several phases[8]. The Changbai project involved a ARC|INFO[9] data base and was initially developed near Munich at the headquarters of ESRI Germany. The data bases is now housed at the Shenyang Institute of Ecology. This data base was largely an inventorying and vegetation mapping tool which was not particularly oriented to conservation of biological diversity and finer-scaled aspects of land management.

In recent years, there has been a modest beginning to identify more rationale management boundaries for Wuyishan Biosphere Reserve and use in fire protection involving the ITC, the International Institute for Earth Sciences and Aerial Surveying of the Netherlands. The project is named "Information Service for Environmental Planning and Decision-making for Sustainable Development of the Wuyishan Biosphere Reserve (WBR)" and has been carried out in conjunction with the Commission for Integrated Survey of Natural Resources, Chinese Academy of Sciences. In addition, there have been recent efforts to establish a g.i.s. for the renowned Woolong Biosphere Reserve with its highly vulnerable populations of pandas.

Functions for a biodiversity conservation geographic information system

There are no generic g.i.s. architectures for objectives as complex as conservation of biological diversity and genetic resources. Regions, landscapes, and cultural systems vary too greatly. Each g.i.s. must be tailored to particular conditions and priorities for management, research, and social development. Data bases vary greatly with operational priorities and with ecosystems, scales, land use patterns, environmental change. For the remaining forests of southern China, some initial priorities begin to emerge based around:

1. tracking the high levels of localized biodiversity across rugged terrain;

2. successional mosaics with highly fragmented forest;

3. integration of inventory and monitoring data into simulation and decision-making for

---

[8] The CERP programme began in 1987 and in the 1987-90 period there were 8 projects at a funding level of US$ 2.5 M. In this second phase, the funding level is at US$ 1.4 M and involves 3 projects. The programme is administered as a funding trust between the German Federal Ministry of Research and Technology, Unesco and the CAS with Unesco receiving a 13% overhead for some of the administration.

[9] For an introduction to the particular g.i.s. architecture developed for the Changbai project, see ESRI (1990).

conservation planning; and

4. the importance of local knowledge and the integration of prospective conservation measures with the aspirations of traditional communities.

Based on meetings with a range of Chinese officials and scientists, in 1991 and 1993, the following emerged as important functions for such geographic information systems.

1. All of these biosphere reserves have had years of field research but little has been compiled in usable map formats. Such g.i.s. would first function to organize a great deal of data in spatial terms on to a series of digital map layers.

2. Capabilities for identification of gaps in current levels of conservation, now often referred to as "gap analysis" (Scott et al. 1993) are necessary.

3. Capabilities for identification of various tradeoffs involving lands, boundaries, conservation activities, land use, and regulations are necessary.

4. Facilities for easy input of monitoring data and ongoing revisions and calculations are necessary.

Technical components of a geographic information system for biodiversity conservation

The components of the geographic information systems envisioned in this report can be broken down into four functional categories that involve a range of computerized tools and software. The activities are all dominated by the fact that these areas are under-inventoried and that major gaps in ecological knowledge are decades from being filled. In the case of determining the vulnerability of species, this situation is especially problematic. And given the persistent rural poverty in the region, the methodology must also reflect requirements for data for environmental management that contributes to "sustainable development" (Redclift 1987, Wang and Chen 1990, Rao 1993).

<u>data compilation</u>

- ■ Much of any g.i.s. is a fairly simple filing system organized into map layers with some cross-referencing capabilities.
- ■ Species distribution, occurrence and density data (Haslett 1990), as well as that on landscape processes and land use, is entered into digital files as points, lines, and polygons.
- ■ Aspects of the data can be tagged in terms of such things as quality, date of origin, and source. This tracking facility is key to managing and culling out-dated and poorer quality data in subsequent years.
- ■ Fresh data can be entered on an ongoing basis through Global Positioning Systems (GPS) that are input directly into the g.i.s.
- ■ More elaborate architectures for organizing and cross-referencing certain forms of information can be attempted.

<u>computation</u>

- ■ Most standard g.i.s. packages have a range of calculation features such as for determining area.
- ■ More specialized and customized calculation features can be developed as strings of macros for

specific conservation purposes.[10]

- Computations can have either statistical or spatial output or both. They can be stored and used as additional layers of information or even for subsequent calculations.

simulation

- Simulations are forms of "what if" calculations. They are based on some actual data combined with variables surmised from trends embedded into "models" (Shugart 1984, Burrough 1985, King 1990, Sklar and Costanza 1990, Turner and Dale 1990). Given the need to be prepared for a range of possibilities in rapidly changing, and often deteriorating environments, simulations are key to pre-emptive problem-solving.
- Simulation output can be both statistical and spatial.
- Simulations can be combined with statistical and trade-off analysis for hypothesis testing (Fahrig 1991).
- With the rapid increase in graphics capabilities, there can be "visualization" capabilities (Hamilton and Flaxman 1992).

expert systems

- Expert systems are based on evaluation (Chen et al. 1991) of the output from the first three functions for repetitive decision-making.
- Expert systems usually have a focus on a relatively small sub-set of variables and possible decisions.
- Various strategies are identified, before hand, and the system "chooses" from a relatively small number of possibilities.
- Expert systems are by no means a panacea for the "adaptive management" (Baskerville 1985) of biological resources. Social and land use conditions are often too complex and unpredictable and there is a wide range of conservation intervention needs for the various populations of vulnerable species.

