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Tradeoff analysis in planning networks for *in situ* conservation of wild plant genetic resources

ABSTRACT
Efforts to plan, design, and manage networks of *in situ* conservation of wild and weedy plant populations with genetic resources have been constrained by limited compatibility with conventional protected areas. In areas with high rates of genetic erosion, it is necessary to swiftly identify and utilize the widest pool of possible conservation interventions - many of which would not result in areas that appear like parks. Better quantification, in conjunction with spatial decision-making tools such as geographic information systems, is needed. Conservation measures are grouped into three categories: protected area allocation; reserve management; and regulation of land use external to protected areas. Three kinds of tradeoffs in interventions are postulated: between total area in habitat protection and requirements for subsequent management; between total area of habitat required for genetic maintenance goals and the condition of respective habitats; and between management within protection zones and regulation of land use outside of those reserves. The extremes of these tradeoffs can be organized into eight generic strategies where the sets of measures most compatible with both priorities for maintenance of desired levels of intraspecific variation and for locally defined social development can be better identified.

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There is always more than one way to establish and maintain a system of protected areas that support minimum levels of conservation of wild and weedy genetic resources. This essay outlines planning and design (Ingram 1996b) processes that begin to integrate the goals of *in situ* conservation of wild and weedy genetic resources into land management in anticipation of increased use of such digital tools as geographic information systems and related simulation. For lack of space, this essay does not extend to *in situ* conservation of primitive cultivars (Brush 1995, Louette et al. 1997) though such an analysis of introgression between weedy populations and landraces could be added -- and in most cases is necessary. Typically, planning *in situ* conservation of wild plant genetic resources should include the

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following phases:

1. ecogeographical surveying with sampling;

2. genetic analysis of samples in conjunction with compilation of environmental data for respective sampling sites;

3. mapping of populations, spatial aspects of genetic architecture, cultural land use factors, patterns of genetic erosion, and new threats;

4. formulation of conservation objectives as based on
   a. genetic architecture of populations,
   b. threats to the gene pool and populations,
   c. needs for germplasm, desired level of security in conservation, and ecosystem-related research;

5. assessment of conservation prospects, identification of possible conservation "measures" (Brockhaus and Oetmann 1996) and analysis of the viability of particular regimens of measures;

6. choice of conservation measures and their location which is effectively the spatial design of the networks;

7. implementation of conservation regimens;

8. monitoring of populations, evaluation of conservation effectiveness, and post-establishment analysis of network; and

9. periodic redesign of network and adjustment of conservation measures on an indefinite basis.

This essay is particularly concerned with principals for steps 5 and 6 -- the phases after initial surveying and gene pool assessment. In order to construct a rigorous regional planning (Slocombe 1995) framework, that analyzes and can simulate, as based on genetic, spatial, and environmental data, I begin by outlining some of the tenets for an emerging theory of environmental planning for this vital subset of biological diversity. I group possible interventions for maintaining prescribed levels and compositions of genes in what are nearly all, to varying degrees, cultural landscapes. I then explore possible "tradeoffs" (Ingram 1989, Millar & Libby 1991) in the size, location, and management of reserves and regular of adjacent land use. Through identifying a range of strategies for conservation, involving alternative regimens of interventions, we could choose a design which optimizes compatibility with locally defined goals for economic and social development.

By "tradeoff," I mean a potential constellation of alternative measures that could lead to comparable outcomes - in this case relatively similar levels of conservation for a particular set of species, populations, genes, and respective evolutionary process. But while genetic conservation could be similar, the implications for both local human communities and germplasm consumer could be markedly different. Perhaps in the cynicism, that often grips policy analysis, the value of identifying the widest set of conservation possibilities in order to hopefully find viable compromises, might appear naïve. But regardless of the social pressures and development and conservation ideologies, *in situ* conservation of genetic resources requires some kind of reflection on the options that are available. I argue that a tradeoff framework for the design and management of networks of protected areas with genetic resources, where gaps (Ingram and Williams 1993) must be filled on an ongoing basis, is not only necessary for effective and long-term *in situ* conservation but, along with ecogeographical surveying and ongoing monitoring, constitutes the core activities for any set of land-based interventions with goals for maintenance of regularly reproducing genetic material. In this discussion, I focus on three sets of tradeoffs: between area and boundaries of networks of reserves, between internal management of such protected areas and between regulation of surrounding land use.

INTEGRATING REQUIREMENTS FOR MAINTENANCE OF INTRASPECIFIC DIVERSITY INTO LAND MANAGEMENT

As soon as decisions are made about land, *in situ* conservation, as the coordinated sampling, maintenance, and monitoring of prescribed levels of intraspecific variation through habitat protection, becomes as much about environmental management as about genetics. Such environmental management involves decisions about territory, ecosystem management, and constraints on human activities within broader frameworks of land use planning. Ultimately, the *in situ* conservation of genetic resources is a kind of highly specialized landscape architecture that to be effective must reflect both the genetic architecture of gene pools and natural and cultural selection factors.

