COMMERCIAL WILDFLOWER PRODUCTION IN THE FYNBOS BIOME AND ITS ROLE IN THE MANAGEMENT OF LAND-USE

BY

GEORGE WILLIAM DAVIS

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To the spirit of justice, peace, and co-operation which must prevail for conservation of a viable human environment in South Africa

ABSTRACT

The wildflower industry of the Cape, South Africa, utilizes ecosystems and vegetation of the Fynbos Biome either directly by harvesting of natural plant populations, or indirectly by land transformation for agro-horticultural production. This thesis reports on a study of conservation and management issues arising from: (a) direct veld-harvesting; and (b) primary annexation of land for controlled production of material. A review of the industry's structure and the controlling legislation, indicated a need for integration of current management strategies.

A potential means of anticipating population degradation and local extinction of plant species through over-utilization was investigated by construction of a computer model. Lack of data describing the flow of material and revenue was highlighted as an impediment to resource management by means if modelling.

Experimental work investigated the effects of marginal cultivation on mountain fynbos ecosystems as utilized by the industry. Work was conducted at a site in the Highlands Forest Reserve in the south-western Cape. This experimental system was cleared by burning, and tilled as if for commercial production. Disturbance effects on system parameters were monitored. These included energy and water regimes, aspects of community structure, plant growth, and water relations of the natural vegetation. Results showed that tillage altered the system during the dry summer months by increasing reflectivity of the soil surface to solar radiation, reducing soil temperatures, and increasing soil water content. Response of the vegetation included reduction of species richness and diversity, a reduction in projected foliar cover, and an increase in the productivity of some, but not all, of the naturally occurring dominant species.

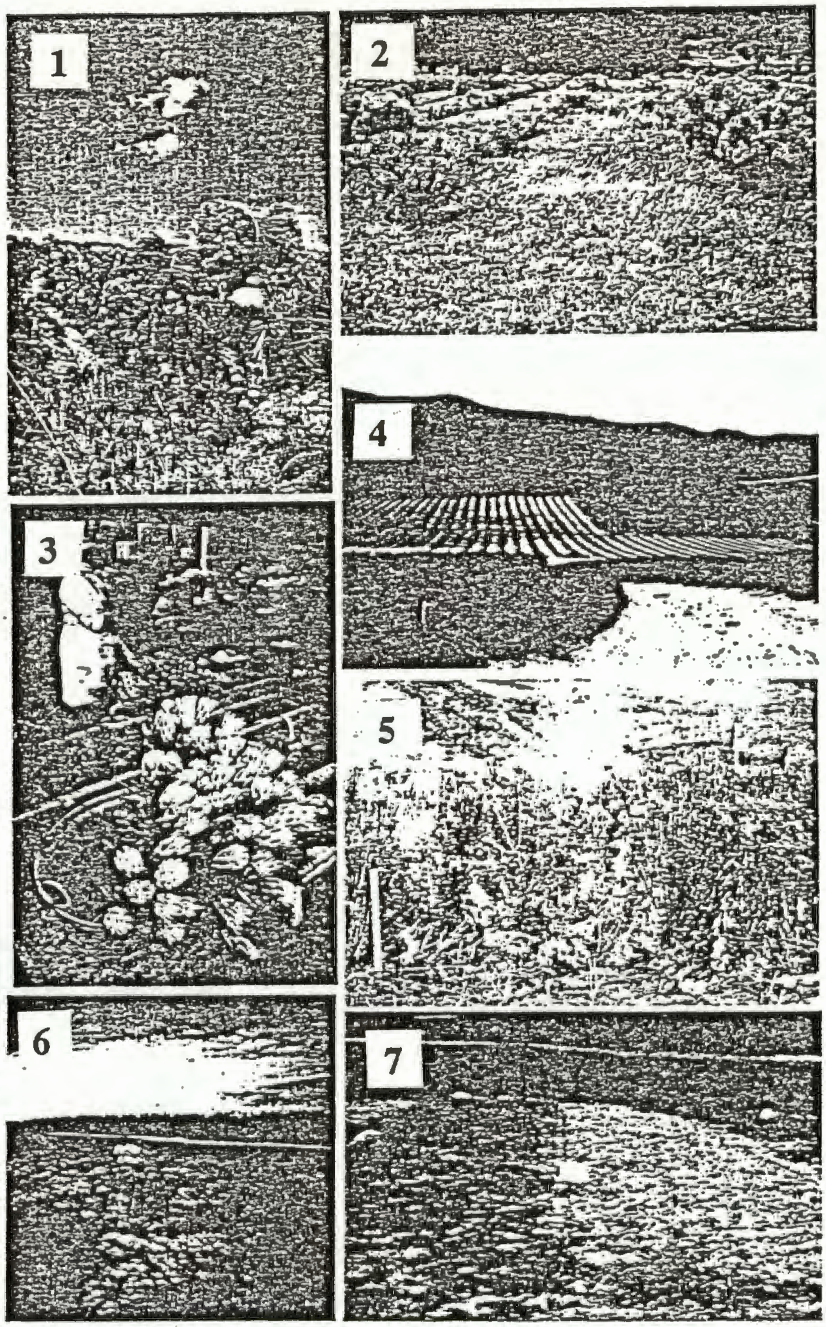
Two commercially favoured species of *Protea* were also introduced to the site. Survival and productivity of these populations were monitored as responses to substrate disturbance. Results showed that the treatment was significantly associated with better survival for *P. cynaroides*, but better productivity for *P. repens*.

A concluding review suggests that there are general paradigmatic blocks between the economic and ecological facets of natural resource utilization which prevent implementation of optimal environmental management strategies. The wildflower industry is nominated as a small bridge for that gap.









CAPTIONS TO PHOTOGRAPHS IN FRONTISPIECE

1. Flowers and foliage of the "greens" species *Erica longifolia* are harvested from the veld in the south-western Cape (see Chapter 1)
2. *Protea* species growing under orchard cultivation in the south-western Cape (see Chapter 1)
3. *Protea repens* inflorescences for sale at a street market in Cape Town (see Chapter 1)
4. Strip tillage for cultivation of proteaceous floricultural material on a farm near Kleinmond, south-western Cape. This is the same approach as adopted for the experimental work described in Chapters 4 to 7
5. Clearing vegetation at the Highlands study site by fire prior to experimental work (see Chapters 4 to 7)
6. Mature vegetation at the Highlands study site prior to clearing, with the yellow leaves of *Leucadendron xanthoconus* visible in the foreground (Chapter 3)
7. The Highlands study site following tillage by rotavation, with planted *Protea cynaroides* visible on the tilled soil at the right (see Chapters 4 to 7)

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PREFACE

Involvement in this study came my way by default as an employment opportunity. It is therefore not through love of ornamental floristry that I found myself investigating the wildflower industry of the Cape. In fact the notion of removing inflorescences from indigenous fynbos flora, whether cultivated or in the veld, is, and probably always will be, mildly anathematical to me. But in South Africa, a country where a vast spectrum of opinions, life-styles, and cultures have to be accommodated for a viable future, my personal indifference to the aesthetics of bouquets is not important. Interesting and relevant issues, however, are often not far beneath the surface. A common criticism that has been levelled against the harvesters of wildflowers in the fynbos, a trade which has existed informally for over a century, is that they are raping the veld, or at the very least abusing its unique and spectacular purity. Considering the very special character of the Cape Floristic realm, these emotionally protective attitudes are understandable and speak well of people's higher ideals, however much they might be seen as irrelevant by the aloof scientific and mercantile communities. As I became familiar with the project, I discovered that this seemingly frivolous and indulgent exploitation of the heathlands, which are a large part of the Fynbos Biome, has ramifications into much broader conservation and social issues.

It is perhaps arrogant and unscientific of me even to hint that I suspect floristry to be unnecessary, just as I am critical of narrow utilitarian attitudes which discount the creative arts. Modern society is an elaborate structure with many obscure struts and ties, few of which are totally redundant. Correctly handled, the consumer's desire for products of the fynbos veld can assist in the conservation of this natural resource. With foresight and compassion, it can even assist in undoing some of the constitutional injustices which plague South African society as it struggles to emerge into a new and democratic era.

The demands which are made by humans on the natural resources of the globe are many, varied, and often unreasonable. They are also the results of a complex social, political, and philosophical evolution. The Nature Conservation ethic of the modern developed countries, together with the astounding television documentaries which reach into the most inaccessible corners of the earth like a fibre-optic probe down the arteries of a cardiac patient, sets admirable standards for the conservation of biotic diversity and the preservation of natural ecosystems. But I cannot shake the feeling that as human observers of natural processes, we are tending to discount our own role in the set of equations which we are attempting to formulate, and finally, to solve. It is critically important to heed the call for conservation of species, the habitats which allow these species to exist, and the systems which maintain their habitats, or otherwise face the spectre of a global wasteland. But human beings have to be included. Modern *Homo sapiens* may be an aberrant species in terms of the impact it has on its own environment, but it is still a biological player in the evolutionary game.

The tendency in the wildflower industry, as with most modern commercial enterprises, is to organize its production line into a productive, economical, and predictable operation. This is leading to the establishment of a sound agro-horticultural sector within the industry, and probably the most financially lucrative part of it. However, living as we do on the brink of crisis with respect to the global depletion of resources such as fossil fuel reserves, clean air, and adequate water supplies, humanity needs to be mindful of the concept of sustainability. And this, I believe, is where we have a valuable model in the wildflower industry. It may provide insights into how we should be linking the sphere of human activities which have been emerging since *Australopithecus* (or whoever) first learned to use tools and contemplate its own destiny, and those functions which evolution selected for our biological survival. In the context of South African pre-history, I heard the comment recently that when the hunter-gatherers of the south-western Cape were displaced by the immigrating pastoralists, the pattern of land-use changed from an internal systemic utilization of a resource base, to an external exploitation by a process of "comoditization" to meet already structured needs. This trend continued and intensified with agricultural, and later industrial annexation of land during the colonial era (*pers. comm.*, J. Parkington, Dept. of Archaeology, University of Cape Town). By way of a loose analogy, I see potential in the wildflower industry's veld harvesting sector to provide us with some insights into the relationship which hunter-gatherers might have had with the land they used as a perpetual and sustainable resource. From the environmental manager's perspective, the wildflower industry may be seen as an eyelet through which management techniques can be laced for integrating components of our environment into an effective land-use strategy.

ACKNOWLEDGEMENTS

For a project which is about the interrelatedness of components in systems, not least of all the role of human beings in those systems, it should not be necessary to belabour my own dependence on funders, colleagues, and humanity in general, for paving significant portions of the pathway. But nevertheless acknowledgement of some of the many contributions is appropriate, and a promissory note for reciprocation as and when I am able. On the level of funding and infra-structural support - not to say that personal and human contact was absent in this category - I must acknowledge the total funding of the project from my employers, formerly the Botanical Research Institute, but now amalgamated with the National Botanic Gardens to form the National Botanic Institute; the University of Cape Town (UCT) for providing office and laboratory space; the Directorate of Forestry for allowing me use of fynbos land inside the Highlands Forest Reserve, and more specifically for the assistance from the Highlands personnel in burning and tilling of the experimental plot; personnel of the Cape Department of Nature Conservation for many parts in the evolution and execution of the study; the Botanical Research Institute herbarium at Stellenbosch for most of the official plant identifications; and the Foundation for Research Development (CSIR) for support of the *Working Group on Commercial Wildflower Resources*. On a more personal level, for their help in reading and commenting on parts of this, and other related typescripts, for valuable discussion relating to the project, and generally for being there, I would like to thank, amongst many others, the following people: Sean Archer, William Bond, Bosie Bösenberg, Gert Brits, Chris Burgers, Richard Cowling, Adam Davis, Deryck de Witt, Sidwell Dolo, Elsie Esterhuysen, Andrew Flynn, Tisha Greyling, Margie Jarman, Richard Knight, Anelise le Roux, Barry Low, Walter Middelmann, Guy Midgley, Eugene Moll, Shirley Pierce, Mike Rutherford, Melanie Simpson, Peter Slingsby, Stent, Chris Swanepoel, Francois van der Heyden, Ed Witkowski, all the members of the working group, anonymous referees of the papers reviewed for publication, and the many students and staff at UCT (including Xecol BRI) who contributed to a more than viable working environment. Special thanks, however, are due to: Andrew Flynn, whose unflinching help under many an adverse condition in the field, laboratory, and computer room, has assisted in establishing the data sets which underpin the chapters on the experimental field work (especially Chapter 5); Guy Midgley for his part in the work towards Chapter 6; Dr. Mike Rutherford, boss and critical reviewer of much of the work; and Prof. Eugene Moll, my supervisor, who takes delight in looking for other perspectives, and in whose perspective I usually take delight.

A GUIDE TO THE STRUCTURE OF THE THESIS

BACKGROUND

The thesis reports on work concerned with conservation and management of a natural resource. This resource contributes to the total environment of humans in the southern and south-western Cape, and more specifically acts as a basis for the wildflower industry. I have not dealt with the agro-horticultural portion of the industry because that is in the skilled and capable hands of an established community of farmers, plant-breeders, plant pathologists, entomologists, and others. As a botanical ecologist I saw it more as my role to address the questions surrounding ecosystem conservation, especially with regard to the vegetation component. As part of the broader perspective, however, socio-economic aspects have been addressed. The thesis is organized into what are intended as stand-alone chapters to facilitate the publication process that must follow. Repetition of background information and motivation was therefore inevitable, but attempts have been made to keep it to a minimum. Following a **SUMMARY** of the full text, the volume is arranged as follows:

GENERAL, PHILOSOPHICAL, AND THEORETICAL MATERIAL

The general and philosophical aspects of the work have been placed in the first and penultimate chapters, with **CHAPTER 1** providing an outline of the industry and its management, and **CHAPTER 8** a perspective on reconciliation between the often antagonistic thrusts of ecological conservation and economic development. **CHAPTER 2** is a slash at a large dragon with a small sword, if that is an adequate description of the attempt to model a multi-million rand industry with a micro-computer and few data. Nevertheless the work was done, initiated as a filler project in an apparent lull in the experimental work. It has provided a useful framework for some of my thinking on the role of the wildflower industry in fynbos ecology. I have included it hoping that it will contribute to that same debate in a wider forum.

EXPERIMENTAL WORK

CHAPTERS 3 TO 7 form the core of the project as initially conceived, before the broader implications of renewable resource utilization on a shrinking planet struck me as being fundamental even to the harvesting of flowers from a nutrient-poor heathland. **CHAPTER 3**, already published (*Bothalia* 18(2), 1988), is a description of the study site prior to the experimental work, while **CHAPTER 4** and **CHAPTER 5** consider the effects of marginal cultivation on the physical and the vegetational components of the same fynbos system as a result of strip tillage by shallow rotavation. This is a technique often employed by producers to assist in the establishment of commercially desirable species at non-native sites, and may in many cases be considered the experimental annexation of agro-horticultural land. **CHAPTER 6** looks at aspects of the water relations of the three dominant species in the natural plant community at the study site, and includes the physical disturbance of tillage as an experimental treatment. The work involved in this chapter was shared with a colleague, and has been accepted for publication with Guy Midgley as co-author (*South African Journal of Botany*, in press (1990)). Although we were both involved in field-work and discussions around the subject matter, I claim both responsibility and credit for the experimental design and for the basic writing of the text. **CHAPTER 7** is a pilot study which deals with the performance of two *Protea* species which were introduced to the site in order to mimic the actions of a commercial flower grower.

ADDITIONAL MATERIAL

CHAPTER 9 is a short synthesis which consolidates the findings and conclusions generated during this work. It is followed by a list of the **REFERENCES** cited in the body of the document, after which is attached **APPENDIX I**, the source code of the model described in CHAPTER 2, and **APPENDIX II**, a reprint of a previously published short communication relevant to the description of the study site used for the experimental work.

SUMMARY

This thesis comprises a series of chapters describing selected aspects of the decorative wildflower industry in the south-western Cape Province, South Africa . The industry uses as its resource-base the vegetation of the Fynbos Biome, a region characterized in part by its mediterranean-type climate and sclerophyll vegetation. My work adopts a broad conservation management perspective, and attempts to integrate the ecological, economic, and conservational factors which underlie the pattern of land-use in the industry. The chapter contents are summarized sequentially below.

CHAPTER 1

The fynbos wildflower industry relies on both natural undisturbed systems for wild products, and on transformed ones which provide the location for relatively controlled cultivation of those indigenous species proven amenable to domestication. The material harvested from the natural veld contributes an estimated 65% to the total mass of fresh material, and 90% to that of dried material, reaching the consumer market. But the bulk of the money earned in the trade, the current total estimated to be in the region of R29 million per year, is mostly from the export of inflorescences of *Protea* and *Leucospermum* species (Proteaceae) which are often cultivated using sophisticated horticultural techniques. Thus production by natural ecosystems tends to be discounted relative to cultivation. Some conservationists argue in favour of bringing production methods in the wildflower industry entirely within the realm of conventional agriculture and horticulture, and then applying preservationist policies towards conservation of the remaining fynbos vegetation. In Chapter 1 I argue in support of integrating the activities of the veld-harvester and the marginal cultivator into an overall management plan, and to allow their activities to generate commercial incentive and a vested interest in active conservation.

Although there are more powerful acts of parliament which may take precedence in the case of broader national interests, the wildflower industry is regulated almost solely by a provincial ordinance, the Nature and Environmental Conservation Ordinance No. 19 of 1974. This ordinance makes complex provision for a system of permits, licences, registrations and authorizations which are difficult

to police, and frustrate even co-operative producers. Furthermore, the legislated permit system provides no feedback to managers and researchers regarding the levels and patterns of resource utilization. An "adaptive management" approach which uses such feedback, coupled with multiple land-use policies, would probably be suitable for fynbos management. The wildflower industry is identified as a possible starting point for broaching more complex socio-ecological issues using these tools. By alluding to the inseparability of environmental and social problems, an appeal is made to ecological scientists to involve themselves in the seemingly less wholesome political processes which are essential for effective environmental management.

CHAPTER 2

A computer model was constructed which attempts to simulate the pattern of resource utilization in the veld harvesting sector of the wildflower industry. The source code, written in a structured programming language (True BASIC version 2.01), comprises a structured set of subroutines which compute the availability of floriculturally valuable material to an imaginary wildflower producer. This is done on both an annual, and a population life-cycle basis. The model, dubbed VELDFLOW, resolves each year into 52 weeks, and assesses the impact of cumulative annual harvest on populations of exploited species by balancing the production of material against the demand generated by the market.

Central to simulation of the biological processes are four submodels which describe: (a) the natural pattern of availability of flowering material, assumed to be Gaussian in distribution between the start and finish of flowering; (b) the pattern of productivity over the lifetime of the population, which is broken down into a pre-productive seedling stage, a juvenile period of increasing productivity, a mature phase of constant productivity, and a senescing phase during which productivity declines geometrically by a constant factor; (c) the response of plants to harvesting, described as a "pruning effect", in which floricultural productivity during the following season can be stimulated or depressed according to the species and the level of harvesting; and (d) the reduction of population size as a response to harvesting level, in which population is reduced by an amount proportional to the extent to which a safety threshold has been exceeded.

Sensitivity analyses were performed for two of the parameters defining the producer's attitude towards the resource. These operational parameters were: (a) the intensity with which he (or she) was willing to harvest populations of target plant species, and (b) the margin of profit demanded before executing a simulated retrieval of material from the veld. Results of these and other test runs indicate that verification of the model is probably complete, but the extreme paucity of real data make comprehensive validation impossible at this stage.

CHAPTER 3

Aspects of the role of mountain fynbos as a resource for the wildflower industry were investigated by establishing an experimental study site in a stand of mesic proteoid-restioid vegetation in the mountains close to Botrivier in the south-western Cape. A survey of the chosen system was conducted, and a description compiled for the *Leucadendron xanthoconus* (Proteaceae)/*Chondropetalum hookerianum* (Restionaceae) co-dominated community, as well as for its climatic and edaphic environments. The study site was categorized according to existing classifications, and by comparison with other fynbos systems. Comparison of rainfall and temperature data with those collected at an agricultural research station in the region indicated high variability in the spatial and temporal pattern of precipitation, and an air temperature regime which was influenced by the topography. Analysis of vegetation data revealed a species richness lower than other fynbos communities, but a species turnover of similar magnitude. The soil of Table Mountain Group origin comprised a colluvial A-E horizon with a well-defined stone-line, and residual B and C horizons of shale origin. It had low pH and nutrient status, with a high measured concentration of aluminium, especially in the B horizon.

CHAPTER 4

An often employed method of wildflower production involves low maintenance cultivation of produce. This can be done by introduction of commercially desirable species to rudimentarily prepared fynbos veld. This method was simulated on an experimental plot at the study site described in Chapter 3. Preparation involved burning the vegetation during late summer, and rotavating strips during winter of the same year. The tilled strips were regarded as the experimental treatment, and the untilled inter-strip areas as the control, although comparison of soil nutrient levels, and other system attributes included observations

from the adjacent unburned areas. Parameters measured included: pH, electrical resistance, P and K by Bray extraction, C.E.C., exchangeable cations, organic C, and total N. No significant differences were found between mean parameter values of the tilled, untilled, and mature vegetation treatments, except that electrical resistance of the tilled soil was greater than that of the mature stand, with untilled soil representing an intermediate between them. Selected physical parameters of the tilled and untilled systems were monitored during the 18 months following application of the experimental treatment. Results showed that tillage significantly altered the energy and water regimes of the system during the summers months, but that these differences were not apparent during winter when soil water content was at, or above saturation. Short wave reflectivity of the soil surface was enhanced on the disturbed soil during the dry season only, resulting in cooler temperatures on this treatment down to the maximum monitored depth of 300 mm. The summer water content of the tilled soil was also significantly higher than that of the untilled soil. Ordination (Principle Components Analysis) of sample stations against variables describing soil water and soil energy budgets at different times of the year, showed no distinct grouping of tilled and untilled samples. Vectors representing albedo, soil water content, and soil temperature during summer were approximately orthogonal to their equivalents during winter, indicating no correlation of parameter values between seasons for the set of sample stations. Results of a general correlation analysis showed that albedo was significantly correlated ($p < 0.05$) with near surface soil water, positively during the summer and negatively during the winter. The same was true of albedo's relationship with soil surface temperature, except that the correlations were opposite in sign (viz. cooler and reflective in summer, and warmer and more absorptive in winter). The density of *Leucadendron xanthoconus* seedlings, the dominant shrub species at the study site, bore the same type of seasonally reversing correlations with the same two parameters, positively correlated to soil surface temperature, and negatively with near-surface soil water, during summer. The complex interrelationships between abiotic factors, and their influence on re-establishing plant life is depicted in a conceptual model for flows and influences of water and energy, the two parameters apparently most affected by tillage in the experimental system.

CHAPTER 5

After the experimental plot had been cleared by fire, re-establishment of the natural vegetation was monitored on both tilled soil, and the untilled interstrip control. The scope of these data were extended by including observations of some aspects of community structure for: (a) species re-establishing themselves on the firebreak surrounding the experimental plot; and (b) vegetation at similar sites which had been similarly prepared for wildflower production by commercial producers on their own land. Vegetation parameters chosen for this portion of the study were: (a) total projected foliar cover; and (b) community structure as measured by species richness (S), the Shannon-Wiener diversity/equitability index (H'), and the Simpson index of dominance (C). The performance of species dominant in the mature pre-disturbance community at the Highlands site was also assessed during the post-disturbance phase by measurement of above-ground productivity. Results of the experimental work showed that within the set of mountain fynbos systems considered, disturbance by tillage was invariably associated with a depression of foliar cover, a reduction in S and H', and a rise in C. Data from the other sites were generally corroborative with respect to changes in projected foliar cover and community structure related to disturbance. Detrended correspondence analysis (DECORANA) of the Highlands data showed an overall convergence in ordination space of the tillage and non-tillage sample sets. After three years, however, these traces were still far removed in ordination space from the point representing adjacent unburned mature vegetation. The mean biomass produced by *Leucadendron xanthoconus* and *Erica cristata* plants was significantly greater on the tilled than on the untilled soil. *Chondropetalum hookerianum* showed no such positive response to a tilled environment. The occurrence of the alien *Pinus pinaster*, a species cultivated locally in large plantations in the forest reserve approximately 0.5 km distant, was noted as being more frequent on tilled, than on untilled soil. It is concluded that although tillage may have distinct advantages for the producers of indigenous wildflower species, it constitutes a distinct threat to species diversity in similarly disturbed systems.

CHAPTER 6

In this chapter the effects of fire and tilling on the water relations of *Leucadendron xanthoconus*, *Erica cristata*, and *Chondropetalum hookerianum*, were investigated. Measurement of the diurnal pattern of xylem pressure potential in young plants of a post-fire community showed that tilling of the soil was associated with an increase in the availability of water, and with less stressed conditions in the *Leucadendron* and *Erica* plants. *Chondropetalum* seedlings, however, were equally stressed on both of these burned treatments. Relative to their mature counterparts in the unburned vegetation, *Erica* and *Chondropetalum* of the burned but untilled treatment were more stressed, whereas the *Leucadendron* plants showed no significant difference. The observed patterns of stress are interpreted in terms of the reduced vegetational cover following tilling, and the different rooting and seedling establishment strategies displayed by each of the investigated species. Findings presented in this chapter suggest that consideration of an altered water regime may be an important part of the management and conservation planning which regulates human impact on fynbos vegetation.

CHAPTER 7

The *Protea* species introduced to the study site for simulation of a situation which might be faced by a commercial wildflower producer, were *P. repens*, and *P. cynaroides*. Sets of plants in their second year of growth were planted on adjacent strips of disturbed and undisturbed soil, and their subsequent survival and growth was monitored for the three consecutive years. Results indicated that while *P. repens* plants located on the disturbed soil were significantly more productive over the study period in terms of shoot elongation than those on the untilled soil, *P. cynaroides* displayed no significant benefit from the tillage. The pattern of plant survival however was different, with *P. cynaroides* individuals being significantly more likely to survive on tilled than on untilled soil, and *P. repens* showing a reversed but insignificant trend of better survival on untilled soil.

A brief study of the diurnal pattern of leaf conductance in a subset of *P. cynaroides* individuals during their fourth summer since germination, showed that plants growing on the tilled soil had significantly higher leaf conductance values than those on the drier tilled soil. It is suggested on the basis of the information presented in this chapter that release from water stress may have allowed better survival of this species, but that other factors could be limiting productivity.

CHAPTER 8

In this penultimate chapter, the perspectives of the ecologist and the economist are juxtaposed in an attempt to identify some of the reasons why conservationists and commercial exploiters of the fynbos veld may not always agree on management priorities. Written from an unabashedly ecological point of view, it is concluded that modern economic paradigms are leading us away from the biophysical basis which is best suited to the sustained utilization of resources. The wildflower industry, because it uses fynbos resources more directly that most other human enterprises in the biome, may act as a catalyst in the development of ecologically sound land-use policies and management strategies.

CHAPTER 9

This chapter concludes the thesis with an interpretive summary of the major findings and insights gained during the course of the project.

CHAPTER 1

THE COMMERCIAL WILDFLOWER INDUSTRY IN THE FYNBOS BIOME

- a potential catalyst for the re-assessment and restructuring of conservation strategies

A MOTIVATION FOR ACTION

One of the most compelling reasons for devising a globally effective set of environmental management strategies, is the current growth rate of the human population. In South Africa in 1985 (including the so-called independent states, or homelands) the population was measured as 30.3 million, an increase of approximately 17% over the previous five years (Central Statistical Services 1985). Uncontrolled land use will cause severe degradation of all but the most inaccessible natural areas. The spectre of a land devoid of most natural vegetation, and the animal populations that it supports, is becoming increasingly influential in the trend to place restrictive controls on as much natural land as is available to the public conservation agencies. The floristically rich Fynbos Biome of the Cape, which in the south-western and southern regions is characterized by a mediterranean-type climate (Aschmann 1973), provides a large variety of habitats suitable for human habitation and exploitation. The mountainous nature of much of the terrain has to date helped in preserving large tracts of natural land in the inaccessible and less fertile areas (Moll and Bossi 1984), but the increasing human pressure continues to elicit concern.

Proponents of protection measures for the world's diminishing set of natural ecosystems often have to base their arguments either on complex ecosystem relationships, or on the less tangible qualities of aesthetic, ethical, and scientific value (Kruger 1981). Rarely, except in the case of nature reserves supporting large game animals which generate an income from tourism, can economic importance of an unutilized ecosystem be cited on the free-market as a reason for its conservation. The wildflower industry of the south-western and southern Cape (see Figure 1-MAP), which relies to some extent on diversity for the quality of its product, is deserving of special attention because it may act as an intermediate type of human activity to facilitate the reconciliation of mercantile and ecological perspectives. The flora of the Fynbos Biome, which comprises approximately 8600 flowering plant species, 68% of which are endemic (Bond and Goldblatt 1984), is the basis of an

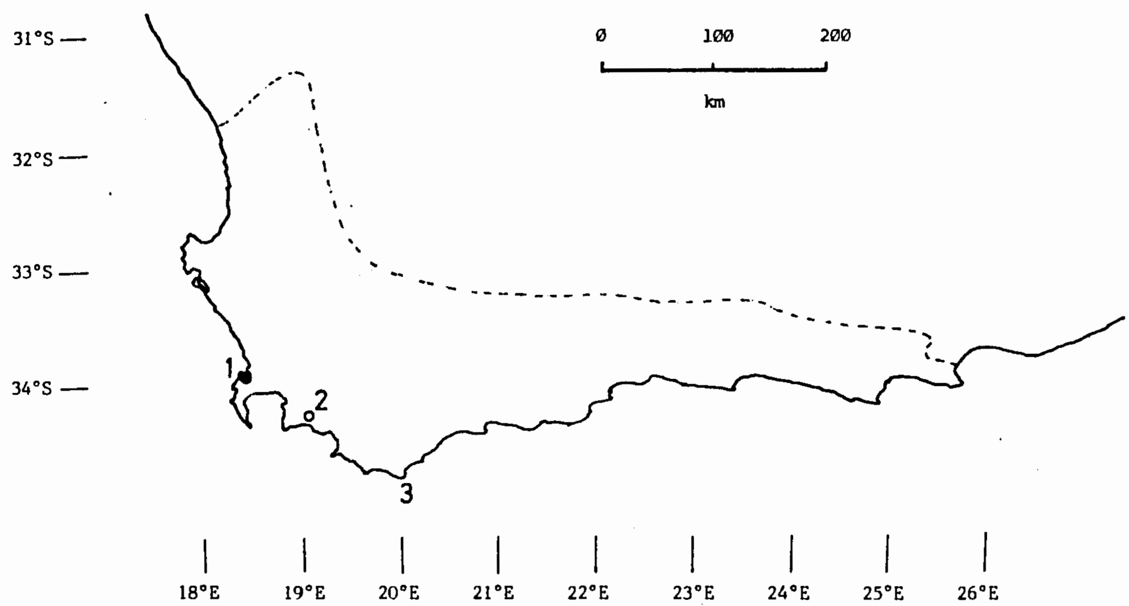


FIGURE 1-MAP. Map of the fynbos region of the Cape Province, South Africa. The broken line approximately delineates the extent of the major fynbos vegetation types occurring in the Fynbos Biome. The labelled points, referred to in this and other chapters of the thesis, are:

1 the city of Cape Town;
2 Highlands State Forest (see Chapters 3 to 7);
3 Cape Agulhas.

important wildflower industry. The international portion of this commercial activity earned over R10 million in foreign exchange during 1985 (Commissioner for Customs and Excise 1985), the last year that export figures were available for publication. (Since then, export trade figures have been unpublished and classified as secret, possibly as a defensive reaction to the intensifying international anti-apartheid campaign for trade sanctions against the present South African regime.) Projections from pre-1986 figures, together with informal estimates from the commercial sector, suggest that the subsequent export trade did not decline, and that the gross total income earned by this industry, including transport earnings, was approximately R29 million per annum during 1988 and 1989, more than 90% of which was related to the export trade (Middelmann *et al.* 1989).

HISTORY AND DEVELOPMENT OF THE WILDFLOWER INDUSTRY

Before the European outlet for fynbos material was developed during the 1960's, use of the flora as decorative material was much less formal. Up until 1938 flowers and foliage could be harvested directly from the veld without any restriction regarding the species picked. Therefore the main traders in this commodity at that time, the street vending flower-sellers of Cape Town, were free to harvest directly from the veld, with trespass as the only limitation to the acquisition of produce. The first restrictions on this *laissez faire* trade came with the publication of a list of protected wildflower species in the provincial Wild Flower Protection Ordinance (No. 15 of 1937), and later introduction of a permit system (Wood 1977). Although flower vending has survived, and remains a prominent feature of Cape Town streets (see Frontispiece), its relative importance in the exploitation of fynbos as a floricultural resource is slight, as the figures quoted above indicate (Middelmann *et al.* 1989). The international trade was established by a small number of entrepreneurial farmers in the early 1960's (Roux 1979) who had access to the capital and the floricultural resources necessary for such a venture. Roux (1979) reported that the first proteaceous material exported from South Africa did so as dried flowers in 1962, with the first consignment of fresh material following two years later. By 1979 twenty exporters of fynbos wildflower products had established themselves in the western Cape (Roux 1979). The overseas markets, such as wholesalers in Switzerland, Holland, Germany, and the flower market at Aalsmeer in Holland (Maister 1974) proved to be very viable, and rapid growth of the lucrative international trade during the 1970's (Brits 1984a) led to development of more sophisticated production techniques (Brits 1984b). But because a number of commercially desirable species have not yet been domesticated - either on account of their recalcitrance (*e.g.* members of the Ericaceae) or their abundance in the wild (*e.g. Leucadendron* spp.) - the older style of veld-harvesting still exists under the more competitive conditions of the modern global industry (Middelmann *et al.* 1989). Pressure from the international market has, on the whole, raised the degree of organization to be found in wildflower production practice for two reasons. Firstly, the overseas market, whether in response to consumer demands, or shaped by market manipulators, is now much more critical of the quality of material entering it. Producers competing in that milieu need to be acutely aware of factors which affect product quality (Jacobs 1989), which include stem length, the shape and colour of the inflorescence, flowering time, the degree to which leaf tissue is subject to discolouration after harvesting, *etc*. Control over these attributes allows international trade intermediaries the chance to plan in advance. A second consideration associated with the export of indigenous flora, is the set of stringent requirements which importing countries impose regarding the freedom of material from potential pest organisms accompanying the consignment (Odendaal 1988). These include the insects and fungi commonly associated with *Protea* species (Coetzee *et al.* 1989). Developments in the trade have thus favoured attempts to propagate suitable material under conditions which can be controlled by the producer for an optimum yield to effort ratio. This approach has worked well for many species in the Proteaceae (Vogts 1982), and has resulted in some sophisticated techniques, such as the development of distinctive and marketable cultivars (*e.g.* Brits 1985; Brits 1988a), control of florigenesis (Brits 1988b; Malan 1988), breeding systems for the development and assessment of plants with disease resistant roots as root stock donors (Brits 1989; von Broembsen 1989), research techniques for promoting and achieving the post-harvest preservation of floral and foliar tissue (de Swart *et al.* 1987; Reid *et al.* 1989), and control of insect and fungal pests (Benic and Knox-Davies 1983; Coetzee 1986; Knox-Davies 1988). Many fynbos species are nevertheless still only available from the natural veld. This is indicated by the number of non-proteaceous species utilized by the commercial wildflower industry (Table 1-1), most of which are not under cultivation.

Structure of the industry

The commercial demands, historical development, and biological constraints associated with the industry have led to the evolution of a diverse set of channels

TABLE 1-1. Families of plants and the number of species in each utilized by the fynbos wildflower industry (from Simpson 1985; Manders 1989; Simpson 1989).

Taxon	Number of species used: Indigenous	Alien
PTERIDOPHYTA		
Schizaeceae	1	0
ANGIOSPERMAE		
-Monocotyledonae		
Asphodelaceae	2	0
Cyperaceae	6	0
Haemodoraceae	1	1
Iridaceae	4	0
Juncaceae	2	0
Poaceae	6	7
Restionaceae	31	0
Typhaceae	0	1
-Dicotyledonae		
Anacardiaceae	1	0
Asteraceae	41	0
Bignoniaceae	0	1
Bruniaceae	14	0
Ericaceae	49	0
Fabaceae	4	2
Grubbiaceae	1	0
Lamiaceae	1	0
Liniaceae	1	0
Myrsinaceae	1	0
Myrtaceae	0	8
Penaceae	1	0
Plumbaginaceae	1	0
Proteaceae	101	7
Retziaceae	1	0
Rhamnaceae	8	0
Rubiaceae	1	0
Rutaceae	5	0
Selaginaceae	1	0
Sterculiaceae	0	1
Thymeleaceae	4	0

through which material finds its way to the market place. The resource base of the wildflower industry can also be classified as having three major components. These are: (1) the cultivated material produced by intensive horticultural and/or agricultural techniques, which is necessary for the development of the cultivar based portion of the industry, and that sector which Jacobs (1989) sees as the major thrust of the industry in the future; (2) the marginal cultivation of material, where relatively undisturbed veld is prepared by combinations of tillage, brush-cutting and planting of target species in higher densities, and in geographical locations not normally encountered in nature; and (3) veld-harvesting of material from natural populations of the desired species.

The material itself can be placed in several categories. That which fetches the highest price for a producer is the material comprising the showy inflorescences of *Protea* or *Leucospermum* spp. (Proteaceae), the group best established as a horticulturally-based resource. The decorative material which provides backing for these showy inflorescences in a compound arrangement, or is often used in textured bouquets without a showy focal piece, is known in the trade as "Cape greens", or "loof". This comprises just about any fynbos species which might be suitable in terms of demand from the market, but it is characterized by tried and tested species of *Erica* (Ericaceae), *Brunia* and *Berzelia* (Bruniaceae), *Leucadendron* (Proteaceae), *Phylica* (Rhamnaceae), and others (Simpson 1985). Oddities such as the woody cones of *Leucadendron* species, or the reed-like culms of the Restionaceae, provide additional material available for exploitation by veld-harvesting producers. In addition there are the alien species utilized by the trade. Some of these are cultivated especially for the industry such as the *Banksia* species (Proteaceae) indigenous to Australia, while others, also mostly Australian, have become naturalized in the fynbos for other reasons. In this latter group are the woody infructescences of *Hakea* spp (Proteaceae) and *Eucalyptus* spp. (Myrtaceae), and the delicate flowering structures of some common grasses (e.g. *Avena* spp., *Hordeum vulgare*, *Zea mays* (strawberry corn)) (Simpson 1985).

The volume and content

The "free-on-board" (FOB) revenue earned by the international trade was, until early 1986, published in the trade abstracts of the Department of Customs and Excise. This was done according to the classification summarized in Table 1-2. Throughout the 1980's there was an increasing international awareness of South Africa's internal policies, and a widening response to the calls of anti-apartheid

TABLE 1-2. Classification of plant material used by the Department of Customs and Excise (C & E) for analysis of foreign exchange earned by their export. This summarizes the relevant entries from Table 7 of the *Monthly Abstract of Trade Statistics*, published by that Department up until 1986 (see text).

C & E category	Description
06.	Live trees and other plants including cut flowers and ornamental foliage
06.03	Cut flowers and flower buds of a kind suitable for bouquets or for ornamental purposes: fresh, dried, dyed, bleached, impregnated, or otherwise prepared
06.03.10	Proteas
06.03.20[a]	Everlastings (sewejaartjies)
06.03.30	Dried flowers
06.03.90	Other
06.04[b]	Foliage, branches, and other parts of trees .....

[a] Everlastings only sporadically represented in the record
[b] Assumed to comprise largely the "Cape Greens"

activist organizations for the strengthening of trade sanctions against South Africa in protest of its racially discriminatory internal policies. Withholding of international trade figures from publication was an attempt to hinder campaigns aimed at persecution of South Africa's foreign trade partners. While I venture no opinion here on the efficacy of this purported attempt to deal with perceived "enemies of the State", it is probably true that classification of these figures has retarded development of effective management of renewable resources, such as those utilized by the wildflower industry. An indication of the industry's growth during the period prior to 1986 is given in Figure 1-1. (On request, a very much more aggregated set of figures for the years 1986 to 1988 was forwarded to me by the Department of Agricultural Economics and Marketing, with the request that they be treated as strictly confidential.) The data in Figure 1-1 indicate that the industry has grown substantially in the recorded categories over the documented period, even if matched against a nominal inflation rate of 10 %. Furthermore it may be assumed that during the same period, the industry has become more sophisticated, and is probably more efficient with respect to its overhead commitments to production and transport techniques. The implied growth is therefore probably underestimated.

Another aspect of the export trade is its seasonality. Using data derived from the local trade publication *SAPPEX News*, the journal/newsletter of the South African Protea Producers and Exporters Association (SAPPEX), the annual pattern of mass of material exported is been depicted in Figure 1-2. This shows a distinct peak in exports during the period September to December, a time when European consumers are caught up in the lavishness of the pre-Christmas and New Year season, and when decorative material is in high demand for festive social functions at an institutional level. This pattern of demand, however, is badly timed with the flowering behaviour of many of the desirable species. Species of the Proteaceae in the south-western Cape for instance are primarily winter and spring flowering (June to October; see Chapter 2, Table 2-1), with the exception of a few ecotypes from the eastern part of the Fynbos Biome where rainfall during the summer period is more substantial than in the southern and south-western Cape (Fuggle and Ashton 1979). This factor alone has motivated horticulturalists to look seriously for controls of anthesis in the hope that manipulation may effect better timing. This area of research has to date borne potentially useful results, as is evidenced by the ability of researchers to delay flower harvest of "pincushion" cultivars (*Leucospermum* spp) by more than 37 days, with an average lengthening of the flowering period by 67% (Brits 1988).

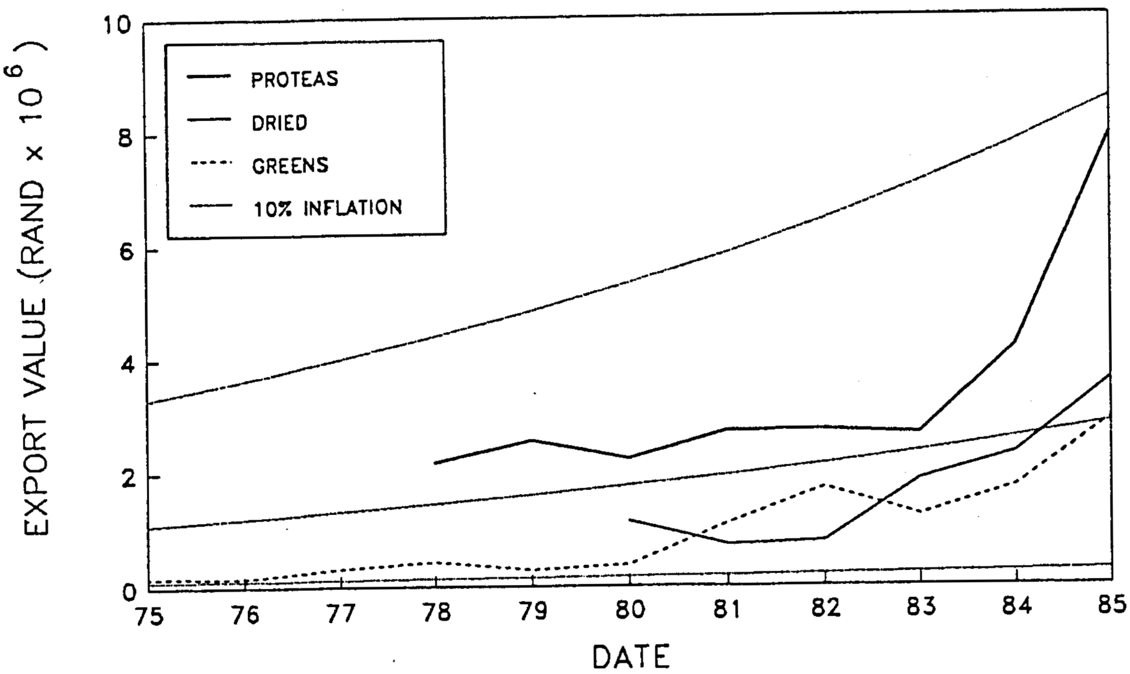


FIGURE 1-1. Growth of exports in the cut and dried flower industry during 1975 - 1985. Figures are in millions of Rand "free on board", and are taken from the *Monthly Trade Abstracts* of the Commissioner for Customs and Excise, Pretoria. As a guide for the inflationary background, 10% inflation curves are included.

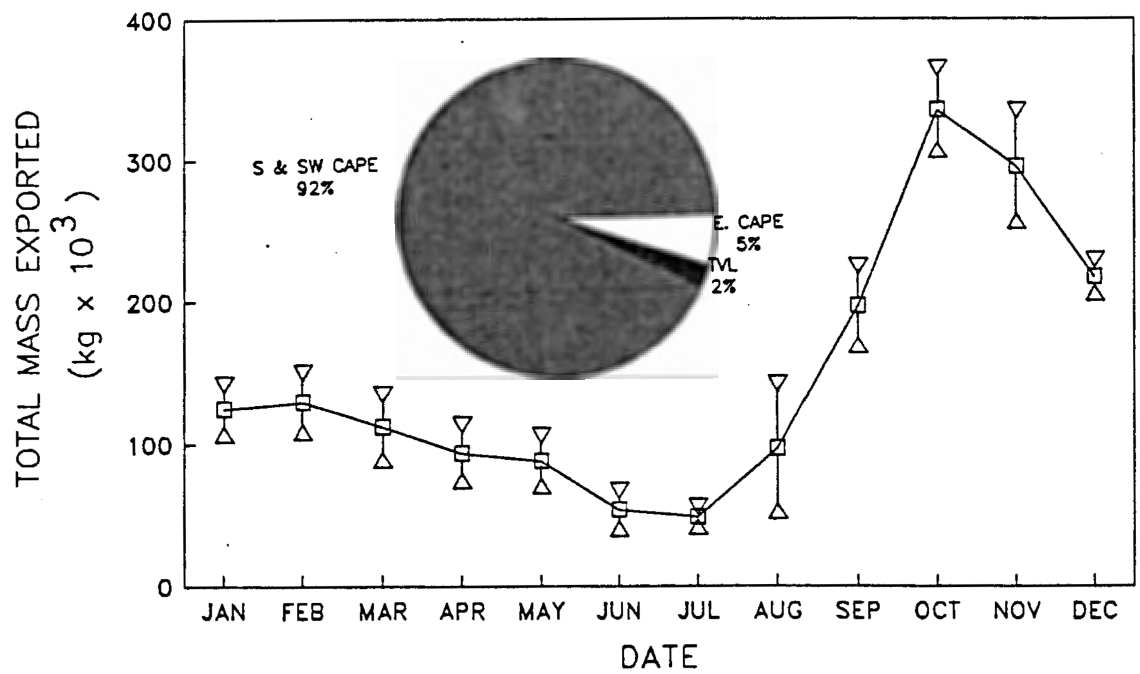


FIGURE 1-2. The seasonal pattern for combined exports of "proteas" and "Cape greens" (viz. fresh fynbos material) during the period 1979 to 1986. Connected data points represent the mean monthly mass exported over that period, and the vertical bars ± one standard deviation. Inset is the mean annual distribution of that mass between the sources of: the southern and south-western Cape; the eastern Cape; and the Transvaal (data from *SAPPEX News* volumes 46 and 53).

Conduits and controls

Although the pacesetters of production techniques in the wildflower industry favour the control that cultivation offers for improving the quality of the product, the fact remains that most of the material in terms of mass harvested is still derived from the natural veld, a proportion which Middelmann et al. (1989) place at 65% for fresh material, and 90% for dried. The channels via which material can move from source to consumer destination (ignoring its ultimate destination in the urban trash-cans of Europe), are manifold. In the case of the cultivated, and marginally cultivated produce, production is probably most often associated with large and organized infrastructures. Access to machinery for tilling, and tenure of land by ownership, promote reasonably long-term commitments to economic growth and resource conservation. By contrast, veld harvesting is a low-cost, low-return, and higher-volume enterprise, suited to the employment of labour on casual or piece-work bases, and to small independent operators with limited capital. The latter type of producer is often reliant on larger land owners, from whom he/she can lease veld for the harvest of saleable material, and on established wholesalers and exporters to whom produce can be sold for inclusion in larger export consignments. In the case of the South African market, however, material can travel between source and the less structured local market in the hands of the small veld-harvesting producer. At present, the knowledge of relative quantities of material that are distributed via the different channels to the different destinations, and the species composition of those amounts, is very poor. In Western Australia (W.A.) there exists a similar wildflower industry which uses indigenous vegetation as a floricultural resource. The W.A. State Department of Fisheries and Wildlife, which manages this resource, instituted a system of obligatory data returns for the channeling of harvest information back to managers from the commercial pickers, an innovation which was shown to be useful for gaining information about the patterns of plant usage by the commercial trade (Burgman and Hopper 1982). Some type of monitoring system will need to be introduced into the toolbox of fynbos conservators if the necessary knowledge for correct management of this resource is to be obtained.

The South African legislation which governs the conservation of indigenous plants was reviewed by Fuggle and Rabie (1983). They point out that, although the legislation protecting plant life from direct damage was "reasonably satisfactory" at that time, the ecosystem and habitat conservation was poorly provided for. The pieces of current legislation relevant to conservation are listed, together with their stated objectives, in Table 1-3. The most recent of these is the Environmental

TABLE 1-3. Legislation governing the conservation and utilization of Fynbos as a natural resource for the wildflower industry.

