Ecological Reserves in the Cape Fynbos: Toward a Strategy For Conservation

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Recommendations are given, on the basis of both theoretical and practical considerations, for the attention that needs to be given urgently to protect a major biome was of unique scientific and aesthetic importance.

Aanbevelings word gemaak, op grond van beide teoretiese en praktiese oorwegings, vir die aandag wat nodig is om 'n belangrike boom van unieke wetenskaplike en estetiese betekenis te beskerm.

Introduction

Fynbos is a broad category of diverse evergreen sclerophyllous shrublands, comprising Acocks' Veld Types 47 (Coastal Macchia), 69 (Macchia) and 70 (False Macchia). Taylor enumerates the characteristic features of the type as follows: a very high degree of species richness in plant communities; the invariably presence of the family Restionaceae; the restioid, ericoid and proteoid physiognomic elements.

This type of ecosystem is, by virtue of a peculiar combination of evolutionary, biogeographic and ecological features, of unique scientific importance. However, it is also of great direct and indirect economic value, principally as the only present source of water for the established and developing industrial and agricultural economy of the region and as the setting for a rapidly growing recreation and tourist industry. The need for adequate conservation of the fynbos ecosystem has been widely recognised, yet the extent of the natural fynbos communities has been reduced from some 46 000 km² to about 18 000 km²—a factor of 60%. Development in the region has thus diminished and fragmented the natural communities: invasive alien plants, too-frequent fires, and concentrated, unplanned recreational use serve to degrade the remainder, with the decline in the condition of Table Mountain serving as an indicator of their net effects.

There is no doubt that conservation of fynbos is entering a critical phase. The problems will be solved only through a combination of approaches, including the land-use planning and scientific management systems which will permit a measure of reconciliation between development and conservation. Nevertheless, the prerequisite for long-term success is an adequate network of ecological or biosphere reserves. These are conceived of as reserves representative of the types of ecosystem in the biome, which will serve to maintain, in perpetuity, adequate samples of the landscape and the biota, and the functional integrity of the ecosystems. The reserves would also serve for ecological and environmental research, provide facilities for education and training, and provide opportunities for outdoor recreation. In the fynbos, the reserves would often coincide with catchment areas which are the major sources of water for industry and agriculture.

Increasing demands placed on available natural lands, decrease in the extent of these lands, and rising costs of acquisition and management of reserves necessitate efficient design of an effective network. As elsewhere, fynbos reserves have in the final analysis been selected mainly by chance. "If a chance process of reserve selection continues, it may produce a network of reserves that is both very expensive in terms of hidden management costs and very inefficient in terms of preserving a diversity of ecosystems." Not only should the reserve system be efficient in terms of conservation, but also in relation to the national economy—land should not be withdrawn unnecessarily from direct economic production.

Since ecological reserves must serve over evolutionary time it is best to use the 'worst case' as a starting point in the design of the network; that is, one assumes that the intervening lands will ultimately be so modified that the reserves are effectively isolated from one another and new barriers to migration are thus erected. That this assumption is reasonable is reflected in a number of instances where such conditions already obtain.

It is this problem, the design of an effective network of
ecological reserves, which is addressed in this paper: the problem reduces essentially to four questions, relating to (i) the location of reserves, (ii) their sizes, (iii) their number, and (iv) the configuration of individual reserves and of the network as a whole, each of which will be examined in relation to fynbos.

Location of reserves in fynbos

The optimum strategy is to place reserves so as to represent different ecosystem or vegetation types in the fynbos biome and thus ensure the representativeness of the network, but there is no adequate classification of fynbos types.\(^1\)\(^2\) Acocks himself stated that his subdivision of three types was a misleading simplification; he maintained that, in addition to Mountain Fynbos (types 69 and 70), one should recognize a distinct type, the Arid Fynbos. Coastal Fynbos, he felt, consisted of at least three veld types, the dwarf fynbos of the Elim flats, that of the limestones near Bredasdorp, and the remainder. Even these tentative additional subdivisions will not form a realistic framework for planning the location of reserves, since there is evidence of major patterns of heterogeneity within these categories.\(^2\)

Plant geographers have studied the information on distribution patterns of various taxa at length without much success in determining overall biogeographic patterns (see ref. 2 for a comprehensive review). Weimarck\(^8\), however, did distinguish and map six phytogeographical regions on the basis of the distribution of endemic taxa, and these patterns have received some confirmation in subsequent studies (see, for example, refs 10–13). Such plant geographic subdivisions could form a further basis for planning a reserve network, but the information remains inadequate. Furthermore, the studies have emphasized the concentration of endemic species in the western and south-western areas, and a strong element of "insularity" in fynbos biogeography. These factors further complicate planning.