"*In situ* conservation" (Possiel et al. 1995), the protection of any population of organisms in various forms of "protected natural areas" (Given 1994, 85 - 114), involves political economic inventions as much as biological research. There are also elements of multiple use and aesthetics typical of other kinds of design and management for natural and cultural landscapes. *In situ* conservation is a social process in the sense of being based on coordinated regulation of land use. Much of modern biological conservation has emphasized national parks and state control and ownership in order to protect prescribed sites, territory and living entities. But notions of the "nature reserve," the "sacred grove," the "natural park," and even experimental sites and the more recently proposed "genetic management system" (Millar and Libby 1991: 160) involve richer discourses that go back decades and in some cases centuries. There are a lot of different ways to go about the *in situ* conservation of genetic resources and since our task is typically so difficult, identifying the most cost-effective, and socially compatible approach, for a district or a gene pool, becomes an imperative.

GENETIC RESOURCE CONSERVATION GOALS RELATED TO HABITAT PROTECTION

The goals of *in situ* conservation can be highly variable depending on the gene pool, the biology of the species, the threats to populations and the intraspecific variation, the demands for security of conservation, and the pressures for access to germplasm. These sometimes contradictory pressures could be translated into more quantitative objectives such as:

the minimum size for protected populations;
the number of populations necessary for protection;
protection of populations with associated species and habitat attributes;
protection of populations with successional phases embodying both stability and disturbance factors; and
protection of sets of populations over environmental gradients.

But rarely can or should habitat be protected solely because of requirement for maintenance of a plant genetic resources. The previous kinds of goals are typically worked into broader frameworks of land management involving various combinations of land use and conservation. Even within ecological reserves and national parks, there is the issue of multiple use - even when just confined to balancing pressures for lower impact and nonconsumptive activities such as ecotourism and procurement of genetic resources. And specific conservation measures always tend to favour the persistence of certain biological, ecosystems, and landscape resources over others.

ADAPTING PROTECTED AREAS FOR EFFECTIVE CONSERVATION OF PLANT GENETIC RESOURCES

The essence of a park or nature reserve is a strategy for minimizing further loss and fragmentation of natural habitat. But each design with its subsequent ecological edges, ecotones, and breaches in protection favour the survival of some species and genotypes over others. In every conservation decision is a bit of favouritism for particular populations, species, and ecosystems. A network for *in situ* conservation of genetic resources is less of an independent entity than a set of efforts, perhaps a strategy, to better assert the priority, among many, for those species, genotypes, and strategic sites (Schonewald-Cox et al. 1992; Buechner et al. 1992).

Since the mid-nineteenth century, the guiding metaphor of nature conservation has that of the island or the castle -- to invoke Kafka. In the last decade, with rapid rates of habitat loss and fragmentation along with other forms of regional environmental degradation, it has become obvious that no park or other kind of protected area, including those for the preservation of certain genes and evolutionary processes, is really an island. In recent years, conservation strategies have shifted to maintaining networks (Ingram 1989) of protected habitat, as interdependent nodes in highly vulnerable natural membranes (Hansen, di Castri and Naiman 1988) sometimes conceived of as part of landscape "matrices" (Forman and Godron 1986, pp. 159, 162 - 166). Rather than attempting to make nature reserves for wild and weedy plants with genetic resources function as isolated fragments, when most boundaries are porous and the total areas are too small for long-term viability, the general goal in conservation planning is to create an entire membrane that links natural "cores" through "buffers" (MAB 1974) and corridors of less natural but regulated areas.

Ecosystem management across landscapes (Grumbine 1994) has emerged as the central concept, in deed something of a paradigm, for the conservation of both the biological diversity of particular locales and of wild and weedy populations with genetic resources. However, a theoretical framework to integrate conservation biology into environmental planning has been slow to emerge. This has been in large part from what Machliss and Tichnell (1985) termed the "historical lack of ecological management" which threatens the capacities of protected areas to maintain biological resources.

Modern concerns for *in situ* conservation began to be articulated more widely with Jain's 1975 essay on the need for "genetic reserves" and the proposals by Hugh Iltis for the conservation of the habitats of wild maize. Development of new theory, that sufficiently integrates the distinctive set of social and economic pressures for the conservation of genes with conservation biology and landscape ecology has been and difficult and especially problematic because of the reductionism that has lingered in crop science. The international movement for the more secure and comprehensive conservation of plant genetic resources really began in the early 1980s (Ingram 1984). This was also the time when the (neo)colonial and socially obstructive origins of national parks, were being more exposed (Lusigi 1978). These postcolonial critiques of the park as neocolonial instruments were part of the "paradigm shift" (Kuhn 1970) away from the metaphor of the park as an isolated island and towards the more provisional but realistic notions of district-wide regional, ecological membranes. This was also the time when vague, contradictory, and somewhat naïve notions of "parks for sustainable development" (Ingram 1983) were being articulated. While these movements have recognized the need for locally managed genetic conservation, both the theory and the methodologies have been rife with contradictions.