Legislation	Stated objective
1. Physical Planning Act No. 88 of 1967 as amended by 73/1975; 104/1977; 51/1981; 87/1983; 104/1984; 92/1985; 109/1985; 97/1986	To promote co-ordinated environmental planning and the utilization of the Republic's resources.
2. Mountain Catchment Areas Act No. 63. of 1970 as ammended by 63/1975; 41/1976; 76/1981	To provide for the conservation, use, management, and control of land situated in mountain catchment areas
3. Conservation of Agricultural Resources Act No. 43 of 1983	To provide for control over the utilization of the natural agricultural resources of the republic in order to promote the conservation of the soil, the water sources and the vegetation, and the combating of weeds and invader plants .....
4. Environmental Conservation Act No. 73 of 1989	To provide for the effective protection and controlled utilization of the environment ...
5. Nature and Environmental Conservation Ordinance No. 19 of 1974 (Cape Province) as ammended by 11/1981; 15/1983; 24/1986; 26/1986	To consolidate and amend the laws relating to nature conservation .....

Conservation Act (73/1989), which reflects a growing awareness on the part of the legislators, and probably a greater degree of involvement from biologists in the process of law-making, by recognizing the need to maintain ecosystem integrity. Part I, 2(1) of that Act makes provision for the Minister (of Environment Affairs) to determine the " ... general policy to be applied with a view to -

(a) the protection of ecological processes, natural systems and the natural beauty as well as the preservation of biotic diversity in the natural environment;

(b) the promotion of sustained utilization of species and ecosystems and the effective application and re-use of natural resources;

(c) the protection of the environment against disturbance, deterioration, defacement, poisoning or destruction as a result of man-made structures, installations, processes or products or human activities ......"

This recent law has obvious relevance for the manner in which the remaining portions of relatively undisturbed fynbos are managed and utilized by exponents of the commercial wildflower industry.

These provisions are superficially encouraging from the ecological perspective. The clumsiness and inappropriateness of the political machinery does, however, instil a feeling of despair. In this case the Minister retains the power to make or rescind decisions regarding such environmental policies. This is done after consultation with a *Council for the Environment* (appointed by the Minister), and the Administrator of each province, and in concurrence with other Ministers, including the Minister of Finance, and the Minister of Economic Affairs and Technology. Given the historical precedent which favours domination of the political sphere by non-scientists generally, and non-biologists more specifically, legislation by no means ensures a rational ecological perspective. As was pointed out by Glazewski (1989), although the legislation broaches some compelling environmental principles, virtually all of the important provisions rely on the Minister of Environment Affairs gazetting their implementation.

The immediate legal framework within which the commercial wildflower producer must operate is provided by the Cape Provincial Ordinance No. 19 of 1974. This piece of legislation is accompanied by schedules listing, *inter alia*, the plants and animals which are endangered, and those which are protected. It prescribes the conditions under which the flowers of plant species in the above two categories can be picked and handled as a commercial commodity, as well as the conditions applying to unprotected indigenous flora. These conditions are complex, and involve: (1) the status of land-ownership and agreements between lessors and lessees; (2) the possession of permits for picking; (3) the registration and licensing of flora sellers; and (4) the possession of permits for exportation of flora from the Province. The regulatory measures placed on the different classes of flora are summarized in Figure 1-3. The maximum penalty stipulated by the Ordinance (as amended by Ordinance No. 11 of 1981) for first offences involving endangered flora is R 3000 (or 12 months imprisonment), or R 1500 (or 6 months imprisonment) for those involving protected and unprotected indigenous flora. As was pointed out by Greig (1984), there appears to be an imbalance between the values of the free-market, and those of the conservation ethic. This observation was made in connection with the blatant and willful contravention of several sections of the Ordinance by a wildflower harvester, who earned between 8 and 19 cents per flower (*sensu lato*) for a large proportion of the estimated 563 368 endangered and protected flowers which he picked illegally over a two year period, and who was fined R 300 for removing protected flora from a property without the owner's permission (plus 18 months imprisonment suspended conditionally for three years for theft from that landowner) (Greig 1984). Persistence of that type of bias will undermine the prerequisite intergenerational justice (Costanza and Daly 1987) which must underlie authentic conservation of our resources. For further discussion along these lines, see Chapter 8 of this thesis.

Also stated in the Provincial Ordinance is the 12 month limitation on the validity of "...any permit, certificate, written authority, licence or exemption issued thereunder..." (section 74), and the limit of 3 years in the case of a flora seller's licence (section 65). The imposition of a 12 month limit on the planning horizon of a commercial wildflower producer is probably wise while a strategy for management of the resource is incompletely resolved. It reflects the concern which nature conservation legislators have for preservation of the large number of endemic species which characterize the Cape flora. But with the growth of the wildflower industry, the agro-horticultural sector of the industry has developed a sophisticated understanding of the propagation and maintenance of both wild species and cultivars within the Proteaceae (Brits *et al.* 1983). The requirement for these producers to be answerable to laws designed implicitly for the protection of natural habitats, and explicitly for the protection of a flora constituting natural heritage, perhaps indicates a cue for reviewing the objectives of the relevant legislation. Provided that the practice of cultivation is maintained without any further annexation of the natural habitats of indigenous organisms, it may be profitable to

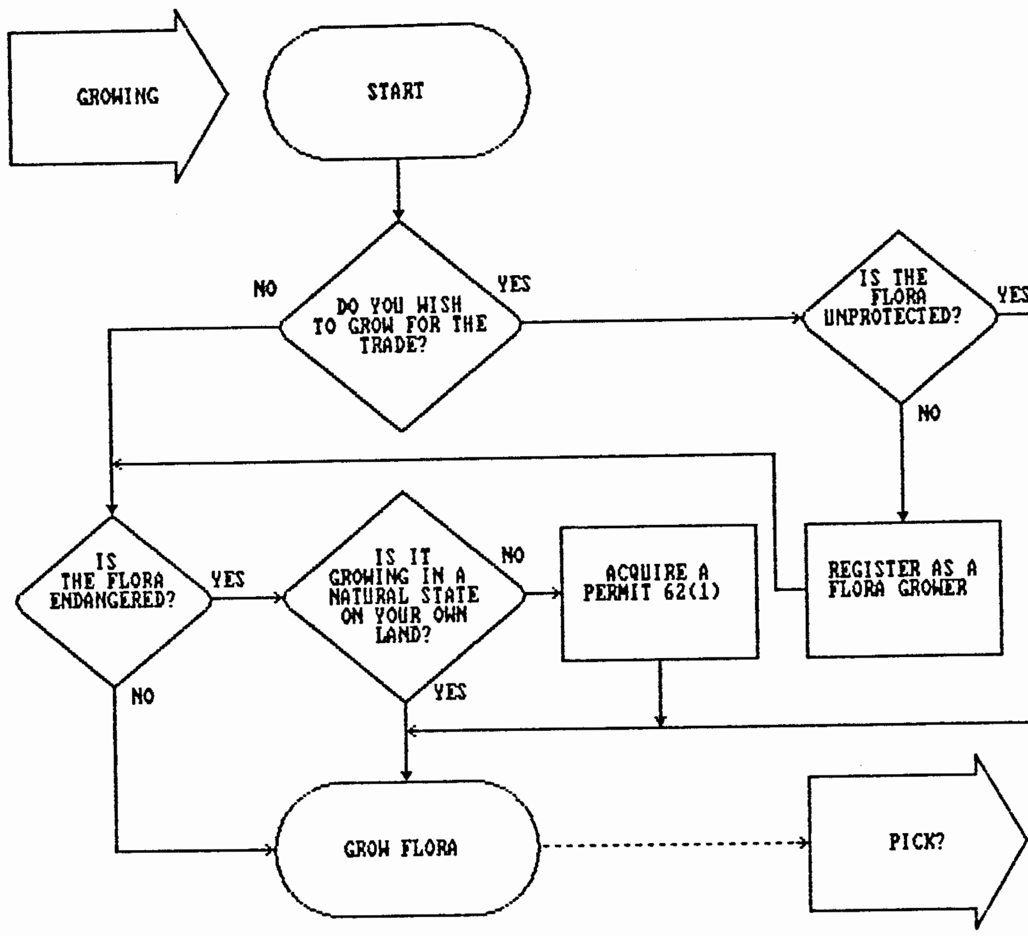


FIGURE 1-3A. A flowchart map for penetrating the legislation of Cape Provincial Ordinance No. 19 of 1974 (as amended). In order to determine the requirements and restrictions on any class of activity in the wildflower industry, proceed to the appropriate arrow and note the permits, licences or other restrictions encountered. Definitions used are those provided in the Ordinance, the key ones being as follows: FLORA means "...endangered flora, protected flora, indigenous unprotected flora, and includes the whole or any part of the plant, whether dead or dried"; ENDANGERED, and PROTECTED are those species specified in Schedules 3 and 4 of the Ordinance respectively; and to PICK includes "...cut, chop off, take, gather, pluck, uproot, break, damage, destroy". (See parts B to E on the following four pages for the remainder of this flowchart).

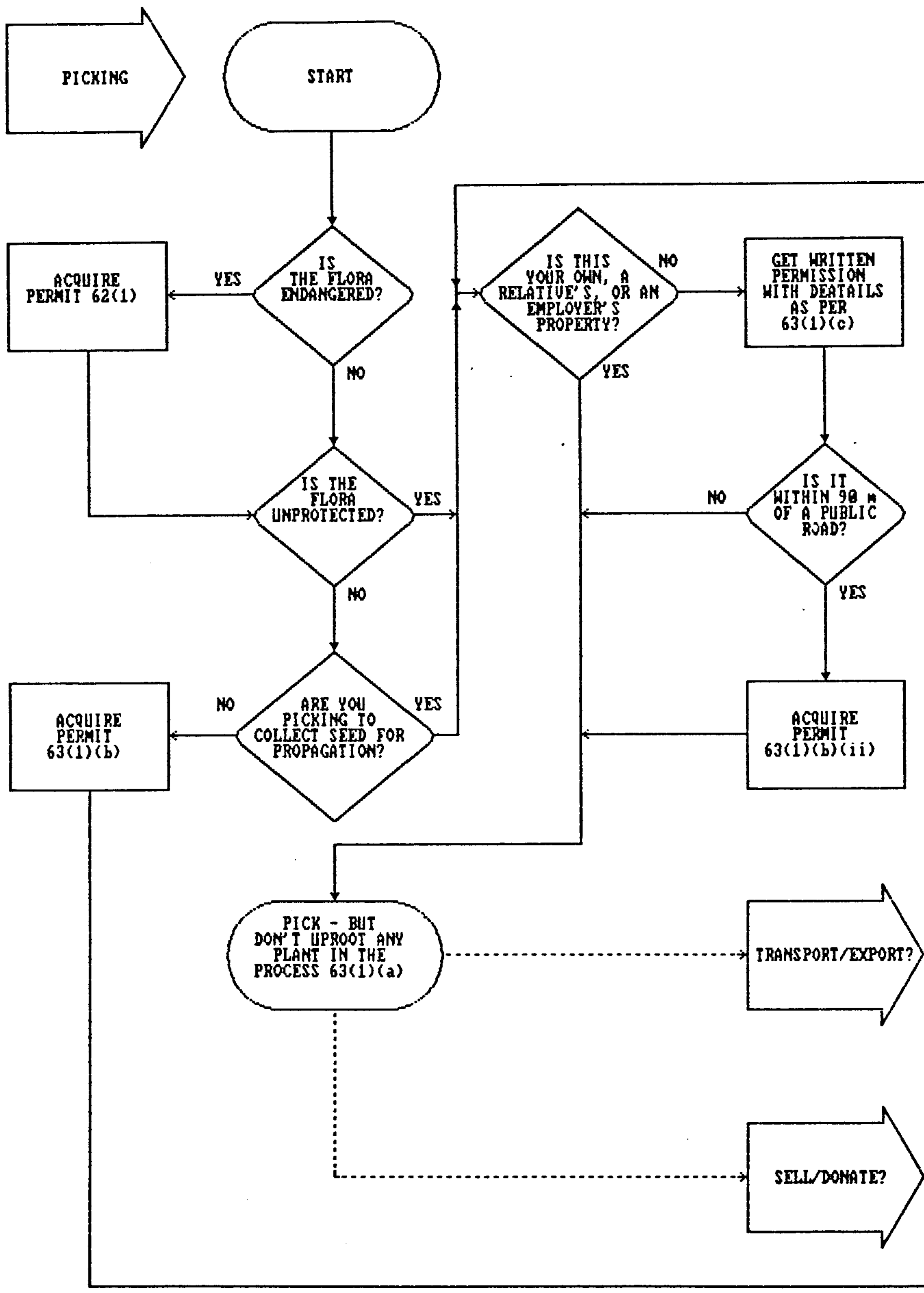


FIGURE 1-3B. (carried over from the previous page, and continued on the next)

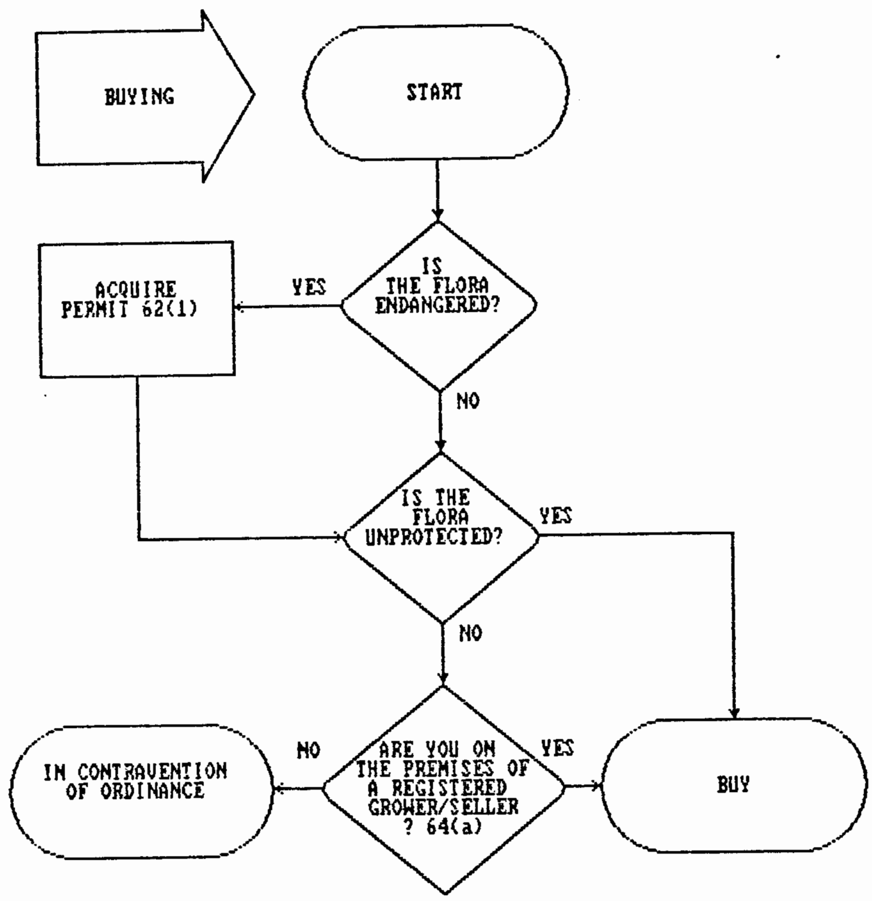


FIGURE 1-3C. (carried over from the previous page, and continued on the next)

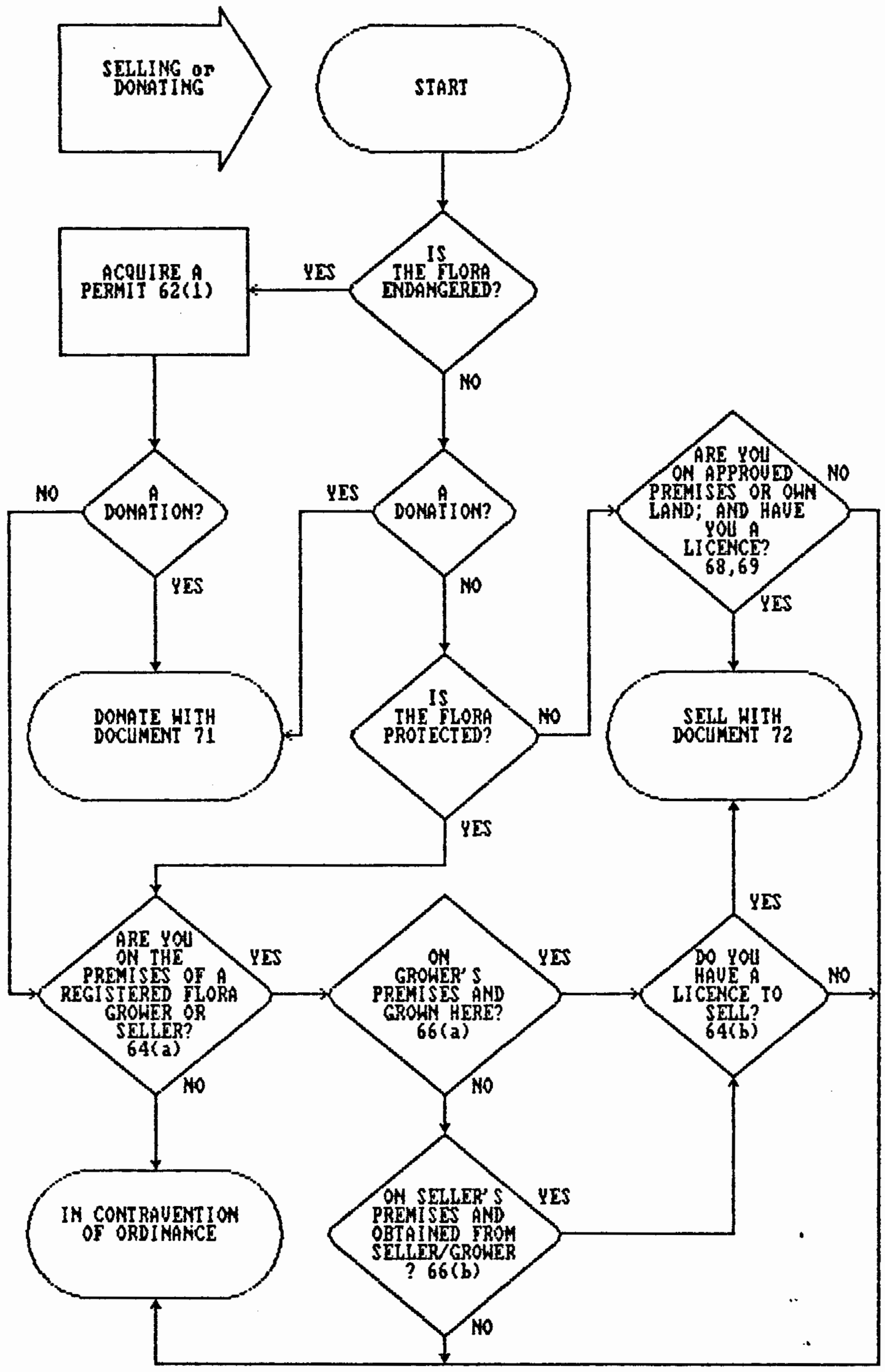
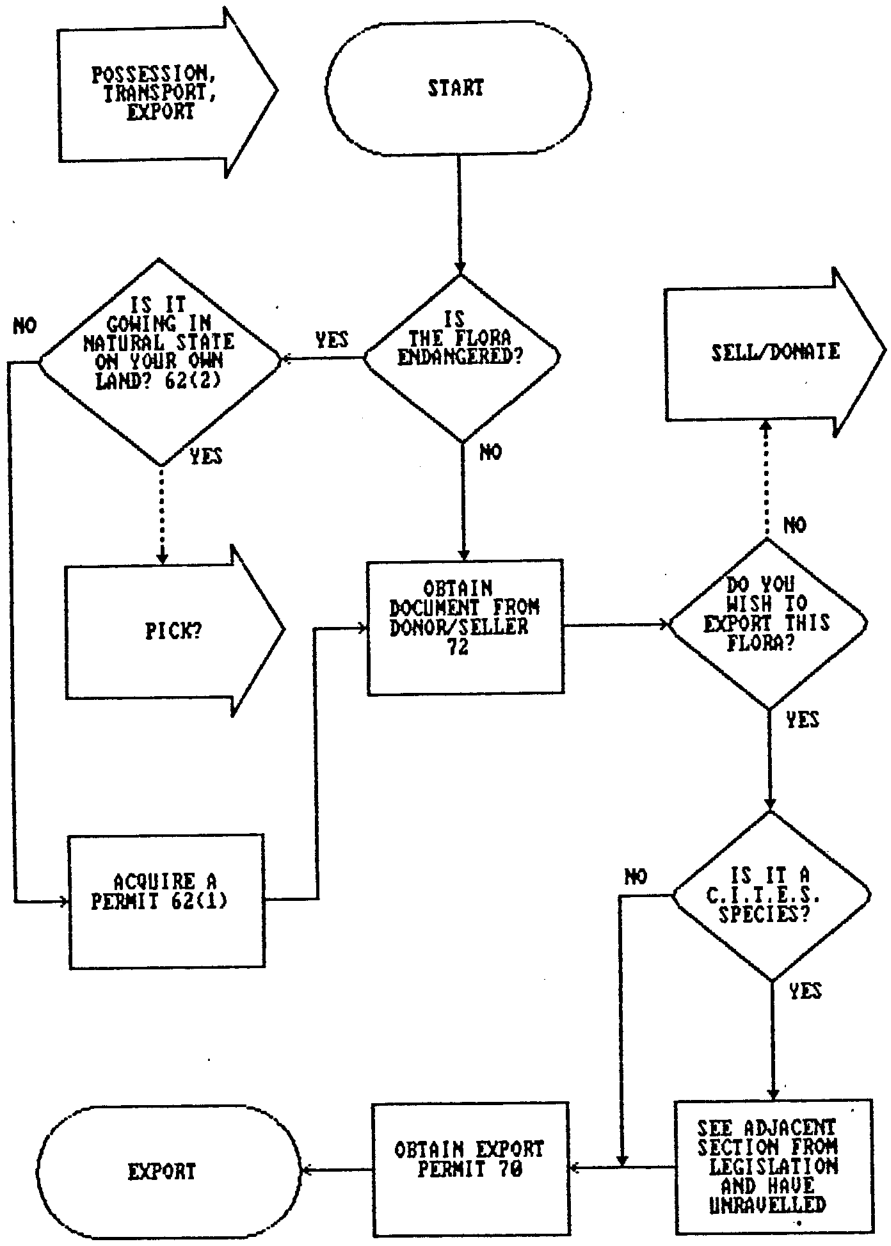


FIGURE 1-3D. (carried over from the previous page, and continued on the next)



AMENDMENT (No 26/1986) REGARDING THE *CONVENTION ON INTERNATIONAL TRADE IN ENDANGERED SPECIES* (C.I.T.E.S)

No person shall without a permit -

(a) export any flora from the Province; provided that the provisions of this paragraph shall not apply to the export by any person of any flora, except endangered flora and protected flora referred to in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora, Washington, 1973, which he legally obtained from any registered flora grower or registered flora seller who is the holder of a permit to export such flora contemplated by this paragraph; provided further that such person, while he is exporting such flora, shall be in possession, in addition to any document contemplated by sections 71 and 72, of a document in which the number and date of such export permit of such flora grower or flora seller are reflected, or

(b) import into the Province any protected flora (....specified under C.I.T.E.S.)

FIGURE 1-3E. (carried over from the previous page) release that portion of the industry which is well established in an horticultural sense from the constraints of protective conservation legislation. Veld-harvesting and marginal agriculture (*viz.* annexation of untransformed veld) are the practices which need to be under constant scrutiny of producers, conservators, and research ecologists if a formula for non-destructive utilization of fynbos systems is to be developed. The priority for finding solutions to the problems associated with natural veld utilization has been recognized by workers co-operating in a review of the industry's role in fynbos management (Greyling and Davis 1989). The network of conduits between the industry's sources and sinks, and the controls which are placed on it by the Provincial Ordinance, are summarized in Figure 1-4.

The checks and controls provided by the Ordinance may regulate human behaviour with regard to its exploitation of the fynbos as a resource, but as is pointed out by Fuggle and Rabie (1983), an essential component of a successful conservation is acquisition of the goodwill of landowners and other members of the community. The willingness of the landowner to co-operate with conservation measures was shown by McDowell and Sparks (1989), and McDowell et al. (1989), to bear a complex relationship with the cultural and educational background of the individual. Provision of economic incentives in the form of tax deductions and subsidies (McDowell 1986b), is probably a more successful means of acquiring co-operation of land-owners than is the promulgation of restrictive legislation (McDowell 1986a). Incentives to conserve, however, are not apparent in the legislation (McDowell 1986b), and landowners, through ignorance, may easily eliminate populations of rare or endangered species. In the Fynbos Biome, with its high degree of endemism (Hall and Veldhuis 1985), there is a high risk of this.

The Provincial nature conservation strategy, as administered by the Chief Directorate: Nature and Environmental Conservation (CDNEC) in the Cape Province, involves a certain amount of liaison work with wildflower producers. This includes site inspections prior to granting of a permit for the harvesting of species for commercial purposes (specified in the Ordinance), and an information brochure (published by CDNEC) which encourages land-owners applying for a permit to be wary of the dangers of leasing to irresponsible harvesters. The formalized portion of the industry, represented by the trade body South African Protea Producers and Exporters Association (SAPPEX), has filled an important niche in bridging the gap between the conservation authorities and the commercial user, both in the Cape and on an international level. By means of its in-house journal, *SAPPEX News*, it provides a channel for the flow of information regarding preferred methods of

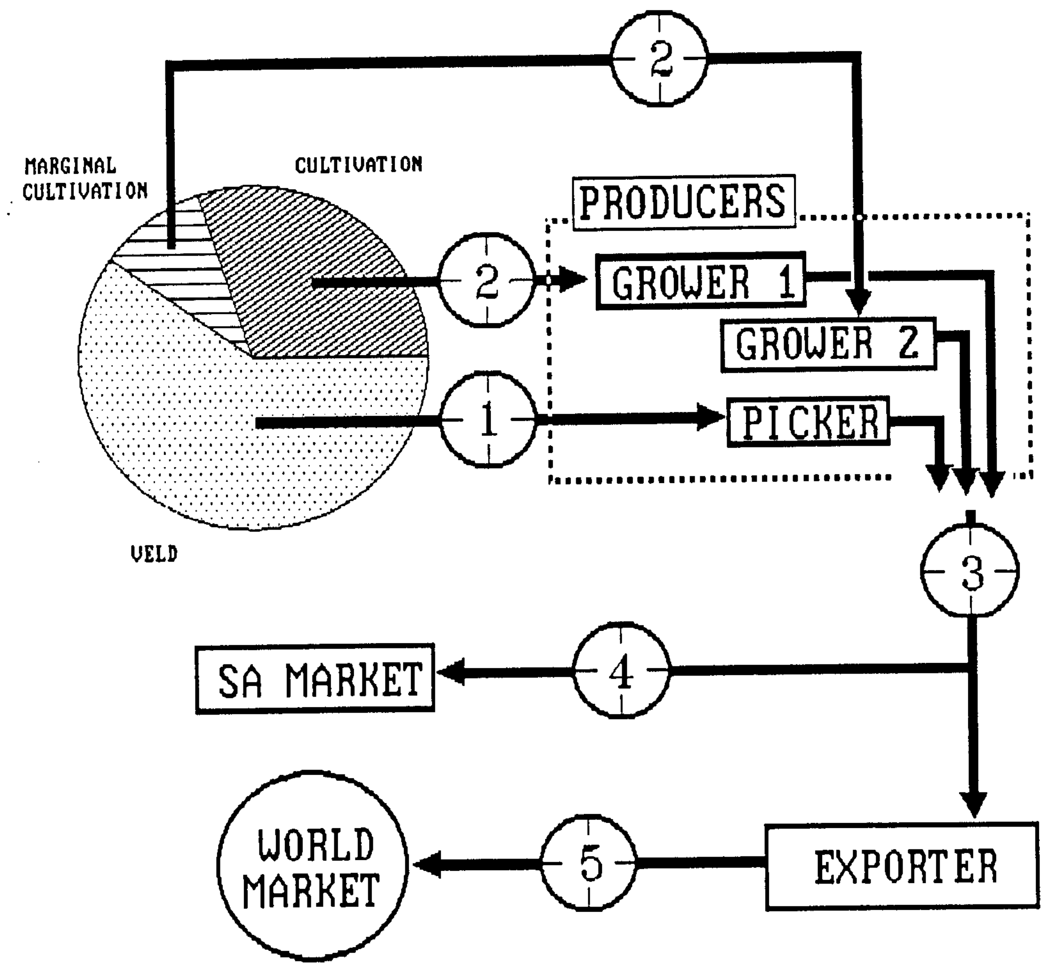


FIGURE 1-4. The flowpath of floricultural material from its fynbos source to local and international sinks. Producers are differentiated as discussed in the text, while the controls 1 to 5 summarize the mazes represented in Figure 1-3. Control 1 represents a permit, 2 includes registration as a grower, 3 involves registration and licensing for selling, 4 is a permit to export from the Province, and 5 includes the controls on phytosanitation, customs, etc.

management for exploited natural veld. Because it is rooted in the private sector, it has more credibility with the more sceptical members of the commercial wildflower production community, whose independent and pioneering spirit may be mistrustful of the uniformed authority of the CDNEC.

MANAGING RESOURCES

Equipping the toolbox of managers with effective and ecologically sound legislative tools is in itself no easy task. On the one hand it is entrenchment of historical values that provides the points of reference, and some of the safeguards against arbitrary and despotic action, while on the other this same inflexibility hinders the effecting of urgent changes that will become increasingly necessary for the conservation of resources in the future. Somehow our trust needs to be placed in the hands of practitioners whose moral integrity and will is not hampered by negative aspects of the bureaucratic edifice. A species can go extinct, or a plant community be destroyed by unsound and indulgent development far quicker than legislation can be mobilized to protect it.

Theoretical considerations

Economic models such as those of cost-benefit optimization are often valuable as an aid to understanding natural processes (eg Givnish 1986), but these are usually microeconomic parallels of resource partitioning and allocation (Rapport 1986). A more profound analogy has been attempted by Rapport (1986), who used broadscale macroeconomic theory as a standpoint for viewing ecosystems. Although incomplete as an analytic tool, this approach provides possible insights into the fluidity, unpredictability, and interconnectedness of ecosystem components. His recognition of ecosystem aggregation and complexity echoes the recent trends in ecological thinking which contemplate the complex influence of factors such as disturbance and stochasticity (Pickett and White 1985; Barbour *et al.* 1987). The addition of a human component to any ecosystem model represents a quantum leap in complexity. Yet for correct management of our diminishing resource base, its inclusion is a necessary step.

By reassessing the priorities and perceptions of land-use practice, it may be possible to reduce the disparities which have developed through historical time, and to maximize compatibility. A certain degree of conflict will, however, be inevitable. It would be difficult for instance, on the same parcel of natural fynbos land to maintain an intact natural plant community with its full floristic complement, as well as to produce high quality protea blooms for the export market, and even less to produce economical pine timber for the building industry. The question to be resolved is: "Which of these options is the most beneficial to present and future generations of *H. sapiens*?" The answer is clearly not a simple one, because it involves not only the philosophical stance of the questioner, but also a host of unpredictable variables describing the future systems. Custodianship of natural ecosystems is based on care of the human environment, and hence maintenance of the long-term practical and sustainable value of those systems to *H. sapiens*. This is in all respects, including the aesthetic, ethical, and economic reasons referred to by Kruger (1981). Keeping options open against unforeseen events or miscalculation is another important aspect of that commitment.

To create organizational structures for land management, we are forced to layer regulatory measures on existing frameworks of knowledge. But there are many weaknesses inherent in those knowledge bases due to severe limitations in our understanding of environmental interactions. Problems can arise when the underlying perceptions change, and we are left with a hollow bureaucratic crust originally designed for social, economic, and environmental stability, but which has been invalidated by unexpected events (Holling 1978). Although it is not possible to plan for the unknown, management policies need to be flexible and accommodate events which alter the knowledge base and highlight current practices as sub-optimal. International attention is being paid to these types of problems using an approach known as "adaptive management", which focuses on allowing rapid feedback of experience into policy (Holling 1978; Walters 1986).

The broader perspective

The search for models which integrate known phenomena into adequate descriptions of functioning systems, is the basis of the ecological perspective. The more complex a system is, the less likely it is that a model describing it will be accurate, and possess any degree of predictive power. Especially now that a rapidly expanding human population has reduced the environmental buffer space for the provision of resources, the absorption of effluent, and the physical accommodation of human biomass, the management of human affairs within the biosphere desperately requires to assess its options at the highest level of integration possible. Naveh and Lieberman (1984), in their treatise on landscape ecology and the growing need for an "holistic" approach to the planning, management and conservation of the environment, present an outline for the integrated management of mediterranean landscapes. They suggest that application of a multiple-use management approach for co-operative sharing of land resources between different interest groups, as proposed by the International Union for the Conservation of Nature (IUCN), would be particularly suitable for semi-agricultural systems. In the fynbos heathlands, the mixing of flower harvesting with water catchment, silviculture, and recreation is often a *de facto* reality, but formalization and extension of this philosophy to strictly administered conservation areas and privately owned land would require considerable adjustment of outlook. An even larger step which needs to be taken in the case of natural resource management in the Fynbos Biome, is that of accommodating the different cultural backgrounds of potential future users. A pointer to this is the recent (first noted) incident of bark being stripped from tree species in a local forest reserve in the Cape Town area, for use in the practice of traditional herbal medicine (Bowers 1990). This interface between ethnic demands on natural resources, and the conventional first-world conservation ethic, is an important aspect of resource management in South Africa (Cunningham 1985; Cunningham 1989). The economically induced influx of rural people into the western Cape clearly places new pressures on natural ecosystems, and education will have to play an important role in devising an equitable but effective strategy for conservation of those as resources for future human generations. If co-operation of this large immigrant population, as well as that of other underprivileged urban communities is to be obtained, then concepts of habitat maintenance communicable across both cultural and socio-economic barriers will need to be developed by the agents of conservation. A prerequisite for this type of communication, however, will be the attainment of certain fundamental political aspirations - most importantly the sharing of political power (Huntley *et al.* 1989) - which have been denied Black South Africans by the governing classes for the greater part of this century (Troup 1975).

Resolving conflicts of interest

Involvement of all classes of land-user is necessary if effective management techniques are to be developed. Havel (1986), who reviewed the phenomenon of land-use conflicts in mediterranean type ecosystems, perceived from a case study that scientists can play a contributory role in their resolution by providing objective assessment and arbitration. Clearly where compromises are made, an equitable sharing of the loss of benefits to interested parties must be decided upon. This is the difficult step, because the value of a parcel of land can be defined differently by different interest groups at different historical times, and an objective basis for judgement of relative needs and merits is far from complete.

Models and guides

The fundamental problem remains, however. The knowledge required to make correct decisions in managing and conserving the fynbos is far from complete. Over the past decade (1979 - 1989) the Fynbos Biome Project, a multi-disciplinary project co-ordinated and partially funded by the para-statal Council for Scientific and Industrial Research (CSIR) (Moll and Jarman 1984), has contributed significantly to the base-line knowledge of ecosystem function in the biome. Several research efforts arising from this project have addressed questions which either directly or indirectly focus on the use of natural fynbos as a resource for the wildflower industry. These include studies of seedbanks and their projected response to wildflower harvesting (Cowling 1989), and the potential effects of removing inflorescences from natural stands of plants on the nutrient pools of the host systems (Esler *et al.* 1989), as well as the direct responses of plant populations to the trauma of tissue removal (Rebelo and Holmes 1988). But the didactic models which might assist commercial producers, and integrate them into a co-ordinated management strategy are as yet poorly developed, with most scientifically acquired information shrouded in the uncertainties which characterize products of quantitative ecological research. With the growing awareness that co-operation of the commercial sector will be necessary for the conservation of the remaining natural biota, an effort is being made by some researchers to arrive at more immediately useful formulations of their work. In a synthesis of knowledge appropriate to management within the wildflower industry, Rebelo (1987), presented a simple model for the exploitation of "greens" species relative to observed growth rates. Milton (1987) tackled the problem of predicting safe commercial harvesting levels for four species of fern in the forests of the southern Cape, and came to the conclusion that a single annual harvest was the most intense utilization that any of these species could sustain, the detail of which was added to by Milton and Moll (1988) for one of those species, *Rhumora adiantiformis*. The CDNEC pamphlet (referred to above) advises landowners that "a general rule should be to remove no more than 80% of all flowerheads, seedheads or cones from individual plants of any type". Based on budgets of nitrogen and phosphorus, and the amount that may be exported in the flowerheads of proteaceous species, Cowling (1989) concluded that a more conservative annual harvest of 50% of the current years flowers would be unlikely to have negative system effects. Using unpublished seedbank data of four harvestable proteaceous species in the Agulhas Plain region, Mustart (*pers. comm.* 1990, University of Cape Town, Botany Dept.) proposed a more stringent picking formula of a 50% harvest every second year for the large flowered Protea species, which serves as a supplement to the guideline derived by Forestry researchers who suggested a maximum harvest level of 50% for foliage, 60% of healthy and well-formed flowers, and complete abstinence from harvest the year before a prescribed management burn (Manders 1989). In this thesis I present an heuristic computer model to predict the jeopardy to natural populations of indigenous plants against a backdrop of economic constraints and incentives. But all of these attempts are based on small, specific, patchy, or sometimes non-existent data-bases. The challenge to conservation researchers is the identification and tackling of problems which might contribute optimally to insights at the ecosystem and landscape level. The time required to build management strategies brick by informational brick from reductionist certainties, will in all probability be greater than the expected life of most of those systems under the present circumstances of environmental degradation.

Fynbos wildflower resource management

The historical pattern of land tenure in South Africa leaves much of the natural mountain fynbos veld in private hands - privately-owned mountain catchment and protected forest areas constitute 31% of this vegetation type, a figure close to the 42% which is permanently conserved in state and semi-state conservation areas (Hilton-Taylor and le Roux 1989). Combined with a complex set of laws and regulations, this places the onus on landowners to act as custodians of natural resources such as fynbos. An anomalous and telling legal situation exists where a landowner may be entitled to plough up a natural plant community for an uncertain farming venture in terms of the Conservation of Agricultural Resources Act No. 43 of 1983, while he may be prosecuted for picking flowers from the same plants under the Provincial Ordinance No. 19 of 1974.

The relationship between the wildflower industry and fynbos conservationists is a small part of the total land-use management problem. It is complicated by the cultural differences that exist between traditional herbalists and suburban hikers (each with a different perception of the value of bark from indigenous trees), or between cross-country motor-cyclists and bird-watchers. What is important in that relationship is the common interest in maintaining fynbos vegetation in a productive state. This common ground provides the opportunity for addressing issues arising from the differently motivated interests and perspectives of the parties involved: *viz.* commercial producers of wildflowers (who are doing the human thing of utilizing a resource), biological researchers (who are attempting to develop insights into the workings of nature, and humanity's impact on it), and conservation managers (who have the Herculean task of deciding what's best for everyone for posterity). The starting point is the common ground between the parties with vested interests in conserving the resource. More difficult, and the part that needs to be actively pursued, is consideration of the elements which lie outside of that safe area of mutual benefit. And beyond that lies the *world problematique* (Ozbekhan 1976), the total human environment with its multiplicity of interactive functions, which has to be resolved, understood, and manipulated, if land is to be managed, and ecosystem functions preserved.

A FOOTNOTE ON SCIENTISTS

Scientists, it has been noted, are able to play an important role in the complex business of establishing viable management policies because of their (relatively) impartial approach to problem-solving and phenomenon observation. Regrettably legislation is more prone to the influence of vociferous campaigners than to the reticent and guarded expositions from the scientific community. A partial solution would be for scientists to become more involved in the political processes both to gain access to the medium, and to develop insight into the socio-political aspects of human ecosystems. To quote Havel (1986): "I believe that besides being scientists we are also part of the human race and we cannot stand by whilst far-reaching decisions are being made, seeing we have a valid contribution to make".

CHAPTER 2

PREDICTING JEOPARDY TO FYNBOS PLANT POPULATIONS EXPLOITED BY THE WILDFLOWER INDUSTRY

- a model called VELDFLOW, in which the the influence of financial well-being and ecological awareness of an exploiter are considered.

INTRODUCTION

The commercial value of a natural ecosystem is necessarily relative to a human perspective, and is biased by the economy of the society with custodianship over it. This is a fact which is becoming increasingly important in conservation thinking, especially where local cultural values are integrated with that custodianship and can effect some form of sustainable utilization (Cunningham 1985; Moll and Moll 1989a; Moll and Moll 1989b). In the southern and south-western Cape the original land-users were the hunter-gathering Khoisan people, who maintained their subsistence economy until pastoralism was introduced approximately 2000 years ago (Deacon 1986), although their presence might have altered the natural fire regime (Macdonald 1989). The expansive technologically-based cultures that arrived during the European colonial era (17th century and later), imposed a very different type of land-use pattern on the region. This chapter attempts to address some of the problems encountered in the reconciliation of the modern human economy with the value of natural ecosystems in the Fynbos Biome. It adopts the perspective of the wildflower industry in the south-western Cape, South Africa, and simulates the activities and decision-making processes of a small commercial operator, who at a stretch of the imagination, could be considered as a type of modern hunter-gatherer.

The Cape wildflower industry draws almost exclusively on the heathland vegetation of the Fynbos Biome as its resource, and annually exports more than 2×10^6 kg of fresh material, and considerable amounts of dried plant products (Middelmann *et al.* 1989) to markets concentrated in western Europe. Fresh material comprises two major categories *viz.* (1) showy inflorescences mostly of the proteaceous genera *Protea* and *Leucospermum*, and (2) the textured filler material (called "greens" in the trade) which includes small-flowered species such as *Erica* (Ericaceae) and *Phylica* (Rhamnaceae), and *Leucadendron* species with brightly coloured leaves and cone-like inflorescences. Dried flowers are mostly of the Asteraceae, and include genera such as *Helichrysum*, *Edmondia*, and *Phaenocoma* (Simpson 1985).

The objective of this work was to construct a computer-based system for assessing: (1) results of the consumer demand for decorative wildflowers harvested from natural populations of fynbos plants; and (2) models of the biological capactiy for those populations to meet that demand. To place the exercise in a commercial context, and one of which ecologists and conservationists are becoming increasingly aware (Huntley *et al.* 1989), the routine was constructed to simulate the decision-making processes of a veld harvesting wildflower producer whose economic gains could be seen in relation to the impact of exploitation on the modelled plant populations.

MODELLING APPROACH

Models describing population growth and its limits in natural organisms have been a tool of quantitative ecological research since the pioneering work of Lotka and Volterra in the 1920's (Jorgensen 1986). These abstractions have reached a high degree of sophistication for some aspects of natural resource conservation, such as decision-making for harvest levels in the fishing industry (Clark 1976, Bergh and Butterworth 1987), or the management of wildlife/rangeland systems (Starfeld and Bleloch 1986). Classical population models are difficult to apply to the problems of fynbos management for the wildflower industry because of the patchy nature of the vegetation used as a resource. Animals such as fish or game are generally mobile with respect to their nutritive environments, and their populations are governed by ongoing demographic processes of recruitment and depletion. The aggregation of environmental factors is therefore often sufficient for modelers to assume levels of homogeneity which permit the use of elegant mathematical techniques for describing variables such as primary productivity at a landscape level, consumption of primary production during grazing and browsing, secondary production of biomass by the animal populations themselves, *etc*. The populations of fynbos plants exploited by the wildflower industry, on the other hand, are sessile and usually parts of communities in landscapes with complex floristic structure. Their host systems are driven by intermittent disturbance of fire (Kruger and Taylor 1979; Campbell and van der Meulen 1980; Bond 1983; Breytenbach *et al.* 1986; Cowling 1987). The varied topography in this mountainous region, and the somewhat stochastic nature of the fire events both in time and space, make it unamenable to classical modelling methods. Perspectives which include long time-periods, or large areas would assist in smoothing out the large scale patchiness inherent in fynbos vegetation, but that would ignore the diversity upon which the wildflower industry depends, and blur the resolution needed to identify the individual species threatened with local extinction by overutilizaton, an event that might occur if factors such as the size of seed-stores and fire regimes are not properly managed (Bond *et al.* 1984; Kruger and Bigalke 1984).

The model described in this chapter has been dubbed VELDFLOW, and adopts a coarse "bottom-up" approach which is detailed below. Plant populations of different species were regarded as discrete entities, each with their own independent contribution to the resource-base from which the hypothetical producer operated. (This producer for convenience will be referred to as WILFRED, the **WIL**d**F**lower **RE**source **D**ealer.) The rationale was to provide the producer with information at regular simulated time intervals which described (1) the types and quantities of material available from the veld, and (2) the amount that the market was willing to absorb, and at what price. He was then required, according to selectable criteria of profit and conservation-mindedness, to decide how much to harvest. By applying modelled plant responses to the actions of the producer, VELDFLOW's task was to monitor: (1) the fate of individual plant populations; (2) a measure of their propagule store; and (3) the financial well-being of the producer.

For this project the practice of direct veld utilization in the fynbos vegetation by the wildflower industry was assumed to be embodied in a system defined by three fundamental units. These units were taken to be: (1) the resource component, made up of the populations of exploited species; (2) the producer component (WILFRED), representing the wildflower producer; and (3) the economic and regulatory component which influences the producer in the making of financial, legally obligated, and ethical decisions regarding the business.

During execution of the model, the state of the total system is determined on an annual basis. The resource and economic components are used to influence the decisions made by, as well as the financial well-being of, WILFRED (see Figure 2-1). Adjustment is made in the following annual cycle to the resource state according to the estimated impact of harvesting during the current season. The biological processes of the resource component (*viz.* life history, phenology, seed store, and population dynamics of the commercially important species) have not yet been fully characterized by botanical research, and accessible data describing material and revenue flow between producer and consumer is scant (Middelmann *et al.* 1989).

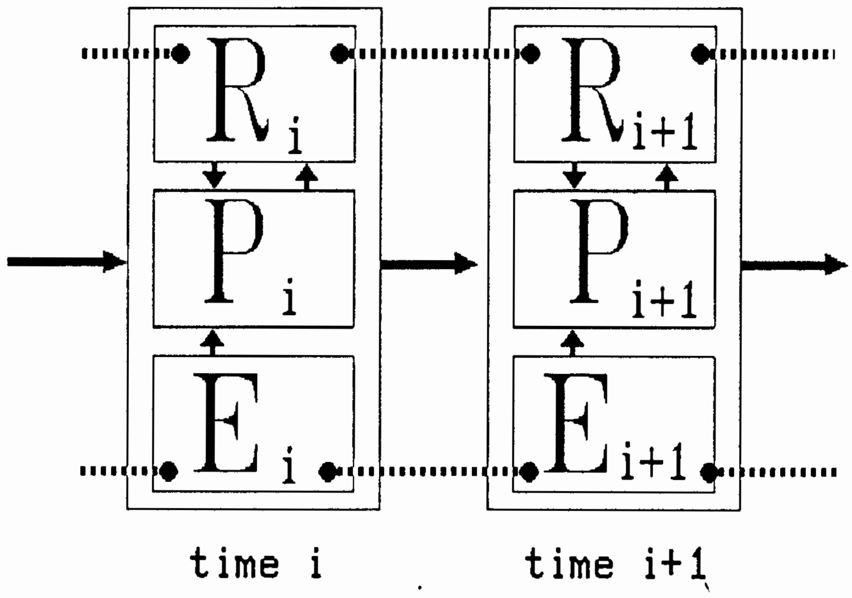


FIGURE 2-1. Compartments of the model VELDFLOW housing components of the resource environment (R), the economic environment (E), and the production outfit (P), representative of a wildflower producer. These together form the structure of the whole model which moves through time in discrete steps, with R and E compartments impinging on P to influence decisions regarding the harvesting. Feedback of harvesting on R is considered for the next step, while influence of the producer on the market (E) is taken to be negligible. Both R and E have their own underlying time dependent patterns, signified by the broken horizontal lines.

For these reasons I decided to place the model on an heuristic basis to allow manipulation of most variable values at the node points between financial years (the boxes of Figure 2-1). In this way the user of VELDFLOW may override the variable values generated by the model and simulate unique phenomena such as the effects of a pathogen epidemic, an extreme drought, an economic depression, or a change of conservational attitude by WILFRED.

STRUCTURE OF THE MODEL

The biological resource component was subdivided into four submodels. These describe the availability of commercially useful material, and the response of plants to utilization both at an individual, and at a population level. The commercial component of the model has, due largely to the lack of background information, been treated as a simple pattern of demand from the market, with WILFRED being too small to have an influence on its behaviour. Details of the submodels are described below.