Development of software modules

Development of the biodiversity g.i.s. and the special features for calculation, simulation, and expert decision-making could involve the following customizations.

- The text of the data base could be bilingual, in Chinese character and English.
- There could be audio components with various Chinese dialects.
- There could be overview files, with photograph and video files, on particular species, ecosystems, and sites.
- Aspects of the "talking map" concept, involving "polite advice" rather than the actual decision-making could be used as an alternative to an unwieldy expert system.

The following are some of the most useful modules that could be developed.

- There have been some fairly successful attempts at setting minimum viable population thresholds

---

[10] For an example of some calculation features related to soil conservation in China, by a Canadian-supported project, see Band and Fu (1993).

and then to identify vulnerable populations and sites for pre-emptive measures.

- Tracking "cumulative impacts" (Sebastiani et al 1989) and how they could destroy particular biological resources is extremely useful.
- Monitoring disturbance (Sousa 1984, Middleton 1988), landscape process and patterns of change (Turner 1989, MacMohon 1980, Baker 1989, Moss 1985) as they could effect the survival of vulnerable populations is crucial. Given the status of these remaining forests, a range of tools for ascertaining and envisioning means to counter "fragmentation" (Hastings et al. 1982, Harris 1985) and manage of forest succession (Shugart 1984) would be necessary.
- A set of modules on species and respective populations, with possible genetic resources, is crucial to maintaining high levels of intra-specific variability. This could be linked to monitoring of "genetic erosion" (Ingram 1990A) and subsequent land management and conservation interventions. Other modules for the tracking of gathering and germplasm procurement, particularly related to the smaller more vulnerable populations, would be worthwhile.
- A range of protected area planning tools would be useful both at different scales and for particular populations, such as for the *in situ* conservation of species with genetic resources (Ingram 1987, Ingram and Williams 1993).
- One of the most immediately useful set of planning tools would be for determination of core, buffer, and transition area boundaries and less formal management units.
- Given the mounting tourism pressures on these areas, many of which are sacred mountains, planning and design modules for the siting of structures and infrastructure are crucial.
- Modules for monitoring and exploring options for expanding traditional use is increasingly necessary especially for areas with numerous overlapping minority communities such as Xishuangbanna.

Project phases

Phase 1. **Determination of the boundaries of regional unit and study area**

The spatial extent of each biosphere reserve regional management unit needs to be established early on. This study area should include all of the cores, buffers, the "transition area" and adjacent areas within the natural and cultural landscape unit. The following are some necessary research and compilation activities:

- review of the legal boundaries of the Nature Reserve / Biosphere Reserve;
- review of the natural boundaries of surrounding district and landscape units;
- review of the cultural groups in the area and historical boundaries;
- identification of other public lands in the vicinity;
- identification of watershed boundaries;
- establishment of final criteria for the boundary of the study area;
- compilation of relevant map data at a regional scale (optimally 1:50,000);
- final delineations; and
- development of a strategy for subsequent "tiling" and map subunits within the g.i.s.

Phase 2. **Compilation of spatial data**

"Acquisition and input of data is typically the most costly and time consuming portion of g.i.s. implementation."

Jack Dangermond founder of ESRI Corporation and author of ARC|INFO

There is a wide variety of spatial information that must be compiled and tracked for subsequent evaluations.

- Topographic maps are available from government sources though in some cases there is limited access for use in data bases that might be shared outside of the country;
- Various kinds of aerial photographs, of different qualities and dates, are usually available through government sources but in some cases their access and use is restricted.
- There are a number of international sources for satellite imagery:
- LANDSAT imagery, particularly Thematic Mapper (TM), data is the most readily available satellite data with a wider spectral range. It is also cheaper than SPOT data and fairly comprehensive in availability.
- SPOT imagery, has a more narrow spectral sensitivity but has a smaller pixel size which means that it is more precise (for example for discerning different types of forest gaps such as between natural mosaics and those with swidden gardens).
- NIMBUS satellite imagery is used for weather forecasting and monitoring.
- There are some resource and vegetation maps available from various national and regional institutes of variable quality and relevance.
- As for already digitized maps at the necessary scales (at 1:50,000 or finer), it is highly unlikely that files at this level of precision will be commercially available in the next several years for these areas. However, digitizing costs remain relatively low in China.