NETWORKS OF PROTECTED HABITAT AS ALTERNATIVES TO CONVENTIONAL

PARKS

In their essay on the role of national parks in Italy, Giacomini and Romani (1978) described a shift from parks as "protectionist instruments" to "elements of total planning." They viewed parks as open systems and stated that,

> "attempts to create or operate in a park while considering it as a closed system are destined to failure."

The central metaphor of conservation planning is now linked assemblages of concentric membranes of habitat protection. External boundaries function as filters rather than moats and are highly sensitive to the interplay of external and internal forces. For example, populations of annuals such as the wild relatives in the gene pool of pearl millet, *Pennisetum* spp., in the Sahel, shift inside and outside of reserve boundaries depending on the recent pattern of rainfall. The better protected populations may support certain genotypes associated with more stability. In this sense, some disturbance-related gradients may harbour relatively high levels of allelic diversity -- but only to a point. In their multi-disciplinary boundary model, Schonewald-Cox and Bayless (1986) developed the concepts of the administrative boundary and the generated edge. The former is a mapped construct while the latter is often a volatile ecological gradient outside or inside of a reserve boundary. Too often such disturbance-generated edges extend well inside of administrative boundaries. Protected area management, particularly in the context of underdevelopment, is often focused on degraded edges that increasingly dominate habitat mosaics and threaten the viability of cores of protected habitat. The struggle is to make natural areas the ecological infrastructure, the matrix that connects the landscape, as an alternative to the heavily degraded lands of desperate rural poverty that will typically support a less diverse set of habitats.

Different combinations of allocation, management and mitigation measures can be ascertained to satisfy a set of objectives for maintenance of local biological diversity (Slayter 1974). In more ideal situations, it might be possible to confine impacts of land use activities to intensities, frequencies, and spatial distributions which are similar to those of less human-induced disturbance processes -- thus limiting the dominance of unnatural edges. Recognition of the supple interplay of possibilities for allocation, management, and mitigation in conservation planning and subsequent management has emerged from both empirical research in biology and policy analysis of conservation frameworks.

In their paper on conservation of macropods in reserves in western Australia, Main and Yadov (1971) first explored the relationship of reserve size to requirements for management. Almost a decade earlier, Starker Leopold et al. (1963) provided the rationale for active management by suggesting that few of the national parks in the United States were sufficiently large to be self-regulatory ecological units. This early notion of tradeoffs in conservation planning was codified by Pyle (1980) when he stated that,

> "The fewer and less intense the hostile pressure from outside the reserves, the larger the area set aside, the lower the number of visitors and the friendlier the social climate in which the reserve exists, the greater its defensibility and manageability."

And the same factors apply to efforts for more comprehensive conservation of intraspecific variation of plant gene pools especially for populations with genotypes associated with more mature successional phases and relative stability.

ALTERNATIVE REGIMENTS OF CONSERVATION & LAND USE

Identification of relatively intrinsic relationships between combinations of conservation measures requires a basis for analyzing regimens of interventions as strategies with political economic implications. But in terms of decisions, that essentially modify or constrain land use, there are some underlying institutional relationships, and respective categories of information and intervention, that are comparably stable in relation to the larger political economy. Knowledge of the entire range of possible conservation interventions, "fields of management" (Barker 1982), is key to identifying options for programmes. Three rough and overlapping categories of conservation interventions have emerged in the Twentieth Century -- in large part as a result of the colonial era:

1. protected area allocation and acquisition;

2. protected area management; and

3. regulation of human activities outside of protected areas.

Such categories can be seen as uneven sets of ecologically oriented but historically and institutionally situated conservation instruments. The categories of protected areas, the legislation (de Klemm 1985), the means to administer and implement "on the ground" all form a means to counter, partially mediate, though not resolve social conflicts (Machlis 1992). More precise and effective employment of these instruments will require the filling of institutional gaps in implementing conservation through new legislation, agencies, and funding vehicles. Evaluation of institutional capacities for conservation of plant genetic resources can be linked to more comprehensive gap analysis of *in situ* conservation with subsequent proposals for expansion of territory in reserves and other protection activities.

The problem of integrating biodiversity conservation into social development was addressed, directly, in the *Convention on Biological Convention* (Martinez 1995) though since its ratification there has only been a modest degree of innovation and increased effectiveness. Many species, no matter how rare or endangered, are often more adaptable and able to persist in a range of conservation regimens than adjacent human communities. Three sets of tradeoffs that are often most evident and are between:

1. area and ongoing interventions, such as management and restrictions on adjacent land uses;

2. quality of the protected habitat and the extent of necessary management and mitigation interventions in subsequent decades and centuries; and

3. between internal interventions, management, and restrictions on land use external cores often conceived of as mitigation.