Phenology submodel

The main source of natural variation in the quantity of material available for the market recognized by this model, is the seasonality of the growth, and reproductive phases in the life cycle of the commercially useful plant species. Although there is some detailed information available describing the pattern of flowering in a few fynbos species (Sommerville 1983; Pierce 1984), most accessible material is contained in anecdotal form in the "floras" and field guides which cover the area (*e.g.* Adamson and Salter 1950; Kidd 1973; Burman and Bean 1986), with observations of the approximate time and duration of the flowering period. For the purpose of the phenology submodel, the flowering period of each species (also assumed to be the period of usefulness to the wildflower producer) is taken to be according to a Gaussian distribution between start and finish of flowering, covering a total of eight standard deviations. Hence the distribution of material available during any week of the year is given by:

$$f = (1/(\sigma\sqrt{2\pi}))\exp -\tfrac{1}{2}(x^2/\sigma^2) \quad \text{..........(1)}$$

$$\text{.......for } x_0 < x < x_f$$

$$\text{and} \quad f = 0 \quad \text{.......for all other } x$$

where w = week of year;
w_0 = start of flowering;
w_f = end of flowering;
$\sigma = (w_f - w_0)/8$;
$x = (w - w_0)$;
$x_0 = -(w_f - w_0)/2$;
and $x_f = +(w_f - w_0)/2$

Life cycle submodel

During the period that any population of plants is useful to a wildflower producer, the development of individual plants from seedling through maturity to senescence must be taken into account. In the case of the fynbos, the fire prone vegetation is predominantly even-aged. For the purposes of this submodel, all plant populations are assumed to be synchronous with regard to the development of member individuals, and that it takes place in four phases. On an annual basis therefore, the flowering pattern described in equation (1) is modified by the following age-related productivity function to give an average yield per plant of:

$$
\begin{aligned}
Y' &= 0 && \text{for } a < a_0;\\
Y' &= (a - a_0).Y / (a_1 - a_0) && \text{for } a_0 < a < a_1;\\
Y' &= Y && \text{for } a_1 < a < a_2;\\
Y' &= Y.(P/(a - a_2) && \text{for } a_2 < a
\end{aligned}
\quad \text{.....................(2)}
$$

where Y = maximum intrinsic yield per plant;
a = age of plant;
a_0 = age of first flowering;
a_1 = onset of maturity;
a_2 = onset of senescence;
P = decay rate factor $(0 < P < 1)$

Response to pruning submodel

It has been noted by workers involved with horticultural aspects of the wildflower industry, that plants, especially those in the Proteaceae, may respond either negatively or positively to the pruning associated with harvesting (Brits *et al.* 1986), and that this may alter the productivity of plants in the following years. A submodel was introduced to VELDFLOW to take this type of response into account. It allows for a stepped response of plant productivity to different levels of harvesting intensity. As set up for the sample runs described in this chapter, one of four responses is assumed to be evoked, which alters the quantity of material available in the following year, depending on the quantity that was removed during the current one. This step function describes a factor (c) by which yield is adjusted proportionally:

$$\begin{array}{llll} & c = c_1 & \text{for } h \leq 0.25 & (\text{harvest} < 25\%) \\ \text{or} & c = c_2 & \text{for } 0.25 < h < 0.5 & \\ \text{or} & c = c_3 & \text{for } 0.5 < h < 0.75 & \\ \text{or} & c = c_4 & \text{for } 0.75 < h & (\text{harvest} > 75\%) \end{array} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Population response submodel

Another assumed effect of commercial utilization of a natural plant population, is the physical damage which the harvesting process can induce by severity beyond a safe limit. In this instance a submodel reduces the population size by an amount proportional to the degree that the safe limit of harvest was exceeded. This takes into account the killing of plants by over-pruning through loss of photosynthetic or meristematic tissue (Rebelo and Holmes 1988), or indirectly through the decimation of populations by access paths (Manders 1989). This simple factor is given by:

$$\begin{array}{lll} & m = 0 & \text{for } h < H \\ \text{or} & m = (h - H)/(1 - H) & \text{for } H < h \end{array} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where h = actual harvest level;
and H = the nominal safe harvest limit

The combined production component

Combining the four submodels described above gives a general formulation for the production of floricultural resource material (R) by any one population of plants during a single year as:

$$R = \Sigma\, m.N.f.c.Y' \qquad \text{over the 52 weekly steps}$$

where N is the population size for the given year.

The market demand submodel

The demand relationship between the market and the producer is assumed to be described by a simple seasonal pattern which was derived from the published statistics of exported material (Figure 2-2). Those data also gave a coarse division of different classes of material, which has been included in this simple market component of the model. Although not included in this version of the model, the option of changing the market demand from year to year can be invoked with a minimum of reprogramming.

General operation

Each annual cycle of the model simulates the processes which occur during a year in the life of a producer (WILFRED), who is dependent on the harvesting of wildflowers for part of his income. The variables considered by the model are those impinging on the financial state of the producer. These have been assigned interactive relationships with that central variable, as displayed in Figure 2-1. The overall structure of the model and its operational flow are given in the flow diagram (Figure 2-3), showing the annual cycle which the model simulated in order to move the system from one state to the next. Each of these annual actions is subdivided into 52 weekly transitional steps to accommodate the seasonality of market demand, and the phenology of the floricultural resource material. Although the emphasis is on flowering material, and estimates of seedstore for population maintenance are derived from the distribution and yield of commercially valuable material from submodels (1), (2), (3) and (4), those patterns may also describe the availability of non-reproductive material for sale in the market-place.

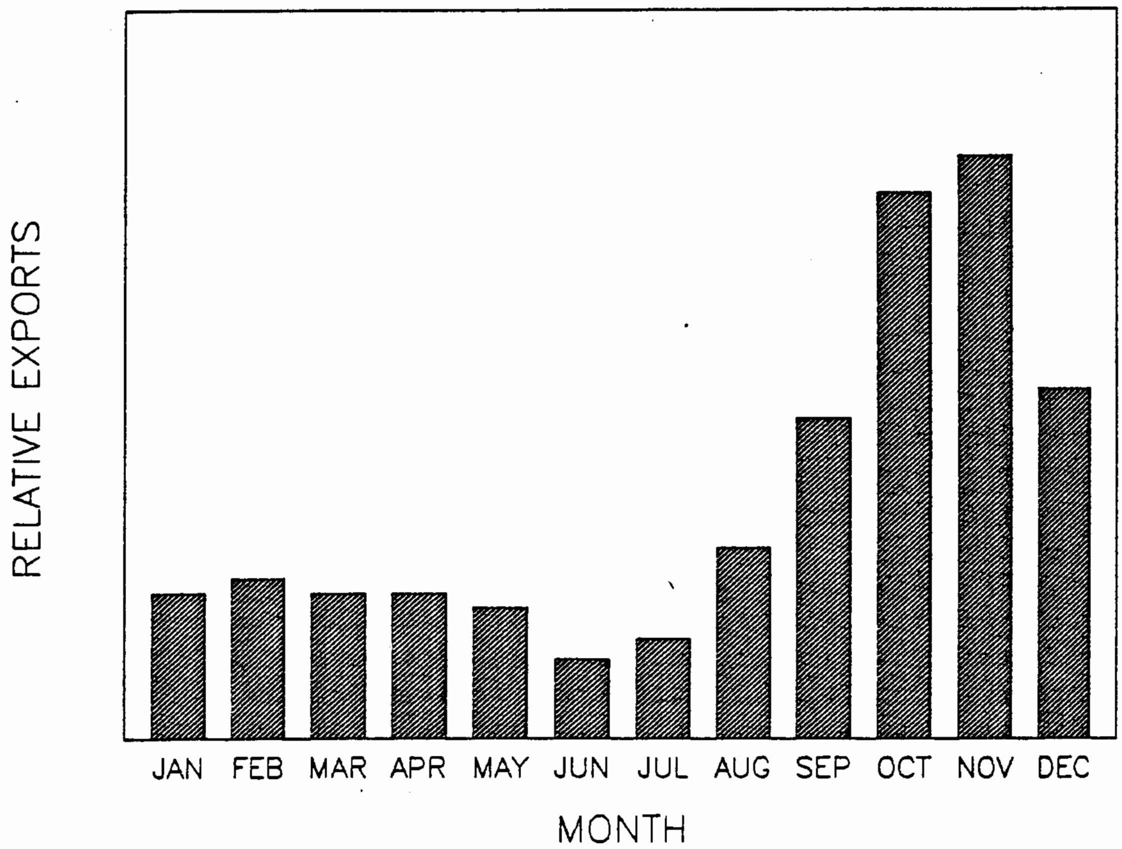


FIGURE 2-2. The assumed pattern of market demand for produce from the veld over an annual cycle. This is based on the export figures for fresh material from South Africa between 1979 and 1986, and reflects the high demand for floricultural material in the early northern hemisphere winter.

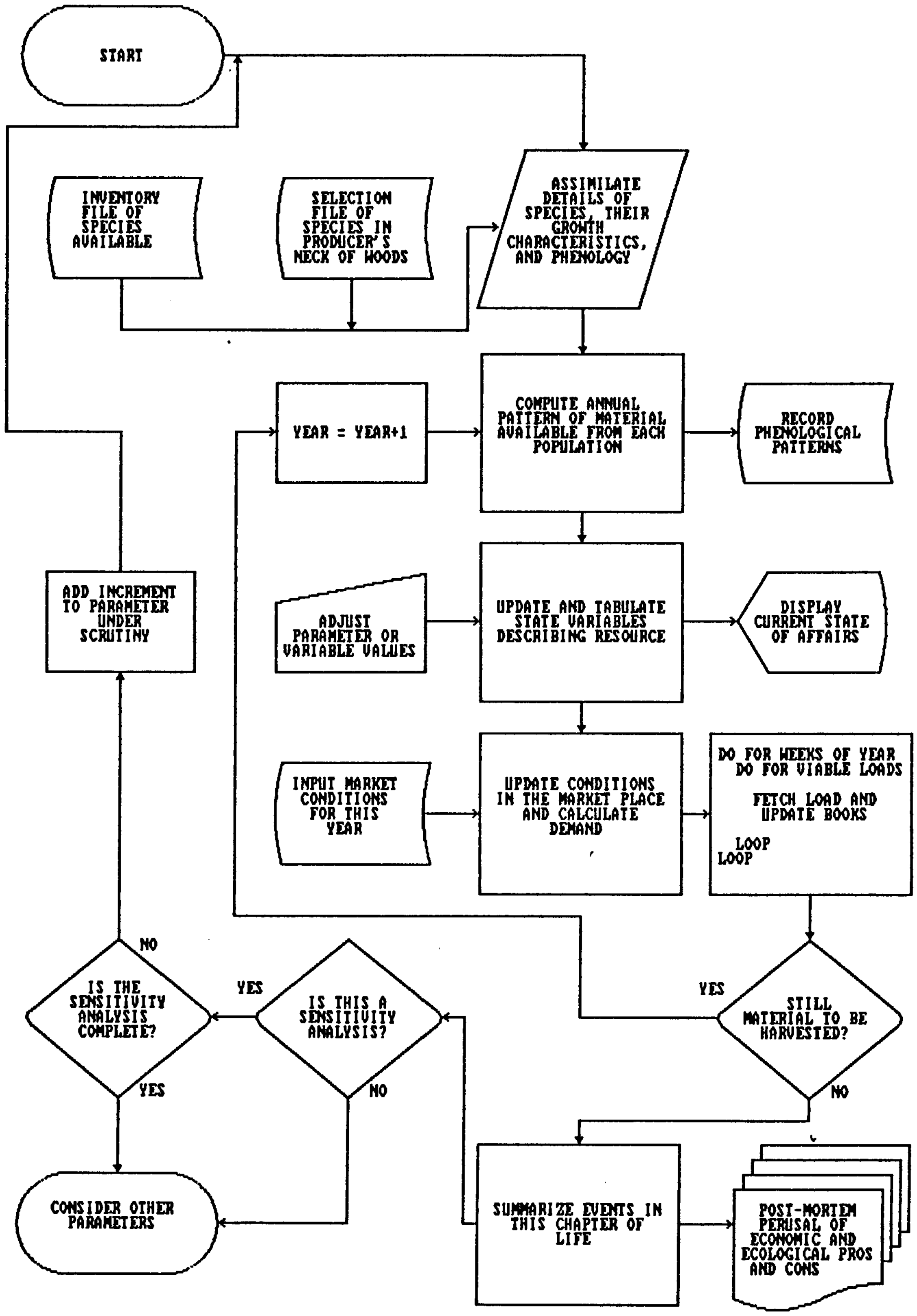


FIGURE 2-3. A flow chart of the VELDFLOW programme as finally formulated, showing the main points of data input and output, and where heuristic manipulation can be applied.

Selection of species and their characteristics

For a single run of the model, the user selects from the inventory list (file SPPCHARS.PRN) the species that WILFRED will utilize. Also contained in that inventory are the intrinsic characteristics of the listed species as far as is known (Table 2-1), while the details of the specific populations which are to be exploited are contained in the producer's request file (POPCHARS.PRN) whose contents are listed in Table 2-2. The intrinsic character descriptors include details of the species' life cycle (i.e. age of first flowering, age at maturity, age at onset of senescence, floricultural yield, and the rate at which productivity drops off during senescence. The seasonal distribution of flowering (or otherwise floriculturally useful) tissue is assumed to follow a Gaussian distribution between the given starting and termination dates (Equation 1). This underlying information regarding seasonality of the resource is determined by a subroutine RESOURCEOUT, and is stored in an output file (RESOURCE.PRN). Typical annual distributions of this material are shown in Figure 2-4. This basic pattern of material availability is then adjusted for each annual cycle according to the lifecycle pattern determined from the input variables.

Impact of utilization on a species is assumed to occur in the two possible ways described above as the pruning and population response submodels. Either production of floriculturally useful material is affected positively or negatively by the harvesting of material, or population size may be reduced through overutilization *viz.* plants are killed by excessive reduction of photosynthetic tissue, trauma of excision, or incidental trampling associated with that harvesting level. In the case of pruning response, yield for the following year is adjusted by a factor associated with a stepped utilization/response relationship included in SPPCHARS (Table 2-1, columns G to K). Mortality is assumed to occur in direct proportion to excessive harvesting above a critical level (Table 2-1, column F), which can also be independently specified for each species, and which in the model is arbitrarily defined as the legal limit - an unlikely case of conservation managers being in exact agreement with nature. Where it has a fixed value as described in this chapter, it has been set at an arbitrary 50%, a level of harvest estimated by Esler et al (1989) to be safe with respect to loss of nitrogen and phosphorous from exploited stands of *Protea* species, and one recommended for foliage harvest in guidelines set by

TABLE 2-1. An inventory of the species from which the producer, WILFRED, may select his resource set. Included are descriptors of the intrinsic properties of each according to the following column identifiers: Column headings: A = type; B = desirability (not used); C = yield (kg)/plant; D = start of flowering (week); E = end of flowering (week); F = safe harvest (%); G to K = productivity response to pruning; L = age at first flowering (years); M = end of juvenility (years); N = onset of senescence (years); P = decay rate during senescence (% per year compound).

ID#	SPECIES	A	B	C	D	E	F	G	H	J	K	L	M	N	P
1	Protea repens	1	10	7	23	35	50	100	70	40	10	5	9	13	50
2	Protea neriifolia	1	10	8	19	31	50	100	70	40	10	5	9	13	50
3	Protea compacta	1	10	6	27	35	50	100	70	40	10	5	9	13	50
4	Protea longifolia	1	4	2.5	40	52	50	100	70	40	10	5	9	13	50
5	Protea sussanae	1	9	5	45	5	50	100	70	40	10	5	9	13	50
6	Protea magnifica	1	10	8	23	35	50	100	70	40	10	5	9	13	50
7	Protea mundii	1	8	3	36	48	50	100	70	40	10	5	9	13	50
8	Erica longifolia	2	9	2	14	31	50	100	70	40	10	3	5	15	50
9	Leucadendron xanthoconus M	2	5	3.5	1	52	50	100	70	40	10	3	5	15	50
10	Leucadendron spissifolium	2	8	5.5	33	42	50	100	70	40	10	3	5	15	50
11	Erica plukenetii	2	7	2.5	1	52	50	100	70	40	10	3	5	15	50
12	Leucospermun truncatulum	2	2	4	33	50	50	100	70	40	10	3	5	15	50
13	Leucadendron xanthoconus F	2	2	5	35	20	50	100	70	40	10	3	5	15	50
14	Phaenocoma prolifera	3	2	2	37	7	50	100	100	100	100	1	3	7	50
15	Helichrysum vestitum	3	2	0.1	46	3	50	100	70	40	10	1	3	7	50
16	Edmondia pinifolia	3	2	0.1	37	7	50	100	70	40	10	1	3	7	50
17	Brunia albiflora	2	2	3	11	15	50	100	70	40	10	3	5	15	50
18	Brunia nodiflora	2	2	3	11	24	50	100	70	40	10	3	5	15	50
19	Brunia laevis	2	2	3	33	3	50	100	70	40	10	3	5	15	50
20	Staavia radiata	2	2	3	1	52	50	100	70	40	10	3	5	15	50
21	Berzelia alopecuroides	2	10	3	37	3	50	100	70	40	10	3	5	15	50
22	Erica longiaristata	2	10	2.5	50	15	50	100	70	40	10	3	5	15	50
23	Erica patersonia	2	10	2.5	15	33	50	100	70	40	10	3	5	15	50
24	Erica holosericea	2	4	1.5	37	46	50	100	70	40	10	3	5	15	50
25	Erica sessilifolia	2	9	1.8	15	37	50	100	70	40	10	3	5	15	50
26	Protea holosericea	1	10	1.5	24	37	50	100	70	40	10	5	9	13	50

TABLE 2-2. The species selected by the producer for exploitation during the simulated 20-year period covered by VELDFLOW. Species identities in the first column are selections from the sequential list of Table 2-1. See text for a description of the other parameters.

SPECIES	POPULATION SIZE	DIRECTION	DISTANCE (km)	VALUE (R/kg)	HARVEST LEVEL (%)
1	1000	2	10	1	100
2	1000	1	10	1	100
3	1000	7	10	1	100
8	1000	2	10	.25	100
11	1000	6	10	.25	100
13	1000	4	10	.25	100
14	1000	2	10	.1	100
15	1000	6	10	.1	100
17	1000	7	10	.25	100
21	1000	6	10	.25	100
23	1000	5	10	.25	100

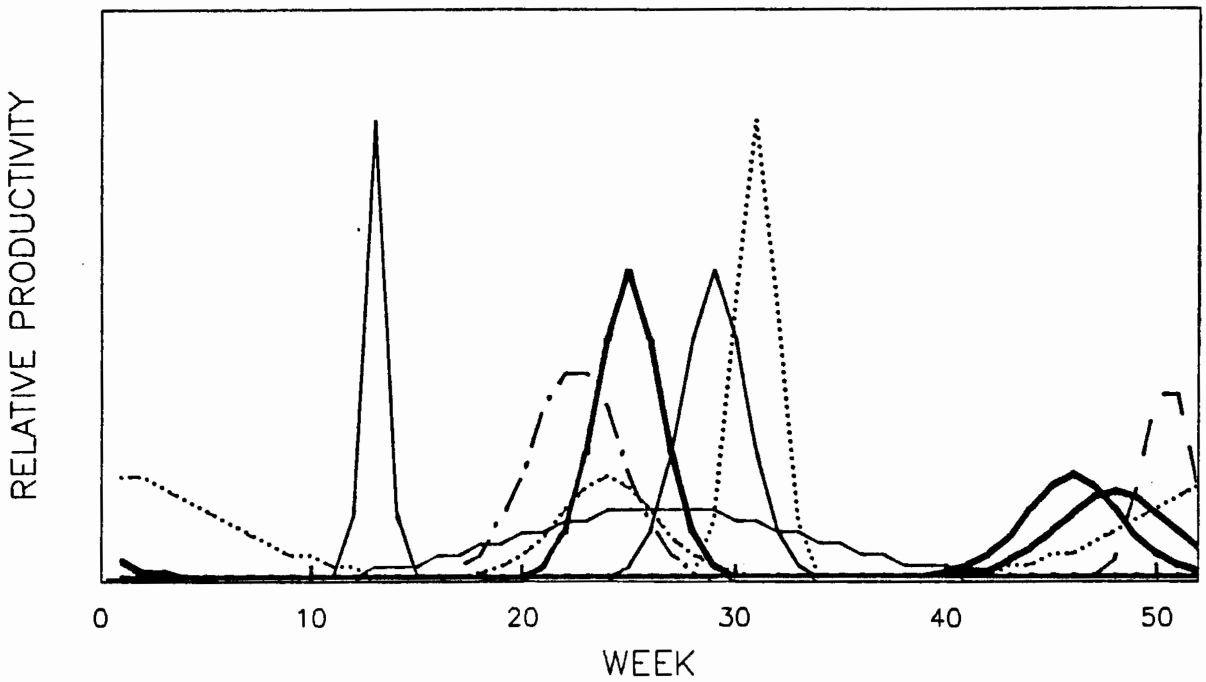


FIGURE 2-4. The annual availability of floricultural material from the 11 species as selected for the run described in this chapter.

conservation authorities (Manders 1989). Files are updated annually to monitor WILFRED's financial status, and to keep a record of the fate of each plant population. In cases where the material taken as yield is representative of reproductive tissue, output can (in the case of reseeding species) be obtained which may be interpreted as the current seedstore, and hence a measure of the ability of that population to survive a fire at that point in space and time.

The programme VELDFLOW was written in *True BASIC* (version 2.01) under site licence to the University of Cape Town. The source code listing appears as APPENDIX I, but the programme also can be obtained on request by sending me a floppy disk. In the latter case both compiled and uncompiled versions will be supplied to allow potential users with access to the programming software the option of modifying the code as they find necessary.

Verification and validation

For the purposes of this report, the terms *verification* and *validation* are used *sensu* Pritsker (1984), who considers verification of a simulation model to be confirmation of the internal consistency and accuracy, and validation the demonstration of correspondence with the real world. Each component of the model was verified during its construction, and the model as a whole was run using different combinations of dummy data as input. Output was checked for correctness of calculation and, within the range of the data tested, the model appears to be accurate. Detailed validation however, is not a feasible objective at this stage of the development of VELDFLOW. Empirical data describing demographic and productive processes of fynbos species in relation to the impact of harvesting are not readily available. Economic data for the volume and value of material harvested from fynbos veld, as has been discussed above, is also not recorded in any detail at present.

A SAMPLE RUN - RESULTS

Input data

The model was run using the input data shown in Tables 2-1 and 2-2, as described in their captions. The list of species (Table 1) represents some of those that might be found and exploited in the natural veld in the coastal region of the south-western Cape between Betty's Bay and Hermanus. Estimates of their flowering phenology were extracted from the field guides as described above, while life histories and market value were assigned values based on a subjective assessment of the aesthetic quality of the commercially exploited portion of the plant. Market demand was a composite picture based on export trade figures published in *SAPPEX News*, the Journal of the South African Protea Producers and Exporters Association (Anonymous 1985; 1986), and was kept as a constant pattern throughout the runs of the model.

Output

Using the information supplied to it, VELDFLOW produced output describing the history of the target populations, and the benefit to WILFRED. A sample of these generated data is summarized in Tables 2-3 to 2-6. In all but Table 2-4, WILFRED observed the 50% limit to harvesting. From Table 2-3 it can be seen that several populations of plants were only lightly utilized, and some not at all. This reflects either the situation where there is asynchrony between the market demand and the seasonality of flowering, or where the amount produced by the population is too little to cover the cost of retrieval. The damage to populations in the form of plant mortality with no constraints on harvesting (Table 2-4), illustrates a similar concentration of effort on few species, while others are either productive enough to supply sufficient material, or are shielded for the reasons given above. The values of the annual harvest for each species are given in Table 2-5, and the seedstore contribution for each year in Table 2-6.

Figure 2-5 gives an example of the responses of seedstore size, and population size, to the full range of maximum harvesting levels which WILFRED is willing to observe for the lifetime of the model, which in this case tracks 20 years following re-establishment of the population after a fire. An assessment of the combined benefit from the utilization of all chosen species to the producer is shown in Figures 2-6 and 2-7. This benefit is analyzed as a response to the full range of harvesting level limits Figure 2-6), and to a wide range of profitability thresholds (Figure 2-7). Associated with each is a derived index of "environmental cost" (the ratio of total material used to that produced), for all species in the model set. The "benefit/cost" relationship between the two measures shows the relative profitability of the range of harvester attitudes adopted by WILFRED.

TABLE 2-3. The level of exploitation of each population of utilized plants during a lifetime simulated by VELDFLOW. These figures represent a harvesting level of 50%, with a profit threshold of unity (viz any load whose value covers collection costs is harvested - see text).

YEAR	SPECIES: P rep	P ner	P com	E long	E plu	L xan	P pro	H ves	B alb	B alo	E pat
0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
4	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
5	.00	.00	.00	.00	.00	16.76	.00	.00	39.33	24.93	24.93
6	.00	.00	.00	32.90	.00	40.32	.00	.00	45.85	44.16	36.87
7	49.13	49.13	49.54	32.90	.00	30.69	.00	.00	45.85	36.87	36.87
8	49.13	49.13	49.54	32.90	.00	30.69	.00	.00	45.85	36.87	36.87
9	49.13	49.13	49.54	32.90	.00	30.69	.00	.00	45.85	36.87	36.87
10	49.13	49.13	49.54	32.90	.00	30.69	.00	.00	45.85	36.87	36.87
11	49.13	49.13	49.54	32.90	.00	30.69	.00	.00	45.85	36.87	36.87
12	49.13	49.13	49.54	32.90	.00	30.69	.00	.00	45.85	36.87	36.87
13	49.13	49.13	49.54	32.90	.00	30.69	.00	.00	45.85	36.87	36.87
14	49.13	49.13	49.54	32.90	.00	30.69	.00	.00	45.85	36.87	36.87
15	45.53	49.13	49.54	32.90	.00	30.69	.00	.00	45.85	36.87	36.87
16	45.53	45.53	44.14	.00	.00	.00	.00	.00	39.33	.00	.00
17	34.59	34.59	44.14	.00	.00	.00	.00	.00	39.33	.00	.00
18	.00	.00	19.95	.00	.00	.00	.00	.00	39.33	.00	.00
19	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
20	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

TABLE 2-4. The sizes of the exploited plant populations as utilized by WILFRED in VELDFLOW over a 20-year lifetime with no constraints on harvesting. These figures were generated using a profit threshold of unity (viz any load whose value covers collection costs is harvested - see text)

YEAR	SPECIES: P rep	P ner	P com	E long	E plu	L xan	P pro	H ves	B alb	B alo	E pat
1	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
2	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
3	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
4	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
5	1000.00	1000.00	1000.00	684.18	1000.00	387.25	1000.00	1000.00	1.06	233.48	525.06
6	1000.00	1000.00	1000.00	684.18	692.18	387.25	1000.00	1000.00	1.06	233.48	525.06
7	34.86	34.86	18.26	210.92	692.18	215.85	1000.00	1000.00	1.06	233.48	275.69
8	34.86	34.86	18.26	210.92	692.18	215.85	1000.00	1000.00	1.06	233.48	275.69
9	21.48	21.48	18.26	210.92	692.18	215.85	1000.00	1000.00	1.06	233.48	275.69
10	21.48	21.48	18.26	210.92	692.18	215.85	1000.00	1000.00	1.06	233.48	275.69
11	13.24	13.24	18.26	210.92	692.18	215.85	1000.00	1000.00	1.06	233.48	275.69
12	13.24	13.24	18.26	210.92	692.18	215.85	1000.00	1000.00	1.06	233.48	275.69
13	13.24	13.24	18.26	210.92	692.18	215.85	1000.00	1000.00	1.06	233.48	275.69
14	13.24	13.24	18.26	210.92	692.18	215.85	1000.00	1000.00	1.06	233.48	275.69
15	13.24	13.24	18.26	210.92	692.18	215.85	1000.00	1000.00	1.06	233.48	275.69
16	13.24	13.24	18.26	210.92	692.18	215.85	1000.00	1000.00	1.06	233.48	275.69
17	13.24	13.24	18.26	210.92	692.18	215.85	1000.00	1000.00	1.06	233.48	275.69
18	13.24	13.24	18.26	210.92	692.18	215.85	1000.00	1000.00	1.06	233.48	275.69
19	13.24	13.24	18.26	210.92	692.18	215.85	1000.00	1000.00	1.06	233.48	275.69
20	13.24	13.24	18.26	210.92	692.18	215.85	1000.00	1000.00	1.06	233.48	275.69

TABLE 2-5. The relative value of harvests from the exploited plant populations as generated by VELDFLOW. These figures represent a harvesting level of 50%, with a profit threshold of unity (viz any load whose value covers collection costs is harvested - see text).

YEAR	SPECIES: P rep	P ner	P com	E long	E plu	L xan	P pro	H ves	B alb	B alo	E pat
1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
4	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
5	.00	.00	.00	.00	.00	104.75	.00	.00	149.60	93.48	77.90
6	.00	.00	.00	164.47	.00	503.96	.00	.00	244.19	331.22	230.45
7	859.74	982.56	743.15	115.13	.00	268.54	.00	.00	244.19	193.58	161.32
8	1203.64	1375.58	1040.41	115.13	.00	268.54	.00	.00	244.19	193.58	161.32
9	1805.45	2063.38	1560.61	115.13	.00	268.54	.00	.00	244.19	193.58	161.32
10	2407.27	2751.17	2080.82	115.13	.00	268.54	.00	.00	244.19	193.58	161.32
11	2407.27	2751.17	2080.82	115.13	.00	268.54	.00	.00	244.19	193.58	161.32
12	2407.27	2751.17	2080.82	115.13	.00	268.54	.00	.00	244.19	193.58	161.32
13	2407.27	2751.17	2080.82	115.13	.00	268.54	.00	.00	244.19	193.58	161.32
14	1203.64	1375.58	1040.41	115.13	.00	268.54	.00	.00	244.19	193.58	161.32
15	557.73	687.79	520.20	115.13	.00	268.54	.00	.00	244.19	193.58	161.32
16	278.86	318.70	231.76	.00	.00	.00	.00	.00	104.72	.00	.00
17	105.95	121.08	115.88	.00	.00	.00	.00	.00	52.36	.00	.00
18	.00	.00	26.18	.00	.00	.00	.00	.00	26.18	.00	.00
19	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
20	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

TABLE 2-6. The relative seedstores of the exploited plant populations during a 20-year lifetime as generated by VELDFLOW. These figures represent a response to harvesting at a level of 50%, with a profit threshold of unity (viz any load whose value covers collection costs is harvested - see text).

	SPECIES:										
YEAR	P rep	P ner	P com	E long	E plu	L xan	P pro	H ves	B alb	B alo	E pat
1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
3	.00	.00	.00	.00	.00	.00	1000.00	50.00	.00	.00	.00
4	.00	.00	.00	.00	.00	.00	2000.00	100.00	.00	.00	.00
5	.00	.00	.00	1000.00	1250.00	2081.00	2000.00	100.00	910.07	1126.06	938.39
6	.00	.00	.00	1342.09	2500.00	2984.07	2000.00	100.00	1137.09	1675.11	1578.16
7	890.25	1017.43	756.85	939.46	2500.00	2425.78	2000.00	100.00	1137.09	1325.66	1104.71
8	1246.35	1424.40	1059.59	939.46	2500.00	2425.78	1000.00	50.00	1137.09	1325.66	1104.71
9	1869.53	2136.60	1589.38	939.46	2500.00	2425.78	500.00	25.00	1137.09	1325.66	1104.71
10	2492.70	2848.80	2119.18	939.46	2500.00	2425.78	250.00	12.50	1137.09	1325.66	1104.71
11	2492.70	2848.80	2119.18	939.46	2500.00	2425.78	125.00	6.25	1137.09	1325.66	1104.71
12	2492.70	2848.80	2119.18	939.46	2500.00	2425.78	62.50	3.13	1137.09	1325.66	1104.71
13	2492.70	2848.80	2119.18	939.46	2500.00	2425.78	31.25	1.56	1137.09	1325.66	1104.71
14	1246.35	1424.40	1059.59	939.46	2500.00	2425.78	15.63	.78	1137.09	1325.66	1104.71
15	667.27	712.20	529.79	939.46	2500.00	2425.78	7.81	.39	1137.09	1325.66	1104.71
16	333.63	381.30	293.24	700.00	1250.00	1750.00	3.91	.20	637.05	1050.00	875.00
17	200.30	228.92	146.62	500.00	625.00	1250.00	1.95	.10	318.53	750.00	625.00
18	153.13	175.00	105.07	250.00	312.50	625.00	.98	.05	159.26	375.00	312.50
19	109.38	125.00	93.75	125.00	156.25	312.50	.49	.02	131.25	187.50	156.25
20	54.69	62.50	46.88	62.50	78.13	156.25	.24	.01	93.75	93.75	78.13

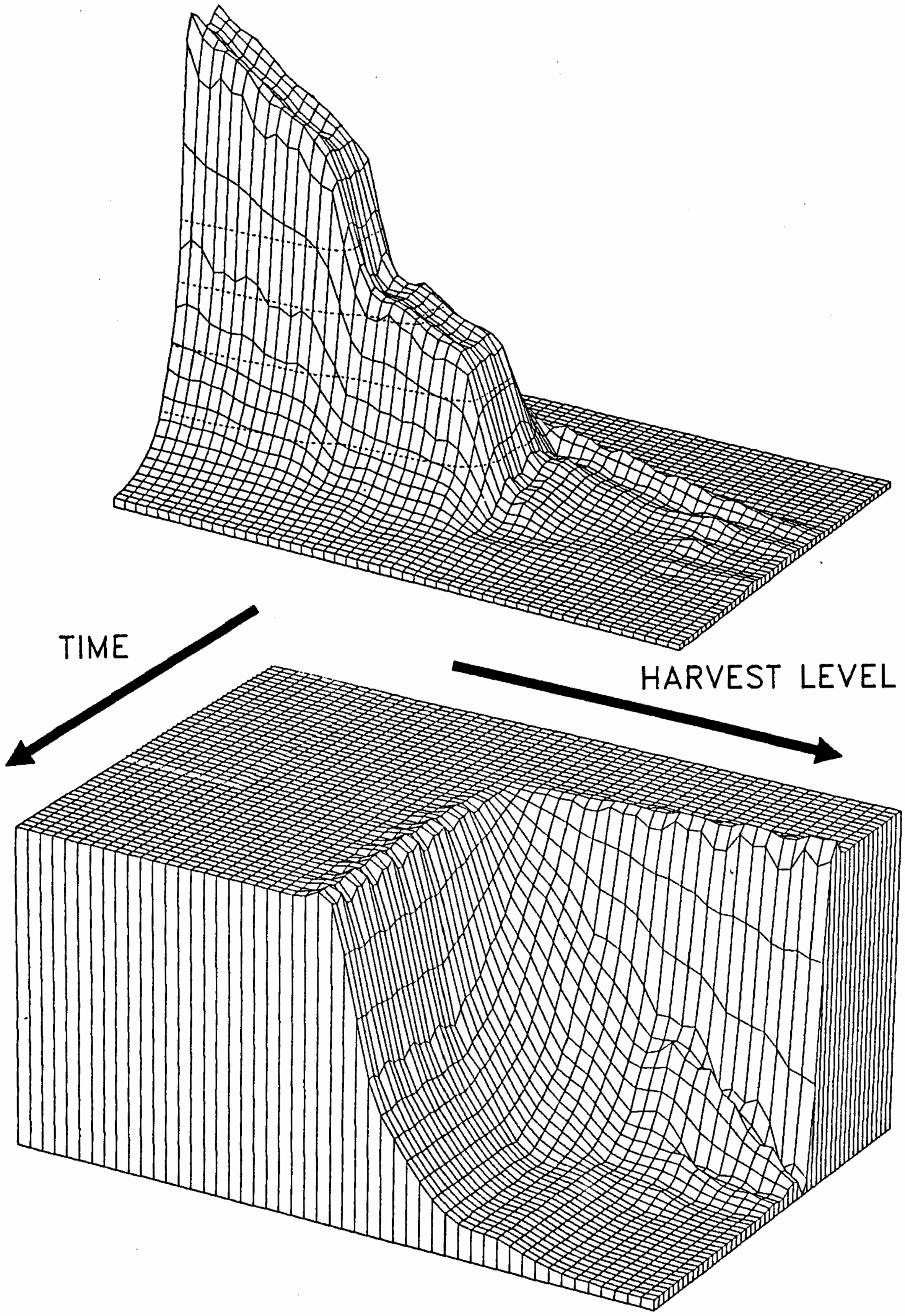


FIGURE 2-5. The effect of maximum harvest level on seedstore (above), and population size (below) in the hypothetical population of *Phaenocoma prolifera* exploited by the producer during the lifetime of the model as described in this chapter. The trace for 0 % harvesting in the case of the seedstore, and 50 % for population size, gives the assumed patterns of these parameters under natural conditions. The contour marked on the seedstore axis delineates potential regions for management and maintenance of minimum viable population size.

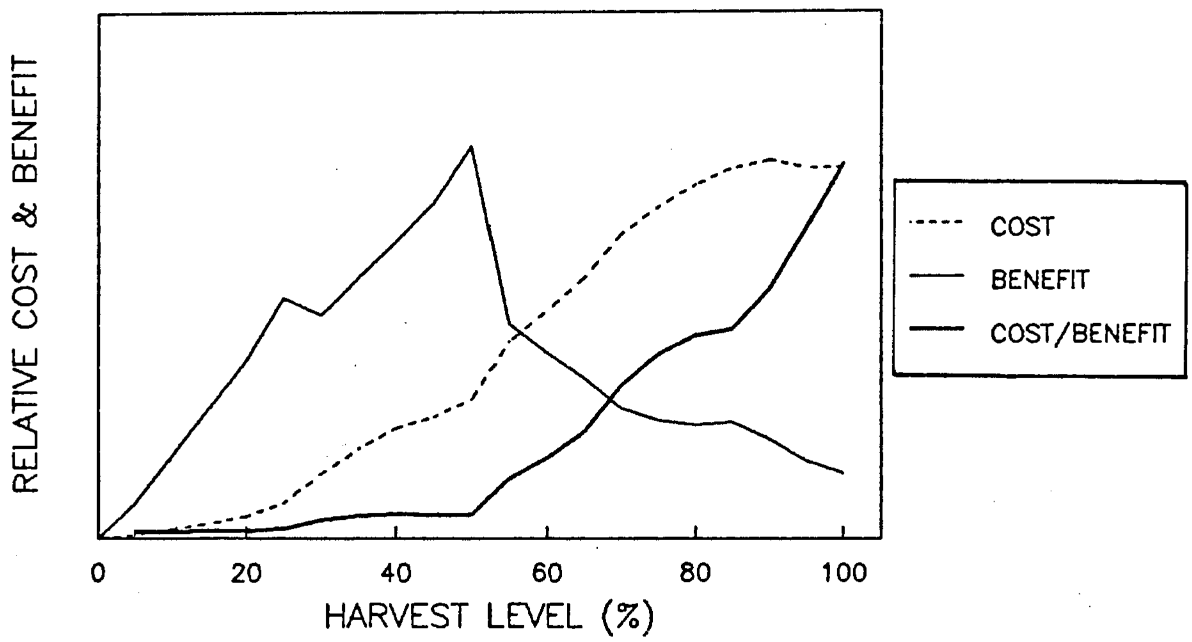


FIGURE 2-6. The relative total benefit (B), total resource cost (C), and the associated cost:benefit ratio (C/B) for different maximum levels of harvest applied evenly to all species. (See text for definition of resource cost).

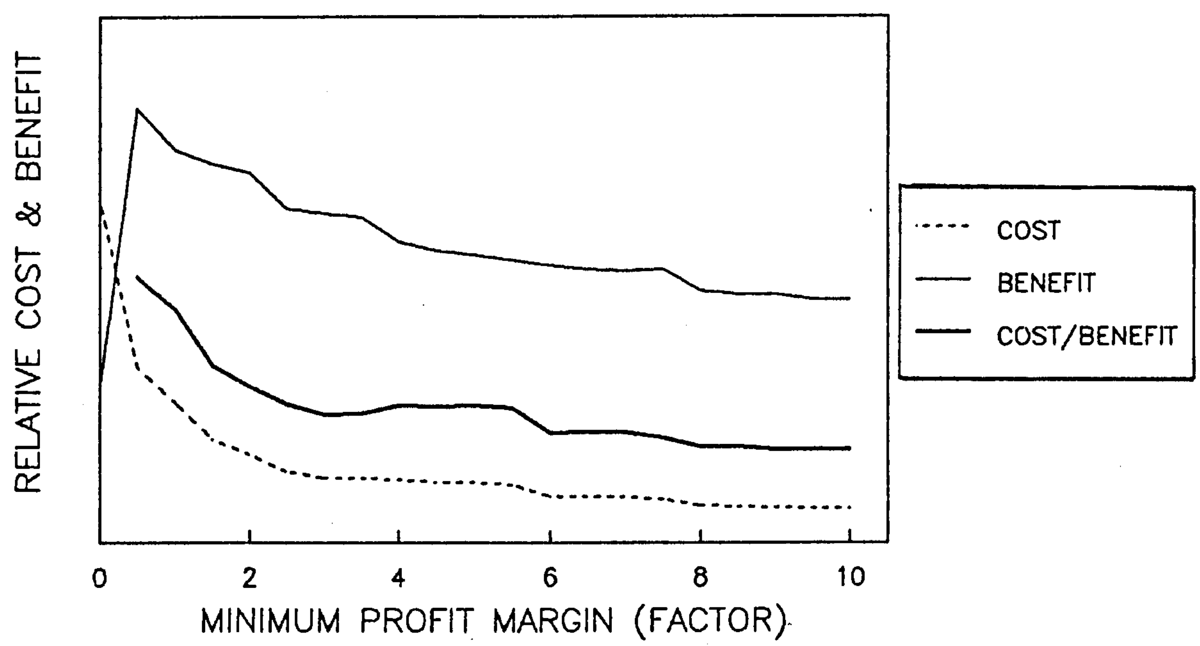


FIGURE 2-7. The relative total benefit (B), total resource cost (C), and the associated cost:benefit ratio (C/B) for different minimum margins of profit applied by WILFRED.

DISCUSSION

Long-term economic survival of a wildflower producer in the fynbos biome is dependent both on the sustainability of production by appropriate management of the exploited plant populations, and on the economic climate which determines profitability of the operation. VELDFLOW attempts to simulate the decision-making processes of a sometimes conservationally-minded producer by accessing ecological and economic information and weighing up the potential costs and benefits associated with different actions. The results generated by the model are not able to be tested in any rigorous fashion at this stage because of the paucity of data describing both the nature and the dynamics of the resource it uses. To the empirical scientist, manipulation of purely hypothetical information might be disturbing, but in terms of modelling it can be considered as an important step for "...lending direction to the taking of data" (Levine 1988). In the case of the fynbos wildflower industry, where influences of the international market on demand for both quantity and type of produce are poorly documented, and where the ecological relationships between target species and their total environments are complex, a preceding model to assist in structuring strategies for the collection of data is probably a necessary step, and one which is being probed by this work.

Output from the model described above is for an extremely limited set of input conditions, with assumptions that: (1) all exploited populations are the same age and the same size; (2) the market demand is uniform during the life of the model; and (3) response characteristics within each type group are the same with regard to the perturbations of harvesting in general, and pruning in particular. The two parameters which were suitable for analyzing sensitivity (*viz.* the maximum level of harvesting and the minimum acceptable profit margin) produced results which were not counter-intuitive over their full range of values, and generally appear to by qualitatively true. From the perspective of a simulation modelling standpoint, where the objective is usually to construct a functional replica of the studied system in a mathematical and/or logical framework, VELDFLOW might be said to have undergone the final step of verification, and is now ready for the iterative revision-calibration-validation procedure (Jorgensen 1986), pending the acquisition of appropriate data.

The patterns shown in Figure 2-5 are useful conceptualizations of the effects of harvest intensity if the maintenance of a minimum viable population size (Bond 1989) is chosen as a management goal, especially for the conservation of threatened species which are also commercially marketable. The contour line in the seedstore graph could for instance demarcate a level above which the propagule store must be kept in order to preserve a viable population in the next generation. Once validated, the interaction of age and harvest level might then dictate management policies governing actions such as the issue of picking permits, recommendation of burning regimes, and possibly even reseeding where applicable for the conservation of threatened or endangered species.

In a brief assessment of the state of the modelling art in renewable resource management, Starfield *et al.* (1988) noted that the set of models available for decision-makers in the management sector tended to be of limited usefulness. Their analysis identified a broad dichotomy between models dealing with marine resources, and those concerned with terrestrial systems. In the former set, individual models tended to be simplistic and biased towards general problems, while in the latter they were usually too complex to be practically applicable for management problems. Costanza and Sklar (1985), in their survey of 87 wetland models, described model complexity by defining an attribute which they dubbed *articulation*. This proposed measure is a function of the model's complexity in time, space and structure, which they found tended to be inversely proportional to the inherent *accuracy* in the set of models reviewed. On the other hand they demonstrated a humpbacked relationship between articulation and *efficiency*, with an optimum efficiency occurring at intermediate levels of complexity. A means of capitalizing on this latter relationship is suggested by Starfield *et al.* (1988), who propose the establishment of a "toolbox" of simpler standard models which might give insight into a range of anticipated resource management problems without being too complex for managers to apply effectively, relieving them of the need to first retrain as mathematical modelers.

Other recent additions to the natural resource management toolkit are the computer-based *expert systems*, and other artificial intelligence techniques. These offer ecologists an aid to reasoning within the wide and diverse spectrum of information that needs to be considered (Rykiel 1989). Although VELDFLOW is far from complete as a conventional simulation model of a system, it does have attributes of an expert system which allow for the interactive testing of data, and even model assumptions. Written as it is in modular form, with algorithms of the submodels either easily accessible in the source code, or operable by appropriate arrangement of the input data, the model can function as a vehicle for testing unknown data against known relationships, or *vice versa*. At its present stage of development it stands as a framework for testing some of the key assumptions made for the purpose of the exercise (*viz.* submodels 1 to 4).

It is clear, however, that more data is needed if the didactic nature of the model is to emerge more forcefully. An inventory of the data required would include information for nearly all of the parameters employed by the model. Only a small amount of this is probably available in the existing literature, and much of it would need to be collected from field observations. On the biological side it might be reasonable to extrapolate observed patterns from one species to other similar ones with a reasonable amount of confidence. But it is the information regarding the movement of material, and the return flow of money, that is almost completely hidden from any potential agency of resource management. The authority bearing the primary responsibility for regulation of the wildflower industry's operation, and its relationship with the fynbos resource, is the Chief Directorate: Nature and Environmental Conservation (CDNEC) of the Cape Provincial Administration. Although the flow of material is well accounted for in the provincial ordinances, which require various permits and licences for all major pathways via which produce normally flows (see Chapter 1), there is no readily accessible information generated which might feed the ecological research effort. In Western Australia, where a similar commercial wildflower harvesting is permitted from the natural vegetation of the state, an obligatory informational return was introduced in the early 1980's. This required each picker to submit details of the species and quantities of material harvested, as well as the geographical location of its source, and it has been shown to provide an encouraging potential means of monitoring the volume and pattern of preference in the picking trade (Burgman and Hopper 1982).

CONCLUSION

The informational gaps highlighted by VELDFLOW stand as an appeal for establishment of a monitoring system from which resource managers may make reasonably expert projections about the nature and extent of direct floricultural utilization of the fynbos vegetation. Consideration of the wildflower industry, however, needs also to be done with as complete an awareness as is possible of the surrounding socio-economic and socio-political environments. Figure 2-8 summarizes the milieu within which the problems must be phrased, and distinguishes those factors which were outside the scope of this project.

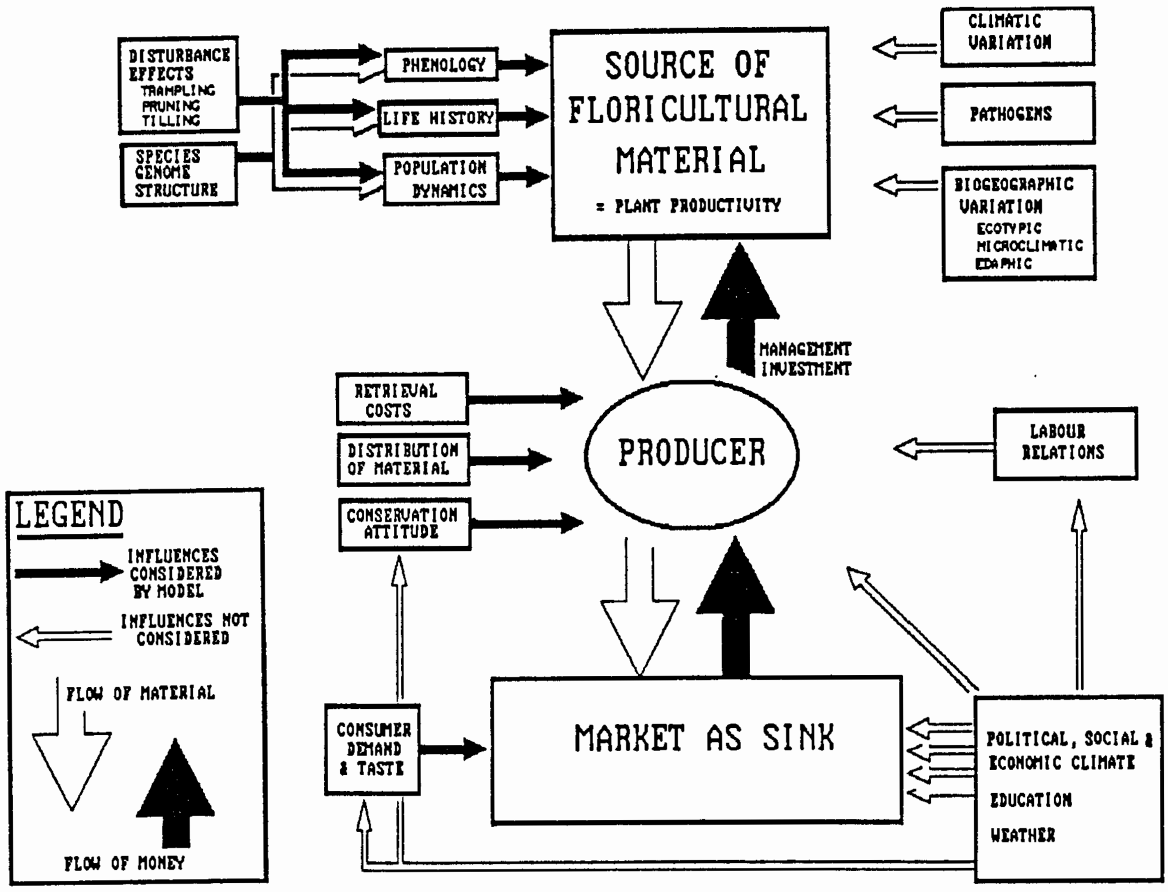


FIGURE 2-8. A summary of the perceived influences exerted by the wildflower industry on the production process. Solid small arrows indicate those included directly in VELDFLOW, while hollow small arrows are deserving of attention.