Phase 3. **Importation of remote sensing data**

- Satellite remote sensing (Harper 1983, Harris 1987) has been used extensively for analysis of landscapes (Quattrochi and Pelletier 1991) and is being increasingly used in biodiversity conservation.
- There has been extensive use of "Landsat" imagery for mapping soil and land resources for development planning (Johannsen and Sanders 1982, Shiva et al. 1990, Prasad et al. 1990, Rao 1993).
- Landscape analysis has been increasingly used in zoning for land use planning (Estes and Senger 1975, Vink 1983, Primdahl 1989).
- Recently, there have been efforts to discern underlying processes, such as patterns of flow, edge, and isolation (Muchoki 1988).
- Both aerial photographs and satellite imagery are desirable where they are available and affordable. Pre-1980 data is useful in discerning recent changes to landscapes and marine areas though it must be carefully labeled and only used in comparison with more recent material.
- In terms of pixel size (related to the level of precision) and spectral ranges (related to the sensitivity of the sensing), a range of options for data are usually available as related to cost, availability and the type of setting.

Phase 4. **Processing of remote sensing data for habitat assessment**

- Image processing involves a software package such as PCI by the Canadian firm, Universal

Systems.

- The technical aspects of use of remote sensing imagery are quite complex and cannot be fully considered in the space of this report. A particular spectral amplitude is identified as representing a specific condition / vegetation type on the ground. This must involve considerable field work called "ground truthing."
- After the initial correlations, there must be geometric correction, registration of imagery to a master image or format, and correction for idiosyncracies related to sensor type such as altitude and "skew."

Phase 5. **Inventory and monitoring: Ecosystem and landscape levels**

Within the study area, the following environmental parameters and landscape processes should be inventoried with maps compiled and digitized:

- topography;
- geology;
- geomorphology;
- climate and microclimate;
- soil;
- hydrology;
- vegetation;
- wildlife;
- biogeography;
- ecosystem units;
- natural disturbance factors and landscape heterogeneity (Romme and Knight 1982);
- patterns of connectivity and natural corridors (Allen and Starr 1982);
- patterns of isolation and natural fragmentation (Freemark and Merriam 1986, ;
- ecological edges (Hansen et al. 1988) / mosaics;
- energy and nutrient flows;
- matrices (Forman and Godron 1986);
- natural corridors;
- historical land use; and
- contemporary land use (Franklin and Forman 1987).

Phase 6. **Inventory and monitoring biodiversity: Vulnerable species and habitats**

A subset of indicator species will be identified in terms of the following criteria for vulnerability:

- endemic;
- disjunctive distribution;
- rareness;
- threatened;
- endangered;
- *K*-selected;

- to any environmental destabilization in general;
- to specific land use-related impacts; and
- to the introduction of particular species.

The status and relevant habitat attributes of each of these species will be described and mapped as a prelude to ongoing monitoring and could include the following categories of information:

- population occurrence;
- population size;
- population densities;
- associated species;
- associated habitat types;
- associated successional conditions and disturbance / lack of disturbance; and
- environmental gradients.

Phase 7. **Inventory and monitoring wild species with genetic resources**

The species with genetic resources, within the study area, could be identified with the following criteria:

- in the primary gene pool of a major crop gene pool;
- in the secondary and tertiary gene pools of a major crop gene pool;
- species with potential as introduction as new crops;
- species with potential for production of modern drugs;
- species that are traditional medicinals;
- species that can provide non-food and technological products;
- species in the primary and secondary gene pools of medicinal and technological products;
- traditional crops;
- species in the primary, secondary, and tertiary gene pools of traditional crops;
- commercial timber species; and
- species used in traditional technologies.

Based on various ecogeographical surveys (Ingram 1990A), the following aspects of each species would be mapped:

- population presence;
- population size;
- population densities;
- associated species;
- associated habitat types;
- associated successional conditions and disturbance / lack of disturbance; and
- environmental gradients (Ingram 1989).

Minimum levels of these attributes would then be set as a basis for *in situ* conservation (Ingram 1987, Altieri 1988, Brush 1991, Riggs 1990, World Conservation Monitoring Centre 1992).

Phase 8. **Assessment of traditional tenure and land management**

The historic (and prehistoric) human presence in the area will be assessed with an emphasis on the following data:

- areas of settlement;
- areas of grazing;
- areas of gathering and hunting;
- ethnobiology;
- patterns of use and ownership of resources;
- patterns of use and ownership of sites and areas; and
- traditional patterns of social constraint on land use.