IDENTIFYING POTENTIAL TRADEOFFS FOR *IN SITU* CONSERVATION

All planning is based on forms of predictive models whether or not they are fully recognized or clearly quantified. A land use plan is the product of an uneven melange of theory, objectives, criteria, and data. In comprehensive conservation planning exercises, an array of quantitative and spatial models of specific relationships are linked and structured. One paradigm for networks of protected areas designed for the conservation of genetic resources could be based on identification of tradeoffs in area / site quality / regulation (tasr).

The area / regulation tradeoff

There are regional and district-wide relationships between the total area in protected habitat and the level and constitution of the social and ecosystem management that will be necessary to maintain the local wild plant genetic resources on an indefinite basis. This concept of regulation, as conservation interventions less focused on acquisition of area, involves both management within designated reserves and regulation of exterior land use around and between networks of protected areas. Greater regulation might allow for less total area in protected habitat in order to satisfy minimum conservation requirements for certain alleles, adaptive complexes and populations. A greater spatial allocation of protected habitat would tend to involve fewer requirements for regulation in order to accomplish the same conservation objectives.

The basis for this tradeoff is that designation of protected areas is not the only determinant as to whether respective habitat will continue to support prescribed sets of organisms over time. The viability of habitat, in terms of persistence of certain organisms, can diminish and even be permanently impaired without interventions which re-establish or substitute for natural processes and which minimize inevitable and often permanent human-induced change. But no amount of internal or external management can provide the basis for persistence of genotypes when certain populations, minimum sizes, and landscape processes are not configured into the spatial design of reserve networks. Early on, Janzen (1983) suggested such a minimum level of conservation when he noted that,

> "As areas of conserved pristine forest are reduced in size they are increasingly susceptible to significant immigration of animals and plants from nearby anthropogenic secondary successional habitats."

Such thresholds of susceptibility necessitate management and mitigation responses or greater total area in buffers of protected natural habitat.

It is in consideration of the two end points, the extremes of this axis of minimum tradeoffs, that the relationships between total size, shape, configurations of area in protection, and regulatory interventions can be explored. The amount of flexibility available depends upon a range of natural and cultural relationships, and underlying cause-effect linkages, across landscapes. Such relationships include population size, demographics, genetic and niche architecture, and habitat requirements as well as a host of landscape processes including spatial dynamics of habitat, cyclical and stochastic episodes, and ecosystem resilience.

The area / regulation tradeoff promises some new opportunities for identifying more possibilities of protection of genetic diversity compatible with priorities for social development. At one end of the axis of minimum tradeoffs, is the possibility of reserves so large that on-going requirements for protection of genetic diversity and resources, through maintenance, regulation, and constraints on adjacent land use, could be relatively low. At the other extreme, land use expansions could be so well integrated into the buffer zones of networks of multi-purpose protected areas, with high levels of monitoring and constraints on human activities (Harmon 1994), that the total portion of the core conservation areas could be modest. These relationships suggest that with tasr, some populations, ecosystems, landscapes, and social pressures might necessitate more total area in conservation than others.

The social dimensions of the area / regulation tradeoff involve constraints on both traditional activities and modern land use, and involve various conservation stakeholders which can be local, national, and international. The more negative and pervasive the prospective impacts of land use operations are, the greater are the requirements for regulatory intervention in land use or designation of more areas of protected habitat. There will always be some intrinsic biological, dynamic social, and technical limits to the range of the possibilities of tradeoffs between allocation of area in genetic reserves and ongoing regulation which in turn could become increasingly expensive.

<u>The area / site quality tradeoff</u>

For conservation of local genetic diversity and resources, some forms of networks and configurations of sites could be more efficient, in terms of allocation of space, than others. Some sites have habitats which support lower densities of particular species. Some configurations involve more edge areas than others. Some adaptive complexes are limited to a small number of locations. This reality necessitates additional protected habitat for species which require habitat attributes associated with more mature successional phases. Typically, larger areas are required to satisfy minimum requirements for populations across more degraded landscapes.

Some sites hold larger numbers of species and habitat attributes than others or contain elements that are particularly strategic, representative, rare, or vulnerable. When sites of high concentrations are protected, it may be possible to keep the total area necessary in protected habitat lower than if conservation efforts had been focused on sites of relatively poorer quality in terms of supporting the persistence of local genetic diversity and resources. But there are fewer choices of sites for rare species and therefore tradeoffs are more limited.

The area / site quality tradeoff lays the basis for identification of tradeoffs between the total area in protected habitat and the capabilities of sites to maintain prescribed subsets of populations and respective genotypes and alleles. If the natural areas with the highest quality of habitat are not chosen for protection, and instead are converted to consumptive uses, the remaining areas available for conservation will be generally less able to support the persistence of certain elements of local genetic diversity and the total area necessary for habitat protection will increase. This tradeoff has implications for the initial phases of conservation planning - the more key natural sites are destroyed before conservation planning, the lower the quality of habitat that will be available, and consequently the greater the possibility of a larger minimum area being necessary. The total area needed for a district network of protected areas would diminish if sites with configurations of more spatially efficient and secure areas of habitat were chosen early in land use planning.