In the absence of an adequate classification of fynbos and with the available evidence of pronounced endemism and distributional disjunctions, an approximate solution on the basis of presumed geographical gradients is the only alternative. Reserves spaced on north-south, east-west and coast-interior gradients should presumably include a fair sample of the range of ecosystems. The strategy would seem the natural course induced by the physical geography of the fynbos biome, except that it requires modification in the light of the marked concentration of fynbos taxa in the west and south-west (more reserves are presumably required there than elsewhere).

Acocks and Weimarck's classifications have been used as a framework and geographical considerations applied in drafting a list of putative zones which would need to be represented in the reserve system: details are presented in Table 1. Others would no doubt suggest additions to the list, but it is probably a reasonable indication of the minimum requirements.

| Size |

| Biogeographic considerations |

Recent developments in biogeographic theory have permitted certain useful generalisations in connection with the planning of reserves. The equilibrium theory of island biogeography as developed by MacArthur and Wilson\(^14\) permits the prediction of the number of species on an island from its age and size and its relation to the nearest "continental source area". The number of species of a given taxon on an island depends on an equilibrium established in time between immigration and extinction. The degree of isolation of an island will affect rates of immigration, while successful colonisation rates and rates of extinction are related to area. Islands in general contain fewer species than equivalent continental areas, and the further they are from the continent, and the smaller their size, the greater the disparity between their numbers of species and those of continental areas.

Major features of this theory have been demonstrated to hold good for various taxa on oceanic islands and for "habitat islands", such as the páramos of the Andes. Man-made islands, such as Barro Colorado in Panama, have provided cases which further support the theory. By analogy and with supportive data it is argued that since any reserve must sooner or later become isolated, partly or completely, the number of species it supports must decline if it is not large enough.

The theory has led ecologists to maintain that any reserve for a biome type should be as large as possible. Diamond\(^8\) states explicitly that: "(i) The ultimate number of species that a natural reserve will save is likely to be an increasing function of the reserve's area. (ii) The rate at which species go extinct in a reserve is likely to be a decreasing function of the reserve's area."

Simberloff and Abele\(^9\) have criticised the unqualified application of these principles. They suggest in the first instance that the time required to reach equilibrium may be so long, at least in the case of certain taxa, that the equilibrium will in fact never be reached. Simpson\(^16\) for example, showed that the floras of Andean páramo habitats and of the Galapagos Islands were "... more significantly correlated with area and distance measures of the glacial forms of the islands than with similar measures of the present-day islands", suggesting that species numbers have not reached equilibrium after about 30 000 years.

Simberloff and Abele show also that, within a biogeographic region, one or a few large reserves will in fact contain fewer species than a number of smaller reserves of equivalent total area, given certain assumptions. Application of the equilibrium theory to conservation therefore requires some caution. Sullivan and Shaffer\(^7\) suggest that "... there may be some transition size below which an area acts as an island and above which it acts as a continent", but go on to point out that many other factors affect decisions on reserve size, including the demography of rare species (especially top carnivores), costs, and management constraints. Few authors have been prepared to commit themselves to a minimum reserve size, but some analyses indicate a minimum of about 100 to 2 500 km\(^2\), and up to 25 000 km\(^2\) (refs. 5, 8, 14).

While data are few, it is worthwhile applying some of the principles discussed above to the problems of the fynbos, by first examining the species-area curve for plants. This curve has the form \(S=kA^n\), where \(S\) is the number of species, \(A\) is the area, and \(k\) and \(n\) are constants determined by the method of least squares. A curve obtained for fynbos by Kruger and Taylor (in

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<thead>
<tr>
<th>Vegetation type</th>
<th>Biogeographic centre</th>
<th>Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal Fynbos</td>
<td>South-western</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2 South coast - Elim flats</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3 South coast - limestone hills</td>
<td>3</td>
</tr>
<tr>
<td>Arid Fynbos</td>
<td>North-western</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5 Karoo Mountain</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>6 East</td>
<td>6</td>
</tr>
<tr>
<td>Mountain Fynbos</td>
<td>North-western</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>8 Groot Winterhoek mountains</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>9 Central</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>10 Southern</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>11 Riverzonederend ranges</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>12 Swartberg</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>13 Little Karoo&quot;islands&quot;</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>14 Lemoenshoek</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>15 Outeniquas</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>16 Kouga River drainage</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>17 Tsitsikamma</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>18 Langeberg</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>19 Zuurberg</td>
<td>19</td>
</tr>
</tbody>
</table>