CHAPTER 3

DESCRIPTION OF THE HIGHLANDS EXPERIMENTAL SITE USED FOR SIMULATION OF MARGINAL CULTIVATION OF TECHNIQUES EMPLOYED BY THE WILDFLOWER INDUSTRY

Previously published as:
DAVIS, G.W. 1988. Description of a proteoid-restioid stand in mesic mountain fynbos of the south-western Cape and some aspects of its ecology. *Bothalia* 18(2):279-287.

INTRODUCTION.

Mountain fynbos is the best preserved vegetation type in the fynbos biome of the Cape (Moll and Bossi 1984). The nutrient poor and highly leached soils of these upland sites (Kruger 1979) have proved unsuitable for conventional agriculture, and direct commercial utilization is restricted almost entirely to silviculture, and the wildflower industry. As a large-scale international trade, the latter is relatively young, and production techniques are in many instances still experimental (see Davis 1984). It is expected that wildflower producers will increasingly favour cultivation over the traditional veld-harvesting method of floricultural production to assist in controlling product quality (Brits *et al.* 1983). Those parts of the relatively unutilized mountain fynbos which contain the preferred habitats of many of the showy proteaceous species, are seen as the logical locations for this branch of agricultural development. This article is based on observations made during the first phase of a study into the possible effects of physical disturbance by agricultural tillage on natural mountain fynbos.

The primary objective of this paper is to describe the chosen study site in terms of existing classifications and other frames of reference normally used for fynbos systems. Where this is not possible, or is not appropriate, comparison with data from other fynbos studies is attempted. The rationale for these exercises is two-fold. Firstly, recognition of common sets of attributes, especially ecologically functional ones, is a necessary basis for formulating the management strategies required for utilization and conservation of mountain fynbos vegetation. Secondly, where the classifications used to describe mountain fynbos systems are incomplete, the task of workers motivated to update them is facilitated by available quantitative data. This paper endeavours also to be a small part of that accessible repository.

The study site.

The chosen site is on the south edge of the Grabouw basin (Caledon District) within a region where quartzite, sandstone and thin bands of shale and conglomerate of the upper Table Mountain Group outcrop, as documented on the 1:125 000 geological map of the area (Government Printer 1966). It lies on a gentle slope of approximately 8%, with an aspect of 246^{o}, and at an altitude of 375 m. It is 10.5 km from the sea on the landward side of a ridge which rises to a maximum height of approximately 500 m. The grid co-ordinates of the site are: 34^{o} 15' 38" S, and 19^{o} 6' 38" E. Until March 1987 the area in which the study site is located was managed by the Directorate of Forestry (Department of Environment Affairs) as a mountain water catchment area. It is now under the control of the Department of Nature and Environmental Conservation (Cape Provincial Administration).

METHODS.

Development of the study site.

An experimental plot 50 m x 50 m was delineated at the site during 1984. Sample quadrats (2 m x 2 m) were delineated at 28 regularly spaced stations, providing a sampling intensity of 4% for the major components of the vegetation. As part of the long-term experimental design the site was cleared by means of a controlled burn in February 1985.

Climatic data

A weather station was set up on the cleared area and a data- logging device (MC Systems, Cape Town) installed. This monitored a set of environmental parameters, including precipitation and air temperature. Regional long-term precipitation data were obtained from records of the Weather Bureau (1985), and from a statistical report issued by the Soil and Irrigation Research Institute (Agrometeorological Division 1983) for the following stations respectively: Highlands forest station (34^{o} 17'S; 19^{o} 6'E; 426 m) over the period 1938 - 1984; and the experimental farm of the Fruit and Fruit Technology Research Institute in Elgin (34^{o} 8'S; 19^{o} 2'E; 305 m) over the period 1963 - 1983. As an estimate of the long-term mean air temperature at the study site, long-term data from the Elgin station (Agrometeorological Division 1983) were adjusted by the differences recorded for this same parameter at the two stations during the period July 1985 - June 1986 (see Results).

For periods when the data-logging equipment was non-functional (a total time of approximately 6 weeks during the sample period of July 1985 - December 1986), precipitation data recorded at the Highlands forest station, 2.5 km to the south-west, have been used. Means of the monthly totals at these two stations during 1986 agreed to within 1.3%. Temperature data were not augmented in this way.

The vegetation.

Mature vegetation was sampled at the 28 stations described above, a 1 m x 1 m subquadrat being used for close inspection of the less conspicuous species. Due to the cryptic form of many species in the mature vegetation, all those recognized as distinct were not able to be identified. Instead a species list has been compiled from all identified species observed on random scans of the plot and its immediate surroundings (a total area of approximately 0.65 ha) during all seasons, both before and after burning.

A single set of nested quadrats (after Whittaker *et al.* 1979) was marked out in veld adjacent to the study plot for the construction of a species-area curve to permit comparison of the site with data from other studies. The number of different species was measured in quadrats of: 1 m^2 (10 replicates); 10 m^2 (2 replicates); 100 m^2 and 1000 m^2 (no replication).

Age of the stand was estimated by counting the number of nodes on the largest individuals of the dominant shrub species, *Leucadendron xanthoconus* (Kuntze) K. Schum., and cross-checked against aerial photographic records of the Dept. of Surveys and Mapping.

The soil.

Description of the soil profile was provided by three shallow soil pits (approximately 0.8 m deep), and a single deeper one (1.8 m). For analysis of the physical and chemical characteristics of the soil, samples were taken from the A horizon, the top of the B horizon, and a single sample from saprolitic parent material at 2 m. Each of these samples was air-dried and sieved to 2 mm. Nutrient analyses were performed by the regional Soil Analytic Laboratory of the Department of Agriculture and Water Supply (Winter Rainfall Region) at Elsenburg using methods described by Jackson (1958), Hesse (1971), the Fertilizer

Society of South Africa (1974), and Moore and Chapman (1986). Bulk density and field capacity were determined on undisturbed soil cores, and texture on 2 mm sieved samples.

As possible factors influencing pedogenesis at the site, incidental observations of plant or animal interactions with the soil were noted, the most apparent of these being the presence of a number of termite mounds.

RESULTS.

Climate.

The climatic diagram (after Müller 1982), derived for the study site from the adjusted data of Highlands forest station and Elgin experimental farm, is given in Figure 3-1. Figure 3-2 shows the total monthly rainfall measured at the study site (with adjustments for missing data - see Methods), together with concurrent and long-term data from other sites. Figure 3-3 demonstrates that on a weekly basis during the sample period the rainfall was very unevenly distributed between the Highlands study site and Elgin, although total precipitation received during 1986 at each station was similar (Highlands = 1110 mm and Elgin = 1090 mm). The weekly Highlands total of 123.4 mm in this latter figure comprises precipitation recorded by the Highlands forest station during a single 24 h period in February 1986 when the data logger system at the study site was not functional. An accumulation type rain gauge at the study site confirmed rainfall in excess of 100 mm for the month of February.

For reasons dictated by the completeness and reliability of the data, air temperature regimes are given for the period July 1985 to June 1986 (see Figure 3-4). The most noticeable differences between these two locations are the consistently warmer mean temperatures during the spring and summer months, and the year-round colder minima at the Elgin station. A 10-day period of missing logged data at the study site during February may cause the reported extreme values to be inaccurate for that month.

The vegetation.

Vegetation at the site was estimated to be 12 years old. Aerial photographs taken in 1973 (Department of Surveys and Mapping) indicated that the area had been recently burned. This agreed with the Highlands forest station records

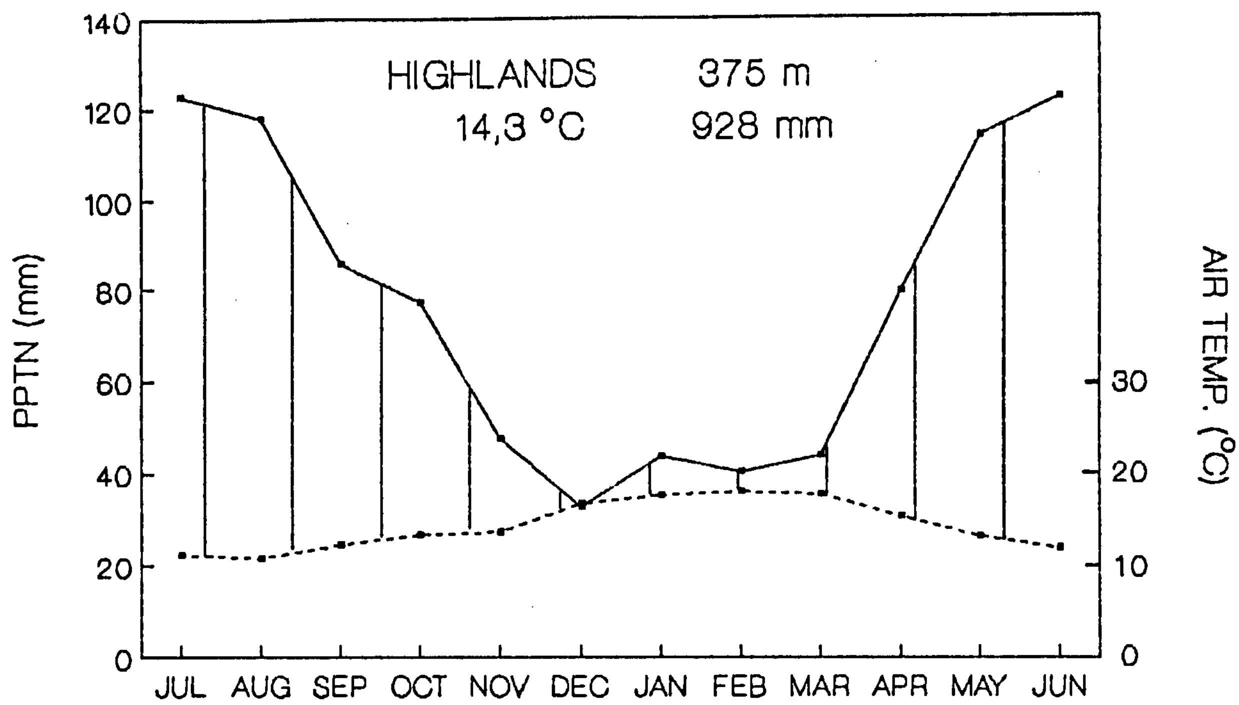


FIGURE 3-1. The derived climate diagram for the Highlands study site. The broken line depicts mean monthly air temperature, while the solid line is total monthly precipitation (after Müller 1982).

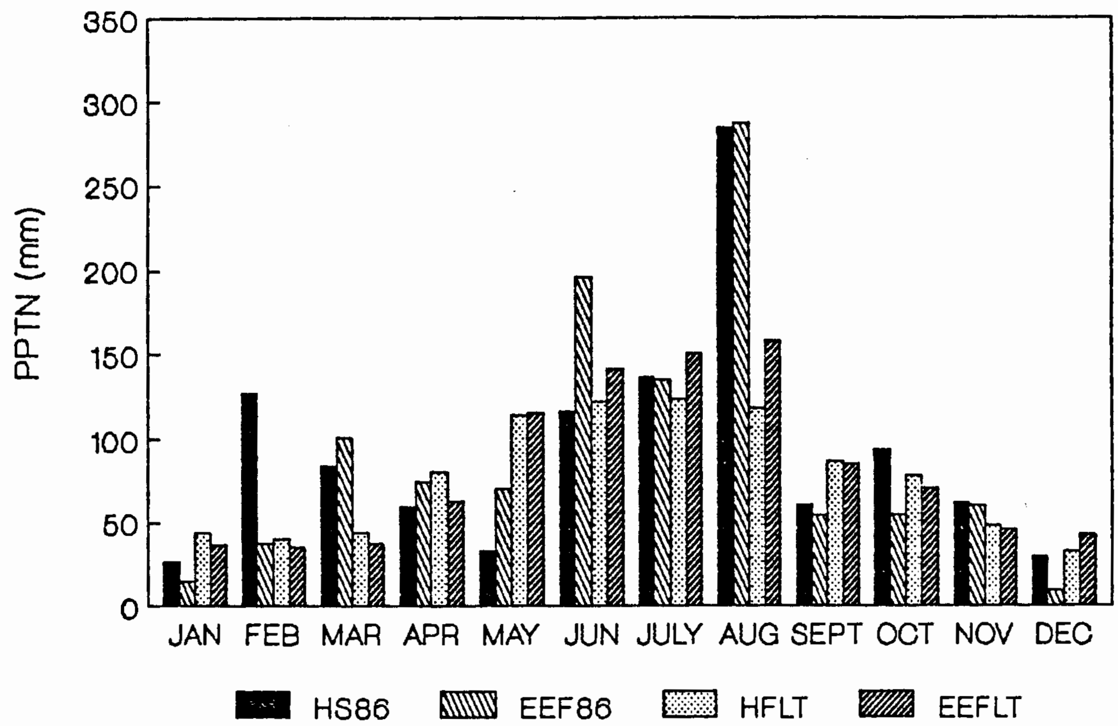


FIGURE 3-2. Total monthly precipitation during 1986, and long-term averages for sites in Highlands and Elgin. Legend symbols are as follows: HS86 = Highlands study site, 1986; EEF86 = Elgin experimental farm, 1986; HFLT = Highlands forest station (1938 - 1984); and EEFLT = Elgin experimental farm (1963 - 1983).

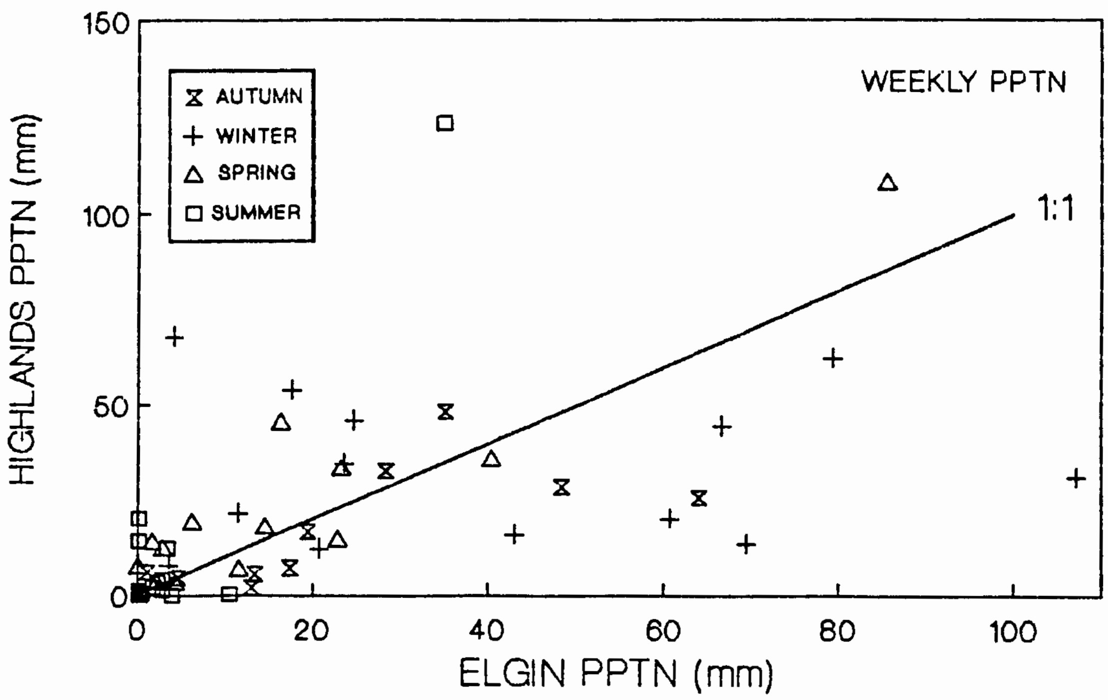


FIGURE 3-3. Comparison of weekly precipitation totals recorded at Highlands (combined forest station and study site data), and the Elgin experimental farm during 1986.

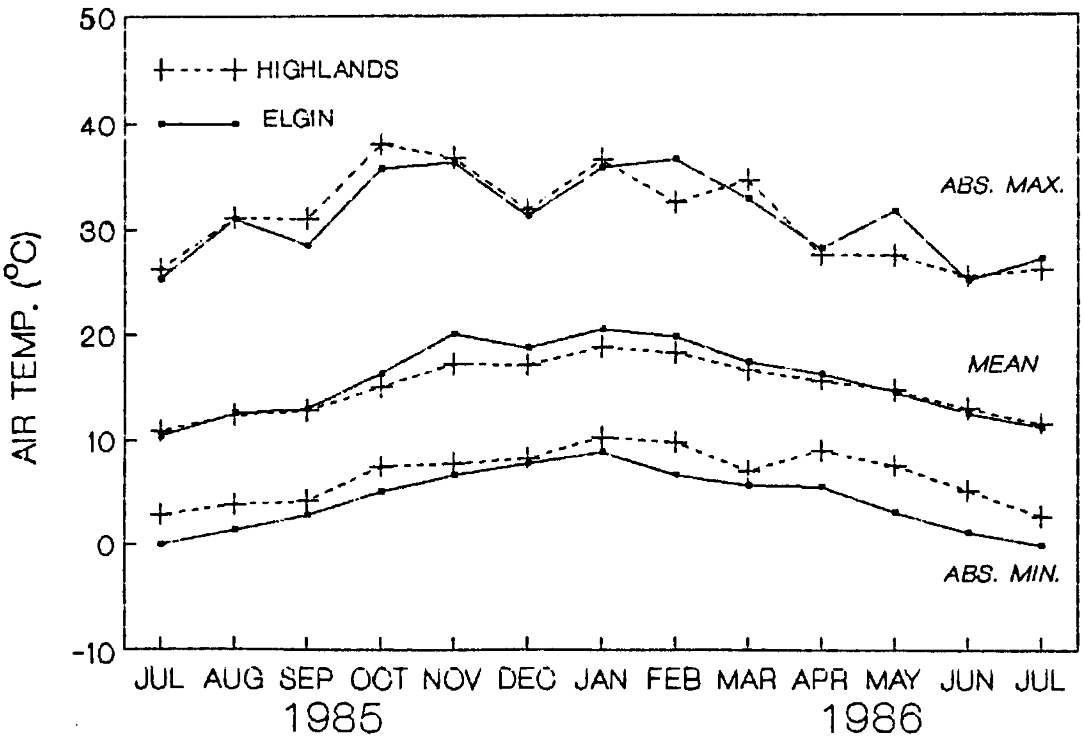


FIGURE 3-4. Mean monthly temperature measures recorded at the Highlands study site and the Elgin experimental farm during the period July 1985 to July 1986. February values for Highlands include a 10-day period of missing data, which could cause the extreme values during that month to be unrepresentative.

documenting an accidental fire during the same year. The plant community was characterized by a shrub layer largely comprising *Leucadendron xanthoconus* (Kuntze) K. Schum., and a dense restioid component dominated by *Chondropetalum hookerianum* (Masters) Pill. The mean measured density of *L. xanthoconus* on the plot was 1.7 mature plants per m^2 (1.23 S.D.) with a mean height of 0.80 m (0.155 S.D.). Approximate projected cover of live restioid shoot material (mostly *C. hookerianum*) was 39%, and that of accumulated dead tissue added a further 35%. A third species which was abundant throughout the site was *Erica cristata* Dulfer. This species had a frequency of occurrence of 93%, but probably contributed little to the aboveground biomass of the system owing to its sparse and rangy habit. Another conspicuous shrub species at the site was *Erica longifolia* Aiton., which was thinly and unevenly distributed (0.48 mature plants per m^2; 1.2 S.D.) with individual heights of up to 1.4 m.

The mean species richness in the set of twenty-eight 1 m^2 quadrats was calculated to be 7.7 species per m^2 (1.7 S.D.), while the 1 m^2 quadrats of the nested set afforded a slightly higher value of 8.6 species per m^2 (1.7 S.D.). The overall mean for these two sets is 7.9 species per m^2. The larger quadrats of the nested set contained 19 (mean of 2); 37; and 56 species in 10 m^2, 100 m^2, and 1000 m^2 respectively. A linear regression between the number of species (S), and the $\log_{10}$ of the quadrat area (LogA) gave the following relationship:

$$S = 6.12 + 16.02 \text{ LogA } (r^2 = 0.984).$$

The compiled species list (see Table 3-1) contains the names of all taxa recorded at the site both before the experimental burn in 1985, and for two subsequent seasons. It therefore includes those which were either absent, or were in cryptic form before the fire.

The soil

Soil at the site was duplex, a category found throughout the south-western Cape (Schloms *et al.* 1983). It comprised a dense underlying stratum of saprolitic shale with a shallow (150 mm to 800 mm) colluvial overburden of predominantly quartzitic material. The top stratum consisted of an orthic A horizon, a leached E horizon, and a basal stone-line (commonly 150 mm thick) of quartz and sandstone rock fragments. In places the topsoil contained more fine shale-derived material, while in others the sandy surface layer was missing entirely, leaving a lithosolic A/E horizon. Rock particles varied in the size of their largest dimension from less than 10 mm, to more than 300 mm, and were usually heavily ferruginized. The B horizon

TABLE 3-1. A provisional list of the species occurring at the Highlands study site in the Caledon district. While the alphabetical arrangement of Bond and Goldblatt (1984) is used here for ease of access, nomenclature and authorship are according to Gibbs Russell *et al.* (1985) and Gibbs Russell *et al.* (1987), except for the Restionaceae, where Linder (1985) has been used.

Schizaeaceae
Schizaea pectinata (L.) Swartz

Pinaceae
Pinus pinaster Ait.

Cyperaceae
Chrysithrix capensis L.
Ficinia albicans Nees
Ficinia bolusii C.B. Cl.
Ficinia ecklonea (Steud.) Nees
Ficinia fascicularis Nees
Ficinia lateralis (Vahl) Kunth
Ficinia paradoxa (Schrad.) Nees
Tetraria brachyphylla Levyns
Tetraria capillacea (L.) C.B. Cl.
Tetraria compar (L.) Lestib.
Tetraria cuspidata (Rottb.) C.B. Cl.
Tetraria fimbriolata (Nees) C.B. Cl.
Tetraria ustulata (L.) C.B. Cl.

Haemodoraceae
Dilatris pillansii W.F. Barker
Lanaria lanata (L.) Dur. & Schinz
Wachendorfia paniculata Burm.

Iridaceae
Anapalina triticea (Burm.f.) N.E. Br.
Aristea juncifolia Bak.
Aristea oligocephala Bak.
Aristea spiralis (L.f.) Ker-Gawl.
Bobartia filiformis (L.f.) Ker-Gawl.
Bobartia gladiata (L.f.) Ker-Gawl.
Gladiolus maculatus Sweet
Ixia micrandra Bak.
Micranthus junceus (Bak.) N.E. Br.
Thereianthus bracteolatus (Lam.) G.J. Lewis
Tritoniopsis parviflora (Jacq.) G.J. Lewis

Liliaceae
Eriospermum sp. Jacq. ex Willd.

Orchidaceae
Ceratandra atrata (L.) Dur. & Schinz

Poaceae
Ehrharta longifolia Schrad.
Merxmuellera rufa (Nees) Conert

Restionaceae
Calopsis hyalina (Mast.) Linder
Calopsis membranacea (Pillans) Linder
Cannomois virgata (Rottb.) Steud.
Ceratocaryum decipiens (N.E. Br.) Linder
Chondropetalum hookerianum (Mast.) Pillans
Elegia filacea Mast.
Hypodiscus albo-aristatus (Nees) Mast.
Hypodiscus argenteus (Thunb.) Mast.
Hypodiscus aristatus (Thunb.) Krauss
Hypodiscus laevigatus (Kunth) Linder
Hypodiscus willdenowia (Nees) Mast.
Ischyrolepis caespitosa Esterhuysen
Mastersiella digitata (Thunb.) Gilg-Ben.
Restio filiformis Poir.
Restio similis Pillans
Restio triticeus Rottb.
Restio verrucosus Esterhuysen
Staberoha cernua (L.f.) Dur. & Schinz
Thamnochortus lucens (Poir.) Linder
Willdenowia c.f. *arescens* Kunth

Apiaceae
Centella restioides Adamson
Lichtensteinia trifida Cham. & Schlechtd.
Peucedanum ferulaceum Thunb.

Asteraceae
Berkheya barbata (L.f.) Hutch.
Berkheya herbacea (L.f.) Druce
Corymbium africanum L.
Elytropappus rhinocerotis (L.f.) Less.
Gerbera linnaei Cass.
Helichrysum cymosum (L.) D. Don
Helichrysum pandurifolium Schrank
Helichrysum teretifolium (L.) D. Don
Lachnospermum umbellatum (L.f.) Pillans
Osteospermum tomentosum (L.f.) T. Norl.
Othonna quinquedentata Thunb.
Phaenocoma prolifera (L.) D. Don.
Senecio pubigerus L.
Senecio triqueter DC.
Stoebe capitata Berg.
Stoebe plumosa (L.) Thunb.
Ursinia paleacea (L.) Moench

Balanophoraceae
Mystropetalon thomii Harv.

Bruniaceae
Berzelia lanuginosa (L.) Brongn.
Brunia laevis Thunb.
Brunia neglecta Schltr.

Campanulaceae
Lightfootia unidentata (Thunb.) A. DC.
Lobelia tomentosa L.f.
Roella ciliata L.

Crassulaceae
Crassula ericoides Haw.

Droseraceae
Drosera cistiflora L.
Drosera trinervia Spreng.

Ebenaceae
Diospyros glabra (L.) De Winter

Ericaceae
Erica coccinea L.
Erica corifolia L.
Erica cristata Dulfer
Erica cruenta Soland.
Erica longifolia Ait.
Erica nudiflora L.
Erica pulchella Houtt.
Erica spumosa L.

Euphorbiaceae
Euphorbia silenifolia (Haw.) Sweet

Fabaceae
Argyrolobium filiforme Eckl. & Zeyh.
Aspalathus sp. L.
Otholobium rotundifolium (L.f.) C.H. Stirton
Rafnia sp. Thunb.

Gentianaceae
Chironia linoides L.

Geraniaceae
Pelargonium ellaphiae E.M. Marais

Lobeliaceae
Cyphia volubilis (Burm.f.) Willd.
Merciera leptoloba A. DC.

Oxalidaceae
Oxalis polyphylla Jacq.

Penaeaceae
Penaea mucronata L.

Polygalaceae
Polygala bracteolata L.

Proteaceae
Aulax umbellata (Thunb.) R. Br.
Diastella thymelaeoides (Berg.) Rourke
Leucadendron salignum Berg.
Leucadendron xanthoconus (Kuntze) K. Schum.
Leucospermum truncatulum (Salisb. ex Knight) Rourke
Protea cordata Thunb.
Protea longifolia Andr.
Protea scabra R. Br.
Serruria barbigera Knight
Serruria elongata R.Br.
Spatalla racemosa (L.) Druce

Rhamnaceae
Phylica atrata Licht. ex Roem. & Schult.
Phylica ericoides L.
Phylica imberbis Berg

Rosaceae
Cliffortia complanata E. Mey.

Rutaceae
Diosma oppositifolia L.

Selaginaceae
Selago scabrida Thunb.

Stilbaceae
Campylostachys cernua (L.f.) Kunth
Stilbe ericoides (L.) L.

Thymeleaceae
Gnidia anomala Meisn.
Struthiola eckloniana Meisn.

Zygophyllaceae
Zygophyllum fulvum L.

was composed exclusively of the shale-derived material, showed weak structure, and tended to be gleycutanic. The deeper soil pit (see Figure 3-5) which was dug outside of the study plot and adjacent to an area with outcropping sandstone, revealed in the sub-soil horizon a layer of pre-weathered sandstone approximately 1.2 m thick, bounded above and below by shale-derived material. This band dipped at an angle of approximately 45^{0} and it is thought that the C horizon throughout the study plot was effectively within the upper shale stratum. With regard to the classification system developed by MacVicar *et al.* (1977), the soil could be placed in the Kroonstad form (Mkabati or Avoca series), although where the B horizon displayed more prismatic structure and darker cutans, association with the Estcourt form was stronger (Uitvlugt or Estcourt series). Identification of the soil series was equivocal on account of the variability of the clay content of the E horizon, a diagnostic feature of both forms.

Results of the physical and chemical analyses performed on samples taken from the site are summarized in Table 3-2.In terms of the textural classification included by MacVicar *et al.* (1977), soil of the A horizon lies on the border between loamy sand and sandy loam. Field capacity of the top layer of soil, expressed as gravimetric water content, was measured as 22.5% (3.57 S.D.).

The following features which might influence profile development were observed at the site: (i) surface soil movement under the influence of winter runoff; (ii) waterlogging of the colluvial stratum, but not the B horizon during winter; (iii) the presence of termite colonies (*Amitermes sylvestris*) whose mounds were present with a mean density of 120 per ha, and a mean height of 350 mm; (iv) the occurrence of earthworms (infrequently observed); (v) occasional mole or molerat activity; and (vi) the penetration of roots into the dense B horizon. This latter phenomenon was limited to structural faults, and was noted as occurring to the maximum investigated depth of 1.8 m. These roots probably belonged to *Leucadendron xanthoconus* individuals, the only species whose roots were positively identified as penetrating into the B horizon. Fungal hyphae were also observed in old root channels in this horizon.

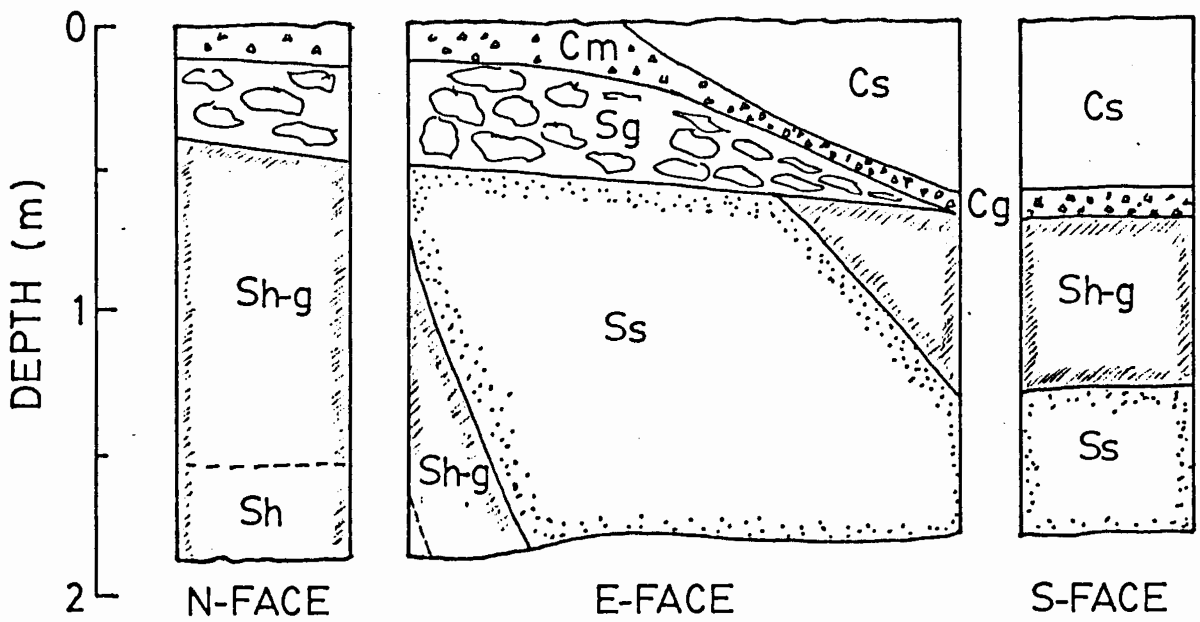


FIGURE 3-5. Soil profile at the experimental site. Shown above are three faces of a soil pit adjacent to the site at the edge of an area where sandstone rocks are common at the surface. The symbols used in the sketch are defined as follows: **Cs** = colluvial sand as an orthic horizon; **Cg** = stone line of predominantly ferruginized quartz fragments; **Cm** = mixed colluvium of sand, sandstone fragments, and ferruginized quartz fragments; **Sg** = large sandstone rock fragments of varying size (most < approximately 30 cm); **Sh** = shale-derived material (**-g** indicates some degree of gleying); **Ss** = sandstone-derived material, tending towards semi- consolidated rock at the deeper levels. The **south face** of the pit is similar in profile to that found at other parts of the site, with the exception of the presence of the underlying layer of preweathered sandstone. Root tissue in the sub-soil horizons was found to be restricted to planes of structural weakness in the shale-derived material, while it was more evenly distributed in the upper regions of the sandstone. On the north face an accumulation of decayed organic matter was present as a horizontal layer between the gleyed and ungleyed strata.

TABLE 3-2. Chemical and physical properties of soil at the Highlands study site. Mean values are given for each parameter, followed by the standard deviation of the mean. Values for the C horizon represent a single sample only, and bulk density of the B horizon a set of 2 values.

Parameter	units	A horizon	B horizon	C horizon
N (Kjeld)	$\mu g.g^{-1}$	453 (155)	192 (53)	-
P (Bray 2)	$\mu g.g^{-1}$	7.3 (0.6)	6.3 (3.1)	8
K (Bray 2)	$\mu g.g^{-1}$	79 (18)	59.3 (32.3)	18
Exchangeable cations:				
Na^+	me/100g	0.62 (0.11)	0.36 (0.15)	0.42
K^+	me/100g	0.19 (0.02)	0.1 (0.05)	0.08
Ca^{2+}	me/100g	1.04 (0.28)	1.07 (0.35)	0.35
Mg^{2+}	me/100g	0.75 (0.12)	1.29(0.65)	0.39
C.E.C.	me/100g	3.54 (1.92)	8.82 (1.04)	0.2
Al	me/100g	0.44 (0.08)	10.8 (2.93)	-
C	%	3.32 (0.51)	1.08 (0.49)	<0.05
Resistance	ohms	747 (116)	3687 (1494)	520
pH		4.3 (0.1)	3.9 (0.2)	3.9
Texture:				
clay	%	7.4 (4.1)	27 (3.6)	-
silt	%	8.1 (2.1)	50 (3.0)	-
sand	%	85 (6.1)	17 (7.2)	-
sand texture		medium	medium	-
Bulk density	$mg.mm^{-3}$	1.23 (0.1)	1.45 (-)	-

DISCUSSION.

Climate.

The climate diagram (Figure 3-1) based on long-term data depicts a typical humid mediterranean-type with winter half-year rainfall (May to October) exceeding 65% of the 928 mm annual total, and a distinct winter with at least one mean monthly temperature less than 15 ^{o}C (see Aschmann 1973). As was described by Fuggle and Ashton (1979), the climates of the fynbos biome form a "spatially diverse mosaic" on account of its mountainous topography. Comparison of the observed climatic parameters at the study site and at the Elgin experimental farm illustrate this diversity, with precipitation patterns in the region being especially non-uniform (see also Table 3-3).

The heterogeneity of the rainfall may also play a critical role in the fire ecology of these seasonally flammable areas. The single highest rainfall event at the Highlands forestry station during the sample period occurred in February, the height of the fire-season. Such temporal and spatial patchiness of rainfall acting over the millennia of fynbos evolution could have contributed significantly to a patchy fire history, and hence to the heterogeneous mosaic of the present-day vegetation.

Regional patterns of ambient air temperature appear to be more predictable than those of precipitation (see Figure 3-3). The warmer spring and summer mean air temperatures, and the colder year-round minima of the Elgin experimental farm relative to the Highlands study site, can probably be explained by the location of the former station. Elgin almost certainly experiences: (i) more restricted air-movement during the windier spring and summer period than the study site (partly supported by unpublished data from this study), and (ii) perennial nocturnal drainage of cold air (Barry and Chorley 1982) from the large mountains of the Hottentots Holland and Franschhoek to the north. See Davis (1987) for a brief discussion of wind at the study site.

The vegetation

The criteria established by Taylor (1978) for the definition of fynbos are amply satisfied by vegetation at the study site, and the species which characterize it, all have distributions restricted to the fynbos biome as delineated by Moll and Bossi (1984).

TABLE 3-3. Long-term annual precipitation at various stations within the Grabouw basin.
Abbreviations used are: EF = experimental farm; FS = forest station; Agromet. = Agrometeorology Division; WB = Weather Bureau.

Station	Altitude (m)	Ann. pptn. (mm)	Source
Elgin FS	281	1120	Fuggle 1981
Elgin EF	305	978	Agromet. 1983
Lebanon FS	351	675	Fuggle 1981
Highlands FS	426	928	WB 1985
Nuweberg FS	650	1499	Fuggle 1981
Jakkalsrivier - 1	655	824	Kruger 1979
Jakkalsrivier - 2	817	956	Kruger 1974

Species richness at the site was lower than the much quoted fynbos figure of 121 flowering plant species within an area of 100 m^2 (Taylor 1972). (Unfortunately this figure has become incorporated into the literature as a benchmark of species richness in fynbos (e.g. Bond 1983; Jarman 1982; and Taylor 1978), when in fact it arises from an article written for semi-popular consumption, and, in keeping with that medium, omits the descriptive details usually associated with such often cited points of reference). Better documented figures are presented by Bond (1983), who reports a maximum figure of 104 species in an area of 1000 m^2 in a Jonkershoek stand of *Protea nitida* (waboomveld), the extrapolation of which on the log-scale would agree well with the total of 126 species recorded at the Highlands study site in an area of approximately 0.65 ha. In the same paper, Bond presents a synoptic species-log area curve for fynbos vegetation in the southern Cape mountains. For the formulation $S = b + d\log_{10}A$, where S is the number of species in an area A, he found $b = 16.4$ and $d = 15.8$. These constants of the linear equation represent "point diversity" and species turnover (or community patchiness) respectively (Bond 1983). Highlands data indicate a significantly lower point diversity (t-test; $p < 0.001$), but a similar patchiness for the community at the study site. They are more similar to those obtained by Whittaker *et al.* (1979) for mallee vegetation in New South Wales, Australia ($b = 5.3$ and $d = 15.3$). Based on a sample area of 100 m^2, Cowling (1983) reported species-richness of 26.5 for mountain fynbos in the south-eastern Cape. This is lower than the Highlands figure, while on the other hand the mean of his "point diversity" (sensu Bond 1983) for fynbos shrubland sites was twice that of the study site. The measures of diversity discussed above lend a valuable perspective to the description of the Highlands study site, but as yet the body of available information is insufficient for this parameter to be used as an accurate classifier.

According to the description of post-fire succession in fynbos by Kruger and Bigalke (1984), as summarized by Rutherford and Westfall (1986), the 12-year post-fire stand of the study site was in an early stage of maturity, a phase during which the codominance of phanerophytes, chamaephytes, and hemicryptophytes is best developed. However, the abundance of restioid shoot tissue and the consequent buildup of a dense mat of litter may effectively advance the maturation process in the site community by causing premature reduction in species richness.

Subjectively, the mature vegetation of the study site was best described as a *Leucadendron xanthoconus* stand, with an understory dominated by *Chondropetalum hookerianum* and *Erica cristata*. These species have distributions as follows:

L. xanthoconus and *C. hookerianum* occur from the Cape Peninsula eastward as far as Bredasdorp (Vogts 1982) and Riversdale (Linder 1985) respectively, while *E. cristata* is restricted to the area between Sir Lowry's Pass and the Klein River mountains (Baker and Oliver 1967). Grobler (1964), Boucher (1972; 1978), Kruger (1974), and Durand (1981) have all conducted vegetation surveys within a 15 km radius of the Highlands study site, and although many of the species that are cited are in common with it, none of their community characterizations describe the vegetation of the Highlands plot. Inspection of Boucher's (1978) data for the occurrence of the above three species in his study area between Cape Hangklip and the Palmiet River revealed a pattern (Figure 3-6), which suggests that the convergence of all three at Highlands may be a characteristic feature of the site. Two of the three instances where this occurred in Boucher's study, soil was of the duplex Estcourt form. (It is possible that *E. cristata* and *C. hookerianum* form a commensalistic association, in which physical support of the trailing ericoid by the erect restioid may be an element, a phenomenon observed in the mature vegetation at the study site).

Comparison of the Highlands species list (see Table 3-1) with those of Boucher (1978) and Kruger (1974) confirmed the small degree of overlap at the species level. Of the Highlands species, approximately one-third of the total number was contained in each of the other lists, while less than 20% were common to all three. Kruger and Taylor (1978) have previously demonstrated that a 60% difference in species composition exists between Cape Hangklip and Jakkalsrivier.

The above discussion suggests that while many phytosociological elements of the region are represented at the study site, regional patchiness might easily make manifestation of a previously recognized community unlikely. In an attempt to improve upon the phytosociological approach to classification of mountain fynbos vegetation, Campbell (1985;1986) invested considerable effort in constructing a structural classification with *a priori* rules for classifying communities. He pointed out (Campbell 1985), using stands dominated by *Leucadendron gandogeri* as an example, that some assemblages of plant life will necessarily defy classification by that particular system. Interpretation of the Highlands vegetation according to the key of structural features affords it a similarly equivocal position. Careful consideration of the Highlands vegetation may offer additional information to resolve that particular shortcoming of the structural classification.

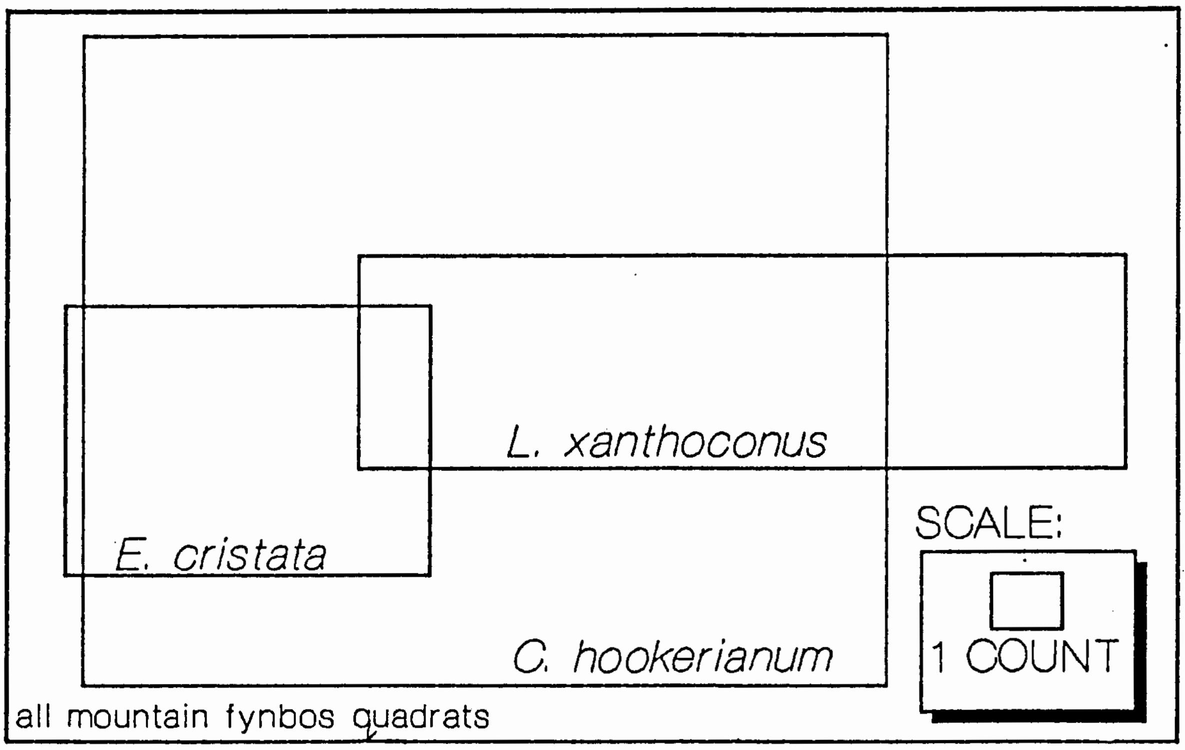


FIGURE 3-6. Frequencies with which the three species *Leucadendron xanthoconus*, *Chondropetalum hookerianum*, and *Erica cristata* occurred at mountain fynbos sample plots in the Cape Hangklip area, and their degree of distributional overlap. Drawn from the data of Boucher (1978).

The soil.

As with the composition of plant communities, soil is a characteristically variable component of the fynbos biome (Moll and Jarman 1984). Boucher (1978) counted eight soil forms (14 series) in his study area of 115 km^2, but some of his classified mountain plant communities included up to six of these. Estcourt, one of the forms identified at the Highlands site, occurred at 15% of his mountain releve's as the Soldaatskraal series, while Kroonstad was not listed at all. Kruger (1974), noted six forms within the 1.58 km^2 Jakkalsrivier catchment, none of which was in common with the Highlands site. Nor did Campbell (1983) in his extensive survey of montane environments in the fynbos biome encounter the forms identified at the study site, although the Highlands data are consistent with the generalized gradients which summarize his work. Considering the shale-derived component of the Highlands soil, his warning against equating non-quartzitic origin in mountain fynbos soil with nutrient-richness is borne out.

In the broad context of fynbos soils, topsoil at the study site is typical in that it is acid, leached, and nutrient poor (Kruger 1979). Being duplex in nature, however, the dense B horizon acts as an impediment to the vertical loss of many of the soil constituents that might normally be removed from the system during the podzolisation process, although throughflow (Trudgill 1977) may account for loss via seeps. (The working definition of nutrient-poorness supplied by Campbell (1983) is easily met for both A and B horizons).

Apart from some intensive studies on lowland systems with narrowly defined objectives (e.g. Low 1983; Mitchell *et al.* 1984; Stock 1985; Witkowski and Mitchell 1987), published data which describe the nutrient status and cycling processes in fynbos soils are limited. Information on nutrients in mountain systems is sporadic in the literature, and usually incidental to broader ecological studies. Comparison of the Highlands data with those describing other mountain fynbos sites (see Low 1983), indicated that total N in the Highlands topsoil was greater than at these other sites by factors of between 1.1 and 3.2. The measured available P was comparable to the values of between 2.5 and $4.5 \mu g.g^{-1}$ reported by Read and Mitchell (1983) for coastal fynbos. The C.E.C. measured at the Highlands site fell into the wide range of values measured by Kruger (1974) for soils at Jakkalsrivier (0.5 to 44.0 me/100g), while it was appropriately lower (for an oligotrophic soil) than the approximate mean of 14 me/100g given by Tucker (1983) for a range of non-carbonate soils in Australia and the U.S.A.

Accumulation of clay particles at the top of the B horizon clearly increased the measured C.E.C. at this level (see Table 3-2), but parallel concentration of aluminium may outweigh the advantage of this to plants by reducing the availability of phosphorous under the inherently acid conditions (White 1979). The ability of Scottish heathland plants to survive on soils with high Al content is demonstrated in a study cited by Woolhouse (1981) where concentrations of 0.17% (18.9 me/100g) are reported for the B_1 horizon. These figures are somewhat greater in magnitude than those obtained for soil of the Highlands study site. It would be reasonable to suppose that the toxic effects of Al are countered either edaphically (see Norrish and Rosser 1983), or physiologically within heathland and fynbos systems, where this element is liable to be common (Hesse 1971).

The observed downhill movement of topsoil during the rainy season at the Highlands site implies that the process of soil creep responsible for the formation of this duplex soil is still in progress. However, root penetration, together with the some activities of the soil fauna, may be acting to ameliorate and stabilize the soil in local patches.

Synthesis

The data which describe phenomena of the Highlands study site are valuable to the ongoing study by providing a base-line for the investigation of ecosystem functions. The immediate objective, however, is to place that information in a general descriptive context which relates to other mountain fynbos systems. This is attempted in Table 3-4.

CONCLUSION

As human demands inevitably increase with time, conservation and effective utilization of natural resources such as mountain fynbos vegetation will depend greatly on the extent to which managers are able to identify and predict responses of ecosystems to the impacts of exploitation. Classification of ecosystem attributes is an important step in establishing a means to extrapolate knowledge of specific sites to larger managerial units. Treating the Highlands site as a test case, we have seen above that hopes for the development of a classification which encompasses the functional complexity of mountain fynbos are justified. This is especially true considering the large body of information which has accumulated over the past decade under the co-ordination of the Fynbos Biome Project of the C.S.I.R. (see Moll and Jarman 1984).

TABLE 3-4. A summary description of the Highlands study site with regard to the climate, vegetation and soil.

Feature	Description
Climate	Humid mediterrranean-type with spatial and temporal stochasticity of precipitation.
Vegetation	Proteoid-restioid (*Leucadendron xanthoconus-Chondropetalum hookerianum*) with species turnover typical of mountain fynbos, but with low point diversity.
Soil	Of Table Mountain Group origin with a quartzitic and shale-derived colluvium (probably mobile) overlying weathered shale; acid, nutrient-poor and seasonally waterlogged.

CHAPTER 4

ALTERATION OF THE EXPERIMENTAL MOUNTAIN FYNBOS SYSTEM BY TILLAGE - THE PHYSICAL ENVIRONMENT

- an inquiry into ecosystem transformation an existing land-use practice in the wildflower industry

INTRODUCTION

Development of the wildflower industry and growing competitiveness in the world market is favouring a swing towards methods that allow more intensive husbandry of horticultural species than can be applied to plants growing in the wild (Jacobs 1989). A reasonable means of producing "species level" products (as opposed to horticulturally derived cultivars), is to introduce the target species to a natural site where the climatic and edaphic environment is compatible with its characteristic adaptations, but where its management as a commercial crop can be facilitated. In this process of *marginal cultivation*, reduction of competition from the natural community is an important consideration. The usual method of preparing fynbos land is to remove vegetation by fire, and to break up the top-soil by tilling *e.g.* disking or rotavating, before planting out pre-established seedlings, or broadcasting of suitable seed. This is an approximate parallel to land preparation methods used in the practice of "shifting agriculture" in the tropical forest regions of South America (Jordan 1985) where natural vegetation is often removed by "slash-and-burn" before the land is cultivated. In this study I investigate aspects of disturbance to an experimental mountain fynbos system caused by burning and rotavation, which simulates land preparation for commercial floricultural production.