The extremes of this axis of the minimum area / site quality tradeoffs vary greatly depending on the requirements of targeted habitats and organisms, the distributions and aggregations of respective populations, and the nature of the pressures for expansion of destructive land uses. Determination of the axis of minimum tradeoffs, between necessary area and site quality for particular biotic districts and social and economic contexts, is useful in a number of ways. The need for specific types and combinations of sites, in contrast to tracts which are chosen mainly out of their lack of consumptive economic values, can be highlighted. Potential sources of conflict, between pressures for extractive operations on certain sites and needs for genetic conservation could be explored at phases sufficiently early on.

The management / mitigation tradeoff

The third tradeoff results from an additional dimension of the first in terms of strategies for regulation. As part of a particular configuration of reserves and boundaries, there is a dynamic interrelationship between possibilities for regulation, through management within protected areas, and those for mitigation of the prospective negative impacts through regulation of land use outside of boundaries of protected areas. With more management inside of reserves, less mitigation would be necessary to regulate activities outside of reserves. The opposite could also be true. But there are limits to the plasticity of the tradeoffs between management and mitigation, and active versus preclusive interventions, both in terms of intrinsic requirements for persistence of certain populations and what is socially, economically, and fiscally feasible at a certain point in time.

Management is implicitly an active affair which involves the substitution or reinforcement of natural processes. In contrast, mitigation involves specific forms of restraint in order to preclude certain negative aspects of expanding regional land use activities. While regulation of land use outside of reserves is by no means passive intervention, its implementation, at the administrative and legislative levels, tends to be preemptive. The temporal dimensions of management and mitigation measures can be quite different. The level of mitigation employed in the early phases of conservation programmes often determines the extent of management necessary for following years. However, the opposite is far less the case. Mitigation regimens largely determine the extent of the negative anthropogenic factors in the landscapes from which arise a large part of the necessity for management.

In conservation planning, there is an opportunity to decide on the general balance of management and mitigation measures, or rather the preemptive versus the more adaptive and internalized strategies for maintenance of populations and habitat attributes. The extremes of this, the third dimension of the tradeoffs, are tied to the feasibility of various kinds of controls over sites, economic relationships, people, and social dynamics in terms of imposition of limitations on land use activities. This relates back to the divergent implications of island versus membrane approaches for the design of regional networks of protected areas and subsequent management of land use expansion. The membrane approach works when land use, throughout a district, is carefully controlled or better self-managed to limit negative impacts.

CONSTRUCTING MODELS AND SCALARS FOR NETWORK DESIGN

The three tradeoffs outlined represent "good sense" postulates. The particular options that these tradeoffs underlie will vary widely with gene pools, conservation objectives, ecosystems, social pressures, and political economies. Such tradeoffs could be quantified in different ways depending on the data available and the scale of precision that was desired for the conservation. Scalars, involving formulae reflecting trends described through genetic and spatial data, could be constructed and linked through g.i.s. to spatial simulations with regulatory dimensions as a prerequisite to reserve design.

The tradeoffs can only be tested as hypotheses in specific situations over the long-term. But in areas of high genetic erosion, and where introgression is being heavily disrupted, there is not sufficient time to wait for complete evaluation before embarking on *in situ* conservation interventions. What can be verified are a few segments for understanding trends as worked into scalars reflecting the relationships of gene pools, land use, and conservation interventions. Whereas the postulated tradeoffs are highly theoretical, the relationships that underlie the construction of scalars can be explored on an ongoing basis.

The following figure represents a place to start in quantifying genetic conservation tradeoffs and in devising digitally generated scenarios. In these proto-formalae, I assume that the objectives that are set for "desired" genetic diversity and germplasm would be higher than those for basic levels of resilience and fitness -- though this is optimistic. And while the axes of tradeoffs are represented as straight lines, they are typically more a set of unique curves with considerable differences in their shapes between each scalar for the same area and gene pool. It is in grappling with this topography of conservation options, even if the vast majority was unworkable, that there is hope of finding a way to make the refuges that will be so crucial to economic development in the coming centuries.