Phase 9. **Contemporary social and land use appraisal**

The current social context will be assessed with an emphasis on compiling the following information:

- human population levels and population distribution;
- location of patterns of settlements and infrastructure;
- patterns of remaining traditional knowledge and "intellectual property" (The Crucible Group 1994);
- current patterns of land use and tenure;
- current pressures for expansion of land use;
- conflicts over resources and sites; and
- prospective impacts of pressures and conflicts on environmental parameters and key species.

Phase 10. **Delineation and monitoring of cultural landscapes**

The key cultural factors that maintain certain species and ecosystems will be identified with an emphasis on the following information:

- gathering patterns;
- traditional agricultural patterns;
- selection factors associated with traditional varieties and agricultural systems; and
- traditional landscape fragmentation and matrix processes.

Phase 11. **Modelling of landscapes, ecosystems, habitat and populations**

Ecological models would be constructed across various landscape scales (King 1990). This involves hierarchy theories in ecology.[11] Models can also be used to test hypotheses (Fahrig 1991). Numerous models can be developed to provide the predictive basis for considering conservation measures such as those related to:

- landscape and land use processes particularly related to fragmentation[12];

---

[11] Different scales can involve divergent determinations of landscape heterogeneity. This relationship between scale and heterogeneity is relevant to database design and data analysis. How aggregates are split, has a major impact on subsequent models.

[12] There would be aggregating of smaller-scale information and models from sites, stands, and patches into broader landscape patterns.

- status of ecosystems and habitat attributes;
- population distributions (Haslett 1990) dynamics; and
- cumulative impacts.

Using spatial concepts of neighbourhood influences and exports and imports converts, one-dimensional relationships can be linked as landscape models (Sklar et al. 1990).

Phase 12. **Design of modules for inventorying, simulation, planning and management**

A range of specialized features of the biodiversity g.i.s. can be developed for the following functions:

- special filing and cross-referencing;
- discerning of various landscape and land use processes;
- discerning thresholds related to species survival and genetic resources;
- identifying sites of conflict as related to land use;
- assessing cumulative impacts; and
- design of boundaries of management areas.

Phase 13. **Delineation of core areas based on landscape processes and biology**

In planning biosphere reserves, we must look not only at species and habitat but also at landscape contexts at various scales (Noss 1983, Noss and Harris 1986). The boundaries of the core areas of biosphere reserve could be determined through compilation of the following:

- the thresholds from the minimum requirements models as related to the vulnerable species and genetic resources;
- spatial analyses of landscape and fragmentation processes;
- spatial analyses of other cumulative impacts and trends in regional land use and environment; and
- policy and management priorities and institutional capabilities (Ingram 1994A) of respective conservation administrations.

Phase 14. **Determination of buffer and transition zone boundaries and management zones**

The boundaries of the areas around the cores are almost more important than those of the cores themselves. The boundaries can be altered more easily over time and are more the product of fluid social conditions.

- Tentative boundaries can first be identified that buffer the ecosystems and species occurring within the cores from the impacts of adjacent and regional land use.
- The current land use and related pressures on these areas can be assessed
- More environmental thresholds can be set and where current or projected land use extends above those levels, buffers for the buffers can be defined.
- Using ecological models of boundaries in the design of conservation areas (Schonewald-Cox 1986), there can be "development of edges in association with the establishment of the administrative boundary."
- Key corridors can be identified and designed based on simulations of species responses and persistence.

Phase 15. **Identification of conservation / land use alternatives**

Models and simulations could be linked for generation and identification of land use alternatives. Neural net technology for multi-objective land use planning (Yongyuan Yin 1992) could also be applied. This is were an extensive expert system for land use planning (Leary 1989, Biggins 1991) could be developed. In using GIS modelling for planning purposes, the quality of the results depends on that of the data and the clarity and processing of the models (Burroughs 1984.)

Phase 16. **Integration of geographic information system into local land management**

The effectiveness of the integration of the g.i.s. into local land management is first a function of how clearly the design reflects local needs and priorities. Such a system must be, from inception in part, locally initiated (Ingram 1994B) and designed with on-going discussions and evaluations about the use and the management of the system.

Some commercially available software

In terms of software needed for such complex functions, use of some form of Unix operating system with customized windows, with compatible programmes in DOS for field computers, is inevitable.

■ Of the available GIS software packages, ESRI's **ARC|INFO** has generally been chosen in China because of its storage capabilities and because it is well-known, internationally, particularly in Canada and in China.

■ Ty-Dac Corporation's environmental modelling programme **SPANS** is also desirable. ■ One of the best image processing software packages is of Universal systems' **PCI**

References

African Centre for Technology Studies. 1993. Convention on Biological Diversity: National interests and global perspectives. Conference Report. Held at the Unted Nations Environment Programme (UNEP) Headquarters, Nairobi, Kenya January 26 - 29, 1993. on file UNEP Nairobi.