In a perceived situation of globally diminishing natural resources, the traditional agricultural practice of tilling is receiving critical attention from agricultural and ecological researchers. This is motivated both by a desire for lower production costs, and by a realization that sources of ecosystem degradation need to be recognized and rectified at the earliest possible stage. Work over the past two decades has established that there exist good reasons under many circumstances to dispense with physical mixing of the topsoil for agricultural purposes (*e.g.* Stinner and Crossley 1980; Stinner *et al.* 1984; Barry and Miller 1986; Galaher and Ferrer 1987; Groffman *et al.* 1987). Some immediate advantages of the alternative no-till system of cultivation are: (1) the obvious savings of expenditure on the fuels, hardware and time necessary to do the job (Hillel 1980); (2) the avoidance of soil compaction by heavy tilling apparati (Russell 1973); and (3) the possible reduction of erodibility of loosened surface soil (Morgan 1980; Spomer and Hjelmfelt 1986). Disadvantages include: (1) the necessary use of herbicides for the control of competitive weeds (Coleman *et al.* 1984), which may have deleterious effects on other parts of the system; (2) a loss of surface applied fertilizers in precipitation runoff (Mueller *et al.* 1984); and (3) predicted loss of near-surface water which is crucial for seed germination and seedling establishment in some species (Hammel *et al.* 1981).

One of the chief long-term benefits of the no-till method is the conservation of soil nutrient pools, which have been linked to an increase in sorghum yields under field trial conditions (Stinner *et al.* 1983). Conventional tillage has also been demonstrated to promote leaching of N and Ca from a sandy-loam soil (Stinner *et al.* 1984). An experimental system under shifting agriculture in Venezuela (Jordan 1985) was shown to incur significantly higher losses of Ca, K, Mg, and nitrates than the control forest system. On the other hand, populations of microbial nitrifiers and denitrifiers, which enhance the mobility of N, and can lead to its loss from the system, have been observed to be between two and 43 times larger under no-till cultivation in Nebraskan corn and wheat fields (Doran 1980 as cited in Coleman *et al.* 1984). Denitrification itself is a function of available carbon (Lalisse-Grundmann 1988) and so may be affected by the dispersal of surface litter during tillage, although Groffman *et al.*(1987) concluded that denitrification losses in an experimental agro-ecosystem were insignificant. With reference to the ecology of soil microbes and their role in ecosystem stability, Odum (1986) has expressed a general concern that management of ecosystems may tend to concentrate on conspicuous aspects of their function, while overlooking the less obvious "low energy but high quality" subsystems upon which the long-term viability of many systems rest.

Other aspects of physical disturbance which might have serious consequences for the stability of an ecosystem, are the effects it may have on the energy and water regimes of the transformed system. A seminal study of the influence of tilling on physical properties of soil was performed by van Duin (1956, as cited by Hillel 1980), in which he demonstrated that the increased macroporosity of the tilled upper layer formed a thermally insulating stratum. In that study he demonstrated that this phenomenon had the effect of raising the amplitude of temperature variation close to the surface, while damping it at deeper levels. Another factor altered by surface disturbance which has bearing on the energy budget of the soil, is that of reflectivity. Shortwave albedo, or the proportion of the total solar radiation reflected by the land surface, has been shown to be a function, not only of vegetation cover, but also of soil water content (Jackson *et al.* 1976), and soil texture (Bowers and Hanks 1965). Given that tilling almost invariably reduces vegetation cover in the short-term, it might be expected that relative to undisturbed native soil, there would be a reduction in water lost by transpiration from a recently disturbed system. On the other hand, evaporative losses could be greater owing to dispersal of any natural surface litter mulch, although Hammel *et al.* (1981) have shown that the discontinuity in capillarity caused by tillage can also enhance the conservation of subsurface water in disturbed soil.

The on-going till/no-till debate has become a part of agro-ecological research dialogue, and offers a basis for the present investigation of physical disturbance in mountain fynbos systems. It does, however, assume a starting point of agricultural production in already transformed systems, and husbandry techniques adapted to the propagation of artificial plant communities. In the current study the focus is on the resilience of natural systems to stresses imposed by the foreign disturbance of tillage, as might be observed in the commercial production of indigenous floricultural material in newly annexed veld.

In mountain fynbos of the Cape, a vegetation type which requires active management for maintenance of the important water catchment areas (van Wilgen 1984, Wilson 1984), as well as conservation for scientific and aesthetic reasons (Kruger 1977), the implications of physical disturbance need to be carefully examined. The appreciation reported in recent scientific literature of disturbance as an integral part of normal ecosystem function (Pickett and White 1985) has emphasized the lack of environmental stability in evolutionary time, and offered a fresh perspective on the adaptations inherent in population and community dynamics. In mountain fynbos, where fire is the chief endemic disturbance, this approach has generated speculation, debate, and research into the complex pattern of speciation which is thought to characterize the diverse flora of the biome (Cowling 1987; Midgley 1987). The insights gained from these and similar studies will assist construction of models which describe present day structure and function of these systems. Management agencies, however, urgently need to know about their ultimate resilience - or how far systems can be stretched by human use and abuse without irreversible degradation and loss of resource-value. Because the theoretical basis of ecological understanding is still lacking in maturity (Loehle

1987), it is necessary to rest quite heavily on empirical investigation to learn something about ecosystem resilience.

Although removal of vegetation by burning is a traumatic event with regard to system processes, its role as an integral part of the *disturbance regime* of mountain fynbos has been well established (Kruger 1979; van Wilgen 1981; Bond *et al.* 1984; Kruger 1987). Further disturbance by tilling however, represents a physical disruption rarely experienced by these upland sites (a landslide perhaps being the closest natural equivalent). Vegetation would not therefore be expected to comprise elements especially adapted to disturbance regimes of this nature, and it could be hypothesized that such a system is susceptible to irreversible changes by their imposition. Or in terms of the conceptual landscape model of Godron and Forman (1983), such a system may be easily displaced from its "metastable state".

An adequate definition of disturbance is that of an agent of site modification which alters the resource level and physical environment of a site for member species (Bazzaz 1983). Measurement of the magnitude of resource level shifts, or site changes, can similarly be used to gauge the extent of a disturbance. To employ this approach however, a set of control data describing the normal state of the system is required. Understanding of the natural processes operative in fynbos systems has grown during the past 11 years of semi-coordinated research in the CSIR's *Fynbos Biome Project*. Several contributions have been made in the areas of nutrient cycling (*e.g*. Brown and Mitchell 1986; Mitchell *et al.* 1986; Stock and Lewis 1986; Mitchell and Coley 1987; Witkowski and Mitchell 1987; *inter alia*) and plant-water relations (Miller *et al.* 1983; Moll and Sommerville 1985; Miller 1985; Jeffery *et al.* 1987; van der Heyden and Lewis 1989; *inter alia*), many of these with direct applicability to the subset of montane systems. Fynbos studies, until the recent past, have largely ignored anthropogenic disturbances and their effects in favour of a more complete knowledge of the structure and function of natural systems. But there exists an increasing need to understand the nature of perturbations generated by the activities of modern *Homo sapiens*, and to identify the set of possible responses triggered in nature.

The primary objective of this chapter is to quantify some of the effects of tilling on the abiotic components of the experimental mountain fynbos system described in Chapter 3. There are three main lines of investigation regarding the behaviour of environmental parameters following disturbance: (1) the nutrient status, (2) the energy regime, and (3) the water regime. Some data describing re-establishment of the dominant shrub species, *Leucadendron xanthoconus*

(Proteaceae), are included to allow interpretation of the information in the context of a biological environment. The null hypothesis being tested is that physical disturbance, represented in this work by tillage, induces no significant effects on the system parameters outlined. In this way the study intends to assist in identifying and elucidating some of the system mechanisms susceptible to physical disruption, and so to facilitate prediction of long-term effects of anthropogenic disturbance.

METHODS

Site preparation

The experimental mountain fynbos plot (50 m x 50 m) described in the previous chapter, was isolated from the surrounding mature vegetation by a cut fire-break approximately 3 m in width. It was then burned by personnel of the Directorate of Forestry (Department of Environmental Affairs) in February, 1985. In June of the same year, strips approximately 3 m wide were tilled by a rotavator with 100 mm tynes. These strips were orthogonal to the slope and spaced so as to include half the number of permanent quadrats described in Chapter 3.

Soil nutrients, chemistry, and bulk density

Soil samples, excluding the separable surface litter, were collected from random points on the plot and in adjacent mature vegetation during July 1986. A supplementary set was collected from the treated experimental plot only during October 1987. All samples were collected from beneath the litter layer as a core from the surface to 50 mm depth. Sample sizes on the two sampling dates, from the three different treatments were as follows:

(a) July 1986: mature (11), tilled (11), untilled (11);
(b) October 1987: tilled (12), untilled (11);

Soil analyses were performed by the same analytic laboratory, and by the same means as is described in Chapter 3. The attributes determined by these analyses are listed in Table 4-1 in RESULTS. Due to limitation of facilities at the soil analysis laboratory, measures of pH, electrical resistance (R), and organic carbon (C) could not be obtained for the October 1987 sample set.

Soil bulk densities samples were taken from the 0 - 50 mm layer of tilled ($n = 13$) and untilled ($n = 14$) soil, using a cork-borer (30 mm diameter). Samples were weighed following oven-drying at 105°C.

Remotely collected data

A data logging system (MC Systems, Cape Town) was installed at a point on the plot where the soil was approximately 300 mm deep above the basal stone-line. This apparatus was programmed to monitor the outputs of eight soil temperature probes (thermistors) which had been placed at depths of 30 mm and 150 mm on the tilled treatment, as well as on the burned but untilled control (*viz.* n = 2 for each depth and each treatment). Nylon clad AC resistance probes (as described by Slavik 1974) distributed in the same pattern were also monitored by the logger. Outputs from a shielded and passively ventilated air temperature probe, a tipping-bucket rain gauge, and a DC generator anemometer (see Davis 1987, included also as Appendix II), were also logged. A channel was left open for the measurement of solar radiation during site visits when the upper sensor of a double-glass-domed net radiometer (Middleton) was connected to the logger and the unit positioned on a tripod with the sensor approximately 1.2 m above the ground.

Manually collected data

Additional monitoring of environmental parameters was carried out at 22 paired stations (11 tilled + 11 adjacent untilled), arranged at random points along two parallel transects which co-incided with tilled strips traversing the width of the experimental plot. Shortwave albedo of the soil surface (Rosenberg *et al.* 1983) on the burned and tilled treatments was measured on site visits during cloudless periods between the times of 12h00 and 15h00. During the same period measures of maximum and minimum soil surface temperature within a 1 m x 1 m area at each station were obtained using an infra-red thermometer (Barnes). Soil temperature profile readings supplementary to the logged data were taken from *in situ* copper-constantan thermocouples. Additional soil moisture information, against which the resistance block data were calibrated, was obtained gravimetrically from samples collected during site visits. (See RESULTS, Figure 4-6 for dates of sampling).

Vegetation

Results of a broader vegetation survey (see Chapter 5) were used to determine the species which were most frequently encountered within the study plot. The abundance of these species was measured approximately 18 months after tilling using a standard quadrat of 1 m x 1 m (or a subquadrat of 0.5 m x 0.5 for very abundant species) at each of the sample stations. These data were included in a correlation analysis which attempted to identify relationships between environmental parameters and the distribution of species across the site.

Data analyses

All data were analyzed using the commercially available statistical computer software package STATGRAPHICS (STSC, Inc.). Chemical and nutrient data sets were subjected to one-way analyses of variance (ANOVA) with "tilled", "untilled", and "mature" as treatments of the single factor, and significantly different groupings were sought by multiple range tests (95% confidence intervals). Comparisons between treatments for other time-based data were performed by applying two-sample t-tests to the subsets of data for each collection date. Interrelationships between the system parameters were investigated by means of the principle components analysis (PCA), and correlation analysis routines.

RESULTS

Soil nutrients, chemistry, and bulk density

Statistical analyses of the chemical and nutrient data revealed no significant differences between the treatments for the parameters measured, except that the electrical resistance (R) of the "mature" soil was significantly greater than that of untilled soil, while the value for tilled soil was in an intermediate group indistinguishable from either. (This applies only to the July 1986 data as R values were not obtained on the next occasion). The results for the first collected data set are summarized in Table 4-1. Similar analyses of the data derived from samples collected during October 1987 showed no significant differences for any of the measured parameters.

Bulk densities were slightly, but insignificantly different ($p = 0.217$; t-test), with that for untilled soil being 1.13 $mg.mm^{-3}$, and tilled soil 1.08 $mg.mm^{-3}$. These values, however, were both significantly lower ($p < 0.05$) than the value of 1.23 $mg.mm^{-3}$ obtained for "mature" soil (see Chapter 3), although sampling for this comparison, due to the layout of the plot, may be construed as pseudo-replicative (Hurlbert 1984).

TABLE 4-1. A summary of the nutrient analyses performed on soil samples collected from the two unburned treatments (re-establishing vegetation), as well as for mature veld adjacent to the experimental plot. Analysis of variance (ANOVA) and associated multiple range tests indicated that there were no significant differences ($p < 0.05$) between the three treatment levels (tilled, untilled and mature), except between sets of electrical resistance values recorded for mature and tilled soil.

	MATURE		UNTILLED		TILLED	
	mean	std	mean	std	mean	std
pH	4.26	0.19	4.38	0.08	4.32	0.22
Resistance (ohms)	2624	1060	3541	768	4330	791
P-Bray (µg/g)	2.91	3.82	2.73	1.88	3.32	3.40
K-Bray (µg/g)	71.64	14.74	62.82	11.19	58.00	14.85
CEC (me/100g)	1.86	0.34	1.78	0.34	1.76	0.43
Exchangeable cations						
Na (me/100g)	0.19	0.11	0.13	0.05	0.13	0.05
K (me/100g)	0.18	0.03	0.16	0.03	0.16	0.05
Ca (me/100g)	0.58	0.21	0.62	0.19	0.57	0.26
Mg (me/100g)	0.48	0.09	0.53	0.10	0.56	0.15
Base saturation (%)	76.87	6.14	81.58	3.73	79.84	7.76
C (%)	2.55	0.29	2.52	0.30	2.61	0.60
N-Kjeldahl (µg/g)	471	109	455	91	499	78

Energy

The effects of disruption by tillage on the reflectivity of the soil surface, and the consequences for soil temperatures are summarized in Figures 4-1 to 4-4. The pre-dawn surface temperatures shown in Figure 4-4 indicate that while untilled soil absorbs more incoming solar radiation than tilled soil, it does not transmit the stored heat by blackbody radiation at a high enough rate during the hours of darkness to reach a lower temperatures.

A regression of seasonal data describing the difference between maximum surface temperatures of the two treatments against the corresponding peak in incoming solar radiation was computed. The best fit was provided by the exponential curve:

$$y = 0.0916\ e^{4.07x} \qquad (r^2 = 0.74)$$

where y = diff in temp between tilled and untilled soil surface temperature in ^{o}C, and
x = incoming solar radiation in $W.m^{-2}$

This emphasizes that alteration of the system's energy budget was most pronounced during the summer months, when insolation was highest and soil water the lowest (see following section).

Water

The seasonal pattern of precipitation and soil water movement (Figure 4-5), as well as soil water content (Figure 4-6), shows that differences between tilled and untilled soil are not constant throughout the year. Logged data generated by the nylon resistance blocks during the summer period, are expressed in Figure 4-5 as a daily differential so as to give a picture of the dynamics of water movement on the two treatments

Synthesizing analyses

The various elements of the study are presented in synthesized form in Figures 4-7 and 4-8. The Principal Components Analysis (PCA) indicates clearly the groupings of associated variables, and the seasonality of that relationship. All winter variable weights (W) can be seen to lie on axes orthogonal to the main axis of distribution of the principle component values for sample sites. The model portrayed in Figure 4-8 is based on the correlation analysis of the same data set,

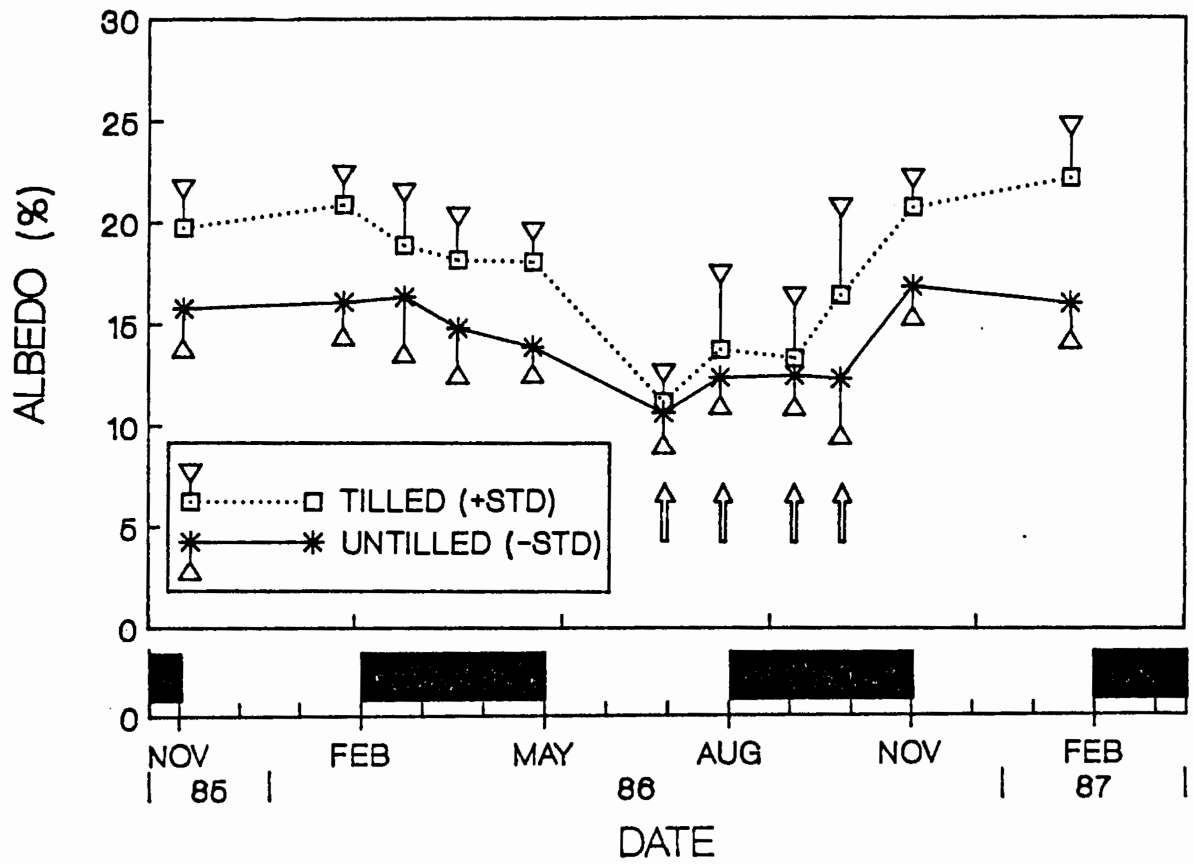


FIGURE 4-1 The seasonal pattern of reflectivity (shortwave albedo) on tilled and untilled treatments of burned veld at the Highlands experimental site. The tilled treatment shows higher reflectivity at all times (t-test; $p < 0.05$) except those marked with an arrow. Labelled months on the abscissa represent the end of that month, and alternating bars the nominal seasons.

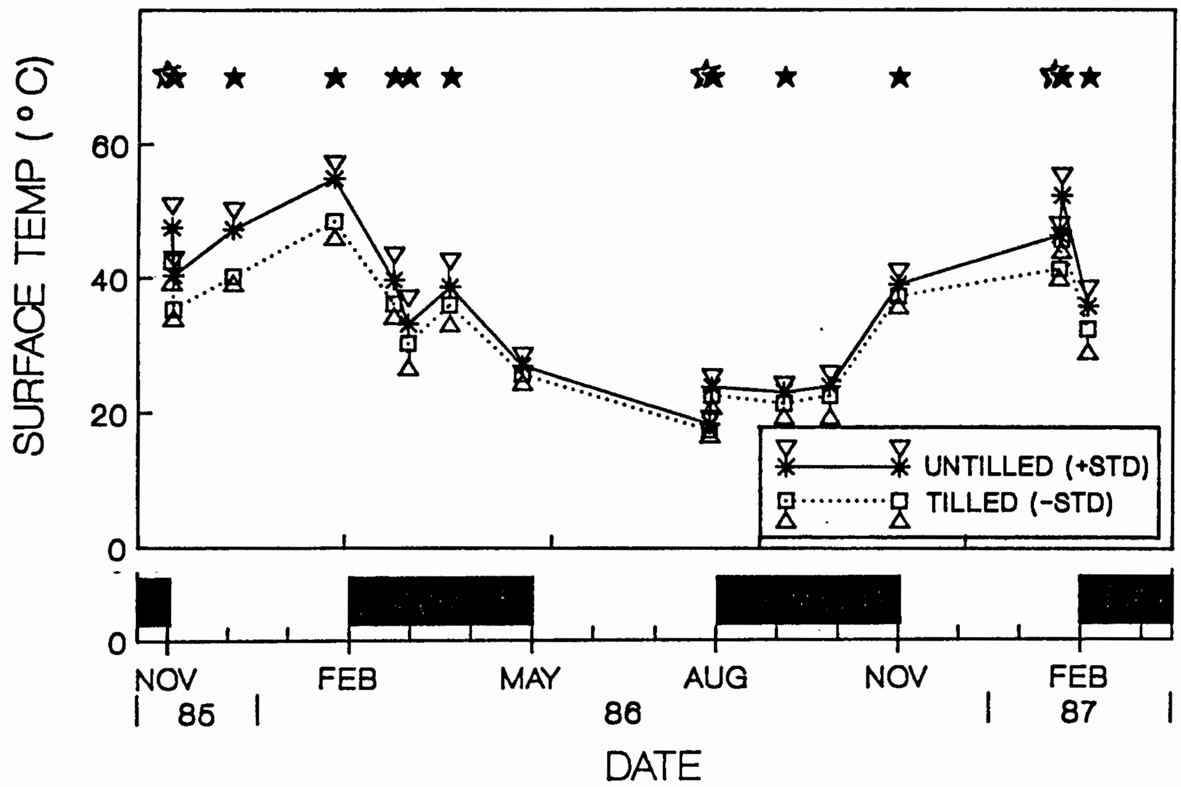


FIGURE 4-2. Daytime soil surface temperatures measured on tilled and untilled soil at the Highlands study site (see METHODS). Significant differences (t-test; $p < 0.05$) are marked by a star.

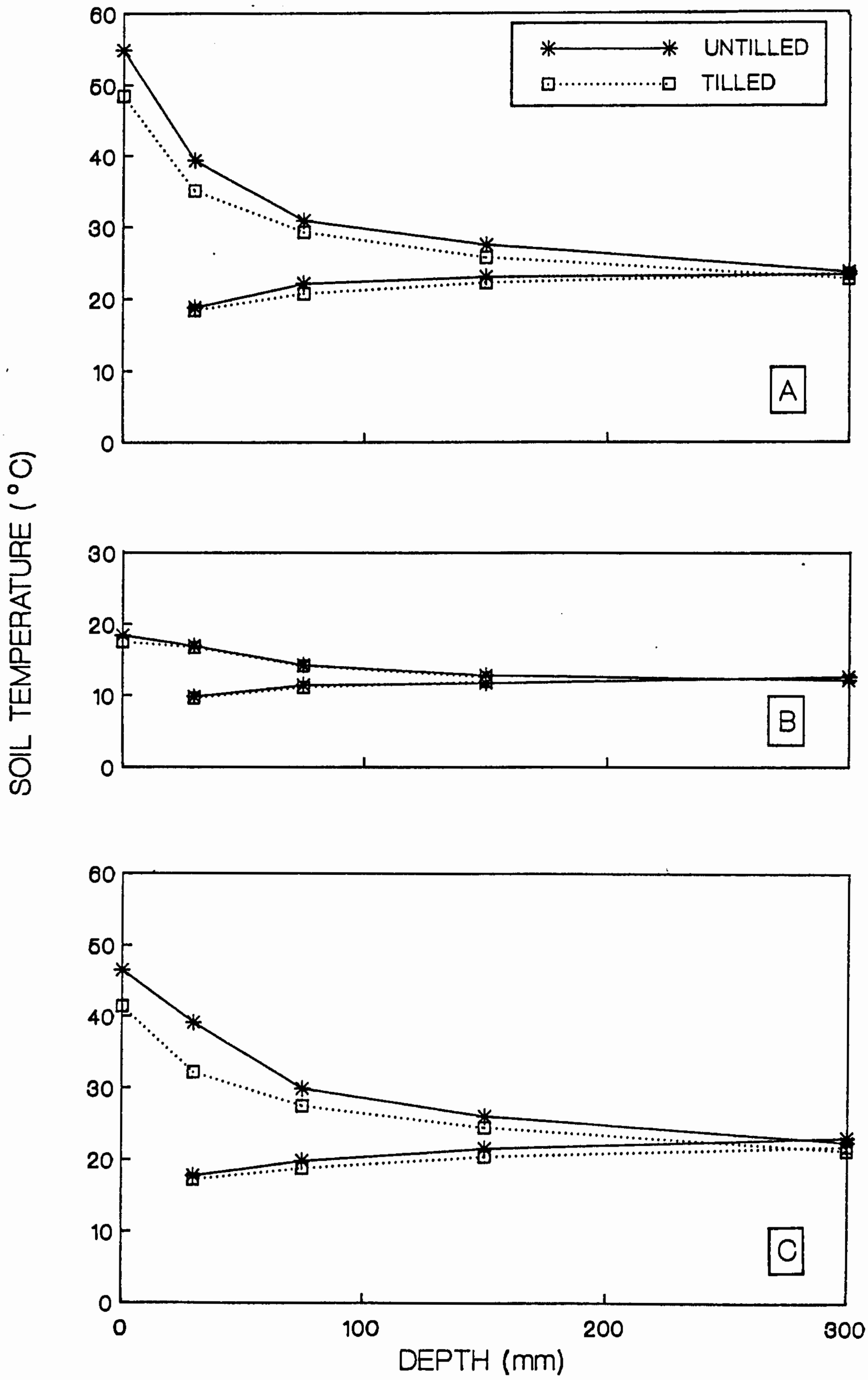


FIGURE 4-3. Soil temperature profiles between the surface and 300 mm at three times during the study period: (A) January 30, 1986 (B) July 31, 1986; and (C) January 15, 1987. The warmer profile of each was measured between 12h00 and 15h00, while the cooler represents the night-time between 00h00 and 03h00. Differences in daytime surface temperature are significant (t- test; $p < 0.05$) in all three instances, while the logging system generating the data for sub-surface temperatures was unable to supply sufficient channels for statistically useful replication.

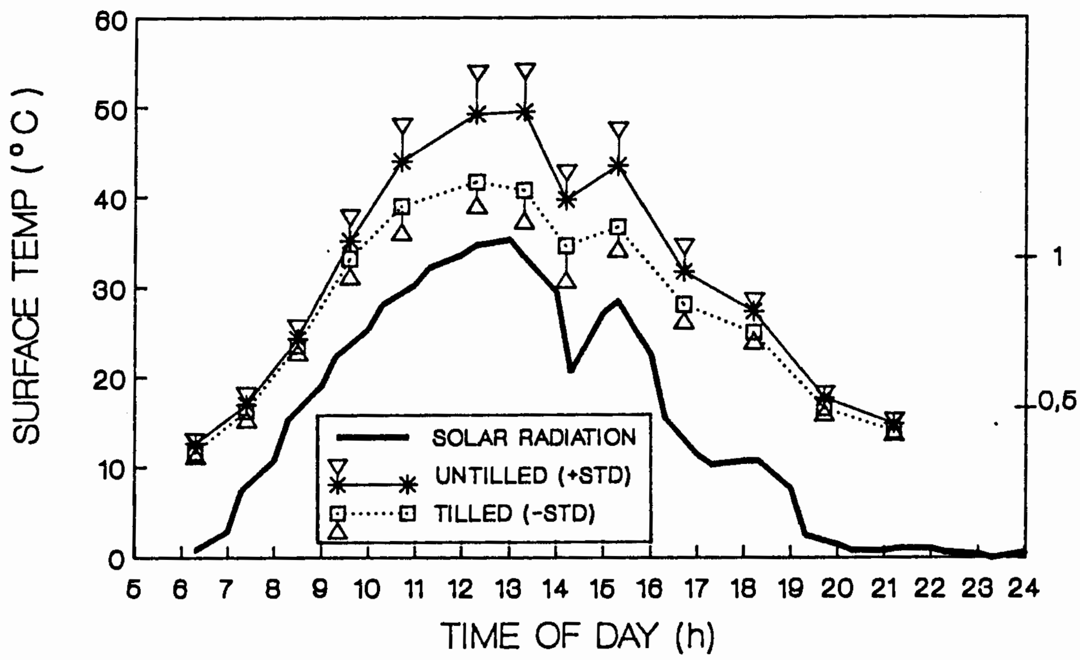


FIGURE 4-4. Diurnal pattern of soil surface temperature as measured on January 29, 1987, and the associated incoming solar radiation. All differences in surface temperature are significant (t-test; $p < 0.05$) except at the point marked with a hollow arrow. Apparent anomalies between the solar radiation and the surface temperature can be accounted for by the fact that the former is a mean value over the previous hour while the latter is an instantaneous reading.

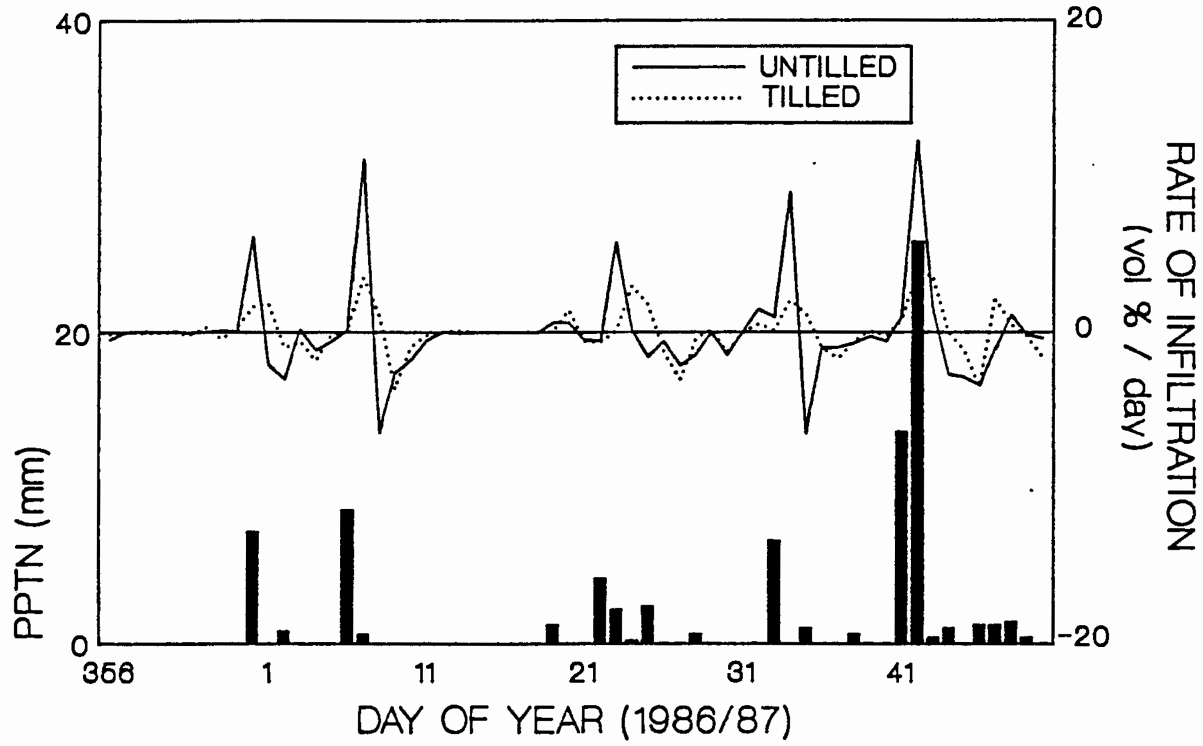


FIGURE 4-5. Infiltration and loss of precipitation in tilled and untilled soil at the Highlands study site. All data represent mean values over the previous 24 hour period, with infiltration being the change in water content at 30 mm during that time. Negative infiltration is the water loss at that depth under the combined influences of evaporation, transpiration, and gravitational flow.

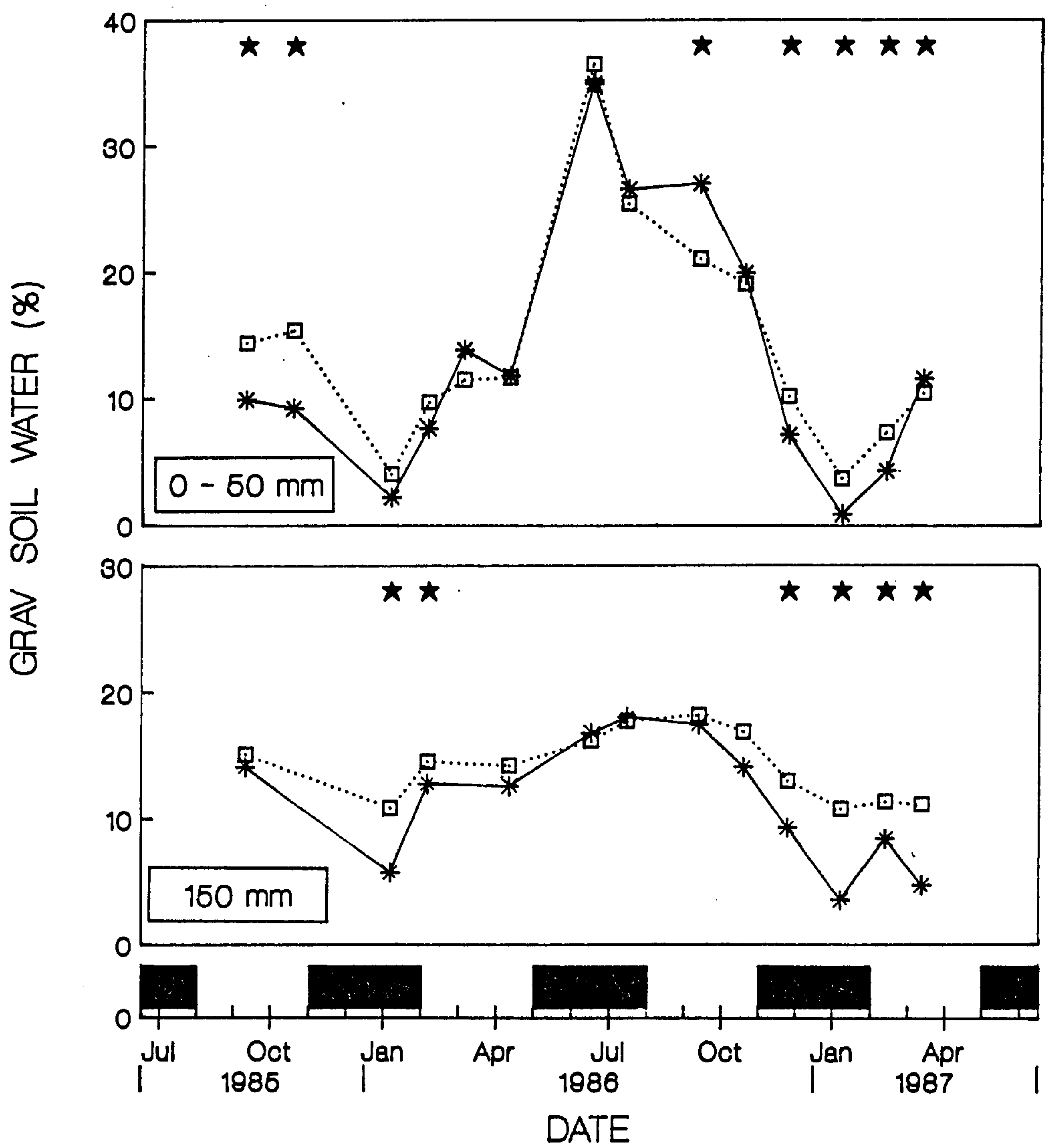


FIGURE 4-6. Seasonal soil water content (gravimetric) in the surface layer (0 - 50 mm), and at 150 mm during the monitored portion of the study period. Stars indicate significant differences (t-test; $p < 0.05$).

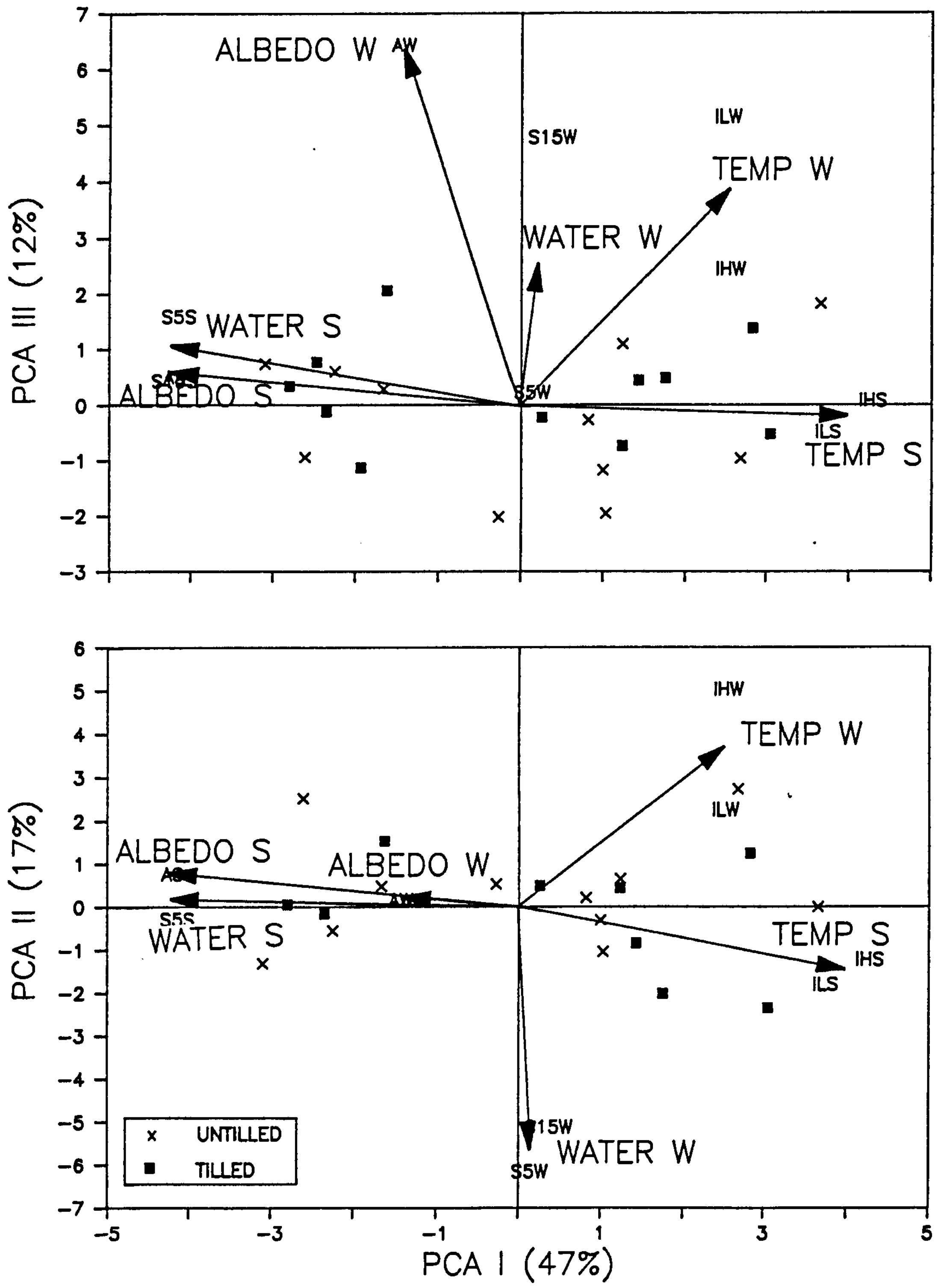


FIGURE 4-7. Plots representing the 3-dimensional output from a Principal Components Analysis (PCA) of environmental variables measured at the 11 pairs of sample stations. Labelled arrows summarize the ordination of the data sets, which were arranged to distinguish between the extreme seasons (S = summer; W = winter), while alphabetic characters are their actual ordinations (IH & IL are surface temperatures of hotspots and coolspots respectively, S5 and S15 are soil water contents between 0 and 50 mm, and at 150 mm respectively, and A is shortwave albedo) Symbols represent the sample sites (crosses = untilled; blocks = tilled).

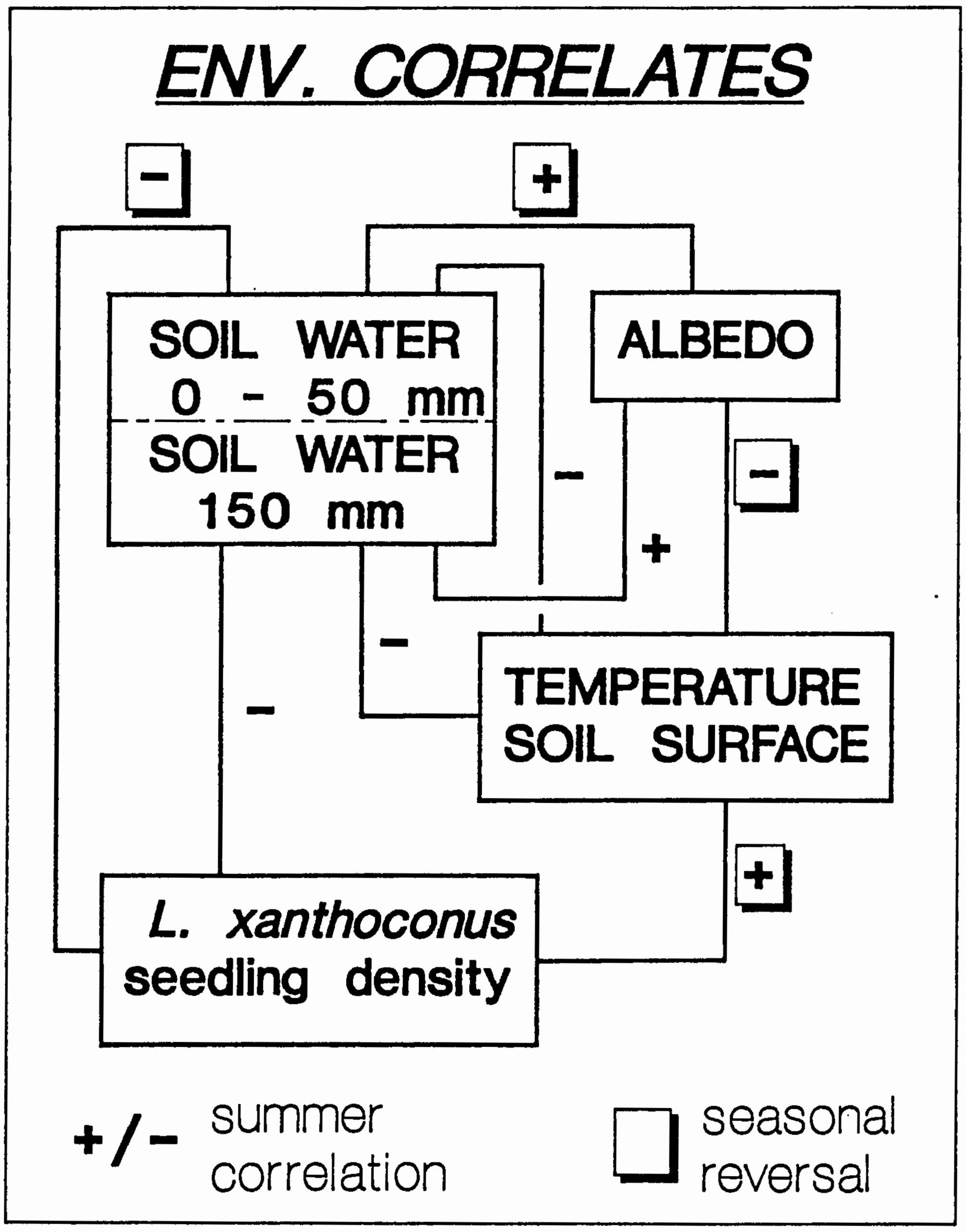


FIGURE 4-8. Summary of the correlation analysis of selected environmental and vegetation data. The algebraic signs (+ or -) indicate the presence of a significant correlation of that sign between indicated parameters under summer conditions ($p < 0.05$). For unboxed signs the correlation is insignificant during winter, while the box indicates a significant correlation during winter, but of the opposite sign. *Leucadendron xanthoconus* (Proteaceae) is the dominant shrub species at the study site, and one of the few whose measures of seedling or resprout density showed a significant correlation with environmental variables.

and summarizes the quantified interrelationship between the measured water and energy parameters, as well as a biotic component (*viz.* the density of *Leucadendron xanthoconus* seedlings). All correlations indicated in that figure were significant ($p < 0.05$) during the summer months, but some of those assumed significance of the opposite sign during the winter - *e.g.*. Such seasonally reversible correlations link *L. xanthoconus* seedling density to the soil surface temperature and the near-surface soil water content, which is to say that *L. xanthoconus* seedlings tend to grow in places which are warmer and drier during the summer and cooler and wetter during the winter.

DISCUSSION

Fire-driven systems are characterized by the occasional dramatic loss of all living plant tissue above the soil surface, with the exception of seeds stored in the inflorescences of adapted serotinous species. This apparently denuded environment is a critically important link between generations of the community, and one which selective processes have responded to during the evolution of many endemic species of the fynbos flora. Beneath the soil, root systems of many species are killed together with the abovergound parts, while rhizomes, corms, and other organs of vegetative regeneration are relatively well protected by the insulating properties of the soil (Kruger and Bigalke 1984) and are ready to produce shoot tissue almost immediately. Soil microbes and fungi which are more than a few centimeters from the surface are also probably unscathed by the above-ground conflagration, and even thrive on the enhanced die-back of root tissue from the obligately reseeding plants. At the surface itself the burnt litter and ash comprise a large proportion of the nutrients which will be incorporated into the next generation of plant life at the site.

Nutrients

The intrinsic oligotrophy of natural fynbos soil (Kruger 1979; Low 1983; Davis 1988), the small inputs of nutrients from outside the system *e.g.* symbiotic nitrogen fixation (Rundel *et al.*) or atmospheric input of phosphorous and nitrogen(Brown *et al.* 1984; Stock and Lewis 1986), imply that limiting nutrients are relatively efficiently recycled from generation to generation of native fynbos veld. The mechanisms which recapture nutrients from their tenuous state in the ash and litter of the burned environment probably represent a well integrated system finely tuned to conditions of oligotrophy, seasonal drought, and the stochastic occurrence of fire. Tillage may therefore justifiably be suspect as a potential spanner in the ecological works. The nutrient data collected in this part of the study however, do not provide a sufficiently detailed or resolved body of information able to test the general null hypothesis that tillage invokes no significant changes to the nutrient cycling mechanisms in mountain fynbos systems. But the gross level of the inquiry does not address the more refined questions which need to be asked to form an accurate picture of the network of processes. Seasonality, a recognized factor in nutrient availability (Vaughn *et al.* 1986), has been demonstrated to play an important role in cycling and utilization of nutrients in some Fynbos systems (Stock *et al.* 1987). The different chemical forms in which nutrients may occur in the soil (Mitchell *et al.* 1984; Stock and Lewis 1986; Witkowski and Mitchell 1987), also represents an aspect of nutrient cycling susceptible to alteration by tillage which lies beyond the scope of this particular study.