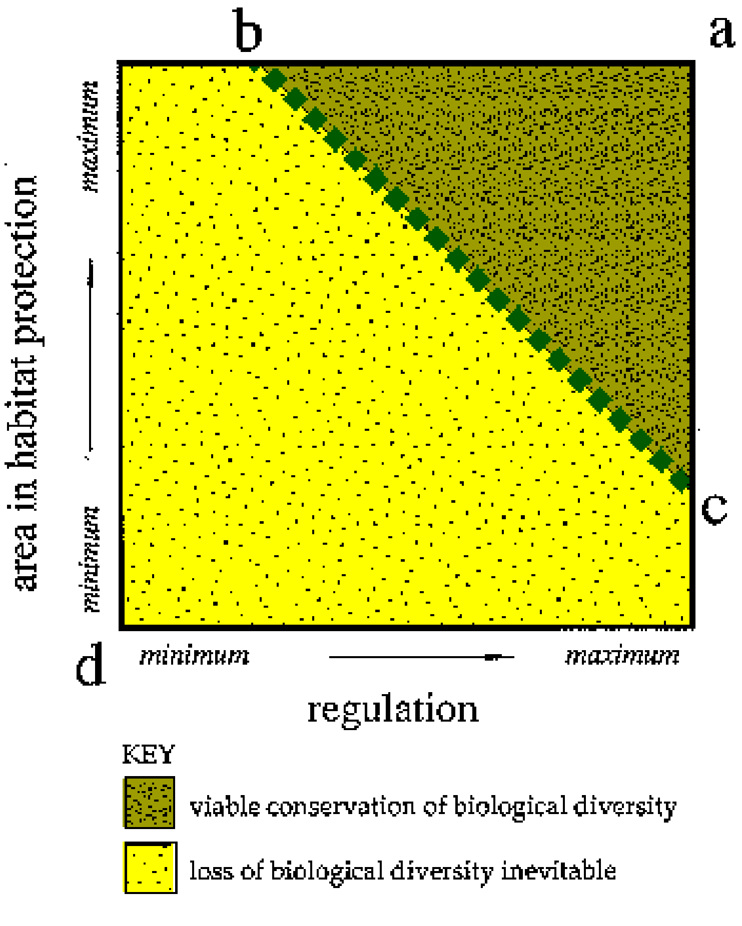

figure 1.
area / regulation postulate

FIGURE 1.

SOME INITIAL SCALARS FOR CONSERVATION INTERVENTIONS

The area / regulation tradeoff

[**a**] In all three tradeoffs, this point represents the maximum area of habitat in protection and maximum level of regulation for genetic resource conservation. This point represents the highest relative naturalness of habitat, with a full complement of the local and indigenous genetic diversity and resources, where all remaining natural areas are allocated as protected habitat and where all potentially damaging land use activities are fully controlled. If there existed human-related disturbance, point [a] might represent the maximum habitat protection possible without indefinite efforts for ecosystem restoration. This arcadian point, more mythic than reality, suggests some kind of either sparsely populated or wild condition with only a few human impacts or some kind of relative steady state. There are few districts on Earth that remain in this condition and if they do, should probably be allowed to remain in that way.

[**b**] This point represents the total area of protected habitat necessary if there was minimal use of regulatory measures. This suggests a large and relatively unpopulated wilderness area or undeveloped park.

[**c**] This point is the opposite of [**b**] and represents the maximum level of regulation and the minimum amount of protected habitat for the maintenance of minimum levels genetic diversity. Rather than wilderness or minimal impact land use, point [**c**] suggests highly manipulated habitat fragments.

[**d**] For all three tradeoffs, this point represents both the total lack of conservation measures or what little habitat protection there is having limited impact on the accelerating losses in local intraspecific genetic resources.

[**b - c axis**] This line represents the axis of the minimum tradeoffs between the least total area of a district necessary as protected habitat and the corresponding levels of regulation necessary for maintenance of local genetic diversity. Below this threshold, loss of local genetic diversity and resources is inevitable.

[**area between a, b, & c**] This area represents the subset of possible tradeoffs between the total area in protected habitat and regulation that can secure long-term conservation of local genetic diversity and resources. The points in this area represent viable regional conservation strategies.