Allen, T. F. H. and T. B. Starr. 1982. Diversity and connectedness. In *Hierarchy: Perspectives for ecological complexity*. Chicago, University of Chicago Press.

Altieri, M. 1988. Rethinking crop genetic resource conservation: A view from the south. *Conservation Biology* 3(1):77-79.

Baker, W. L. 1989. A review of models of landscape change. *Landscape Ecology* 2(2): 111 - 133. Batisse, M. 1982. The biosphere reserve: A tool for environmental conservation and management. *Environmental Conservation* 9 (2): 101 - 111.

Band, L., and L. Y. Fu. 1992. Chapter 3. Structure and operation of SEMGIS (Soil erosion management geographic information system). In *Soil erosion Management geographical information system (SEMGIS) in the Wangjiagou Experimental Basin Lishi, Shanxi Province North China - SEMGIS CIDA China Project 1988-1992*. Final Report Submitted to the Canadian International Development Agency (CIDA) and the Association of Universities and Colleges of Canada (AUCC). Annual Report. on file University of Toronto Institute of Geography, Chinese Academy of Sciences, and Ministry of Soil and Water Conservation, Shanxi Province.

Baskerville, G. L., 1985. Adaptive management: wood availability and habitat availability. *Forest Chronicle* 61: 171-175.

Biggins, J. G. 1991. Dryplan - a computer-based decision-support system for sustainable land-use planning. *Artificial Intelligence Applications* 5 (3): 57-59.

Brown, P. J. 1984. *Starting with Unix*. Menlo Park, California, Addison-Wesley Publishing.

Brush, S. 1991. A farmer-based approach to conserving crop germplasm. *Economic Botany* 45(2): 153-165.

Burgess, R. L. and D. M. Sharpe (eds.). 1981. *Forest Island Dynamics in Man-dominated landscapes* Ecological studies No. 51. New York: Springer-Verlag.

Burrough, Peter 1985. The Use of Geographical Information Systems for Cartographic Modelling in Landscape Ecology. Methodology in Landscape Ecological Research and Planning. Vol.III: Theme III. Methodology of Data Analysis, (eds.) J. Brandt and P. Agger, pg. 3-15. Roskilde, Denmark: Roskilde University Centre.

di Castri, F. J. Roberson Vernhes and T. Younes (eds.) 1992. Inventorying and monitoring biodiversity. *Biology International* 27. The International Union of Biological Sciences News Magazine.

Chen, Jie. 1992. The way of vegetation resources use of minority nationalities in Xishuangbanna and its effects on tropical forests. In *Proceedings of the International Symposium on Man-Made Community, Integrated Land-Use and Biodiversity in the Tropics*. Kunming, China, Institute of Ecology and Geobotany.

Chen, Jie. 1993. GIS application in Xishuangbanna Nature Reserve. manuscript on file Institute of Ecology and Geobotany, Yunnan University, Kunming, China.

Chen, Ling-zhi (Editor-in-chief). 1993. *Biodiversity in China: Status and conservation strategies*. Beijing, Science Press.

Chen, Shupeng, Huang Xuan, Wu Bingfang, C. H. Zhou, Liu Xia, and Zhao Chunyan (editors). 1991. *Bulletin of Flood Damage Evaluation Information System and Wetland Use*. Beijing, China Science and Technology Press.

Collins, N. M., J. A. Sayer and T. C. Whitmore (editors). 1991. Chapter 17 China and Taiwan. In *The Conservation Atlas of Tropical Forests: Asia and the Pacific*. pages 116 to 125. London, MacMillan (British Petroleum, IUCN, World Conservation Monitoring Centre).

Dallmeier, F., M. Kabel and R. Rice. 1992. Methods of long-term biodiversity inventory plots in protected tropical forest. In *Long-Term Monitoring of Biological Diversity in Tropical Forest Areas: Methods for establishment and inventory of permanent plots*. F. Dallmeier (editor). 11 - 46. Paris, UNESCO.

Dunn, C. P., D. M. Sharpe, G. R. Guntenspergen, F. Stearns and Y. Yang. 1990. Methods for analyzing temporal changes in landscape pattern. In *Quantitative Methods in Landscape Ecology: The analysis and interpretation of landscape heterogeneity*. M. G. Turner and R. H. Gardner (eds.). pages 173 to 197. New York, Springer-Verlag.

ESRI. 1990. *Understanding GIS*. Redlands, California, ESRI (Environmental Systems Research Institute.

Estes, J. E. and L. W. Senger. 1975. *Remote Sensing: Techniques for Environmental Analysis*. Santa Barbara, Hamilton.