Energy

As with nutrients, the effects of disturbance on the energy regime discussed here are relative to the experimental system, but are probably able to be extrapolated to other fynbos sites with similar substrate properties. Lambrechts (1979) points out that the less steep mountain fynbos slopes are characterized by pale-coloured, sandy soils. It is these soils that, because of their accessibility, are likely to be subjected to tilling in the course of expansion of the wildflower industry. A high degree of podzolization, with its associated pallid E-horizon, was a feature of the experimental system, and one which must be considered in interpreting the data. Removal of the litter layer exposes this light coloured soil, especially if rotavation has turned up the mid-E horizon as well, providing a substantially more reflective surface to incoming solar radiation on the disturbed soil. This study suggests (Figure 4-1) however, that the magnitude of the difference is dependent on season. This is probably linked to the seasonal fluctuation in soil water, which influences its reflective properties. Bowers and Hanks (1965) formulated a model which demonstrated that the reflection of radiant energy from soils is inversely related to soil moisture, soil organic matter, and particle size. While the latter two determinants probably contribute to the increased reflectivity of tilled soil in the experimental system on account of fine mineral soil brought to the surface from the lower A/E, or B horizons (see soil texture of the different horizons in Chapter 3), surface soil water overrides this to the extent that albedo on the two treatments is similar during winter. This change of reflectivity necessarily has an influence on soil temperature. The surface, being the interface between atmosphere and soil, manifests a temperature related to the heat-load provided by the solar radiation. In this study, the seasonal pattern of reflectivity (Figure 4-2) echoes that for surface temperatures measured over the same period. The steeper gradients in the soil temperature profiles are evident in the summer, when soil is drier, and the heat load is the greatest, with the greater reflectivity of the tilled soil assisting in keeping it cooler during the summer. The effect of water (discussed independently below) is also to improve the transmission of energy to the deeper soil layers, allowing for temperature profiles with lower gradients. When soil is saturated during the winter months, temperature profiles on the two treatments are therefore similar. Soil energy, apart from its direct role in the movement of water by supplying thermodynamic energy (Slatyer 1967), has some potentially important consequences for development of the system's vegetational component. During the first year after the fire, an alteration of soil temperature may have consequences for the establishment of reseeder populations by shifting germination site temperatures relative to other seasonal factors. Soil temperature has also been shown to have important effects on plant growth (Al-Darby and Lowery 1987; Moraghan 1987; Sena Gomes and Kozlowski 1987). Differences between treatments in the productivity of both native and introduced species between the experimental treatments (see Chapters 5 and 7) may also be partly related to this alteration of the physical environment. The populations of soil microbiota (including pathogens) can also be influenced by alterations to the soil energy balance, but a strong interaction with soil water might be expected.

Water

Like the pattern of energy distribution in the tilled soil relative to the natural post-fire soil (untilled), the water budget seems to be severely altered by the experimental disturbance. On a seasonal basis (Figure 4-6), near-surface soil (0 - 50 mm) has a complex pattern of wetting and drying, with a tendency for the tilled soil to be wetter than the untilled during the summer months (December - February inclusive), a reversal of that in the spring (September - November) and autumn (March - May), but similar water contents during the winter. Deeper soil (at 150 mm) is clearly wetter on the undisturbed treatment in all but the wettest months. The combined effect of higher transpirational water loss from the vegetationally better covered untilled soil (see Chapter 5), and the elevated soil temperature which would increase evaporational losses, probably account for the pattern observed for the deeper soil. Separation of the two factors would not, however be easy, and more budgetary experimental work is required if that is to be investigated. No attempt is made to resolve that aspect of the system's water balance in this report.

Of more immediate relevance to the issue of land management is the phenomenon of wetting and drying closer to the surface. Figure 4-5 suggests that disruption of the surface soil might affect quite profoundly the rate at which water is able to infiltrate, having reduced it to less than 50% in the case of the heavier rainfalls. These data imply that tillage has disrupted soil structure which was developed by previous generations of plant community, *viz.* the natural surface coating of litter, and the sub-surface network of channels formed by outwash of fine soil particles and *in situ* decay of root tissue. Runoff, as a result, is probably higher from tilled soil, with a larger proportion of water being unable to find continuous channels for penetration to deeper levels. During the rainy season, when an excess of surface water is present for extended periods, this slower penetration is sufficient to bring soil to a saturation level similar to that of the untilled treatment, producing the observed similarity between parameters for the winter months.

(Although these data are based on an unsatisfactorily small sample size (two probes at each depth for each treatment), the indication of better infiltration in untilled soil can be entertained as a testable hypothesis, as it has been done here).

General

Results of the correlation analysis (Figures 4-7 & 4-8) show some of the interconnectedness between environmental variables, and the phenomenon of seasonal reversibility for some of these. The change of reflectivity with surface wetting appears to be play a major role in this process, but the difference in thermal conductivity between wet and dry soil must also be taken into account. I have attempted to collate all of the relevant factors and perceived relationships between system elements in Figure 4-9.

The inclusion of seedling abundance data for the dominant shrub species *Leucadendron xanthoconus* in this analysis also suggests the active/passive duality of a plant's relationship with its environment. During the warmer periods, when the disturbed soil is distinctly cooler and moister than untilled soil, it is the drier and hotter areas that support higher seedling densities, while during winter these same well-populated sites are cooler and moister. This suggests that, regardless of tillage

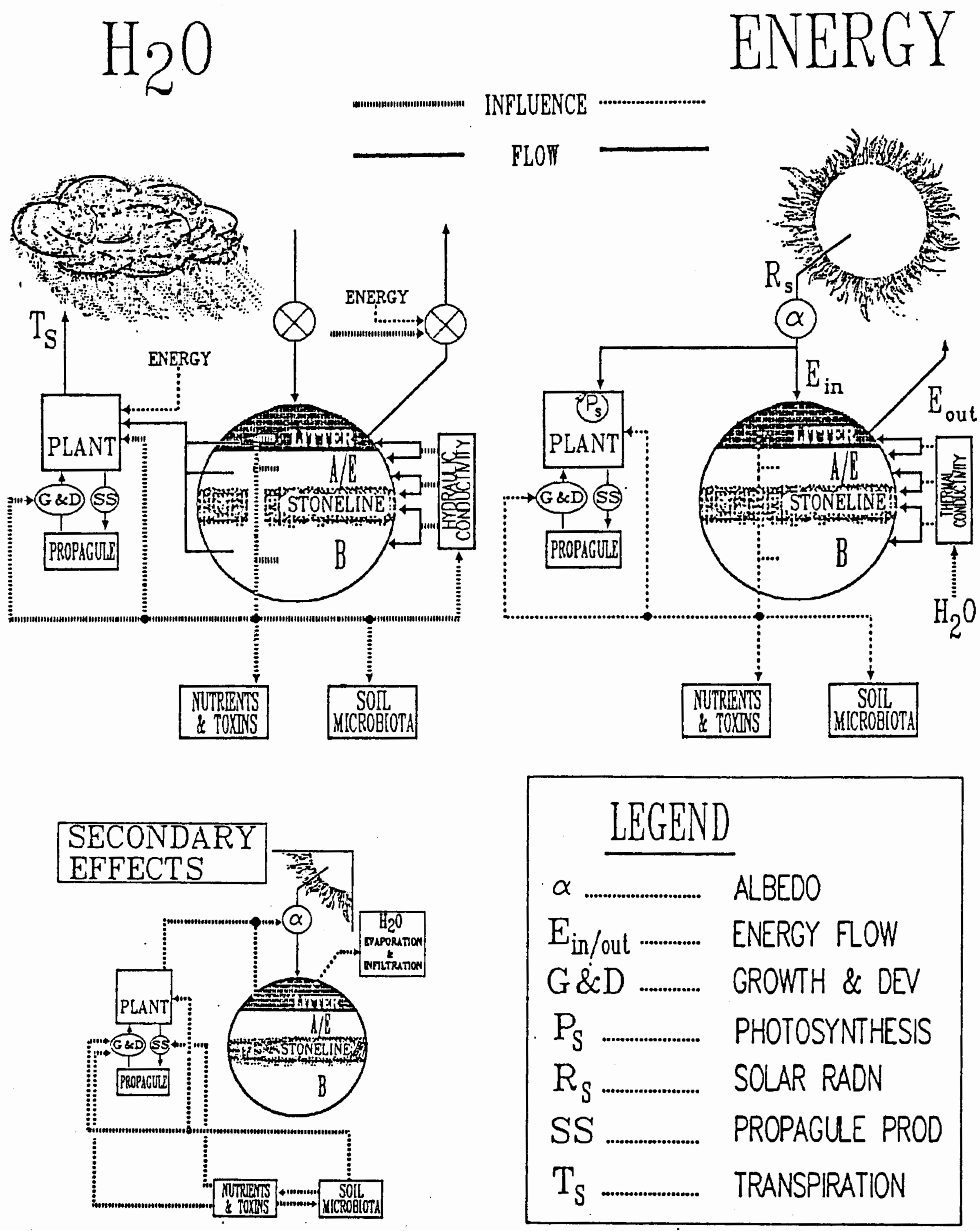


FIGURE 4-9. A proposed scheme of the relationship between elements of the experimental system with regard to the flow of energy and water, as well as the primary (above) and secondary (below left) influences exerted on and by the biotic components. The large circle in each sub-diagram represents the soil, with the three horizons as explained in Chapter 3. Disturbance by tilling, it is suggested, upsets both flows and influences in a complex and interactive manner.

treatment, seed germination and/or seedling establishment (which occurs during the late winter months) is favoured in the moister and cooler microsites, while during the summer established seedlings are able to survive the relative drought which they themselves induce by transpiration.

Implications for management and conservation

The data presented here do not indicate that tillage will have an immediately deleterious effects on the mountain fynbos systems where it is used as a management tool. The practical inability of this study to encompass all aspects of the impact of tillage does, however, leave many unanswered questions, even in the context of the experimental system itself. The distinct alteration of water and energy regimes, parameters of cardinal importance to many ecosystems, may have secondary long-term effects not uncovered by this set of observations. The increased water content of the tilled soil during the drier summer months is probably the main contributor to enhanced growth of plants on this disturbed treatment, but more rapid vegetative growth does not necessarily portend more or superior inflorescences for the commercial wildflower market, and may even open the way for outbreaks of pathogenic organisms such as *Phythopthora* spp. (Wilkinson and Millar 1982; Halsall and Williams 1984).

The conservationist's ideal is to maintain as much natural vegetation in a pristine condition for as long as possible. Annexation and transformation of considerable areas of previously unutilized land is, however, inevitable under increasing human pressure. But optimization of returns from practical compromises must be achieved if we are to leave a reasonable set of options open for an uncertain and overcrowded future where many of our accustomed resources may well be in short supply. For this reason, a clear understanding of the responses and resilience of natural ecosystems to anthropogenic disturbance is essential if a feasible conservation agenda is to be formulated which can accommodate even a portion of the broad spectrum of human expectations.

CHAPTER 5

THE RESPONSE OF MOUNTAIN FYNBOS VEGETATION TO SUBSTRATE DISTURBANCE:

Tillage as a factor in the marginal cultivation of wildflowers for commercial trade.

INTRODUCTION

Extinction of biological species as a result of habitat destruction by human activity is possibly one of the most powerful images which can be wielded by environmentalists in their quest for the conservation of biotic diversity. As ecological awareness amongst biologists has grown, emphasis has moved from the conservation of species *per se*, to the conservation of the habitats which both support these species, and which contribute to the integrity of larger ecosystems. But, apart from the ethical considerations of species preservation, their presence is potentially important as indicators of habitat, and hence ecosystem, condition. From an urban perspective, the estimated status of 58% of all South Africans by the turn of the century (Wilson and Ramphele 1989), biological indicators of environmental quality mean very little, and perception of human habitat degradation is inevitably left in the hands of the experts, wherever they may be. In mountain fynbos, a vegetation which in the south-western Cape will almost certainly be under increasing pressure from the rapidly growing human population of the greater Cape Town area over the next few decades, the concentration of threatened endemic plant species is high (Hall *et al.* 1984). Conservation is therefore an important issue in the Fynbos Biome. Human land-use patterns are responsible for major changes to ecosystems of southern Africa (Macdonald 1989). Development projects such as residential townships, roads, dams etc., can quite easily obliterate entire and unique habitats, driving to extinction species restricted to these sites by their evolutionary histories. The analysis of benefits to humanity, and the related costs of such development projects, is difficult as the criteria for their respective assessments are embodied in wholly incompatible economies. (See Chapter 8 for a discussion of this aspect of resource utilization in the fynbos). Here I consider the relatively benign exploitation of fynbos land in which natural veld is transformed for agricultural production. This type of land-use is effectively only appropriate to the cultivation of wildflower species - usually indigenous - for the commercial production of decorative flowers and foliage, which are supplied in substantial quantities to the local and overseas markets (see Greyling and Davis 1988).

Theoretical considerations

In the development of ecosystem concepts over the past few decades, there has been a shift away from the paradigmatic view, reflected in the Clementsian model of vegetation succession (Clements 1936), that natural systems are governed by intrinsically stable and predetermined processes. The modern ecological perspective, which has grown alongside an increasingly complex world view, recognizes that the observed patterns and relationships of nature are the result of many dynamic, and often stochastically driven influences. The concept of disturbance as a cardinal influence on both ecological and evolutionary events has become a major consideration of biologists (see Pickett and White 1985). Response of natural systems to disturbance, and their ability to recover, has been the subject of considerable theoretical debate (*e.g.* Holling 1973, Odum 1981, Godron and Forman 1983 *inter alia*). If that can be resolved sufficiently for reasonably successful predictive application, this understanding of whole integrated systems will be an important tool for sustainable management of the environment.

Vegetation, however, has proved difficult to describe quantitatively, or even conceptually. Much ingenuity and effort has gone into the development of techniques to model both its structure and its dynamics. From development of the first phytosociological methods by Braun-Blanquet in the 1920's (Pignatti 1980) , there has emerged a diverse set of techniques for describing community structure and its changes in space and time (see Barbour *et al.* 1987, chapter 8). This has produced a number of complex models for the describing the dynamic community processes such as succession (Connell and Slatyer 1977; Noble and Slatyer 1980; *inter alia*). A useful conceptual synthesis of the roles played by different plant survival "strategies" in vegetation structure has been expounded by Grime (1979; 1985). In these publications he adds to the two commonly accepted determinants of plant survival, **competition** and **disturbance**, a third of **environmental stress.** Together these serve as the basis for his triangular equilibrium model. He claims (Grime 1985) that they overcome omissions of the more traditional r- *vs* K-selection strategy model (Pianka 1970) by considering (1) the influence of stress-tolerance as an additional means of surviving in stable but unproductive habitats, and (2) facilitating the description of possible strategy changes during the life-cycle of an organism. Like the more classical approach of the Clementsian school, the triangular model does also assume that an underlying functional equilibrium exists between species of the community, and that the deterministic interactions which shape community history and structure, occur at, or near to that point.

A more *laissez faire* view, anticipated by Gleason (1926), has questioned the assumption that community structure is necessarily highly organized. The application of gradient analysis to vegetation structure, pioneered by Curtis (1955) and Whittaker (1967) (as cited in Whittaker 1975), helped to identify inconsistencies in the Clementsian model. This led to reinforcement of Gleason's (1926) "individualistic concept of plant association" which questioned the cohesiveness of perceived "community units". Based on research of a freshwater marsh plant community, Shipley and Keddy (1987) suggested that both of these models can be applicable, and that the historical dichotomy is too limited.

An additional element which must be considered as potentially important in the structure of communities, and not inconsistent with the individualistic concept, is that of chance. The arrival of propagules at the sites which the mature individuals of that species will occupy may be influenced primarily by the immediate past history of its distribution. Such a model - supported in part by the mathematical demonstration of Hubbell and Foster (1986) and backed by the theory of Levinton (1979) -, implies that diversity of a community can be maintained without invoking predetermined distribution of resources across discrete niches to ensure the survival of the member species. Greig-Smith (1986) cautiously concurs that "(only on small scales) ..... the effects of chance may in some circumstances override the effects of organization and stochastic processes may be the most important factor determining community composition". Fynbos vegetation has been recognized as diverse at the alpha, beta, and gamma levels (Taylor 1978; Kruger 1979 Bond 1983 , Cowling 1983), resulting in high landscape or regional level richness (Kruger and Taylor 1979; Cowling *et al.* 1989), - although the universality of large scale diversity in fynbos vegetation has been questioned by Cowling (1983). In spite of the important role of fairly frequent fires, many communities have a large proportion of species which are obligate reseeders, with up to half of the tree and shrub species in any regional flora regenerating in this manner (Kruger 1983). These factors suggest that stochastic processes may substantially influence community structure in fynbos vegetation. Fire is the intermittent disturbance event that, by virtue of variability in its intensity and frequency, could promote stochasticity in the determinants of community structure. In mediterranean-type ecosystems it is also an aspect of the environment to which most component species have probably been exposed as a selective pressure on an evolutionary time scale, and to which they are therefore adapted (Gill 1977 as cited by Barbour *et al.* 1987).

Physical perturbation of soil, on the other hand, is a disturbance less likely to have been encountered by natural fynbos vegetation. It is therefore one to which most species in the biome are unlikely to be adapted. If Clementsian facilitation were the path whereby communities invariably developed, then we might expect amelioration of a physically disturbed environment, and eventual reconstitution of the former community structure, provided the resource base had not been irreparably damaged. On the other hand, if the stochastic elements of seed dispersal, frugivory, rainfall, solar radiation, fire, etc. form a probability mosaic upon which long-term stability rests, then imposition of an alien event to the repertoire may block the occurrence of other events and cause the community to adopt an altered equilibrium. The question of model validity, it would appear, has not yet been answered.

But an understanding of the mechanisms which dictate the structure, stability, and resilience of natural systems is a *sine qua non* for management of the human environment. Knowledge of how far systems can be deviated from their natural courses before induction of irreversible degradation, *and hence loss of productive potential,* is highly desirable, if not imperative, for maintenance of the resources needed for human survival.

In this chapter I review the data from the experimental portion of the study that describes response of mountain fynbos vegetation to the disturbance of tilling. The experimental treatment, and observed changes to the physical environment are detailed in the preceding two chapters of this thesis.

Vegetation response to tilling was viewed from the following different perspectives:

1. System integrity - overall vegetation cover was taken as a measure of system susceptibility to the erosional effects of wind and water;
2. Community integrity - the relative diversity of the communities re-establishing on tilled and untilled soil;
3. Species performance - the effects of tillage on the productive capacities of selected species of the pre-disturbance community;
4. Invasibility - the susceptibility of the disturbed experimental system to invasion by alien weed species which are problematic in the fynbos biome.

Considering the possible role of both deterministic and stochastic elements functioning within the vegetation, the key question being addressed in this chapter is: "Are mountain fynbos systems resilient enough to accommodate utilization involving physical disturbance without being set on a course towards degradation?"

METHODS

The study site and its preparation

The study site is described in Chapter 3, and the experimental treatment it was subjected to in Chapter 4. A subset (23) of the 28 (1 m x 1 m) sample quadrats referred to in the former chapter were incorporated into the tillage plan in such a way that 12 were tilled, and 11 not. This set of 23 stations was then matched with a second complementary set in such a way as to provide 23 pairs of quadrats each comprising a tilled sample and an untilled control.

Ground cover

During March 1988, at each of the 46 sample quadrats, a 0.5 m x 0.5 m subquadrat was photographed on colour slide film from vertically above, using either supplementary flash lighting, or the shade of a sun umbrella to reduce confusing shadows and contrast. These photographs were then projected onto a prepared grid containing up to 240 interstices, and the coincidence of these with living shoot tissue, dead litter, and bare soil counted. The percentage of hits for each category was taken as the measure of projected foliar cover. Owing to the low frequency of hits, statistical tests were performed on arcsine transformations of those data (Zar 1974). Similar photographs and analyses were performed on half the number of quadrats in the previous two years (see Chapter 3 for the earlier configuration of samples stations).

Community structure

Because of the exaggerated differences in the morphologies of the young regenerating plants, the task of comparing importance between species was difficult. The measure used was a subjective abundance value weighted for each species according to its particular habit and performance over the entire study plot. The abundance of each species was measured at each sample station according to the number of individuals, or an estimate of the projected foliar cover. These measures were placed on a scale of 0 - 3 (with a resolution of 0.25 where necessary) which covered the range of observed potential performances over the whole study site. These abundance measures were used as the basis for deriving relative contributions of species to the overall vegetation on the various treatments considered , as well as their groupings according to family, and regenerative strategy (reseeders, resprouters, and geophytes). They were also converted to provide a measure of relative abundance, p_i (for the i^{th} species), where $\Sigma p_i = 1$ at each station. These latter values were used in the calculations of diversity and dominance described below, and also served as input data for a detrended correspondence analysis (DCA).

Indices of diversity and dominance were derived for each sample quadrat from species presence/absence data, and the relative importance values according to the following formulae:

(1) species richness (S);
(2) Shannon-Wiener index ($H' = -\Sigma p_i \ln p_i$);
and (3) Simpson index ($C = \Sigma p_i^2$)

where S = number of species;
p_i = relative importance of the i^{th} species;
and *ln* is the natural logarithm

(Zar 1974; Whittaker 1975; Ludwig and Reynolds 1988).

These indices were calculated for each sample quadrat on the tilled treatment and the untilled control during the early summers of 1986/7, 1987/8, and 1988/9. During the last sampling period the equivalent data were collected, and analyses performed, for (1) adjacent mature vegetation, and (2) vegetation re- establishing itself on the fire-break which had been cut around the study plot at soil surface level before the fire in February 1985. These latter data had been collected to provide a means of distinguishing (1) between the effects of disturbance by fire and that of tillage, and (2) between the role of clearing by fire, and that of mechanical clearing.

Significance of the differences between S, H', and C on tilled and untilled treatments were tested using a non-parametric test (Mann-Whitney). Indices for the additional mature and cut samples were analyzed using a one-way ANOVA, the non-parametric options being unavailable owing to the unequal sample sizes. The associated multiple range test (based on 95% confidence intervals) was employed to determine the existence of homogeneous groups. Analysis and tests were performed using the commercially available computer software package STATGRAPHICS Version 3.0, Statistical Graphics Corporation).

To extend the information describing effects of tillage on community structure in mountain fynbos, a similar set of data was collected for vegetation on each of two fire-cleared and strip-tilled commercial production sites on the farm *Heuningklip* (B. Gibson, Kleinmond). Vegetation assemblages on these sites were two, and three years old respectively. Ten quadrats (1 m x 1 m) were laid out on tilled soil, and ten on untilled soil at each site, and the data collected were analyzed in the same way as those from Highlands.

A second method of extending the data base for observation of the effects of disturbance on natural vegetation, was to compare species-area relationships of natural vegetation growing on tilled and untilled soil. A suitable established commercial plantation which had originally been subject to complete tillage rather than the strip pattern, together with adjacent undisturbed fynbos vegetation as a control, was located on the farm *Honingklip* (R. Middelmann, Botrivier). A set of nested quadrats after the method of Whittaker *et al* (1979) was delineated on land under the cultivation of *Protea magnifica*, and another in adjacent undisturbed veld, a method not feasible on strip cultivated land. The plantation had been established 15 years previously, and the cultivated plants were approximately 2 m apart in rows spaced at 3 to 4 m intervals. Naturally re-establishing vegetation between the rows had been cleared by disc-cultivation at approximately 2 year intervals initially, and most recently 5 years prior to this survey. The natural veld used as control had been cleared by burning 15 years previously, although it may have been burned subsequently. Data collected was restricted to presence/absence information, and a species - log area curve was derived (see Bond 1983, and Chapter 3 of this thesis).

Ordination of community data

To describe the relative changes in the sub-communities of the untilled and tilled treatments, with mature vegetation as a reference, the annual sets of importance values from the Highlands site were combined and analyzed by detrended correspondence analysis (DCA, or DECORANA), using the programme of Hill (1979) as described by Gauch (1982), and Digby and Kempton (1987). Positions of the sample sites in ordination space, the three-dimensional space defined by the first three ordination axes (DCA1, DCA2 and DCA3), were interpreted in two ways. Firstly the mean output values for each year were calculated with respect to the two treatments, and the time trajectory of each treatment-set plotted. This follows the approach to analysis of successional change adopted by Austin (1977), Belsky (1984; 1986), Cowling and Pierce (1988). A second representation was designed to show the relative movement between members of the paired sets of tilled and untilled samples, and the overall variability in the output data. This was achieved by plotting on a DCA1 vs DCA2 plot all of the paired co-ordinate differences between treatments for each of the sample years separately.

Performance of individual species on tilled and untilled soil

Plant response to the altered environmental factors (see Chapter 4) was measured in terms of above-ground productivity during the experimental period. The species selected as characteristic of the study site were: *Leucadendron xanthoconus* (Proteaceae), *Erica cristata* (Ericaceae), and *Chondropetalum hookerianum* (Restionaceae), a choice which also considered representation of the definitive families of mountain fynbos flora (Taylor 1978). Sets of randomly selected plants on each of the tilled and untilled treatments were designated for harvest during the autumn of each year between 1986 and 1989. These samples were oven-dried at 70 ^{o}C, and weighed. A sampling problem was encountered with *C. hookerianum* because of its developmental pattern. After germinating, it persisted as a slender "epicotyl" between 40 and 100 mm in height for the first one to two years, after which it adopted the recognizable restionaceous mode of seasonal growth by producing relatively more massive culms from its compact rhizomatous crown region. During 1988 the transition from one form to the other was in progress, and sampling was omitted due to the heterogeneity of the population. In 1989 sampling of this species was performed on a unit area basis by sampling all above-ground tissue within randomly placed sample frames 0,1 m^2 in size, in the vicinity of each permanent quadrat site.

Invasion by alien species

To obtain an indication of the influence of disturbance on the susceptibility of mountain fynbos vegetation to invasion by alien woody weed species , the experimental plot was surveyed during the autumn of 1989 for the presence of these species. For sampling, the plot was split into two by a median line running at right angles to the direction of tilling. Each tilled half-row and the immediately adjacent untilled control area was treated as a paired sample, and the number of individuals of each species counted. Distribution of the species over the experimental plot was analyzed by the Mann-Whitney paired sample test.

Statistical analyses

The constraints of site preparation, especially with respect to burning, meant that only a small portion of vegetation in the area could be sampled. Implicit in this experimental design is the risk of spurious results through pseudo-replication, as outlined by Hurlbert (1984). The sites on *Honingklip* and *Heuningklip* farms were intended to overcome this design limitation as far as practically possible. Also problematic with regard to pseudo-replication, because of both nesting and contiguousness, were the data obtained from the nested quadrats at *Honingklip.* Those results should be read as corroborative of the Highlands data only.

RESULTS

Ground cover

Comparisons of the different cover values (Figure 5-1.) between treatments (Mann-Whitney) confirmed that all but the live cover at the 1988 sample time were significantly greater ($p < 2 \times 10^{-3}$) on the untilled soil. The dramatic drop in live foliar cover in the third year on the untilled treatment coincides with lower precipitation during the preceding 12 months as recorded at the Highlands Forest Station. The total annual precipitation between March 1, 1987 and February 28, 1988, was 830 mm, a figure more than 100 mm lower than the totals recorded during the two previous equivalent periods, which were both slightly greater than the long-term average of 928 mm. The seasonal distribution of those annual amounts are shown in Figure 5-2.

Community structure

The relative distribution of species importance between families is shown in Table 5-1, where it can be seen that with respect to the relative importance values described in METHODS above, more than 50% of the vegetation is accounted for by the Restionaceae and the Cyperaceae in the younger vegetation on both treatments, while the Proteaceae and Ericaceae increase in relative importance, and

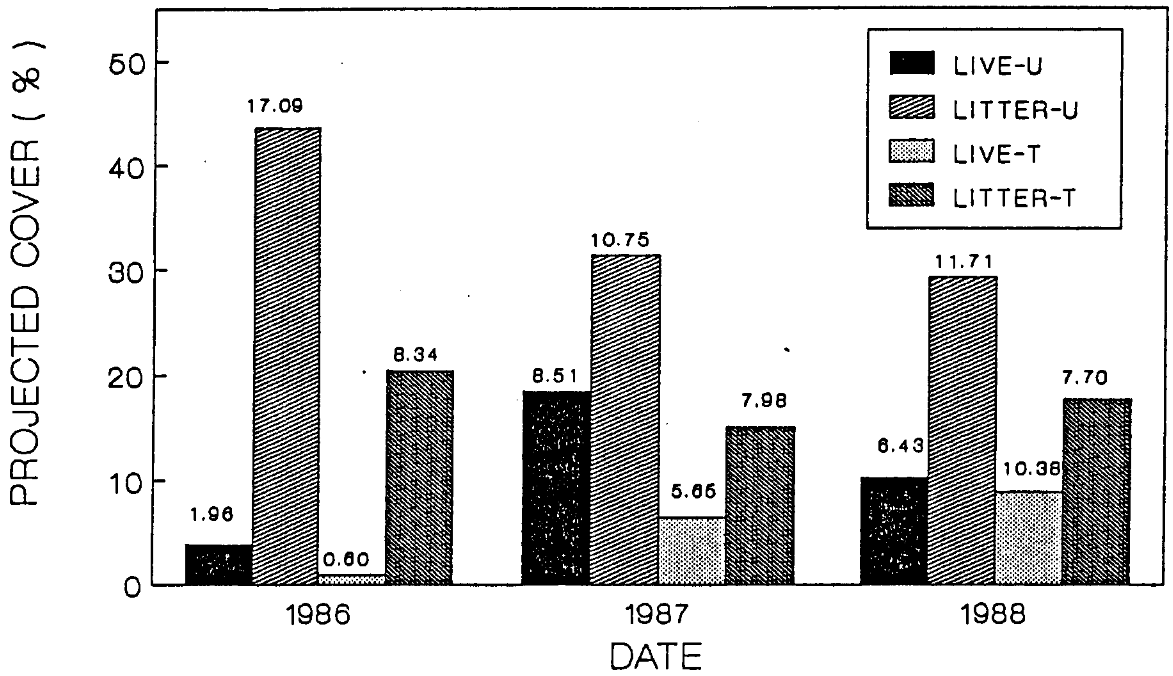


FIGURE 5-1. Projected cover provided by (1) live, and (2) litter and standing dead material, on tilled and untilled soil at the Highlands study site during the observation period. Figures above the bars give the value of one standard deviation. Details of significance of differences are given in the text.

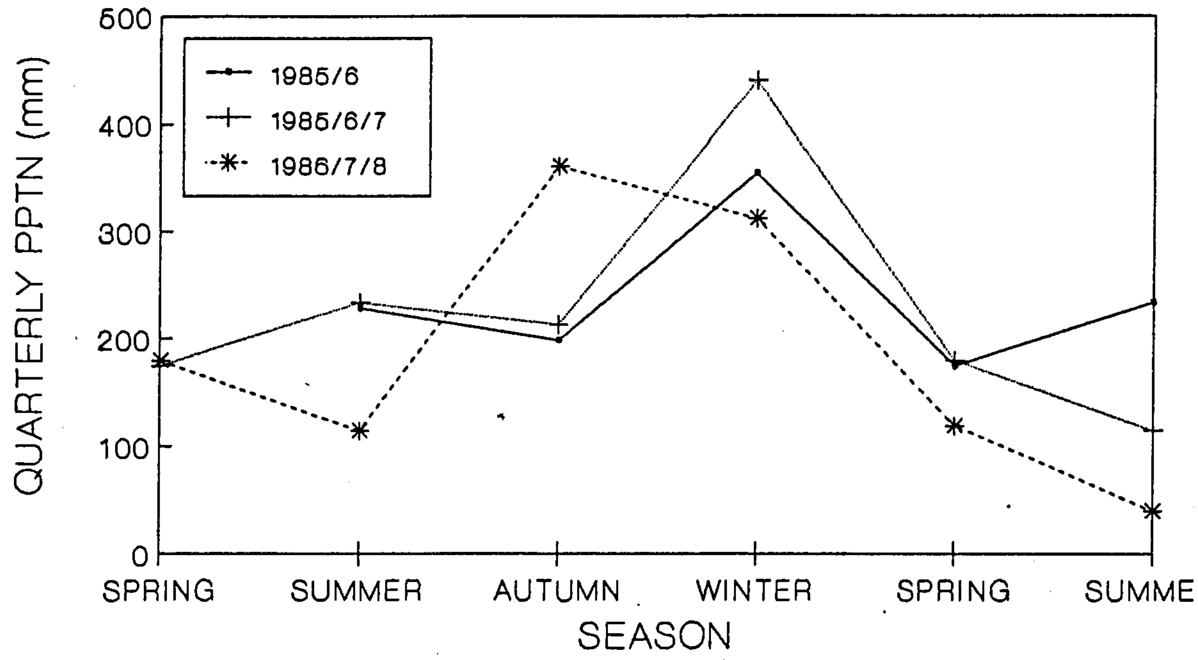


FIGURE 5-2. Precipitation during the five quarters preceeding each annual measurement of projected soil cover on the tilled and untilled soil at the Highlands study site.

TABLE 5-1. Distribution of relative species importance between families during the recovery period and in mature vegetation. Significance values for differences (p, two-tailed) were derived from Mann-Whitney tests performed on arcsine transformed data. In the immature vegetation the tilled and untilled treatments (n = 23 for each) are compared, while mature vegetation (n = 17) is compared with the 3 year-old stand (1988).

FAMILY	TREATMENT		RECOVERING VEGETATION 1986	1987	1988	MATURE VEGETATION
PROTEACEAE	untilled	mean	9.7	8.1	10.0	21.0
		std	8.3	7.2	8.7	18.7
	tilled	mean	4.1	2.5	3.0	
		std	8.3	3.6	4.3	
		p	0.001	<0.001	0.001	0.05
ERICACEAE	untilled	mean	7.2	10.9	15.8	21.7
		std	6.2	6.1	8.2	19.4
	tilled	mean	6.8	16.3	21.0	
		std	5.7	7.2	10.7	
		p	0.99	0.01	0.12	0.39
RESTIONACEAE	untilled	mean	28.9	32.6	26.1	31.3
		std	8.6	9.3	9.3	15.8
	tilled	mean	24.0	40.7	40.5	
		std	9.9	6.9	11.5	
		p	0.10	0.002	<0.001	0.20

next page/....

....TABLE 5-1 continued.

CYPERACEAE	untilled	mean	22.0	28.6	28.5		13.6
		std	11.2	9.7	7.6		7.3
	tilled	mean	16.6	17.6	16.5		
		std	10.8	9.1	8.1		
		p	0.10	<0.001	<0.001		<0.001
POACEAE	untilled	mean	8.6	9.6	6.9		1.0
		std	5.5	7.3	4.0		1.7
	tilled	mean	15.7	12.9	11.0		
		std	14.4	8.9	5.8		
		p	0.16	0.19	0.01		<0.001
TOTAL CONTRIBUTION							
	untilled	mean	76.5	89.8	82.3		88.6
		std	9.1	4.6	7.3		15.2
	tilled	mean	67.3	90.1	91.9		
		std	17.2	5.1	5.1		

the Cyperaceae declines in the case of mature vegetation. Table 5-2 depicts a similar analysis of species importance distribution between the regenerative categories listed. This latter table is less comprehensive in that the regeneration mode of several species (between 5 and 20 % in relative importance) could not be determined with any degree of accuracy. The mean values of S, H', and C are summarized in Table 5-3, together with standard deviations, and the significance level of observed differences. Not shown in this table are the results derived from the data set which included (1) samples of the mature vegetation, and (2) re-establishing vegetation on the cut fire-break strip. These latter analyses showed mature vegetation samples to be different from all other groups for all three of the above indices (S = 9.2; H' = 1.64, and C = 0.27), while the cut set was indistinguishable from the untilled controls for S and C, and constituted an intermediate between the untilled and tilled sets with regard to H'.

Species - area relationship

The species - log area curves derived for the two treatments surveyed on "Honingklip" farm are shown in Figure 5-3. Over the full range of quadrat sizes, the species richness of the natural veld is greater than that of the cultivated land. Species richness (approximate "point diversity", *sensu* Bond 1983) for the two sets of 1 m^2 quadrats are significantly different ($p < 0.05$; t-test) (see cautionary note on pseudo-replication in METHODS).

Ordination of community data

Figures 5-4 and 5-5 summarize the results of the DCA ordination as described in METHODS above. Figure 5-4 shows, in three- dimensional ordination space, the trajectories of mean sample positions during the sample period, and the relative position of the mature vegetation. The convergence of ordination values towards no difference between paired treatment samples (gravitation towards the origin), and the overall reduction of variability in paired values (reduction of scatter), is evident in Figure 5-5. In this latter figure, the migration of the two difference points (marked 1 and 2) into the upper right quadrant, is probably accounted for by the very high importance values recorded for the resprouting restionaceous species *Mastersiella digitata* (point 2), and the pioneer grass *Ehrharta longifolia* (point 1) in the disturbed quadrats of those sample pairs. The latter point also represents the only two quadrats (tilled and untilled), where *Protea longifolia* occurs.

TABLE 5-2. Distribution of importance values between regenerative strategies in the Highlands plant communities. Comparisons and statistical analyses are as for Table 5-1.

STRATEGY	TREATMENT		REGENERATING VEG, 1986	1987	1988	MATURE
SEEDER	untilled	mean	37.2	38.1	36.8	69.6
		sem	3.5	2.6	2.9	5.2
	tilled	mean	21.8	48.2	48.8	
		sem	2.5	3.2	3.8	
		p	<0.001	0.02	0.004	<0.001
RESPROUTER	untilled	mean	39.6	51.4	49.2	18.9
		sem	3.1	2.4	2.0	2.6
	tilled	mean	45.5	41.7	42.8	
		sem	3.9	3.0	3.5	
		p	0.21	0.005	0.009	<0.001
GEOPHYTE	untilled	mean	16.5	4.8	5.4	4.2
		sem	1.7	0.9	1.0	0.4
	tilled	mean	23.3	3.8	3.7	
		sem	3.5	0.5	0.6	
		p	0.36	0.62	0.16	0.29
TOTAL CONTRIBUTION						
	untilled	mean	93.3	94.3	91.5	92.7
		sem	5.5	3.6	8.2	13.2
	tilled	mean	90.5	93.8	95.3	
		sem	7.2	4.6	4.1	

TABLE 5-3. Indices of species richness and diversity of mountain fynbos vegetation as a response to disturbance by tilling. Details of analysis are the same as for Tables 5-1 and 5-2, with additional information from Heuningklip farm in Kleinmond.

INDEX		HIGHLANDS STUDY SITE: RECOVERING VEGETATION 1986[a]	1987[b]	1988[c]	MATURE VEGETATION[d]	HEUNINGKLIP FARM: SITE 1[b]	SITE 2[c]
SPECIES RICHNESS (S)	untilled mean	19.4	20.6	18.4	9.2	14.4	24.4
	std	2.9	3.1	2.5	3.0	3.5	5.0
	tilled mean	12.9	15.7	14.0		11.6	15.4
	std	2.84	2.98	2.94		2.4	3.5
	p	<0.001	<0.001	<0.001	<0.001[e]	0.07	0.002
SHANNON-WIENER INDEX (H')	untilled mean	2.25	2.43	2.50	1.64	2.25	2.82
	std	0.268	0.159	0.168	0.356	0.190	0.315
	tilled mean	2.05	2.25	2.18		2.01	2.30
	std	0.377	0.228	0.343		0.157	0.246
	p	0.06	0.01	<0.001	<0.001e	0.01	0.002
SIMPSON INDEX (C)	untilled mean	0.17	0.12	0.11	0.27	0.13	0.12
	std	0.064	0.026	0.026	0.082	0.028	0.061
	tilled mean	0.21	0.14	0.16		0.17	0.23
	std	0.11	0.037	0.094		0.028	0.190
	p	0.20	0.03	0.001	<0.001[e]	0.014	0.025

[a] to [c] = one- to three-year old vegetation
[d] = 15-year old vegetation;
[e] = comparison with adjacent 1988 Highlands vegetation

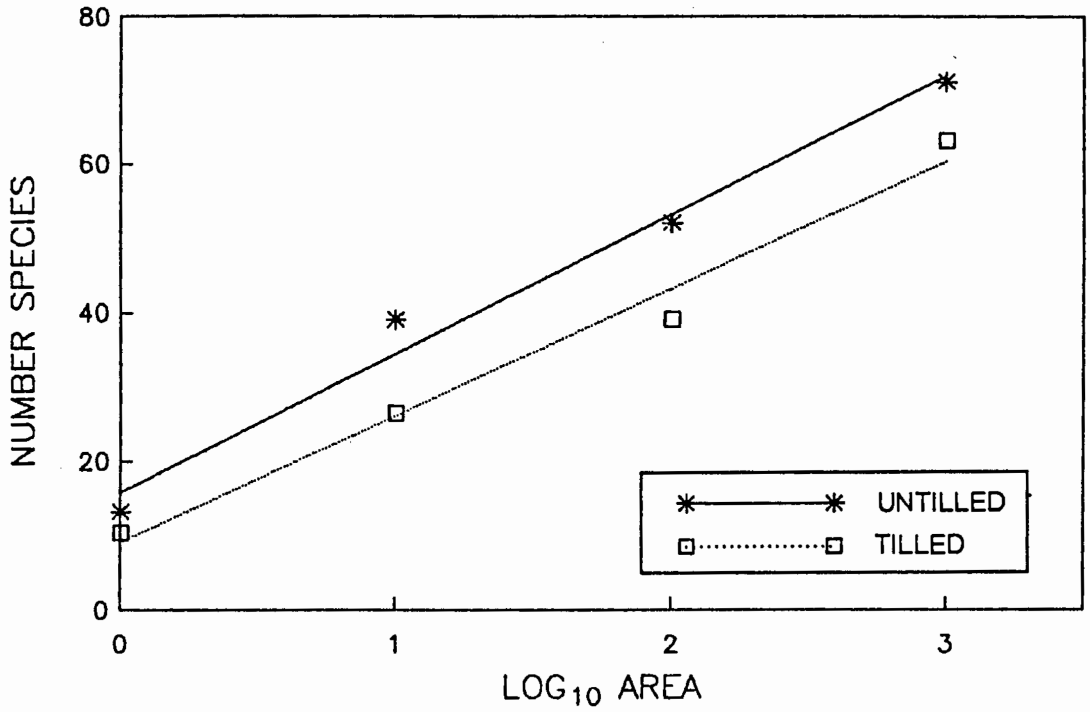


FIGURE 5-3. Species-area relationships in natural plant communities on tilled and untilled soil on the *Honingklip* farm in Botrivier. The two intercepts, representing $\log_{10}$Area = 0 (1 m^2), are based on a sample size of 10, and are significantly different ($p < 0.05$; Student's t-test). The regression lines, which represent correlations between $\log_{10}$Area and the number of species present, are also both significant ($p < 0.01$; with $r^2 > 0.98$ for both).

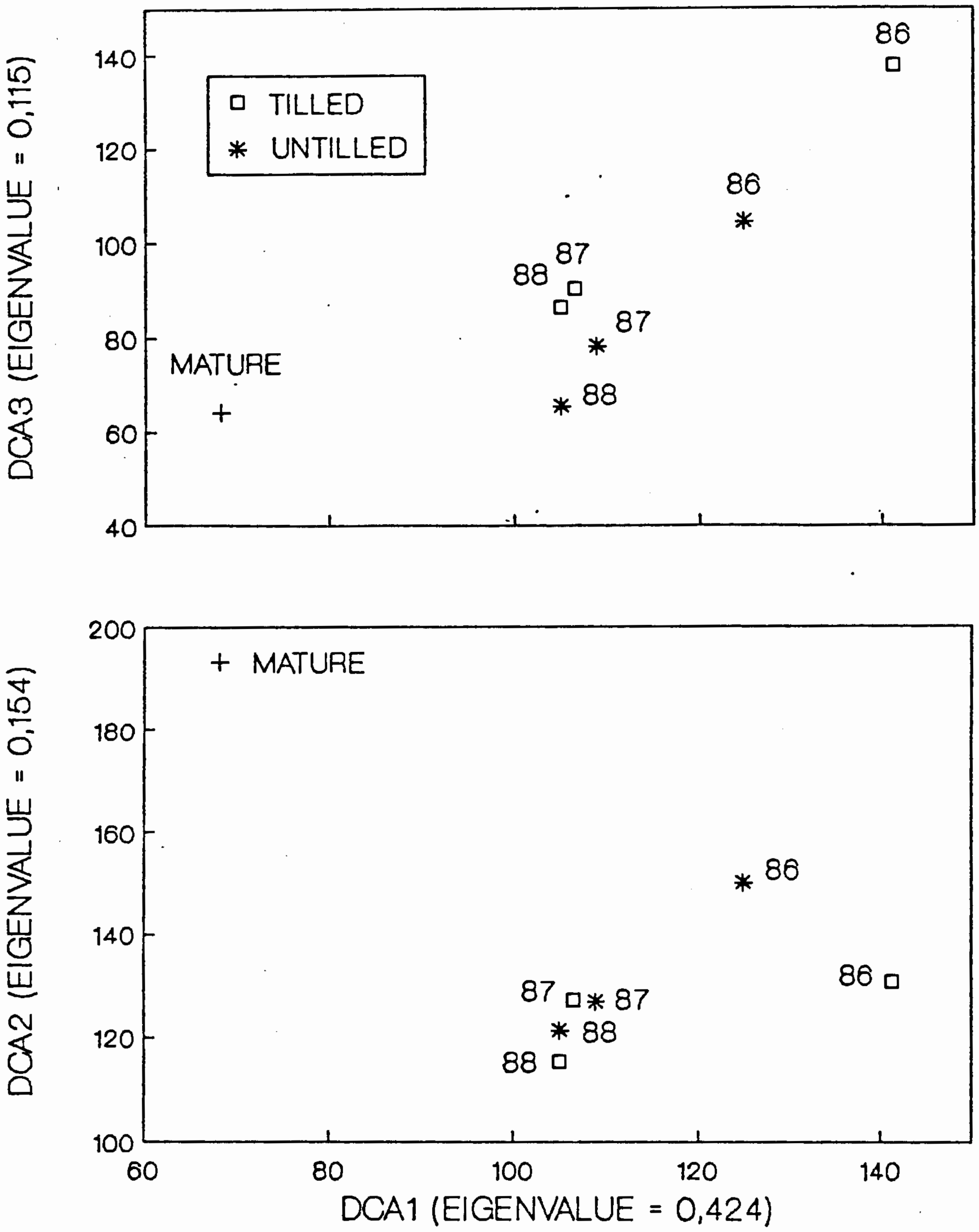


FIGURE 5-4. Detrended correspondence analysis (DCA) of tilled and untilled sample sites, and the relative movement of their aggregate positions in time. ; Included is the position of the mature vegetation, which was ordinated in the same data set.

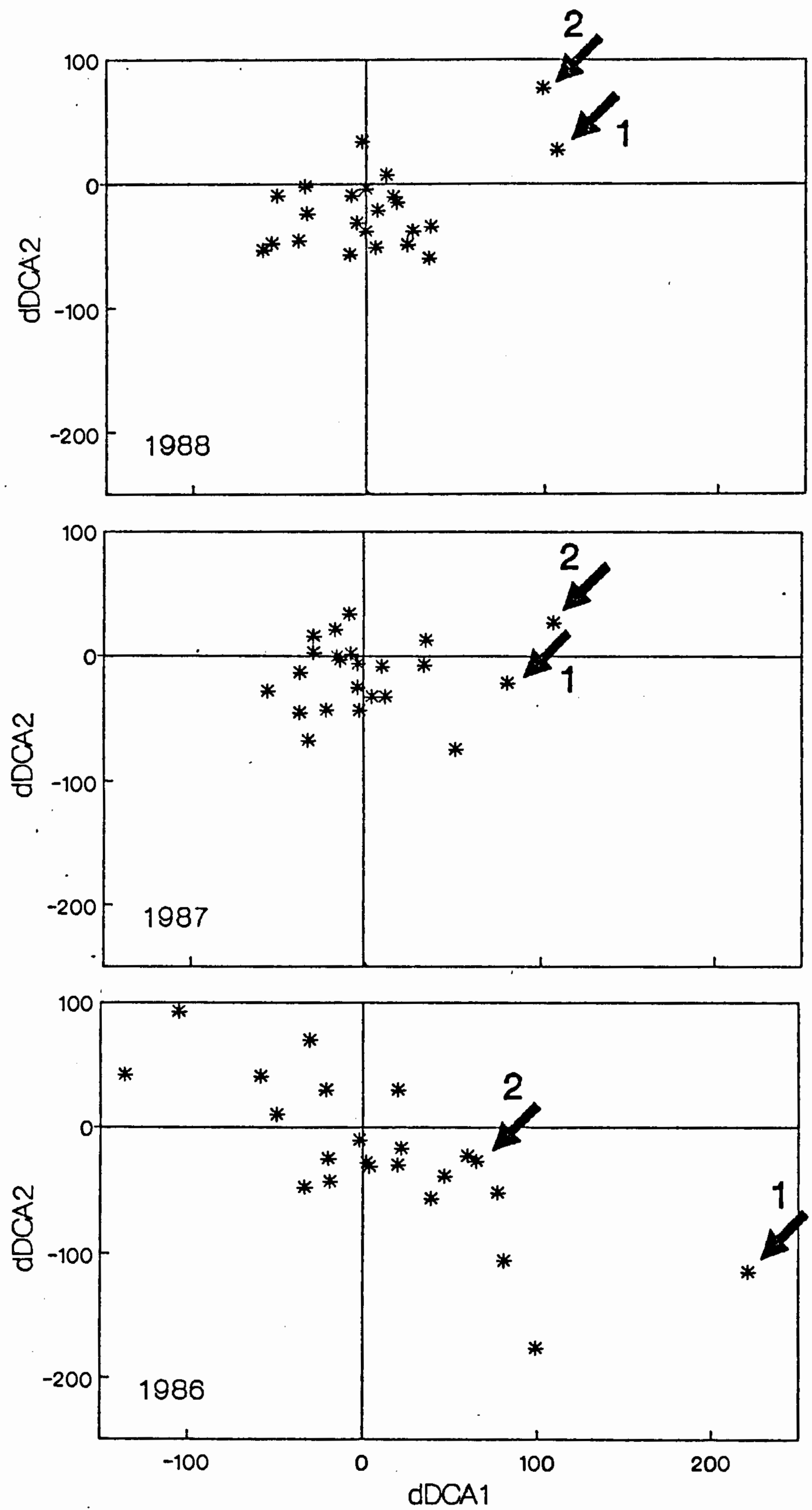


FIGURE 5-5. Convergence over the observation period of the differences between ordination values for pairs of sample sites as analysed by DECORANA. Arrows indicate quadrat pairs where a single species was observed to be exceptionally abundant on the tilled soil (see text).