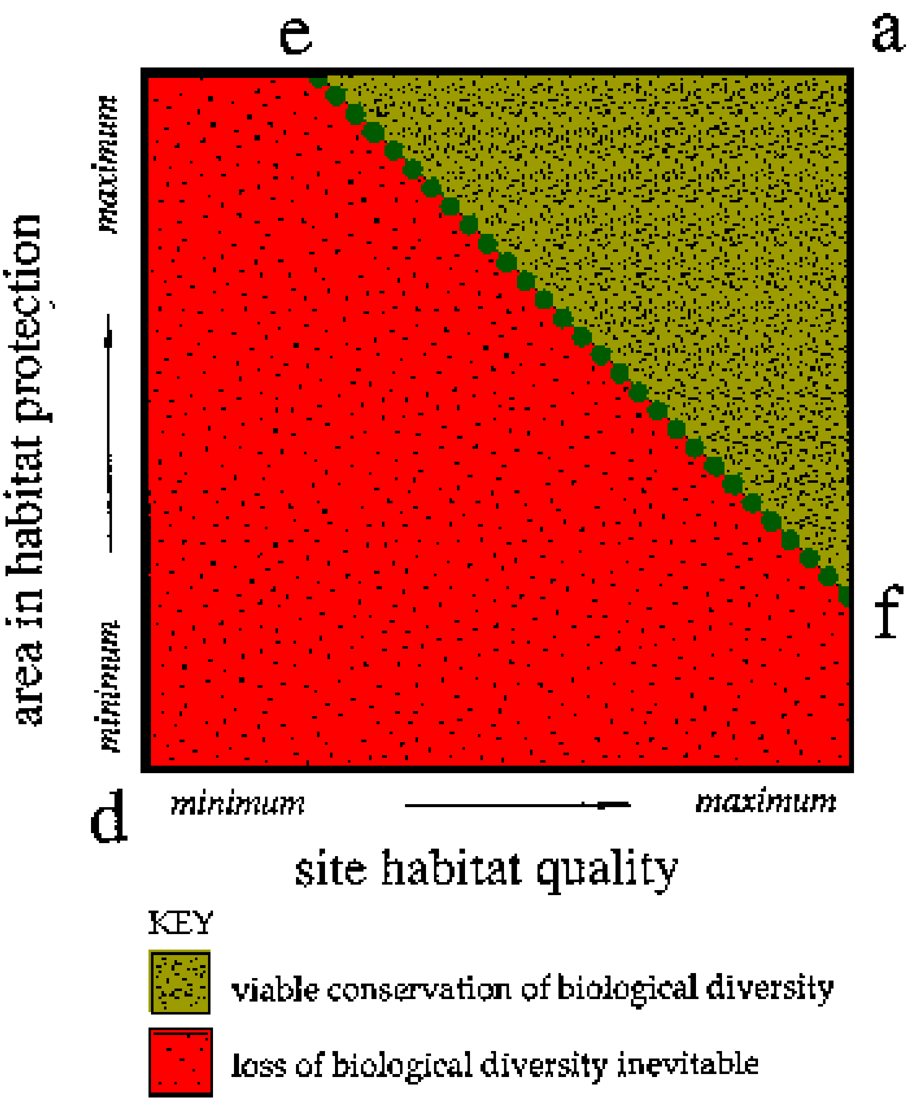

figure 2.
area / site quality postulate

The area / site quality tradeoff

[**e**] This point represents the largest portion of area necessary to allocate as protected habitat when configurations of only lower quality sites, in terms of spatial efficiency for persistence of local genetic diversity and resources, are available.

[**f**] This point represents the minimum total area of a district required for habitat protection when the highest quality sites, in terms of spatial efficiency for the persistence of local genetic diversity and resources are chosen as protected areas.

[**e - f axis**] This line represents the set of tradeoffs, between the minimum portion of the area of a district in protected habitat and the corresponding requirements of the habitat quality of sites, in terms of supporting long-term persistence of local genetic diversity and resources. Below this threshold, loss of local genetic diversity and resources is inevitable.

[**area between a, e, & f**] Like the area between [**a, b, & e**], this area represents the subset of tradeoffs between total area in habitat protection, quality of the sites, and the land use planning strategies associated with them, that provide the basis for viable conservation of local genetic diversity and resources.