Fahrig, L. 1991. Simulation methods for developing general landscape-level hypotheses of single-species dynamics. In *Quantitative Methods in Landscape Ecology: The analysis and interpretation of landscape heterogeneity*. M. G. Turner and R. H. Gardner (eds.). pages 517 to 552. New York, Springer-Verlag.

Forman, R. T. T. and M. Godron. 1986. *Landscape Ecology*. Toronto, John Wiley and Sons.

Franklin, J. F. and R. T. T. Forman. 1987. Creating landscape patterns by forest cutting: Ecological consequences and principles. *Landscape Ecology* 1 (1): 5 - 18.

Freemark, K. E. and H. G. Merriam. 1986. Importance of area and habitat heterogeneity to bird assemblages in temperate forest fragments. *Biological Conservation* 36: 115 - 151.

Gregg, W. P. 1991. MAB Biosphere Reserves and conservation of traditional land use systems. In *Biodiversity: Culture, conservation and ecodevelopment*. M. L. Oldfield and J. B. Alcorn (eds.). 274 - 294. Boulder, Colorado, Westview.

Hamilton, M. P. and M. Flaxman. 1992. Scientific data visualization and biological diversity: new tools for spatializing multimedia observations of species and ecosystems. *Landscape and Urban Planning* 21: 285 - 287.

Hansen, A. J. , F. di Castri and R. J. Naiman. 1988. Ecotones: What and why? Biology International 17: 9 - 56. In *A New Look at Ecotones: Emerging international projects on landscape boundaries*. F. di Castri, A. J. Hansen and M. M. Holland (eds.). Paris, International Union of Biological Sciences.

Harper, D. 1983. Eye in the Sky: *Introduction to Remote Sensing* (2nd edition). Multiscience Publications, Montréal.

Harris, L. D. 1985. *The Fragmented Forest: Island biogeography theory and the preservation of biotic diversity*. Chicago, University of Chicago Press.

Harris, R. 1987. *Satellite Remote Sensing: an Introduction*. New York, Routledge & Kegan Paul.

Haslett, J. R. 1990. Geographic information systems: New approaches to habitat definition and the study of distributions. *Trends in Ecology and Evolution* 5(7): 203 - 230.

Hastings, H. , R. Pekelney, R. Monticciolo, D. Von Kannon, and D. Del Monte. 1982. Time scale, persistence and patchiness. *Biosystems* 15: 281-289.

Hou, H. Y. 1983. Vegetation Map of China 1: 14,000,000. *Annals of the Missouri Botanical Garden* 70 (3).

Hou, H. Y., S. C. Sun, J. W. Chang, M. K. Ho, Y. F. Wang, D. C. Kong and S. C. Wang. 1979 (1982). *Vegetation Map of China Scale: 1: 4,000,000*. Map Publisher of the People's Republic of China.

Ingram, G. B. 1987. Conservation of wild plants in crop gene pools and their intra-specific variation: Current needs and opportunities in the moist forest of southeast Asia. In *The Conservation and Management of Endangered Plants and Animals*. Proceedings of the Symposium on the Conservation and Management of Endangered Plants and Animals, Bogor, Indonesia, June 1986. C. Santiapillai and K.R. Ashby (eds.) 63-85. Bogor, Indonesia, South-East Asia Centre for Tropical Biology.

Ingram, G. B. 1989. Planning district networks of protected habitat for conservation of biological diversity: A manual with applications for marine islands with primary rainforest. Ph. D. dissertation in Environmental Planning. On file, University of California at Berkeley. Ann Arbor, Michigan, University Microfilms.

Ingram, B. 1990A. Multi-gene pool surveys in areas with rapid genetic erosion: an example from the Aïr Mountains, northern Niger. *Conservation Biology* 5(1):78-90.

Ingram, B. 1990B. The management of biosphere reserves for the conservation and utilization of genetic resources: the social choices. *Impact of Science on Society* 158: 133 - 151.

Ingram, G. B. 1994A. Institutional obstacles to conservation of habitat and biological diversity on Fergusson Island, Milne Bay Province, Papua New Guinea. *Pacific Affairs* (Vancouver) 67(1): 26 - 45.

Ingram, G. B. 1994B. Rainforest conservation initiated by traditional island communities: Implications for development planning. *Canadian Journal of Development Studies* (Ottawa) XV(2): 193 - 218.

Ingram, G. B. and J. T. Williams. 1993. Gap analysis for *in situ* conservation of crop genepools: Implications of the *Convention on Biological Diversity*. *Biodiversity Letters* (London) 1: 141 - 148.

International Development Research Centre. 1993. Theme statement on biodiversity, Final Draft - 5 February, 1993. on file, IDRC, Ottawa. 4 pp.

Johannsen, C. J. and Sanders, J. L. , ed. 1982. *Remote Sensing for Resource Management.* Ankeny, Iowa, Soil Conservation Society of America.