Performance of individual species on tilled and untilled soil

The production of above-ground biomass of two of the three selected species is given in Figure 5-6. The advantage which tillage confers on *Leucadendron xanthoconus* and *Erica cristata* is especially dramatically demonstrated by the 1989 data, although the mean biomass was significantly greater ($p < 0.05$; t-test) at all sampling times. The restionaceous species *Chondropetalum hookerianum*, however, maintained the similar above-ground plant biomass on the two treatments, both during the early establishment phase, and the more vigorous later stage.

Measures of abundance of the three species extracted from the field data are shown in Figure 5-7. Both *E. cristata* and *C. hookerianum* show substantial recovery in the second and third years, while *L. xanthoconus* remains relatively poorly represented on the tilled soil. (Note that these measures consider the distribution of population importance between treatments, while results in Table 5-1 (*e.g.* for the Restionaceae) compare relative proportions of the total sample vegetation at each station, and therefore cannot reflect absolute abundance as well.)

Invasion by alien species

The only woody alien species found on the study plot, or in the immediate vicinity, was *Pinus pinaster* Aiton. This species, which was being cultivated for timber production in plantations less than 1 km to the south, occurred as seedlings five times on untilled soil, and 21 times on soil which had been tilled. Using the non-parametric statistical test described under METHODS, it was found that this difference in distribution was significant at the 90% level ($p = 0.06$). This analysis assumed that the two sample areas were equal in size, which they were not. Over the entire plot, untilled soil occupied 2.2 times as much area as untilled soil. The bias introduced by this discrepancy strengthens the interpretation that *P. pinaster* seedlings were more likely to be found on the physically disturbed soil.

DISCUSSION

System integrity

One of the most striking effects of tillage on cover of the mineral soil during the recovery phase, was the reduction of surface litter and standing dead material (Figure 5-1). Over the experimental period, probably under the influences of rain

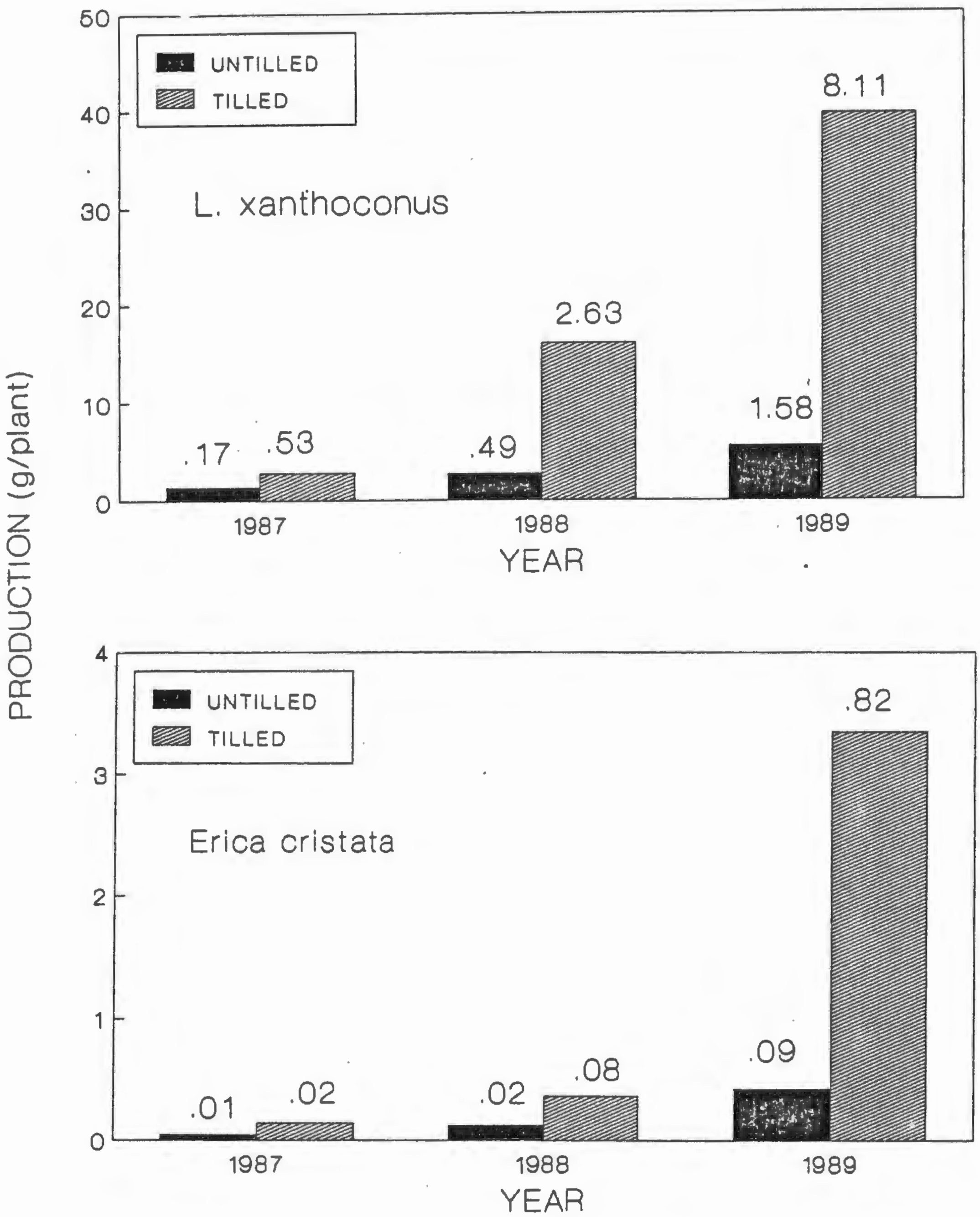


FIGURE 5-6. Biomass production of *Leucadendron xanthoconus* and *Erica cristata* plants on tilled and untilled soil during the experimental observation period.

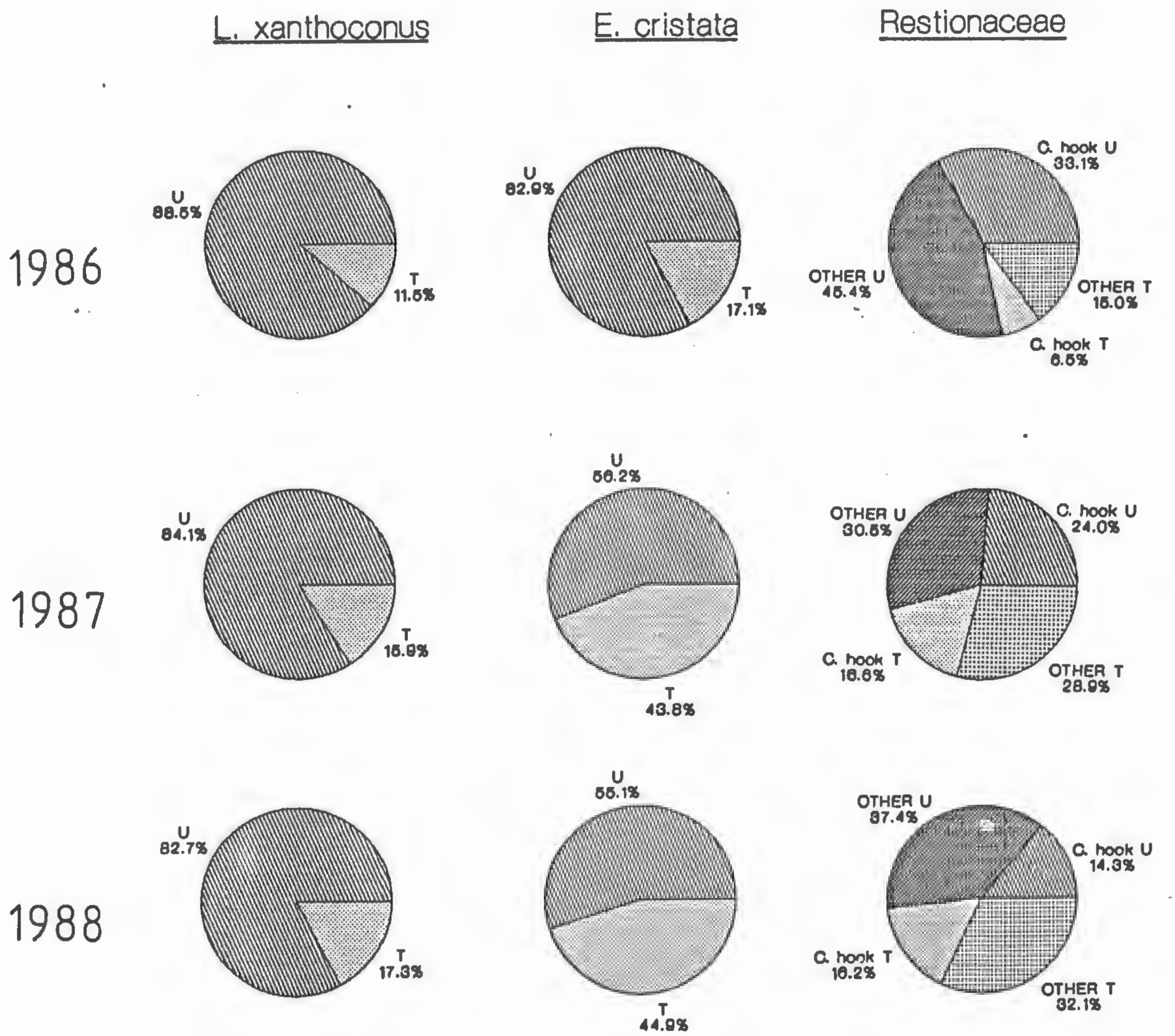


FIGURE 5-7. Comparison of abundance distributions of *Leucadendron xanthoconus*, *Erica cristata*, and *Chondropetalum hookerianum* between the untilled and tilled treatments over the three observation years. Included in the figures for the latter species are the proportions of summed abundances for all other restionaceeous species. Note that the proportions represented by the pie slices refer directly to the field observations, and are not relatavised with respect to all vegetation in the sample quadrat, as are the data in Table 5-1.

and wind, the excess dead material covering the untilled soil was either lost from the system, or redistributed in such a way as to contribute progressively less to soil cover. Live cover production by vegetation on the untilled soil appears to have been prolific during the second year, but with an absolute decline in the third. Tilled soil, on the other hand, supported vegetation that continued producing cover uninterruptedly during the experimental period. The retrogression of vegetation on untilled soil during the third year reflects combined canopy dieback of the early phase grass and cyperaceous resprouters (viz *Ehrharta longifolia*, *Merxmuellera rufa*, *Tetraria* spp.), possibly in response to limited soil water during the summer months (see Chapters 4 and 6). This process, while taking place on both tilled and untilled treatments, was probably exaggerated on the latter because of the elevated competition for water provided by the denser vegetation at that stage.

Loss of cover, both litter and live shoot tissue, from the tilled soil may have implications for erosion management under certain conditions. Tillage, which was shown in this study to reduce overall cover, both reduces the litter and live foliar material available for buffering the impact of heavy rain on the mineral soil surface, and breaks the bonding integrity of the previous generation's root systems. This may well promote erosion on sloping ground if early post-tillage co-incides with a period of heavy rainfall when direct impact and rivulet formation might accelerate soil movement (Spomer and Hjelmfelt 1987). The relationship between vegetation cover and soil erosion is well recognized (Triplett 1982), but what is difficult to predict is the level of denudation which can be tolerated by any particular system without erosion setting in. Thornes (1989) describes extensive experimental work, including some involving mattoral, designed to quantify this critical relationship. He and his colleagues developed a mathematical model to describe the relationship between vegetation cover and soil erosion, and to predict the thresholds between system stability and positive-feedback degradation. Until such models have been demonstrated as reliable tools, management of erosion-prone land should be extremely conservative.

Community structure

The relative distribution of species shows that contributions by each of the family level floristic components (Table 5-1) are affected by tilling, with the most marked differences occurring in the Proteaceae, the Restionaceae, and the Cyperaceae. Should the trends of the first three growth seasons persist as the community approaches maturity, it might be hypothesized that old-field recovery of disturbed mountain fynbos veld, a phenomenon as yet poorly documented in the biome, would favour restionaceous cover over that provided by the Proteaceae, Ericaceae, or even the Cyperaceae. The measure of importance used here was not downweighted in the case of partial dieback, and therefore apparent discrepancies do not necessarily contradict the results describing projected foliar cover discussed above. Analysis of relative importance data according to the mode of post-fire regeneration (Table 5-2), shows that geophytes are important on both treatments in the first year, but that their contribution is suppressed by the remaining vegetation after that. Interesting to note is the difference in that replacement pattern between tilled and untilled soil. In the undisturbed vegetation it is the resprouters that proliferate, while on the tilled soil it is the seeders. Being a relative measure, this is naturally difficult to interpret, but since it is known from observation that seedling recruitment in the second and third years is minimal, it must be accounted for by (a) differential seedling mortality in the prolific seeders *e.g.* *Chondropetalum hookerianum*, and *Erica cristata*, and (b) differential production of shoot material in the hemicryptophytes *viz* the resprouting cyperaceous and restionaceous species. In relative terms then, after initial establishment of the next generation of vegetation, it appears as though untilled soil is more amenable to growth of the hemicryptophytes, and/or tilled soil is less favourable for the survival of the seedlings which germinated during the first winter-spring period after the fire and tillage treatment. The latter interpretation is borne out by the specific data concerning *Erica cristata* and *Chondropetalum hookerianum* (Figure 5-7)

A corollary to Grime's (1979) triangular model of vegetation equilibrium, is the humped-back distribution of species (see Grime 1985). This presentation of vegetation structure describes the distribution of species abundance along an axis of habitat types ranging from those which favour species tolerant of disturbance and/or stress, to those for which competition for resources is most limiting. The hump of high species richness occurs between these extremes, and comprises mainly species which cannot tolerate environmental extremes imposed on them by either biotic or abiotic factors. If applicable, this model suggests an explanation for the observed species richness of fynbos sites following burning (Campbell and van der Meulen 1980; van Wilgen 1981 Kruger 1983), with a the bulk of the richness being provided by relatively non-competitive species. In mediterranean-type systems, clearing of above-ground vegetation by fire, together with its associated die-back of subterranean tissue, is responsible for an early flush of nutrients in both soil and plant tissue (Day 1983; Read and Mitchell 1983; Stock 1985), and probably reduces competitive constraints on both nutrient and water resources enough to permit the observed boom in species richness. In the present study, where soil supporting relict burned vegetation was tilled as well, the influence of initial propagule distribution may be inferred from the biased distributions of the three obligately reseeding species presented in Figure 5-7. In *Leucadendron xanthoconus* that bias persisted for the entire sampling period, while *Erica cristata* and *Chondropetalum hookerianum* displayed a steady recovery. Although a small amount of recruitment (not quantified) did occur, the adjustment appears to be primarily due to attrition of these latter populations in the more competitive untilled environment. The two different responses displayed by the above species populations are somewhat contradictory. Of prime interest in this study is the question of whether or not physical disturbance is likely to lead to irreversible degradation of mountain fynbos vegetation. The concept of community stability could assist in finding an answer. Chesson and Case (1986) in their discussion of community stability, list four of its consequences. These they give as: (1) conservation of member species; (2) recovery of member populations in the event of disturbance; (3) the ability for the community to be built up by immigration; and (4) the irrelevance of member species' histories to their final contribution at equilibrium. Narrowly interpreted, communities within the fire- driven mountain fynbos vegetation cannot be stable. But for cyclic phenomena, given the constancy of the generative force, stability can be described in terms of whole cycle features (e.g. the stability of a sine wave can be gauged by the predictability of an amplitude at any consistent point on the cycle). And so it may be appropriate to consider the stability of a fynbos community by inspecting the mature stand between whole fire- cycles, or perhaps preferably, by regarding the early post-fire phase when less of the member species are in cryptic form. Clearly in these terms the Highlands data are not comprehensive enough to predict the stability of the experimental system, but observed trends suggest that *E. cristata* and *C. hookerianum* display a stability that drives the community structure of the tilled vegetation back towards the natural control, while the *L. xanthoconus* population indicates no convergence. Although the populations of the former two species are regenerated by massive amounts of very small seed, with final population size probably being determined by a small proportion of survivors, the relatively larger seeded proteaceous species relies less on attrition of initially large seedling populations, but rather on a better survival rate of fewer seedlings. This co-incides with Bond's (1988) proposal that populations of serotinous proteas in the Cape are highly unstable. If the experimental community as a whole is stable, then it should be expected that later during its fire driven life-cycle, or perhaps in subsequent cycles, the *L. xanthoconus* populations on the two treatments would converge. Alternatively one might consider the proposition of Shipley and Keddy (1987), that forces which mould communities could operate on a "community-unit" basis and an "individualistic" basis simultaneously. In this case it is possible that certain community elements (viz *E. cristata* and *C. hookerianum*) form part of an association which might be called a "community sub-unit", while *L. xanthoconus* is an "individualist" species more likely to respond to stochastic processes within the environment.

The analyses of diversity and dominance (S, H' and C) indicate that a physical disturbance to the substrate of a natural mountain fynbos system, such as that caused by tillage, can induce a loss of species richness, as well as the evenness with which they are distributed, as reflected by the reduction of S and H' respectively. These, together with the boosted C, indicate that the perturbation favours relative dominance by a smaller number of species in the new disturbed community. Combined with the information derived from the set of data for the sample areas cleared by cutting, as well as the distribution of species between regenerative modes, it appears likely that it is disturbance of the regenerative material *per se*, rather than the consequences of microenvironmental modification, that alters the community structure.

In spite of the fact that it is not a rigorous test of the hypothesis that physical disturbance reduces the diversity of fynbos veld, the nested quadrat data obtained from "Honingklip" farm support it. The similarity of slopes in the species - log area curves for the two 0,1 ha samples implies that diversity reduction is a reasonably uniform phenomenon, with a constant proportion of the community being eliminated by the treatment. A testable hypothesis, supported by the Highlands data, would be that this constant proportion is represented largely by obligately reseeding species, and that seed size is influential.

The validity of DCA as a superior ordination technique has been called into question (Wartenberg *et al.* 1987), but it is still recognized as a useful means of identifying pattern in vegetation based on community data (Peet *et al.* 1988). Results obtained from the ordination in this study (Figures 5-3 and 5-4) show a general trend of convergence in time for vegetation structure of the experimental treatments. The position of the mature aggregate value as a probable endpoint of the re-establishment process is less convincing in the horizontal plane (DCA 1/DCA 2) than in the vertical (DCA 1/DCA 3). Although it is difficult to interpret the data without values for the intervening years (yet to come at the time of writing), it is possible that the offset of the mature point in the horizontal plane suggests a second phase of development. During this phase the community change might be characterized by rapid attrition of species rather than the redistribution of importance. Data of Table 5-3, which shows a relatively elevated species richness for both treatments over the full experimental period, but a relatively low richness at maturity, allow this as a possibility.

Productivity

Biomass production data for the three monitored species indicate that plant response to tillage disturbance in mountain fynbos can be viewed as a species related phenomenon. Interpretation of the observed differences is, however, difficult. The changes to the physical environment shown in Chapter 4 suggest that water and energy are the system parameters most altered by the disturbance, while nutrients are relatively unaffected. The reduction of vegetation cover induced by tilling (Figure 5-1) also implies a relaxation of competition for resources. This could have induced the superior performance of individual plants on the tilled soil, given that other factors - such as a reduced and less favourable soil temperatures during seed germination/seedling establishment, loss of suitable germination microsites by overall litter reduction, or (most probably) an unfavourable dispersal of propagules - had acted previously to reduce population densities. The specific question of whether or not the altered water regime was influential in the performance of established individuals of these three species is addressed in detail in Chapter 6. Penetration of the soil by roots (mechanical resistance) is also an important factor in plant productivity (Letey 1985), and results would be consistent with the observed reduction in soil bulk density (Chapter 4).

Alien species

Although there was evidence in the form of two decayed tree trunks that the plot had been invaded by *Pinus pinaster* prior to the study, it is unlikely that the seedlings enumerated arose from soil stored seed. More probably they were germinants of new seed transported from adjacent silvicultural plantations by the seasonally dominant south-east wind (Davis 1987, included as Appendix II). The tendency for them to occur on disturbed soil possibly reflects a competitive exclusion from the naturally recovering vegetation. Lack of available space in this instance may also be a matter of timing. Most of the species in the natural community would already have germinated or resprouted and annexed their regenerative space by the following summer when the majority of viable *P. pinaster* seed would be likely to arrive.

CONCLUSIONS

The Fynbos Biome and the plant diversity which it supports (Cowling *et al.* 1989), is likely to be under threat of degradation from a number of sources in the coming decades, most of them human in origin. Our knowledge of ecosystem response to disturbance in the fynbos is almost entirely restricted to the effects of fire (Kruger and Bigalke 1984; Breytenbach *et al.* 1986; Kruger 1987), and very little research appears to have been done on the influence of anthropogenic disturbance. Therefore if habitat conservation is a management priority, then land-use practices which alter the behaviour of ecosystems supporting natural vegetation should be circumspect.

Foliage and litter in natural stands of vegetation are able to reduce the energy of raindrop impact during heavy rainfalls and so reduce soil movement (Thornes 1989). Tillage, by virtue of its demonstrated cover reducing effect, is therefore a potential promoter of soil erosion in mountainous regions of the biome. Another result of tillage, indicated by the experimental work, is the relative reduction of species richness and diversity in the plant communities surveyed. All of these observations, including the fact that growth of some species is enhanced by the action of tillage, have implications for the deployment of mountain fynbos sites for cultivation practices.

If a land-owner intends to initiate a veld preparation and planting programme which will yield material for the commercial market (most likely in mountain fynbos to be floricultural material for the decorative plant market), then the following points should be considered:

1. Tilling should not be attempted on a steep slope where erosion can be triggered by the loss of ground cover:
2. Tillage should be done in strips so that species sensitive to physical disturbance of their substrate will have refugia in which they may persist; and
3. the possibility of invasion by alien plant species into the disturbed site should be considered and monitored.

The results described in this portion of my work suggest that management practices need to recognize both resilient and non-resilient elements of exploited fynbos systems. In the case of the commercial wildflower industry, tillage is a management tool which can clearly be used to the producer's advantage.

CHAPTER 6

EFFECTS OF DISTURBANCE BY FIRE AND TILLAGE ON THE WATER RELATIONS OF SELECTED MOUNTAIN FYNBOS SPECIES

- an ecophysiological investigation of the impact of marginal cultivation on naturally occurring species

INTRODUCTION

Effective management of fynbos as a commercial and service resource is ultimately dependent on an understanding of the responses of ecosystems to the disturbances which accompany utilization. Research into heathland ecosystems, especially in mediterranean-type climates (Margaris & Mooney 1981; Miller 1981; Specht 1981; Kruger *et al.* 1983) supports a clear mandate for careful management and conservation of heathland vegetation. Kruger (1981) invokes economic, scientific, and ethical reasons for conservation of South African heathland vegetation in the Fynbos Biome. In spite of its inherently low productivity (Rutherford 1981) relative to other ecosystem types (Whittaker 1975), this vegetation is important (amongst other considerations) in the maintenance of water catchment surfaces, as a refugium for many narrowly endemic plant species, and as a resource for the sizeable wildflower industry (Greyling and Davis 1989).

Fire is the most significant natural disturbance, as well as the single most important agent available for management of mountain fynbos vegetation. It is also one which is gradually coming to be understood in terms of its role in natural mediterranean-type plant communities (Gill & Groves 1981; van Wilgen 1982; Kruger 1983; Gimingham 1987), and system processes such as nutrient cycling and water relations (Raison 1979; van Wilgen and le Maitre 1981; Stock and Lewis 1984). Although there is a strong case for conservation of relatively pristine mountain fynbos systems, physical disturbance in certain forms of utilization is inevitable (Davis 1984, Romoff 1986, Peterson 1988).

Fox and Fox (1986) hypothesized that mediterranean-type communities subjected to stressful summer drought and frequent natural disturbance (*e.g.* fire) are more resilient to disturbances of human origin. Because summer drought is often a feature of mediterranean-type climates, occurring at a time when ambient temperatures are more favourable for the metabolic processes underlying plant growth, water is often a factor which limits plant productivity in these regions

(Miller 1982). Miller *et al.* (1983) suggested that mesic fynbos is functionally more akin to the evergreen forests of north-western North America than to the chaparral, with which it is often compared. They suggest that like the deep-rooted forest species, some fynbos species are able to avoid drought stress by having perennial access to wetter layers of the soil.

The families Proteaceae, Ericaceae, and Restionaceae, which typify fynbos vegetation (Taylor 1978), have been shown to be associated with deep, intermediate, and shallow rooting depths respectively (Higgins *et al.* 1987). Moll and Sommerville (1985) performed a water relations study on coastal fynbos vegetation, comparing *Leucospermum parile* (Salisb. ex Knight) Sweet (Proteaceae) and *Thamnochortus punctatus* Pillans (Restionaceae) as representatives of deep and shallow rooted species respectively. They demonstrated higher water potentials, and probably a lower degree of stress, in the proteaceous species during summer. The different distribution of roots between species in a mature fynbos community possibly represents partitioning of seasonally limited water, but during the early phases of re-establishment it is likely that reseeding species come into more direct competition for this resource. Under natural circumstances this would probably follow clearing by fire, but with the changing patterns of land use, physical disturbance of human origin is often an additional factor. The objective of this study was to identify and quantify differences in water stress experienced by typical mountain fynbos plants exposed to the different types of disturbance incurred by the management treatments of fire and tilling.

METHODS

The experimental approach

Species were chosen to represent the three characteristic fynbos families, and measurements were made during the summer period when drought effects were likely to be pronounced. An established experimental site in mesic mountain fynbos in the Highlands State Forest Reserve near Grabouw, chosen initially for its uniformity of slope, topography, soil depth, and vegetation cover, was used for the study (see Davis 1988 for a detailed description). Samples for the experimental work were taken from the following sets of vegetation: (a) mature 14 year-old vegetation, (b) second-year regrowth on a portion of the site cleared by a controlled burn of moderate intensity in February 1985, and (c) second-year regrowth on a sub-portion of the burned plot which had been rotavated to a depth of approximately 100 mm four months after burning. The soil was duplex in profile, comprising an orthic loamy sand A/E horizon overlying a gley-cutanic silty clay loam B (*sensu* MacVicar et al 1977), with a gravel stone-line in between. Plant species chosen as subjects for the water relations work were: *Leucadendron xanthoconus* Kunth (Proteaceae), *Erica cristata* Dulfer (Ericaceae), and *Chondropetalum hookerianum* (Mast.) Pillans (Restionaceae), all obligate post-fire reseeders common in the study area. Implicit in the experimental treatment was the difference in age between plants of the burned and unburned systems.

Micro-climate of the site

Measurements were made during the summer period, on February 19, 1987. An environmental monitoring system (MC Systems, Cape Town) provided the data which are used here to describe the 60-day period preceding sampling. Rain was monitored by a tipping-bucket rain gauge, and soil water status by nylon resistance blocks. Signals from these sensors were recorded on a daily basis by the system's data-logger.

The factory-produced nylon resistance blocks were checked in the laboratory for similarity of response. An approximate calibration was established for the full set by comparison of recorded output against gravimetrically determined soil water content during a six-month period over spring and summer. They were installed in the field during September 1986 by horizontal insertion into the walls of holes from which soil had temporarily been removed with minimum disturbance. The surface of the tilled soil was levelled in the area of the nylon blocks to eliminate anomalous ponding of rain water. Owing to the non-linearity of output relative to soil water content, and the problems of hysteresis in calibration (Slavik 1974), data derived from the nylon blocks have been interpreted only as a comparative measure of the water status between tilled and untilled soil of the post-fire environment. Limitations of the data-logging system to eight moisture block channels prevented monitoring of soil water in the mature unburned stand. Tilled and untilled soils were each monitored by four probes, two at each of two depths (30 mm and 150 mm).

During the measurement run (on February 19) the data-logger was set to record mean hourly values of: (a) air temperature as measured by a shielded thermistor at 1.3 m above the soil in the two-year old vegetation; and (b) incoming solar radiation as measured by the upper sensor of a glass domed thermopile net radiometer (Middleton). Soil water content was determined gravimetrically from samples collected at the end of the day.

Experimental plant material

To minimize the effects of spatial heterogeneity, juvenile material for the water relations measurements was sampled randomly from a relatively small area containing both tilled and untilled soil (approximately 50 m^2) where regrowth was apparently uniform. An equivalent sampling area for the unburned mature vegetation was located approximately 30 m away. Rooting systems of between four and ten seedlings were inspected by removing each in an intact soil block, and then teasing away the soil. The deeper roots of *L. xanthoconus* were traced *in situ* by excavation. No attempt was made to evaluate rooting pattern in the mature vegetation.

The decision to limit spatial extent of sampling in favour of microsite homogeneity does raise the question of representativeness of the whole populations (Hurlbert 1984). The associated caveat on the interpretation and generalizability of conclusions should therefore be borne in mind.

Plant water relations

Plant xylem pressure potentials were measured using a pressure chamber apparatus (Soilmoisture Equipment, Santa Barbara). Five samples from different plants of each species were taken from each treatment at each nominal sampling time, except the last one, when a sample of three was used. The six reading times during the day ranged from pre-dawn to post-dusk. A different set of plants was used at each sample time to ensure independence of samples. Stomatal conductance in designated sets of *Leucadendron xanthoconus* plants were also taken monitored throughout the day using a null-point diffusion resistance porometer (Li-Cor 1600). Morphology of the other two species (*viz.* the small needle leaves of the erica, and the slender culms of the restioid), especially in the smaller immature individuals, prevented reliable monitoring of their stomatal conductance.

RESULTS

Microenvironmental data

Figure 6-1 describes the patterns of precipitation and soil water content during the 60-day period preceding the experimental run. While the soil at 150 mm depth was clearly less prone to drying during the summer period when physically disturbed, tilled surface soil (probes at 30 mm) tended to be drier. The record also indicates that a rainy period 10 days prior to the run probably caused stressing to be milder than the potential extreme, but previously collected data (Davis 1988) show that summer precipitation can typically be in excess of that recorded for this study. Analysis of soil water redistribution, based on the daily rates of change at the probes, showed that the maximum rate of change in soil wetness at 30 mm depth was up to three times as rapid in the untilled soil as in the tilled. Table 6-1 shows the moisture content of the soil as measured gravimetrically at the time of the experimental water relations run. A two-way ANOVA on these latter data indicates that the differences between soil water content are significant with respect to both disturbance level, and soil depth. A multiple range test of disturbance level (Tukey; 95% confidence level) places the wetter tilled post-fire soil in a homogeneous group different from that containing the other two treatment levels. Solar radiation and ambient air temperature on the day of the run, are plotted in Figure 6-2. Both of these traces reflect a mid-morning cloudy period.

Rooting habits

Leucadendron xanthoconus seedlings were observed to have maximum rooting depths greater than 300 mm, while a single individual had roots traceable to 800 mm which penetrated the dense B-horizon using of channels left by plants of a previous generation. Roots of *Chondropetalum hookerianum* and *Erica cristata*, on the other hand, had maximum lengths of 100 mm, with more prolific branching of the ericaceous roots, and the presence of adventitious roots in the restioid. Typical plant heights in the immature vegetation were: 120 mm, 100 mm, and 80 mm for *L. xanthoconus*, *E. cristata*, and *C. hookerianum* respectively.

Xylem pressure potentials

The relatively high water potential values (close to zero) obtained for the pre-dawn and post-dusk samples suggest that all three species were relatively

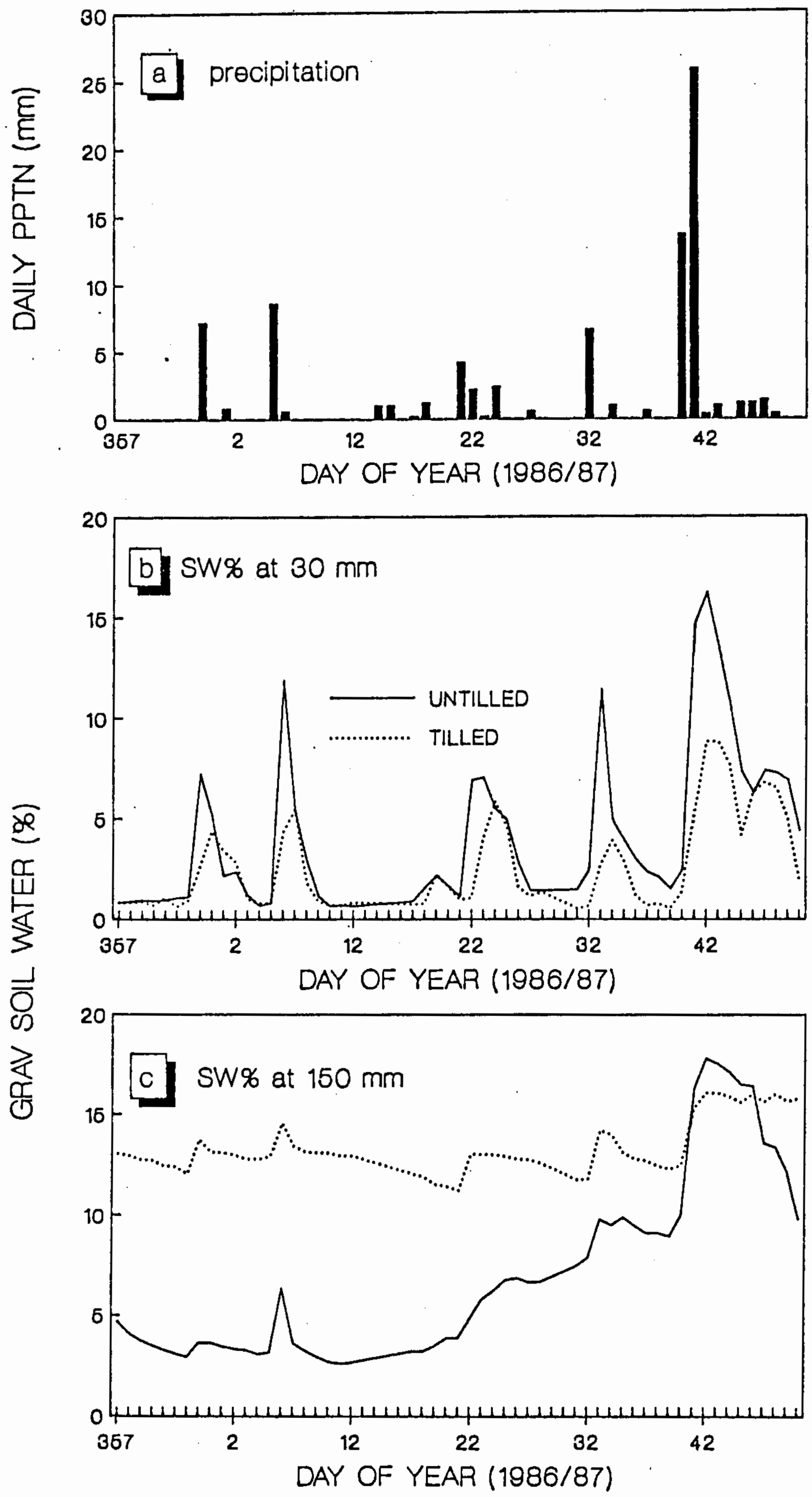


FIGURE 6-1. (a) Daily precipitation, and (b,c) soil water content at two depths on the tilled and untilled soil, during the 60-day period preceding the experimental run.

TABLE 6-1. Mean water content (% of dry weight) of soil samples taken at the end of the sampling day. Figures for three depths on each treatment are followed by standard deviation values in parentheses (n = 7 for two shallower depths, and n = 3 for 370 mm unless indicated otherwise). Homogeneous groups A and B are identified by Tukey's multiple range test (95 % level) for disturbance level.

DEPTH (mm)	MATURE	UNTILLED	TILLED
0 - 50	4.66 (2.47)	4.30 (1.33)	7.35 (1.72)
150	8.10 (1.50)[a]	8.40 (2.26)	11.33 (3.80)
370	5.94 (.056)	5.86 -[b]	9.35 (1.27)
Homogeneous groups	A	A	B

[a] n = 5; [b] n = 2

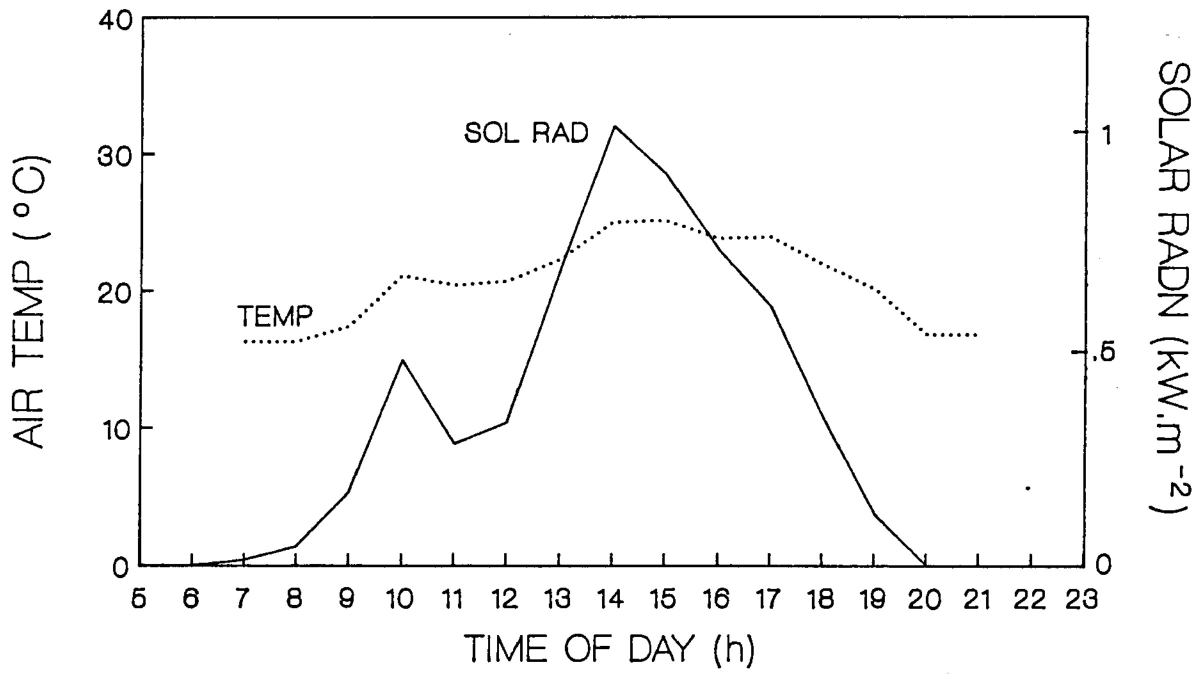


FIGURE 6-2. Logged measurements of ambient air temperature and solar radiation made during the experimental run of February 19, 1987.

unstressed, irrespective of disturbance type. Figure 6-3 shows the pattern of xylem pressure potential which developed in each species, and on each treatment level during the day. (Due to logistical problems the first two sample times were omitted for *Erica cristata*. Statistical tests were therefore performed on the last four sample times for each species to allow for unbiased comparison of three species.) Results of the two-way ANOVA's for the pair-wise comparison of treatment levels using time of day, and treatment level as the two experimental factors, are summarized in Table 6-2 for each species. Comparison of xylem pressure potential values between species growing on similarly disturbed soil indicated that *C. hookerianum* experienced significantly lower water potentials than the other two species on all three treatments (Tukey multiple range test at 95 % confidence level).

The diurnal pattern of leaf conductance with respect to water vapour loss in *L. xanthoconus* is shown in Figure 6-4. Individual maximum conductance values measured during the day were 0.76; 1.04; and 1.14 $cm.s^{-1}$ for the mature, untilled, and tilled treatments respectively. The extreme variability between plants, especially the younger ones in the post-fire environments, prevented identification of statistically significant differences between treatments. The results do, however, indicate the range of leaf conductance values, their pattern of change through the day, and trends between treatments. The trends suggest that seedlings may have higher leaf conductances than mature plants.

DISCUSSION

Soil water

Measures of soil water content on the different treatments indicate that disturbance significantly alters the soil water regime during the dry summer period (Figure 6-1 and Table 6-1). Output from the 30 mm depth soil moisture blocks showed a quicker and greater response to summer precipitation in the untilled soil, but the limited replication makes this pattern difficult to interpret. Hillel (1980) referred to work which shows layering to be important in the infiltration of water into dry soil, both with regard to the rate of infiltration, and the uniformity of the wetting front. If channels of high hydraulic conductivity occur in undisturbed post-fire fynbos soil, perhaps formed at the site of decayed roots from the pre-fire vegetation, then physical disturbance may be associated with an altered pattern of infiltration and wetting.

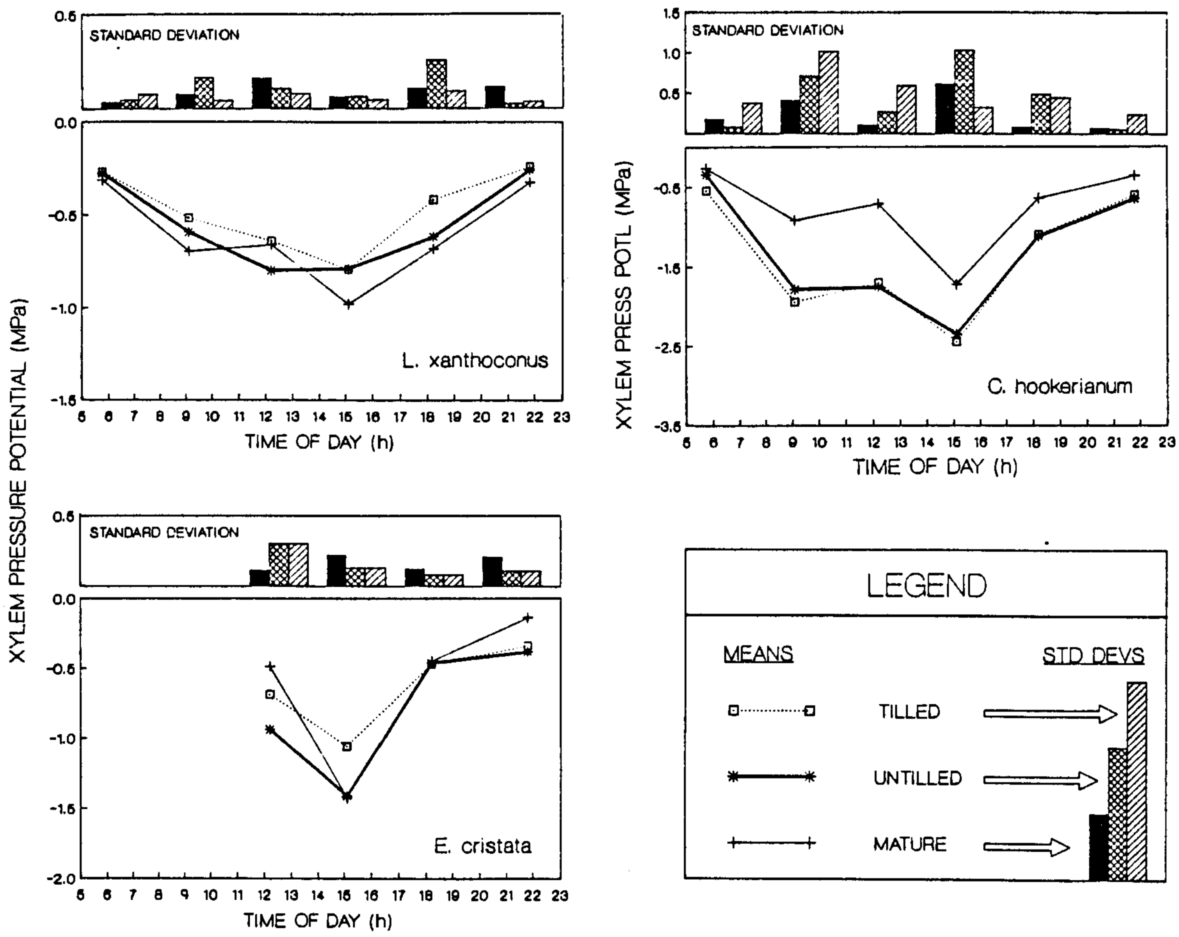


FIGURE 6-3. The measured diurnal pattern of mean xylem pressure potential for each species (line graphs), and one standard deviation on the same scale (bar chart), for each appropriate sample set as indicated in the legend.

TABLE 6-2. Comparisons of xylem pressure potential (XPP) measurements made on February 19, 1987. XPP in plants of the undisturbed post-fire community is compared pairwise with those measured in plant sets of the other treatment levels. Each species is treated separately in a two-way ANOVA (time and treatment as factors). An asterisk indicates significance ($p < 0.05$), while the computed p value is given in parentheses. NS indicates a non-significant difference.

	Leucadendron xanthoconus	*Erica cristata*	*Chondropetalum hookerianum*
UNTILLED vs MATURE	NS (0.296)	* (0.009)	* (0.0002)
UNTILLED vs TILLED	* (0.008)	* (0.004)	NS (0.938)

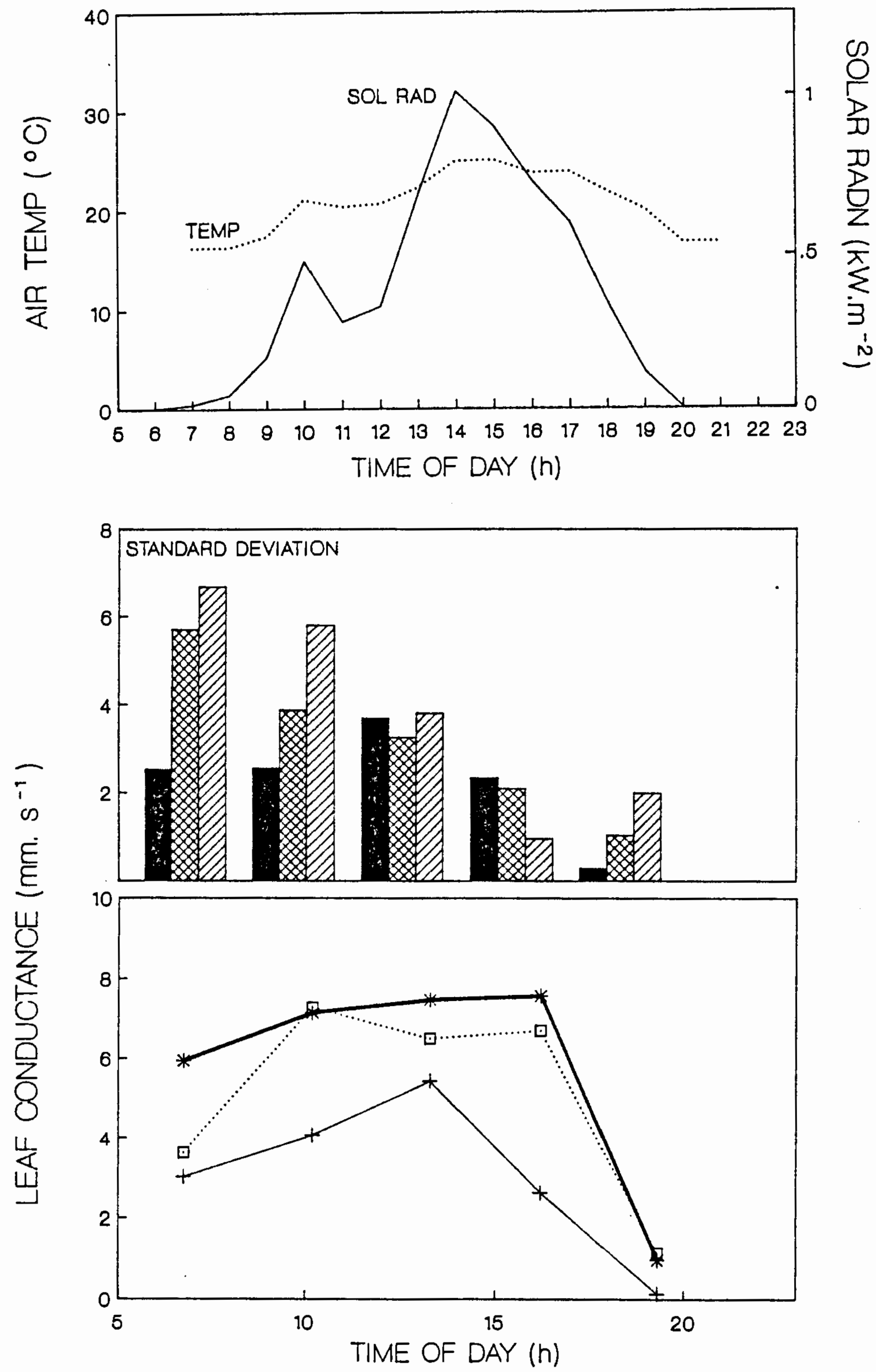


FIGURE 6-4. Pattern of leaf conductance in *Leucadendron xanthoconus* plants of the mature community, and for seedlings growing on tilled and untilled soil in the post-fire area. Line graphs (below) each represent the arithmetic mean conductances of three leaves measured repeatedly, while the bar graph above shows one standard deviation on the same scale. See Figure 6-3 for the legend of codes.

There is an apparent reversal of relative wetness values between the gravimetrically determined, and the remotely logged data in the tilled and untilled near-surface soils of the post-fire plots. This is probably because gravimetric samples represent integration over the 0 - 50 mm layer of topsoil, whereas resistance blocks derive their electrical properties from their immediate environments. Extreme drought at the surface of the tilled soil, with its lack of mulching litter, could account for the observed pattern.

The general increase in soil water at all depths recorded for the tilled soil is probably due mainly to a reduction of transpiring plant cover on the physically disturbed soil. This is parallel to the agricultural practice of fallowing, and places surviving plants at an advantage with regard to the availability of the conserved water. In a fynbos agricultural context, however, this benefit may be offset by upset patterns of infiltration, with possible implications for erosion of surface soil (Spomer and Hjelmfelt 1986). Another disadvantage of increased soil water during the warmer summer months, may be the creation of a favourable environment for potential plant pathogens such as *Phytophthora cinnamomi* (Malajczuk and Glenn 1981), which von Broembsen (1984) found to be widely distributed in the south-western Cape, occurring on both cultivated land and in natural veld, but excluded from drier areas.