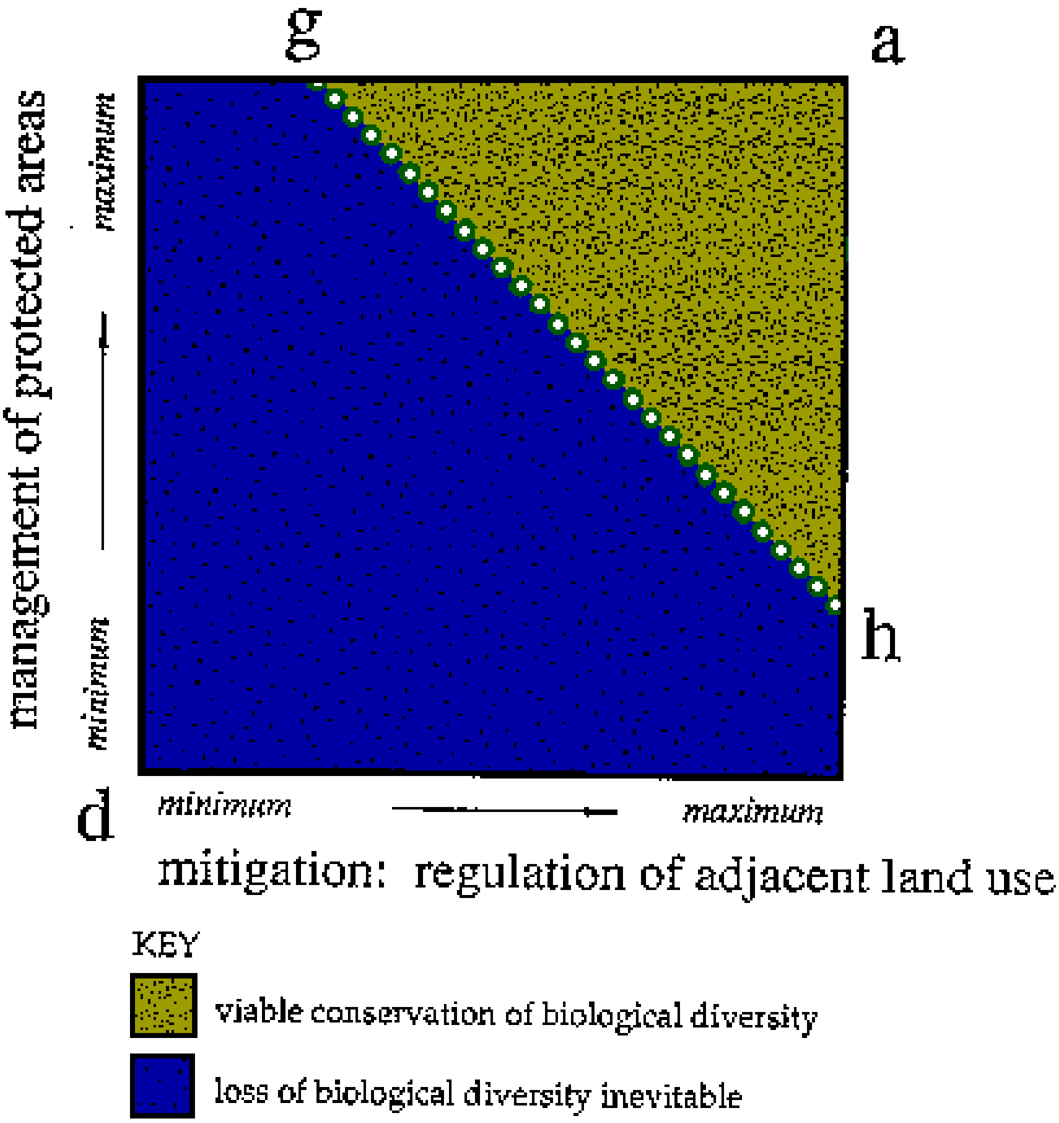

figure 3.
management / mitigation postulate

The management / mitigation tradeoff

[**g**] This point represents the maximum level of social and ecosystem management, in terms of forms and intensities, that can be employed within the protected habitat and the corresponding minimum requirements for regulation of land use activities in areas outside reserves.

[**h**] This point represents the maximum level of possible mitigation measures, for preclusion of certain human-induced disturbances outside of the boundaries of networks of reserves, and the corresponding minimum requirements for management within those reserves.

[**g - h axis**] This line represents the tradeoffs between minimum regimens of management and mitigation, necessary to maintain biodiversity in a network of protected areas. Below this threshold, loss of local genetic diversity and resources is inevitable.

[**area between a, g, & h**] Like areas [**a, b & c**] and [**a, e & f**], this area represents the potential tradeoffs between regimens of management and mitigation measures, and associated land use, that would support long-term conservation of local genetic diversity and resources.

TRADEOFF ANALYSIS FOR IDENTIFICATION OF MORE VIABLE CONSERVATION STRATEGIES

The extremes of the three sets of tradeoffs constitute 8 distinct strategies for *in situ* conservation. Typologies can be described and framed in terms of short and long-term allocation of societal resources including total land area, location of protection, opportunity costs as related to preclusion of other forms of land use, personnel time and other resources for monitoring, problem-solving, management, and enforcement. Some of these strategies emphasize the discrete island approach while other strategies emphasize permeability and connectivity. But these dichotomies are far more supple and multi-dimensional than the earlier SLOSS debates of a single large or several small protected areas summarized by Lomolino (1994).

The "island" strategies, emphasizing large areas in protection and limited management and regulation of adjacent land use, have tended to be associated with large park bureaucracies, with high levels of state and even military backing. In contrast, the membrane strategies are often associated with efforts to allow local people to live within park systems and to direct ecosystem management for both conservation and social development (Ingram 1994). But even with the simple tradeoffs discussed in this paper, there are at least 8 different possibilities and considerable middle ground between them. And this many options has rarely been identified in any design process around *in situ* conservation. For scenario generation and possible application, new indicators (Noss 1990, Ingram 1992) and associated landscape attributes, for both guiding design and evaluating the effectiveness of singular and grouped conservation measures, can be identified.

CONCLUSIONS

The more land use alternatives are identified, the better are the chances of finding a set of possibilities, that might work: that might lead to sustainable conservation and development along with better levels of "ecological security" (Athanasiou 1996, pp. 8, 293 - 295). Simulations, as a basis for conservation planning and design, first emerged from island biogeography theory. But the preoccupation of early conservation biology with reserve size has only limited relevance to slowing genetic erosion. In more precise forms of conservation planning, such as the kinds necessary for efficient and secure *in situ* conservation of gene pools, area in habitat protection is only one of several kinds of interventions. Landscape ecology, as an emerging science, when linked to conservation biology and focused on genetic architecture, could provide the spatialized framework for monitoring and modelling.

Spatial modelling of wild and weedy populations could lead to analyses which could lead to simulations which, in turn, could be organized for the identification of tradeoffs. And tradeoffs analysis could lead to choice of genetic conservation strategies which lead to planning and design at a range of scales from the regional to the site-specific. And a form of social impact assessment, to find the conservation strategy and set of regimens and designs that enhances and does not detract from local development goals, is entirely possible -- if not a moral and operational imperative for areas with crushing rural poverty. But such a complex sequence of assessment, mapping, analysis, monitoring, and simulation activities will require a new wholeness of vision that situates these crucial gene pools into broader contexts of regional ecosystems and political economies.

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