| Table 1. Approximate zones requiring representation in a network of fynbos reserves |
As these authors note, the relationship must be used with caution: for one, it underestimates the total number of plant species in the fynbos biome, because at some point an increasing area must cross a within-biome biogeographic boundary, when species will be added at an accelerated rate. Nevertheless, the information does confirm that any reserve would have to be fairly large to contain a reasonable proportion of the flora. Within a zone of uniform biogeography, a reserve of 30 km² would contain about 1 000 species, but an area of about 1 000 km² would be necessary if we would wish to include 2 000 species. We know intuitively, however, that a number of reserves of optimum size would serve our goals better than a few very large ones, and the arguments of Simberloff and Abele are useful in this respect: they will be pursued below.

We cannot deduce from the species-area curve what the threshold reserve size is to maintain species numbers at "continental" levels, but can approach it obliquely by considering some aspects of demography of natural populations, of management requirements, and of economics.

**Critical population size and habitat area**

MacArthur and Wilson have shown on the grounds of theoretical demography that the likelihood of extinction within a given time span decreases enormously once a certain equilibrium population size has been reached. This "critical population size" is often accepted to be in the range of 100 to 300 individuals, but if a time scale of about 1 000 generations is applied, the demographic evidence is that the minimum population required for survival amounts to thousands. Populations of this size would also have the capacity to survive catastrophes such as epidemic disease.

Some attempts have been made to make reasonable assumptions on these grounds and then determine from a knowledge of species' range requirements the minimum area the critical population would require. This may be especially useful if range-sensitive or rare (or both) species are considered and large carnivores are obvious cases. Sullivan and Shaffer have examined some North American carnivore population data, and suggest that reserves of about 600 to 760 km² would be required to support absolute minimum populations, with no insurance against calamitous mortality. Their example of the mountain lion (eight animals on 760 km²) is unlikely to contain more than a handful of the animals.

The Protea Seedeeater (Serinus leucopterus) is confined to tall sclerophyllous scrub in the fynbos. As it is a rather sedentary endemic it is probably useful as a species indicative of conservation success. Censuses indicate that a pair of birds requires a range of some 0.02 km² (W. R. Siegfried, pers. comm.). Therefore, about 3 km² of suitable habitat would be required to maintain a minimum viable population of about 150 breeding pairs. However, the species appears to favour habitats in which the dominant shrubs have reached maturity, that is, at about eight years. The managed fynbos reserve (see below) would consist of a mosaic of compartments with vegetation in different stages of development, 30% of which would be suitable. About 10 km² of the correct vegetation type would therefore be required and since few fynbos landscapes are covered entirely by this type, the reserve must necessarily be considerably larger.

Turning to the example of rare fynbos plant species, we find further support for the argument for large reserves. Many of these species are characterized by small populations and frequently they comprise a number of disjunct sub-populations. This is illustrated in census data for a handful of species in Table 2. In many cases, populations are so small that it would in principle be best to include the total populations in reserves where possible. Assuming an optimum circular shape⁴ we find from the data in Table 2 that reserves of some 30 km² would often be necessary. In fact, examination of the distributions of different rare species in the Hottentots-Holland mountains has obliged me to recommend that the whole of the natural land (about 200 km²) should be proclaimed a nature reserve if most of these are to be conserved, since their distributions are poorly correlated and there is therefore nothing to be gained by establishing a few separate reserves.

**Management and economics**

Like most other vegetation types of the world, fynbos communities are in a state of continual change and the landscape normally contains a mosaic of vegetation in different phases of development, relating to the fire history of the area. Not only is this state an inevitable result of the particular combination of environment and vegetation of the zone, but there is considerable evidence that maintenance of the communities in their present natural state, including their diversity, is dependent on these fire-induced cycles of change. These considerations have caused the adoption of habitat management systems which, in the fynbos as elsewhere, often centre on the use of prescribed burning as a management tool.

The Department of Forestry therefore employs techniques where a given area of fynbos is subdivided into management units, of which those that require periodic fire are burnt at intervals of about 12 years. This management system has important implications in discussion of the reserve problem. In the analysis which follows, I have assumed, for simplification, that a 10-year burning rotation will be followed.