Kalliola. R., Syrjanen, K. 1991. To what extent are vegetation types visible in satellite imagery. *Annales botanici fennici* 28 (1): 55-57.

King, A. W. 1990. Translating models across scales in the landscape. In *Quantitative Methods in Landscape Ecology: The analysis and interpretation of landscape heterogeneity*. M. G. Turner and R. H. Gardner (eds.). pages 579 to 517. New York, Springer-Verlag.

Laboratory of Quantitative Vegetation Ecology (Chinese Academy of Sciences). 1993. Scientific information system of Qomoloangma Nature Preserve (QNP). on file Laboratory of Quantitative Vegetation Ecology, Institute of Botany, Chinese Academy of Sciences. 5 pp.

Leary, M. E. 1989. A spatially-based computer system for land use planning. *Ekistics* 338/339: 285 - 289.

Li Wenhua and Zhao Xianying. (in English, trans. P. Edwards). 1989. *China's Nature Reserves*. Beijing, Foreign Languages Press.

MacMahon, J. A. 1980. Ecosystems over time: succession and other types of change. In R. Waring (ed.). *Forests: Fresh perspectives from ecosystem analyses*. Corvalis, Oregon State University Press.

Middleton, J. 1988. Measures of ecosystem disturbance and stress in landscapes dominated by human activity. In: *Landscape Ecology and Management*. M. R. Moss (editor). Montreal, Polyscience Publications.

Moss, M. R. 1985. Landscape synthesis, landscape processes and land classification: some theoretical and methodological issues. *Geojournal* 7(2): 155-153.

Muchoki, C. 1988. Remotely sensed relationships between wooded patch habitats and agricultural landscape type: a basis for ecological planning. In: *Landscape Ecology and Management*. M. R. Moss (editor). Montreal, Polyscience Publications.

Noss, R. F. 1983. A regional landscape approach to maintain diversity. *Bioscience* 33: 700 - 706.

Noss, R. F. and L. D. Harris. 1986. Nodes, networks, and MUMs: Preserving diversity at all scales.

Environmental Management 10(3): 299 - 309.

Murphey, R. 1983. Deforestation in modern China. In *Global Deforestation and the Nineteenth-Century World Economy*. R. P. Tucker and J. F. Richards (editors). 111 - 128. Durham, North Carolina, Duke Press Policy Studies.

Prasad, C. R. S., Thayalan, S., Reddy, R. S., Reddy, P. S. A. 1990. Use of Landsat imagery for mapping soil and land resources for development planning in parts of northern Karnataka, India. *International Journal of Remote Sensing* 11(10): 1889 - 1900.

Primdahl, J. 1989. Landscape analysis and zoning as a planning method. *Ekologia CSSR* 8(2): 155 - 165.

Quattrochi, D. A. and R. E. Pelletier. 1991. Remote sensing for analysis of landscapes: An introduction. In *Quantative Methods in Landscape Ecology: The analysis and interpretation of landscape heterogeneity*. M. G. Turner and R. H. Gardner (eds.). pages 51 to 76 . New York, Springer-Verlag.

Rao, U. R. 1993. Remote sensing for sustainable development. Appendix I. In *Information Technology: A Dialogue*. M. S. Swaminathan (ed). pp. 239 - 250. Madras, Macmillan India.

Redclift, M. 1987. *Sustainable development: Exploring the contradictions*. London, Methuen.

Riggs, L. A. 1990. Conserving genetic resources on-site in forest ecosystems. *Forest Ecology and Management* 35:45-68.

Romme, W. H. and D. H. Knight. 1982. Landscape diversity: the concept applied to Yellowstone Park. *Bioscience* 32: 665 - 670.

Schonewald-Cox, C. M. and J. W. Bayless. 1986. The boundary model: A geographical analysis of design and conservation of nature reserves. *Biological Conservation* 38: 305 -322.

Scott, J. M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T. C. Edwards, J. Ulliman, and R. G. Wright. (1993). Gap Analysis: A geographic approach to protection of biological diversity. Supplement to the Journal of Wildlife Management 57(1), *Wildl. Monog.* **123**, 1-41.

Sebastiani, M., A. Sambrano, A. Villamizar and C. Villalba. 1989. Cumulative impact and sequential geographic analysis as tools for land use planning. A case study: Laguna La Reina, Miranda State, Venezuela. *Environmental Management* 29: 237 - 258.

Shugart, H. H. 1984. *A Theory of Forest Dynamics - The Ecological Implications of Forest Succession Models*. Springer Verlag, New York.

Shakya, K. M., Leuschner, W. A. 1990. A multiple objective land use planning model for Nepalese hills farms. *Agricultural systems* 35 (2): 133 - 159.