Conservation officers of the Department of Forestry consider 5 to 15 km² as the optimum size for a compartment, the basic land unit for management planning. Accepting 5 km² as a general minimum, a minimum reserve size of 50 km² would be necessary to allow one compartment to be burnt annually and so maintain an even distribution of habitat age-classes on a 10-year burning rotation. Obviously, circumstances would dictate or allow different sizes of compartment, and different burning rotations. For example, the nature of the topography and vegetation in eastern grassy fynbos biomes permits compartments of an average size of about 1 km² and burning rotations of about 6 years (Von Gadow, pers. comm.). However, the example quoted above will serve as typical. To permit the requisite flexibility in management, reserves should be larger than this minimum so that more than one compartment may be treated annually. Also, many reserves would contain compartments which are not to be burnt.

Economies of scale also apply in the case of reserves and the optimum size at which administrative costs and other fixed overheads reach an acceptable ratio to costs of acquisition and direct management is large. Furthermore, large reserves would permit a higher income from recreation use, which would do much to offset fixed costs. Direct management costs in the fynbos are largely a function of the length of compartment

<table>
<thead>
<tr>
<th>Species</th>
<th>Date of census</th>
<th>Known no. of populations</th>
<th>Mean population size</th>
<th>Maximum distance between populations (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serruria florida</td>
<td>1972</td>
<td>12</td>
<td>12</td>
<td>6.6</td>
</tr>
<tr>
<td>Mimnetes hotentoticus</td>
<td>1974</td>
<td>9</td>
<td>29</td>
<td>6.2</td>
</tr>
<tr>
<td>Giliebroscolia formosa</td>
<td>1972</td>
<td>2</td>
<td>~ 65</td>
<td>6.4</td>
</tr>
<tr>
<td>Styliapera barbatlus</td>
<td>1960</td>
<td>1</td>
<td>?</td>
<td>0</td>
</tr>
</tbody>
</table>
perimeters, since this is where the money is spent in prescribed burning operations. The lower the ratio of perimeter to area, that is, the larger the size of compartments, the lower the unit area costs of management.

These economies of scale must in turn be balanced against costs of acquisition and indirect costs resulting from withdrawal of land from agricultural and other forms of production.

The above discussion scarcely serves to resolve the question of optimum fynbos reserve size, principally because of a lack of biogeographic and demographic data. The analysis does point to the kind of information required for sound decisions, and there is evidence that the absolute minimum size of an effective reserve is of the order of 100 km²; larger reserves of about 1000 km² will probably be necessary especially where conservation of viable populations of larger mammals is important.

Number of reserves

If we reduce our conservation objectives to that of successfully maintaining an acceptable proportion of the plant species in the Cape Floral Kingdom, we may return to the species-area curve as a means to determining the number of reserves required. From this relationship we deduce that reserves of some 100 km² would contain about 200 plant species, and those of 1000 km² about 2000 plant species. From probability theory, we find that about eight 100 km² reserves would be required to include about 80% of the 6000 species in the fynbos flora; four reserves of 1000 km² would be required to reach the same target. Eleven and six, respectively, of the two sizes would be required to include about 90% of the flora. Simberloff and Abele point out that, by this argument, more, smaller reserves would be more efficient in terms of total area required than one or a few large ones, but caution that their individual areas should exceed the threshold "island" size.

This argument serves as a guide but is based on the unreasonable assumption of a random distribution of species populations. Thus the probabilistic argument predicts that if the floras of two reserves contained about 1200 species each, the pooled flora would be 80% larger than that of one reserve. In fact, the pooled flora of Jonkershoek and Cape Point Nature Reserves (each with about 1200 species) is only about 65% larger than that of one of the areas (Kruger and Taylor, in preparation). This case indicates that more reserves will be required to reach the target than the model predicts, particularly since any one fynbos reserve would nearly always contain some species which occur in any other.

The number of ecological reserves could to some extent be optimised by locating them so that they cut across biogeographical boundaries, always with the proviso that the portions on either side of such a boundary are large enough. However, land-use patterns and economic considerations are powerful constraints to such a strategy, especially in the lowlands. We are left then with the framework set out in the discussion of the required location of reserves. It appears that if one reserve were to be established in each of the 19 zones listed in Table 1, a considerable and probably adequate proportion of the total flora and most likely an adequate sample of community types would be incorporated in the system.

Configuration of reserves and the reserve network

Diamond" has shown that: "Explicit suggestions can be made for the optimal geometric design of reserves"; they should be as nearly circular as possible, they should be as close to each other as possible, should be grouped equidistant from each other rather than in linear fashion, and should as far as possible be linked with strips of protected habitat.

It should be possible to meet most of these requirements in a fynbos reserve network, except that the physical geography of the region will force a measure of linearity on the system. Some advantages and constraints inherent to the present patterns of land-use are discussed below.

Great care will be necessary in locating the boundaries of any given area. Fynbos areas have been isolated in many instances and this will be problematic, especially where migratory species are considered. An example is that of the sugarbird (Promerops afer) in the Hottentots-Holland mountains, which is dependent on high-altitude Protea species for summer feeding grounds, and moves to low altitudes for feeding and breeding when other species come into flower in autumn and winter. The ranges of other species have already been truncated, and particularly difficult problems will arise in the conservation of such species as

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The image contains a map of the occurrence of fynbos regimes in the southern Cape. Triangles indicate the location of both existing major reserves and also those likely to be proclaimed in the near future. The map is based on those of Acock's and Weimark. The map includes various regions such as SW Southwestern centre, NW Northwestern centre, LB Langeberg centre, KM Karoo Mountain centre, KN Knysna region, and SE Southeastern centre.
Conclusion

A reasonable deduction from the foregoing is that it will be impossible to conserve a complete set of the extant communities and species of the fynbos biome in the long term. It is tentatively suggested that a target of about 19 reserves, each of at least 100 to 1,000 km² in area, and located so as to represent deduced ecological and biogeographic zones is one which would serve to conserve a representative sample of the ecosystems of an extremely rich and varied landscape. These ecological reserves, designed as to allow maintenance of integral functioning ecosystems, should be seen as a primary requirement for fynbos conservation: appropriate smaller reserves and scientific land-management systems in the intervening areas would make a further contribution.

How do matters now stand in relation to such a target? Edwards has shown that about 15% of the area of fynbos as mapped by Acock is conserved. This is approximately 35% of the remaining area of natural fynbos. Coastal Fynbos and Arid Fynbos are poorly conserved (about 2% of the former in reserves), but Mountain Fynbos enjoys a good status.

These data are, however, not a realistic representation of the true state of affairs. Although unforested State Forests, which represent the bulk of conserved mountain fynbos, are entrenched reserves, there is theoretically a range of uses to which the land can be put and some of these, such as afforestation, would be largely incompatible with nature conservation. Also, many of the reserves are too small. The need remains therefore to ensure that ecological reserves are proclaimed and managed as such.

Table 3. List of existing major reserves in the fynbos. (Reserve names in parenthesis are those likely to be proclaimed in the near future)

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<td>(Groot Winterhoek Wilderness Area)</td>
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the Cape mountain zebra (Equus zebra zebra). Some of these problems could perhaps be solved only through intensive management, but it is possible that the design of buffer zones in which landowners collaborate in an appropriate system of management would provide another solution.

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lands which are unlikely to be developed intensively on a large scale. Nevertheless, it is urgent that the reserves be set aside as soon as possible, if only to allow establishment of budget priorities in conservation and research expenditure, especially for control of invasive plants.

In direct contrast, the situation with respect to Arid and Coastal Fynbos is extremely critical. Public lands in these types are small or non-existent, and, especially on the coastal lowlands, development has severely reduced the extent of natural communities. Urgent steps will be necessary if representative reserves are to be established.

Finally, some aspects of this analysis require explanation. The discussion has centred mainly on the question of species numbers, whereas it is generally accepted that nature conservation is really the business of conserving communities and ecosystems. This reflects in part lack of information on fynbos ecology, but it is not an unreasonable basis for analysis of the question using the approaches employed here, since the number of species in a given unit of land is dependent largely on habitat diversity and therefore the range of communities in it, which in turn is correlated with area.**

Furthermore, I have emphasized conservation and that this should be pursued by establishing large reserves. This does not imply that development and conservation are necessarily incompatible, rather that conservation of this extremely important biome depends in the first instance on an effective reserve network. Smaller reserves and appropriate resource management will nevertheless play an important role in the conservation effort.

This paper is based partly on information collected in the Department of Forestry's conservation research programme and is published with the permission of the Secretary for Forestry.

4 Moll, E. J. and Campbell, B. (1975). The ecological status of Table Mountain, Dept. of Botany, Univ. of Cape Town, Memore Rept.
9 Weismarch, H. (1941). Physiographical groups, centres and intervals within the Cape Fynbos. Land. Ums. A-Reeks, 37, Nr. 5.

(This paper was presented at the 73rd Congress of the South African Association for the Advancement of Science held at Netspruit, 20-23 August, 1976.)