Shiva P., C. R. , S. Thayalan, R. S. Reddy, and P. S. A. Reddy. 1990. Use of Landsat imagery for mapping soil and land resources for development planning in parts of Northern Karnataka, India. *International Journal of Remote Sensing* 11(10): 1889 - 1900.

Shugart, H. H. and S. W. Seagle. 1985. Modelling forest landscapes and the role of disturbance in ecosystems and communities. In *The Ecology of Natural Disturbance and Patch Dynamics*. pages 353 to 368. S. T. A. Pickett and P. S. White (editors). New York, Academic Press.

Sklar, F. H. and R. Costanza. 1990. The development of dynamic spatial models for landscape ecology: A review and prognosis. In *Quantitative Methods in Landscape Ecology: The analysis and interpretation of landscape heterogeneity*. M. G. Turner and R. H. Gardner (eds.). pages 239 - 87. New York, Springer-Verlag.

Smil, V. 1992. China's environment in the 1980s: Some critical changes. *Ambio* I(6): 431 - 436.

Soulé, M. E. 1991. Conservation: Tactics for a constant crisis. *Science* 253: 755 - 750.

Sousa, W. P. 1984. The role of disturbance in natural communities. *Annual Review of Ecology and Systematics* 15: 353 - 391

Swanson, F. J. , T. K. Kratz, N. Caine and R. G. Woodmansee, 1988. Landform effects on ecosystem patterns and processes. *Bioscience* 38(2): 92-98.

The Crucible Group. 1994. *People, Plants, and Patents*. Ottawa, IDRC.

Turner, M. G. 1989. Landscape ecology - the effect of pattern on process. *Annual Review of Ecology and Systematics* 20: 171 - 197.

Turner, M. G. and V. H. Dale. 1990. Modeling landscape disturbance. In *Quantative Methods in Landscape Ecology: The analysis and interpretation of landscape heterogeneity*. M. G. Turner and R. H. Gardner (eds.). pages 323 to 351. New York, Springer-Verlag.

UNEP (United Nation Environment Programme) (host). 1992. *Convention on Biological Diversity*. Conference for the Adaption of the Agreed Text of the Convention on Biological Diversity, Nairobi, 22 May, 1992. version: UNEP/Bio.Div/CONF/L.2. on file, UNEP, Nairobi, Kenya.

UNESCO. 1984. The Action Plan for Biosphere Reserves. *Nature and Resources* XX(4): 1 - 12.

Vernhes, J. R. 1989. Biosphere reserves: The beginnings, the present, and the future challenges. In *Proceedings of the Symposium on Biosphere Reserves, Fourth World Wilderness Congress*, September 14 -17, 1987, Estes Park, Colorado, USA. Atlanta, Georgia, U. S. Department of the Interior, National Park Service.

Villa, F. 1992. New computer architectures as tools for ecological thought. *Trends in Ecology and Evolution* 7(6): 179 - 183.

Vink, A.P.A. 1983 Landscape ecological surveys. In *Landscape Ecology and Land Use*. pg.72-96. London, Longman.

J. H. Vogel. and G. B. Ingram. 1993. Biodiversity versus `genetically coded functions': The importance of definitions in conservation policy. *RECIEL: Review of European Community & International Environmental Law* (London) 2(2):121 - 125.

Wang, S. 1990. Conservation and exploitation of tropical forests in China. *Cathaya* 2:
199 - 206.

Wang, S. and L. Z. Chen. 1990. Future economic development and biological diversity conservation, sustainable utilization and research in China. In S. Wang and X. H. Du (editors). *Proceeding of the Symposium on Biological Diversity*. pages 6 to 11. Beijing, Bureau of Biosciences and Biotechnology, Chinese Academy of Sciences.

Wells, M., K. Brandon, and L. Hannah. 1992. *People and Parks: Linking protected area management with local communities*. Washington, DC, The World Bank.

Wiens, J. A. , C. S. Crawford, J. R. Gosz. 1985. Boundary dynamics: A conceptual framework for studying landscape ecosystems. *Oikos* 45: 421 - 427.

Wilson, E. O. 1988. The current state of biological diversity. In *Biodiversity*. E. O. Wilson (ed.). 3 - 18. Washington, D.C. National Academy Press.

World Conservation Monitoring Centre. 1992. *In situ* conservation of crops and wild relatives of crops. In *Global Biodiversity: Status of the Earth's living resources.* 546 - 549. New York, Chapman and Hall.

World Resources Institute (WRI), The World Conservation Union (IUCN), and United Nations Environment Programme (UNEP). 1992. *Global Biodiversity Strategy: Guidelines for action to save, study, and use Earth's biotic wealth sustainably and equitably*. Washington, D.C., World Resources Institute.

Yin, Y. and X. Xu. 1991. Applying neural net technology for multi-objective land use planning. *Environmental Management* 32: 349 - 356.