Plant water relations

In comparing mature to untilled post-fire vegetation, the relatively deep-rooted *L. xanthoconus* seedlings are seen not to be significantly different from their mature counterparts with regard to the stress they experienced through the day. This was not true of *E. cristata* and *C. hookerianum* however, whose mean xylem pressure potentials were significantly lower (*viz* plants were more stressed) in the untilled post-fire environment.

These observations suggest that whereas the two shallower rooted species (*E. cristata* and *C. hookerianum*) have a limited capacity for acquiring soil water during this portion of their establishment phase, *L. xanthoconus* is able to generate a relatively effective root system, able to tap the more remote water. Comparison of plant water relations in the two post-fire environments indicates that the additional "fallow" water of the tilled soil was effective in relieving some of the diurnal stress experienced by *L. xanthoconus* and *E. cristata*, while *C. hookerianum* was relatively stressed on both tilled and untilled soil. Higgins *et al*. (1987), in their investigation of rooting systems of selected species in a 27-year old mountain fynbos stand, included *Protea neriifolia* R. Br. (Proteaceae), *Erica plukenetii* L. (Ericaceae), and *Ischyrolepis gaudichaudiana* (Kunth) Linder (Restionaceae). They observed these species as having maximum rooting depth ranges of: > 3 m; 0,3 - 0,5 m; and 0,1 - 0,4 m respectively. If the relative ranking of maximum rooting depth recorded by these authors is indicative of functional depth for water uptake, then our observations indicate a similar pattern of rooting strategy in species of the same families, regardless of age. Both *L. xanthoconus* and *E. cristata* plants have well enough developed root systems to take advantage of "fallow" water in their early development phases. On the other hand, the poorly developed roots of *C. hookerianum*, with a tendency towards adventitiousness, are restricted to the top stratum of soil which is subject to drying by evaporation. In the undisturbed post-fire situation, the layer of litter mulch may be important to this species if it is able to take opportunistic advantage of light summer precipitation before it evaporates. Mooney and Hobbs (1986) reported that in severely drought-stricken chaparral systems deep rooted species were able to survive with no observable growth, while shallow rooted subshrubs performed better by being able to utilize the small amounts of precipitation which did occur. If restioids follow this latter pattern, and if patterns of water penetration and runoff are altered by physical disturbance, then survival of summer drought by seedlings of these species may be altered by tillage. The significantly higher (less negative) mean xylem pressure potential of the mature *C. hookerianum* relative to younger plants of the same species, suggests that mature plants possess a root system which has access to a zone either less subject to evaporative drying, or less populated by roots of competing individuals.

L. xanthoconus plants in the post-fire environment behaved differently from mature plants in that they did not show the same rise in xylem pressure (relief of stress) associated with the period of low irradiance which occurred during the late morning of the experimental run. The data set for *C. hookerianum* shows that a similar rise occurred in plants on all treatments for this species (see Figure 6-3). (Due to the missing data, it is not possible to state with any certainty that a similar phenomenon occurred in *E. cristata* plants, although the xylem pressure potentials measured at the first point are high enough that they could represent a local peak). The most obvious explanation for this relief of stress is that stomata of the responding plants reacted to the reduced insolation by closing (Willmer 1983), hence reducing the transpirational loss of water from the plant tissue. Knapp and Smith (1988) in a study of this type of phenomenon, demonstrated that the degree of water stress experienced by investigated subalpine species was positively related to their stomatal responsiveness to intermittent cloud cover. Immature *L. xanthoconus* plants, on the other hand, showed no recovery of xylem pressure potentials during the low irradiance period. Young establishing plants of this deeper rooted species may be adapted to maximize gas exchange - *viz* improve carbon dioxide uptake at the expense of water vapour loss (Levitt 1980) - for accelerated root development, so that access to the deeper and more reliable soil water may be secured within the first season of growth. The observed overall lower leaf conductance of mature *L. xanthoconus* (Figure 6-4) supports this view, but better resolution of the data would be required to test it as an hypothesis.

CONCLUSION

Disturbance of a plant community by fire results in exposure of its component species, especially the obligate reseeders, to a situation in which both the plant and its environment are in forms very different from those characteristic of the relatively stable mature stand. For some species this is a critical nexus in the continued survival of the population. It is suggested by the plant-water relations of this study that this phase of the cycle is relatively stressful for the shallower-rooted ericoid and restioid species, while quicker establishing proteoids are able to avoid that stress by reaching water unavailable to other plants of the young community. When soil is physically disturbed however, reduction of competition relieves stress in all but the very shallow rooted restioid. The altered water status of disturbed fynbos soil may therefore be of direct importance to any marginal agricultural activity (*e.g.* the wildflower industry) by relieving the effects of summer drought on deeper rooted species. Other potential effects of this type of perturbation, such as increased susceptibility to erosion, alien plant invasion, and pathogenic microfloral activity, are as yet not well understood or quantified, and are deserving of attention.

CHAPTER 7

PERFORMANCE OF PROTEA SPECIES INTRODUCED TO A MESIC MOUNTAIN FYNBOS SITE AT HIGHLANDS, CAPE PROVINCE

- an investigation of marginal cultivation as it affects floricultural target species

INTRODUCTION

In the commercial wildflower industry there is great pressure from the competitive international market for producers to keep improving their products. Not only must the producer strive to propagate inflorescences with perfect form and colour, and foliage which is free from the blemishes of insect herbivory (Coetzee *et al.* 1989) and physiological browning and blackening (de Swardt *et al.* 1987, Reid *et al.* 1989), but he or she must have access to plants of appropriate species whose flowering time co-incides with the period of peak market demand (Jacobs 1989). For taxa amenable to domestication, *e.g.* the Proteaceae (Vogts 1982), these factors comprise an incentive to producers for seriously considering the merits of cultivating indigenous fynbos material, and even to develop cultivars which can be tailored to fit perceived mercantile niches (Brits 1988a; Jacobs 1989). Production methods are therefore coming increasingly into the realm of agriculture, with the associated need for preparation and maintenance of an appropriate substrate. A large amount of work has been done with regard to domestication and breeding of the Proteaceae (Brits *et al.* 1983 Soutter 1984 *inter alia*), and many projects designed to improve production methods are currently underway both locally and internationally (Parvin 1984). But relatively simple cultivation of floricultural material at the species level plays an important role in the industry by providing a production niche which avoids the capital intensive methods of cultivar-level production (Jacobs 1989). The practice of introducing commercially desirable species to available land where they do not normally occur, is intrinsically uncertain, but is often worth a producer's time to try on an experimental and non-intensive basis on land which he or she may regard as unproductive. (See Chapters 1 and 8 for counter-arguments to this perspective.) As a result of this approach to production, one might find *Protea magnifica*, a species naturally occurring at altitudes of 1200 - 2700 m, close to sea-level in the Kleinmond area, or the eastern Cape's summer flowering ecotype of *P. repens* growing under cultivation in the south-western Cape (Vogts 1982).

An understanding of the autecology of the species used would help in reducing the uncertainties attached to such ventures. What is not always predictable, however, is the precise nature of the microsite available for utilization. An autecological perspective is therefore needed which might take cognizance of the environmental extremes that the favoured species is likely to encounter under marginal cultivation.

The work described in this chapter assesses the performance of two *Protea* species which I introduced to the Highlands experimental sites shortly after the soil had been tilled as described in Chapter 4. It is an empirical study, and the key question which is being asked is whether or not there is a distinct advantage in tilling the production site soil before commencing with the cultivation of selected floricultural species. The following hypotheses are erected relative to the experimental regime described in Chapter 4, and the simulated cultivation of *Protea cynaroides* and *Protea repens*: (1) survival and establishment of the introduced plants are affected by disturbance of the substrate; and (2) productivity during the early stage of plant development in the test species is enhanced by tillage.

The data presented in this chapter represent a pilot study into the performance of commercially useful fynbos species under *marginal cultivation*, and the limitations imposed by parsimonious sampling intensity and rudimentary experimental design are recognized.

METHODS AND MATERIALS

Prior to planting out of the experimental populations of *P. cynaroides* and *P. repens* plants, the plot was cleared of the above-ground portion of the natural vegetation by burning, and strips tilled by rotavation. (See Chapter 4 for details of this summer burn and winter tillage treatment). Plants used for this experimental work were propagated under nursery conditions, the *P. cynaroides* in the nursery attached to the forest station in the Highlands Forest Reserve, and the *P. repens* at the Protea Research Unit at the Tygerhoek Agricultural Research Station near Riviersonderend, Cape. These plants were in their second year of growth, and were planted out at the experimental site during the winter of 1985 (August). A total of 52 *P. cynaroides*, and 54 *P. repens* plants were introduced to the 50 x 50 m experimental plot. They were arranged in groups of between two and four plant-pairs, each pair having one member on untilled soil, and the other on tilled. In each of four such paired rows, groups were alternated with respect to species, and plants were positioned approximately three metres apart, both within and between treatments. As a measure of plant response to the microenvironmental conditions, productivity was monitored in the following way. The total length of living shoot tissue on each plant was measured every six months, and the survival rate within each group recorded. Dead shoots were discounted from their branching point, and absence of any green foliar tissue was taken to indicate death.

To provide a possible insight into the role of plant water relations in the response to the experimental treatment, the diurnal pattern of stomatal conductance for *P. cynaroides* was monitored by diffusion resistance porometry on a summer day when soil water content was relatively low. During January 1987, a subset of the *P. cynaroides* plants was designated as a linear transect across a portion of the plot, and a leaf on each marked for repeated measurements during the course of the day. The sample set comprised five plants on each substrate-type. Porometry equipment and techniques were the same as those described in Chapter 6 for the study of the natural vegetation. But unlike that experiment, these plants were being preserved for the monitoring of survival and productivity, and no destructive sampling of material was made for determination of water potentials by the pressure chamber technique . Interpretation of water relations, although recognized as incomplete, is therefore made solely on leaf conductance data.

RESULTS

Survival

Survival of the sets of test plants over the three-year test period is given in Figure 7-1. It can be seen that for *P. cynaroides*, significantly more plants succumbed to factors associated with the natural post-fire situation than did those on the tilled soil ($p < 0.05$; Wilcoxon paired sign test). *P. repens*, on the other hand, displayed at the points of greatest difference a reversed (but, by the same test, insignificant; $p = 0.371$) trend in its pattern of survival.

Production

Total axial shoot extension in individuals of the species under investigation during that same period is given in terms of mean total shoot extension per surviving plant in Figure 7-2. Those data show that for *P. repens* plant growth was significantly enhanced by the tillage treatment ($p < 0.01$; Kruskal-Wallis), but not

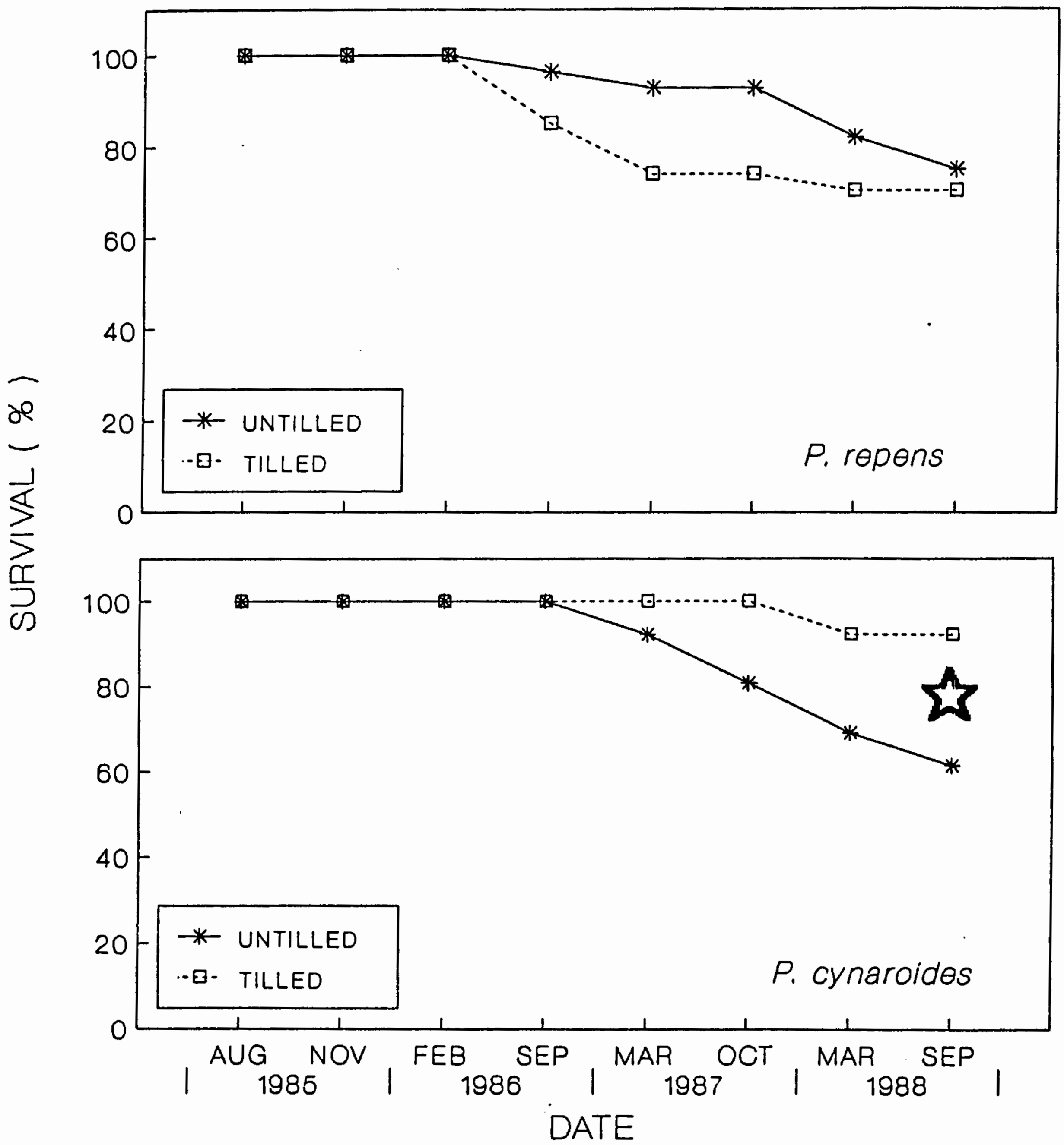


FIGURE 7-1. Survival of *Protea cynaroides* and *Protea repens* plants introduced to the Highlands study site during winter 1985. The five-pointed stars indicate significant differences, details of which are given in Table 7-1.

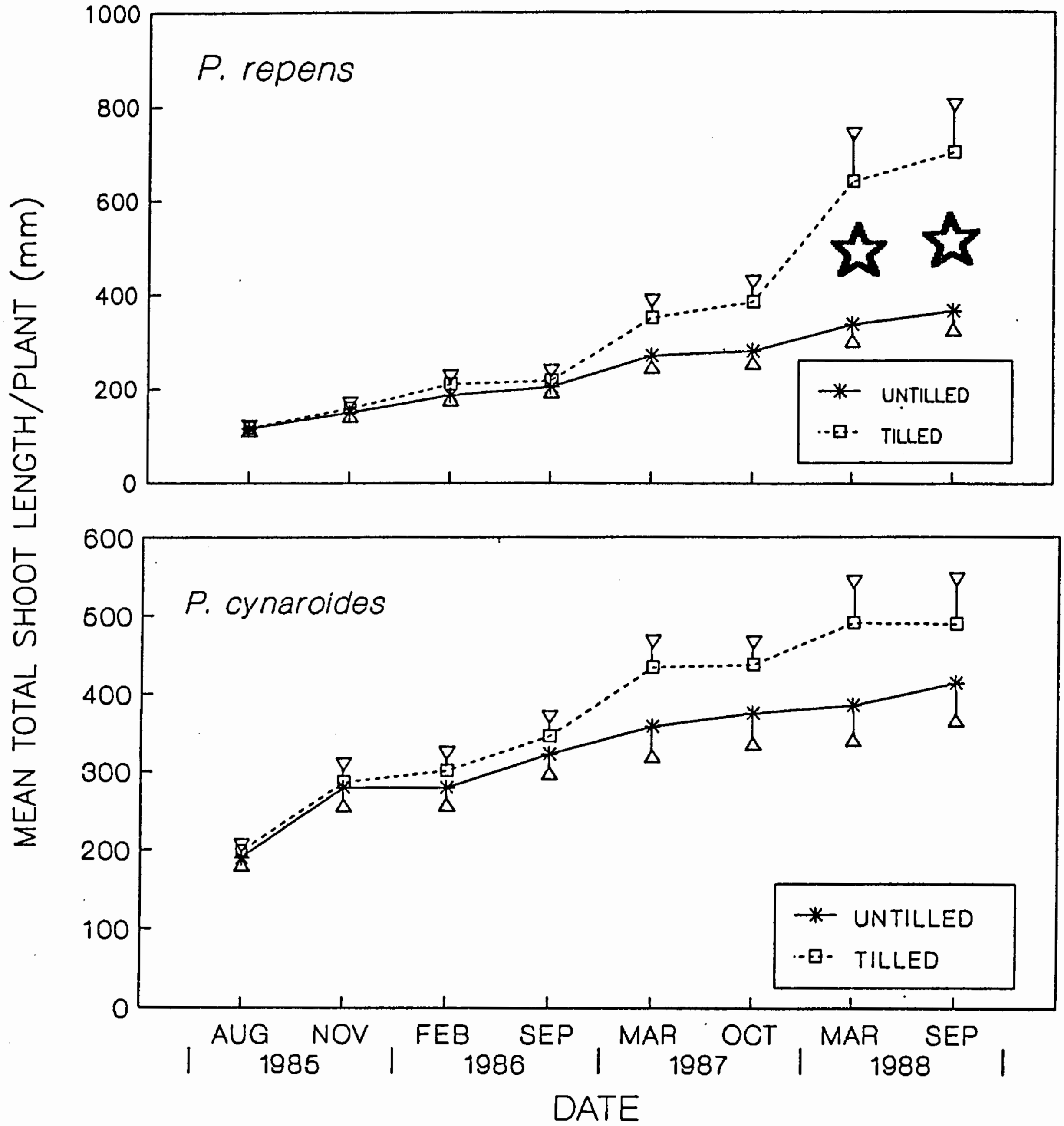


FIGURE 7-2. Mean total shoot length per surviving plant for *Protea cynaroides* and *Protea repens* plants introduced to the Highlands study site during winter 1985. The five-pointed stars indicate significant differences, details of which are given in Table 7-1.

for *P. cynaroides* ($p > 0.18$ at all points), although the associated trend for the latter was in the same direction.

The results of analysis of survival and productivity data are summarized in terms of their significance in Table 7-1.

Water relations

The analysis of gravimetric soil water content of samples collected on the day of the water relations run revealed that soil on the undisturbed soil was significantly drier in both the surface layer (0 - 50 mm), and at 150 mm depth (Kruskal-Wallis; $p \leq 0.01$). These data represent one of the points used in the analysis of soil water regime at the study site (see Figures 4-5 ; 4-6 and 6-1). The pattern of leaf conductance as measured on the paired sets of *P. cynaroides* (Figure 7-3) showed that plants growing on the untilled soil were more resistant to the transpirational loss of water during the test period than were those growing on the tilled soil.

DISCUSSION

Domestication of commercially exploitable species, and the development of reliable cultivars is necessary for an economically viable supply to a sophisticated world market (Jacobs (1989). The knowledge upon which this type of development must be based is, however, very young for the Proteaceae, and even more so for other fynbos species. The work described here is intended as a modest contribution to the development of that information base.

Performance of the experimental populations indicated that during the first three years the two *Protea* species responded differently to disturbance of the soil into which they were planted. The lack of a significant difference in growth response between *P. cynaroides* plants growing on the experimental treatment, and those on the control, suggests that their lower survival on untilled soil may be symptomatic of allelopathic or pathogenic factors, rather than of direct competition for resources. Such agents may, however, be acting on plants already stressed by limiting water on both treatment and control substrates. The greater stress of the untilled environment could then place plants closer to a tolerance threshold, and give rise to the observed greater mortality in this species. The data provided by the porometry measurements, together with the lack of significant difference in productivity (Figure 7-2), imply that when extra soil water is available, the plants of

TABLE 7-1. Significance of differences in the survival and growth responses between plants growing on tilled, and those growing on and untilled soil. Results are of the non-parametric tests as applied to the data depicted graphically in Figures 7-1 and 7-2, where ** ; * ; and NS indicate $p \leq 0,01$; $p \leq 0,05$; and $p > 0,05$ respectively.

	Statistical test	Protea repens	Protea cynaroides
SURVIVAL	Wilcoxon	NS	*
SHOOT ELONGATION	Kruskal-Wallis	**	NS

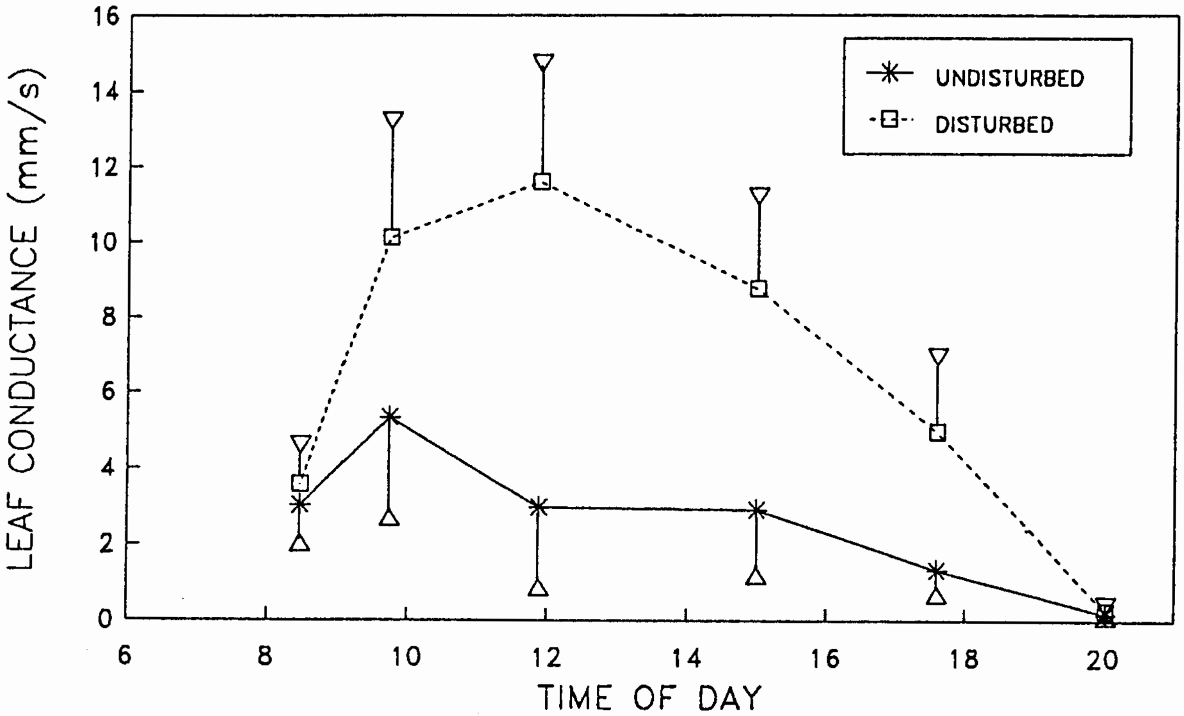


FIGURE 7-3. Diurnal pattern of leaf conductance in *Protea cynaroides* plants growing on tilled and untilled soil at the Highlands study site. Vertical measures represent a magnitude of one standard deviation with a sample size of n = 5 for all but the last set of the day, where n = 3.

this species lower their water use efficiency. This concurs with Schulze and Hall's (1982) observation of a correlation between stomatal conductance and pre-dawn leaf water potential, and the contrasting correlation between CO_2 uptake and the plants drought history. Thus if the pattern of stomatal opening observed during the experimental run persists during times of maximum productivity, it may be concluded that *P. cynaroides* is unable to take significant advantage of the more favourable water regime owing to other limitations in its photosynthetic apparatus. Resolution of the seasonality in growth (Figure 7-2), while clearly showing increased shoot extension over the summer half-year, is not fine enough to provide the basis for definitive interpretation along those lines.

On the other hand, shoot extension data for *P. repens* suggest that the plants used in this experiment were able to derive greater benefit from the altered environment. The more equitable distribution of mortality (with a statistically non-significant bias towards better survival on the untilled soil) implies that the factors responsible for the demise of *P. repens* plants acted differently from those which killed the *P. cynaroides* plants. Should the notion of proximity to a water-stress tolerance threshold be a valid one, it could be that *P. repens* is further removed from it than *P. cynaroides*, and therefore generally better preadapted to sites subject to water stress.

The differences in growth response to tillage between the two species, and the trends shown on Figure 7-2, suggest that both species may benefit from the reduced competition and improved water status on the tilled soil, but that the intrinsic productive capacity of the *P. repens* plants used, is significantly greater than that of *P. cynaroides*, or that it was generally less affected by the stressed under the experimental conditions. A possible explanation might lie in the patterns of root distribution of the two species at this early stage of development, a feature which was not investigated, and a description of which could not be found in the fynbos ecological literature. If *P. cynaroides* plants were able to establish an extensive and deep enough rooting system during the early establishment phase so that resources of water and nutrients from beyond the rooting zone of competing wild species could be tapped, then the productivity of plants on the two treatments would be expected to be similar. In this case the observed differences in stomatal behaviour might have been an extreme situation at the driest time of the year when differences in soil water were most pronounced, a situation which did not persist long enough for differences in productivity to be accumulated significantly.

By contrast, the establishing *P. repens* plants, which were significantly inhibited by the environment of the untilled treatment (Figure 7-2), might have had less well developed rooting systems, but which were extensive enough to avail themselves of the extra available water, and possibly nutrients, on the tilled soil. Better growth on the tilled treatment would then represent opportunistic use of resources by this latter species in response to reduced competition from members of the natural community. It is interesting to note (and speculate further on the fact) that, growing in the wild, the two species investigated have different regenerative strategies. While *P. cynaroides* is capable of resprouting from a persistent rootstock after fire, *P. repens* is an obligate reseeder with a tendency towards serotiny (Rourke 1982; Vogts 1982).

CONCLUSION

What has been illustrated in this chapter is that commercially useful fynbos species, when brought into marginal cultivation, can respond differently to the environment into which they are introduced. Many of the requirements for such species have been well-researched by workers in the horticultural field (Vogts 1982; Brits *et al.* 1983). But producers intent on cultivating natural fynbos species in marginal situations need to consider carefully the microenvironmental peculiarities of each particular site. These must then be weighed against what is known of the adaptations which have allowed the selected species to be successful in their natural habitats. Much basic ecological and eco-physiological still needs to be done if the framework initiated by the horticulturalists is to provide a reliable basis for expanding commercial wildflower production.

This pilot study has broached some of the issues implicit in the relationship between basic ecological research in the fynbos, and the practical needs of the wildflower industry. Key questions for progressing in that direction from this point might be:

1. What are the differences in rooting strategies between the two species, and how might this be of importance in commercial propagation?
2. Are these species intrinsically different in their response to competition from other species?
3. Is there a differential susceptibility to pathogens between the two species?

These questions can provide the framework for phrasing of more refined and testable hypotheses concerning the establishment and propagation of these *Protea* species.

CHAPTER 8

ECONOMICS THROUGH THE ECOLOGICAL LOOKING GLASS

"Well, in our country," said Alice, still panting a little, "you'd generally get to somewhere else - if you ran very fast for a long time as we've been doing."
"'A slow sort of country!" said the Queen. "Now, here, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!"
"'I'd rather not try, please!" said Alice. "I'm quite content to stay here - "

THE INTERFACE BETWEEN ECOLOGY AND ECONOMICS, WITH SPECIAL REFERENCE TO THE WILDFLOWER INDUSTRY OF THE SOUTH-WESTERN CAPE

Conservation and utilization

The natural fynbos vegetation which has escaped the depletion caused by human population growth in the southern and south-western Cape, has done so mainly because it is remotely situated in a rugged and mountainous terrain, and because it grows on soil so impoverished that it holds no appeal for the agriculturalist. But as the inevitable squeeze on space and all other resources continues, much of this infertile heathland will acquire identifiable economic value. Firstly, it will be in demand because it can provide (amongst other things) effective catchment of high quality water for human consumption, and also act as an attraction for tourists with bulky first-world wallets. Secondly, it will be viewed as real-estate with potential for transformation to more directly productive forms, such as those required for afforestation by the timber industry, the building of residential housing complexes, the construction of reservoirs and dams, *etc.*

The decorative wildflower industry is a third option. This characteristic industry of the fynbos biome is a human enterprise which lies symbolically and practically at the interface between ecological conservation and economic development. It generates nearly R 30 million per year from the sale of inflorescences and foliage either cultivated on transformed fynbos land, or harvested directly from the veld (Middelmann *et al.*1989), and has afforded reasons for otherwise neglected land to be conserved and maintained. In this essay I attempt to place that exploitation of the fynbos vegetation in the broader context of humanity's unique ecology and economy.

Defining an economy

As expressed by Cleveland et al (1985), the physical definition of an economy is "...a thermodynamically open system which extracts low-entropy energy and materials from environmental systems, and uses that energy in appropriately designed structures and processes to upgrade materials into new forms" (cited in Christensen 1987). The modern framework, however, has ceased to be purely a vehicle for such transformations. With the adoption of the marginalist approach in the 19th century, the way was opened for complex and artificial theoretical edifices to evaluate the price of a product on the market, as well as the labour, capital and rent which are necessary for its production (Dasgupta 1985). Conflicts between economic and ecological interests have been with us since pastoralists started displacing the hunter-gatherers from their domains, but it is only in the past two-and-a-half decades - perhaps highlighted in the early period by Rachel Carson's *Silent Spring* (1962; Penguin edition 1965) - that the problematic inconsistencies have come into focus. At this stage we are all familiar with the problems of toxic waste, CO_2-enrichment of the atmosphere, ozone depletion, and many others caused by human industry. The economic framework is the basis of many important areas of human negotiation, including those regarding the welfare and quality of life. In many instances the less tangible costs of industrial or other processes which threaten to undermine human welfare have been accepted as a valid part of the balance sheet. Reports of success stories, such as: fish returning to a detoxified River Thames; the reduction of air pollution through use of lead-free petrol and emission control devices for cars; the planning and creation of some benign inner-city environments; etc. are numerous, but these are for the most part only indications of what is possible, rather than evidence of an incipient solution to environmental degradation. In many cases economic considerations limit the extent to which satisfactory solutions can be attained. This is so with one of the wildflower industry's biggest threats - invasion of the natural fynbos vegetation by woody alien species, especially of the genus *Acacia* (Macdonald *et al.* 1986; Holmes 1989). Arresting the environmental degradation caused by these alien invasives, in spite of the real loss of revenue and environmental services such as the provision of pristine water catchments, is not economically viable. The estimated cost of clearing moderately dense infestations is approximately R 1000 ha^{-1} under present circumstances (Ruddock 1989).

Global environmental degradation, and the impetus of economical considerations is perhaps best characterized by the rivet popping allegory of Ehrlich and Ehrlich (1981), in which they liken the human-induced extinction of species to the selling of rivets extracted from a passenger aircraft by an airline company in financial straits.

Public awareness of ecological problems and political lobbying has produced effective solutions in some situations, but many problems still persist. Both free-marketeers and controlled economy proponents tend to regard these remaining problems as soluble, the former convinced that Adam Smith's invisible hand will guide us ultimately to the correct solutions, while the latter reckon that sufficient organization will do it. Ecologists, who have a different view of the overriding economy of nature, are not generally as optimistic. Costanza and Daly (1987), in the introduction to a special issue of *Ecological Modelling* devoted to the conflicts between ecology and economics, state that this is not the case. They see the remaining problems as serious, and beyond the scope of existing economic paradigms.

In the south-western Cape, the special case of the wildflower industry as a direct user-agency of a natural resource has been chosen as a reasonable starting point for probing some of these problems (Greyling and Davis, 1989). Interested parties from the commercial and conservation/management sectors have been joined by academic researchers (mostly ecological) in an attempt to define the common ground for constructive dialogue (see Figure 8-1). To understand the essence of the problem, we need to remind ourselves of the organizational hierarchy which governs biological systems in general, and those inhabited by humans in particular. At the social level, human lives are guided by the constraints and taboos contained in the intersection of several rule-sets, including those of ethics, politics, and economy, bound together loosely as a characteristic culture. This is roughly the operating area for economists. As a species however, *Homo sapiens* is dependent on the suitability of many environmental parameters which lie outside of that composite set (see Figure 8-2). Ecologists and other natural scientists generally prefer to remove themselves from the human milieu, and tend to study relationships between organisms and environments in the quiet corners, where disturbance caused by human activity is less likely to cause confusion (area **e** in Figure 8-2). The need for natural scientists to view the world on an ecological, and even an evolutionary time-scale, leaves them professionally naive with regard to the intricate web of human affairs, where the driving forces of organism-environment systems are not based on the biophysical economies of nature. In the post- *Silent Spring* era, however, consequences of super-industrialization have drawn attention to

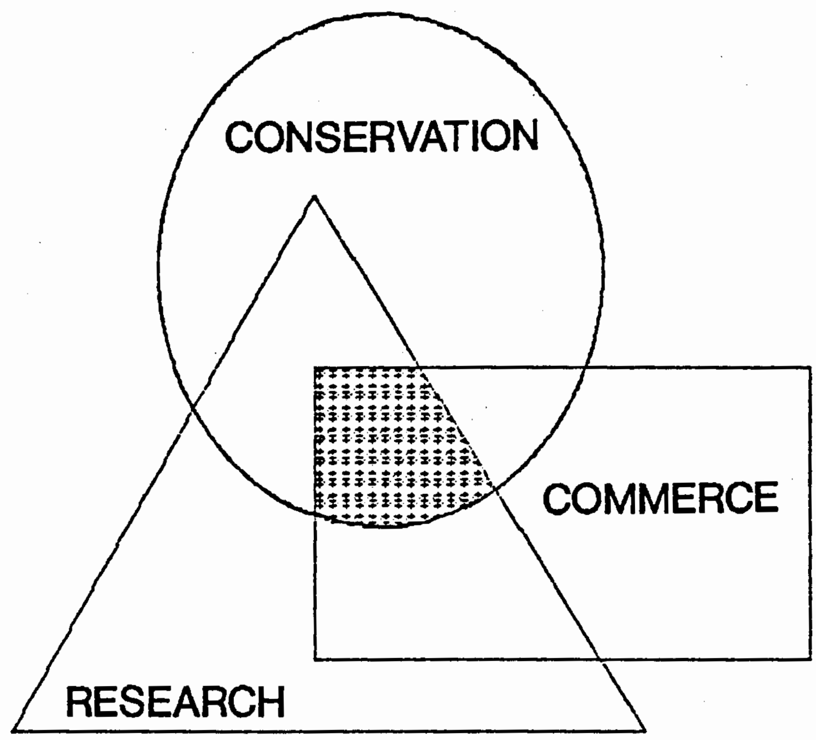


FIGURE 8-1. The starting point for co-operation in the management of natural resources is the philosophical common ground shared by the agents of utilization, conservation, and the pursuit of objective knowledge.

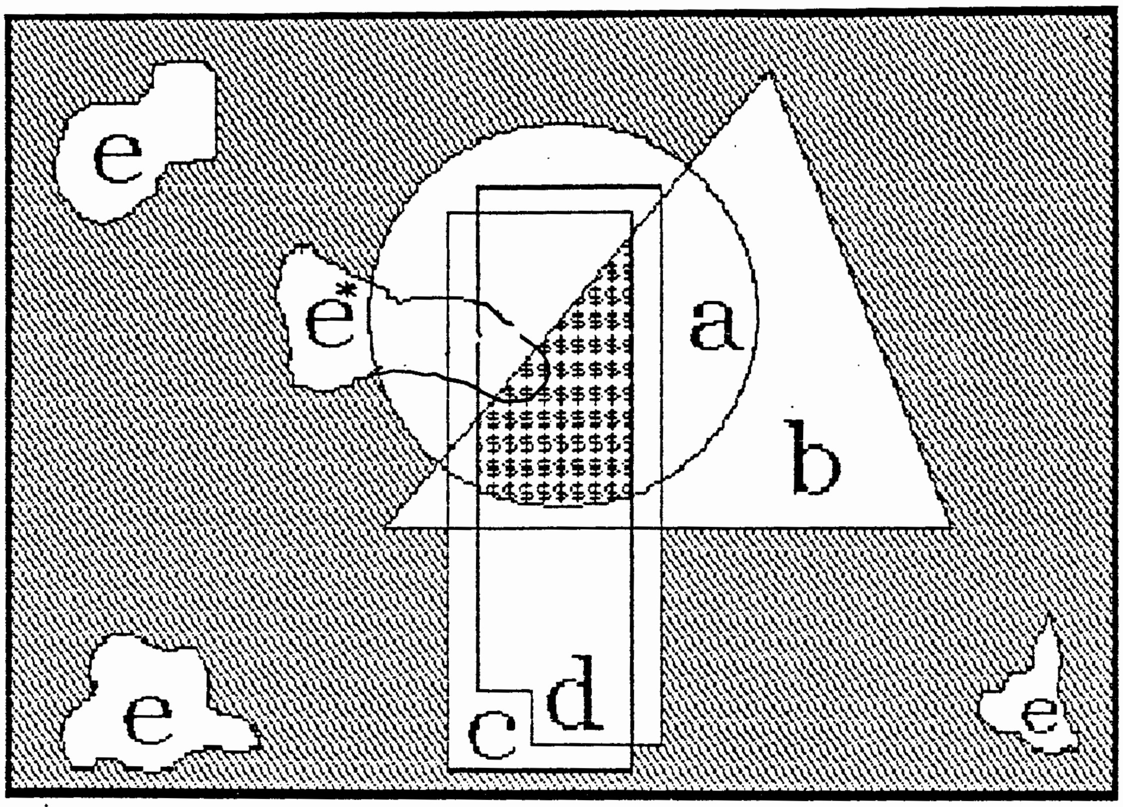


FIGURE 8-2. Representation of human activities in the biosphere. Geometric shapes a-d are areas of direct human concern such as health care, housing, education, food production, etc. Natural scientists normally strive to work in areas uninfluenced by the social milieu (e) in order to obtain data pertaining to undisturbed systems. Effective management research requires understanding of compounded sets (e^*) with their interactions between natural and anthropogenic systems.

degradation of the human environment, and "environmentalism", a social perspective with its roots in the ecological sciences, has drawn biologists into the social realm. But the tight-knit caucus of economic and political power, together with the differences in professional perspective between human and natural scientists, has made it difficult for ecologists to make a forceful contribution to the search for a solution to environmental problems. Efforts are being made , but as will be outlined below, it may be that solutions to environmental problems are being sought within a framework which is not fully cognizant of the ultimate biophysical constraints to ecosystem function.

WHAT IS THE LOOKING GLASS PRINCIPLE?

Imagine that your high security work-place is a brightly, but artificially lit office. There you work your day shift in relative comfort, with all the tools necessary to perform your complex job at hand . On one wall is a large mirror of which you are somewhat suspicious. Although it is useful for checking your personal appearance before those rare visits from the chief managing controller, when you douse the lights at knocking-off time, you are able to discern activity on the other side. After years of observation you have come to the conclusion that it is a shift worker carrying the work on into the night, taking over from you. Your analysis of his dimly perceivable actions lead you to believe that he is performing some important aspects of his work incorrectly, and, being conscientious for now, you fear for the integrity of the whole operation. Entrance to the sector giving access to that room is out of bounds to your rank, and the supervisors, whom you suspect are cynical beyond caring about anything other than their days off and payday, are non-committal about your observations and concerns. Unknown to you similar anguish is experienced by your looking-glass counterpart when he signs on during the mid-afternoon, and peers into your work-room to see the most obvious of blunders being perpetrated. Alice at least had the opportunity to penetrate the reflective interface and quiz the chess pieces on the logic of their world, even if it made no sense to her (Lewis Carroll 1872).

In the spirit of this analogy, I place myself (an ecologist) on the one side of the looking-glass, and am here attempting to set down what I perceive to be the dangerous misunderstandings which occur at this interface. I draw heavily on the astuteness of concerned gazers from both allegorical work-rooms, who have reported their observations and interpretations in the sparse but growing literature covering this topic.

IS THE LOOKING GLASS PRINCIPLE ACTIVE?

The historical treadmill within which modern scientists operate

I make the claim above that there are serious blocks to communication between the disciplines of ecology and economy, and that practitioners from each operate according to different sets of rules. From each one's perspective, the shortcomings are worse on the other side. But, as I have attempted to illustrate in Figure 8-2, there ought to be a superset which includes both, and within which inconsistencies could be identified and explained, allowing adjustment of the models we employ for the management of humanity and its broader environment.

But what is the nature of these inconsistencies? In 1776 Adam Smith set the scene for the classical period of political economy with publication of his *Wealth of Nations*(Smith 1776). In this was included his famous model of the unseen hand, guiding self interest to act in accordance with public interest, a paradigm often unjustly employed by apologists for some of the more ruthless excesses of private enterprise. Smith's somewhat optimistic approach to the study of human affairs was significantly influenced by the French school of Physiocrats, who believed that all wealth was agricultural in origin (Galbraith 1977). This was a view that came fairly close to the biophysical economy which ecologists are more inclined to see as the true economy of nature (Cleveland 1987).

It was two learned Englishmen following closely behind Smith who (unwittingly?) put the callous edge to economics. Thomas Malthus, in his formulation of the *Principle of Population*, saw human populations as increasing exponentially, limited only by a more slowly expanding food supply and the consequent inevitable famine. His close friend David Ricardo, a stockbroker and parliamentarian, saw the Malthusian populations embodied in the working classes, their fecundity a source of labour for the generation of wealth in the landlord class, and their numbers limited by their own wretched poverty. The climate of insurrection which had prevailed in France two decades earlier was not a factor which emerged in the English equation, and development of the political and economic structures proceeded unchallenged.

While Ricardo had merely described in academic terms the *Labour Theory of Value*, the Social Darwinians, spurred on by Herbert Spencer (1820 - 1903), justified their own position in comfortable middle-class society as the "survival of the fittest" (Galbraith 1977). If Darwin was influenced by Malthus in his thinking concerning natural selection, then he in turn was an inspiration for defenders of the right to be wealthy in the face of surrounding squalour and poverty.

The middle-classes of the western world embraced capitalism as their own with something of a religious fervour, while the working classes looked for guidance and support from another perspective, even though it rested on the same capitalist model. Marxism, although it created an important space for the development of aspirations and ideals within the working classes, it did nothing to re-establish links between human economy and the biophysical one left behind with the Physiocrats. Generally the increasing economic complexity of the industrializing nineteenth century world drew more agents into the cycle of production and purchase, and obscured biophysical reality even further.

The new complexity precipitated a need for further additions to the economic toolbox. Some of these were provided by the marginalists, who shifted the emphasis away from the labour theory of value, and the study of production and the distribution of wealth. Instead they perceived the value of produced goods to be dictated by their desirability ("utility") in the eyes of the aggregated consumer market, and their costs to comprise the contributions of as many factors as were necessary to cover the production cost of a unit of output. The values of these factors were then also seen as determined in the markets which competed for them. And so, the development in economic thinking which occurred between the classical era and the neo-classical world of the marginalists accommodated the growing complexity of social systems and the need for a more equitable distribution of wealth. But at the same time, as evidenced by the increasing importance of non-renewable resources such as cheap petroleum (Goodland and Ledec 1987), the gap widened between the world of real biophysical resources, and the models of the human economy. From a cynical standpoint it may even appear to have been a trade off manipulated by the politically powerful middle-classes - made possible by the flexibility of the advancing technology which they controlled - between the rights demanded by the indispensable labouring classes, and the security of the environmental services which support continued human existence.

A modern scientific convention is to accept any reasonable hypothesis until it has been falsified, and in the past some apparently simple relationships have proved remarkably effective and durable. One such relationship is Fisher's Consumer Price Index (Galbraith 1977), perhaps an economic equivalent of Ohm's law for electrical phenomena. It states, in part, that the value of money is inversely proportional to both the amount that is available, and to the rate at which it flows through the economy. It was the principle underlying this empirical relationship that finally alleviated the economic stagnation in the U.S. economy during the 1930's when government borrowed uncirculating money to invest in public projects. The money thus forced into circulation brought down its value and thus made further employment, and hence greater production possible (Galbraith 1987). A problem, the result of either a quirk of fate, or a principle of perversity not yet understood, was that the government spending which finally revitalized the U.S. economy, was on arms for the second world war effort (Galbraith 1987). Even during the 1980's military spending formed an important part of the U.S. economy, with 7% of the gross national product (GNP) being devoted to defence in 1985 (Brown 1986), and a third to half of the country's scientists and engineers being employed by the military (Capra 1982). Even some of the underdeveloped countries, where resources are needed to alleviate the effects of poverty, were reported by Brown (1986) to have spent significant proportions of their GNP's on defence during 1984 *e.g.* India (3.5%), China (8%), Ethiopia (11%), Lybia (17.5%), Chile (4.5%), South Africa (4.3%).

The conclusion one may draw from the observed progression of economic history is that while working models used to guide the interactions between people and their resources have become more accurate, and sometimes even reasonably predictive, they have wandered far from the biophysical economy which supports life *per se*. It may be argued that the marginalist approach, with its cognizance of the different factors influencing production, could include the ecological costs of supply. The fact, however, is that for the marginalist model to work, absolutely free trade and open competition must prevail to allow for the equilibration of market forces. The influences must therefore theoretically be *post hoc* - *viz.* the influence of sperm whale population size on the price of gearbox oil, or the contamination of goundwater by radioactive leakage on the price of electrical power, can only be evident after the environmental threat has been realized. Concerns about this pattern of environmental degradation and its relation to commodity pricing are further confused by a faith in technology to supply solutions, such as synthetic gearoils and decontamination strategies. For the free-market approach to be ecologically sound, the market must be aware of *all* the costs of production, and reflect them in its willingness to pay the price, rejecting as too expensive products which will contribute to environmental degradation. Adaptation of this economic ideal to an increasingly stressed set of global ecosystems will require much more comprehensive analyses of human cause and ecosystem effect than we have been able to produce till now. (The fashionable consumer reaction to C.F.C.'s in under-arm deodourant and the commercial catch-word of "ozone-friendly alternatives" may help, but it is not a convincing argument that this is effectively happening.)

In the heterogeneous global village that we live in, with some human populations too impoverished to argue, or too sparse to have political power in negotiating factors which affect their immediate environment (reminiscent of the Ricardian labour force living at physiological subsistence), exploitation of the global environment by institutions with vested interest but no immediate checks on their behaviour, seems inevitable.

HOW DO ECOLOGISTS AND ECONOMISTS PERCEIVE THE PROBLEMS?

The biophysical basis forsaken

From the ecologist's standpoint, what are the features of the economist's work-place that appear to be awry? In the biophysical sense, biologists too are concerned with economies. An important difference is that natural scientists work against a backdrop of Darwinian selection, which they are inclined to believe has guided the adaptive processes to achieve a high degree of parsimony, even if it has not fully optimized organism/environment relationships (Givnish 1987). The human economies of today, on the other hand, have shed their immediate reliance on the biophysical world by mining the energy stored in low entropy fossil fuels. They now operate according to paradigms that may be consistent within the reference frame provided by human ideals and activities, but are not necessarily totally compatible with the natural ecosystems upon which they are superimposed. Many biological aspects of the broader human environment are therefore regarded as externalities, and in many ways may defy inclusion in the working models of economics.

Following the dictates of the market

Economic theory, like ecological theory, attempts to represent complex real-world phenomena in terms of relatively simple models which can be more easily comprehended by the limited human mind. As with all scientific theories, models are statements of our understanding of the relationships between components of the real world, and are allowed to stand unaltered and unqualified until they have been proven deficient. A model utilized heavily in the application of economic theory is that of *supply and demand*. Within a marginalist framework, this model relates the volume of production to both the unit cost of production (supply), and to the willingness of consumers to purchase that product (demand). What troubles some ecologists is the determination of the supply function, and its representativeness of real costs (Pearce 1988). Profit-making, according to the long-lived principle of Adam Smith, should be pursued uncompromisingly for it to work, and for it ultimately to act in the public interest. Because of the complex structure of modern human societies, the boundaries between resources to which individuals, communities and groups have access, have become blurred. As a result, the unseen hand itself needs instruction from parties with vested interests (and regretfully has been taught the art of the pickpocket, or in some cases the major felon). In order to maximize their earnings, profit-makers are inclined to depress the supply curve by not acknowledging the less immediately obvious costs to society (and indirectly to themselves), and by ignoring difficult-to-quantify externalities such as long-term resource depletion, environmental pollution, species extinction, etc. (See Figure 8-3).

Ethically speaking, the misdemeanor of the self-seeking profit-maker is the utilization of resources which are in fact the property of other individuals, other communities, other generations and, conceivably, other species. The terms *intergenerational* and *interspecific justice* have been introduced to the ecological literature (Pearce 1987) to describe the latter two concepts in a relatively unemotional way.

Discounting the future

Although divorced from the biophysical world, modern human economies do tend within themselves towards optimization. Investors like to benefit as much as possible from their investment, labour always negotiates the best possible settlement, and in the private sector, economically important resources are not wasted. Projects, whether they are private for profit, or public for community

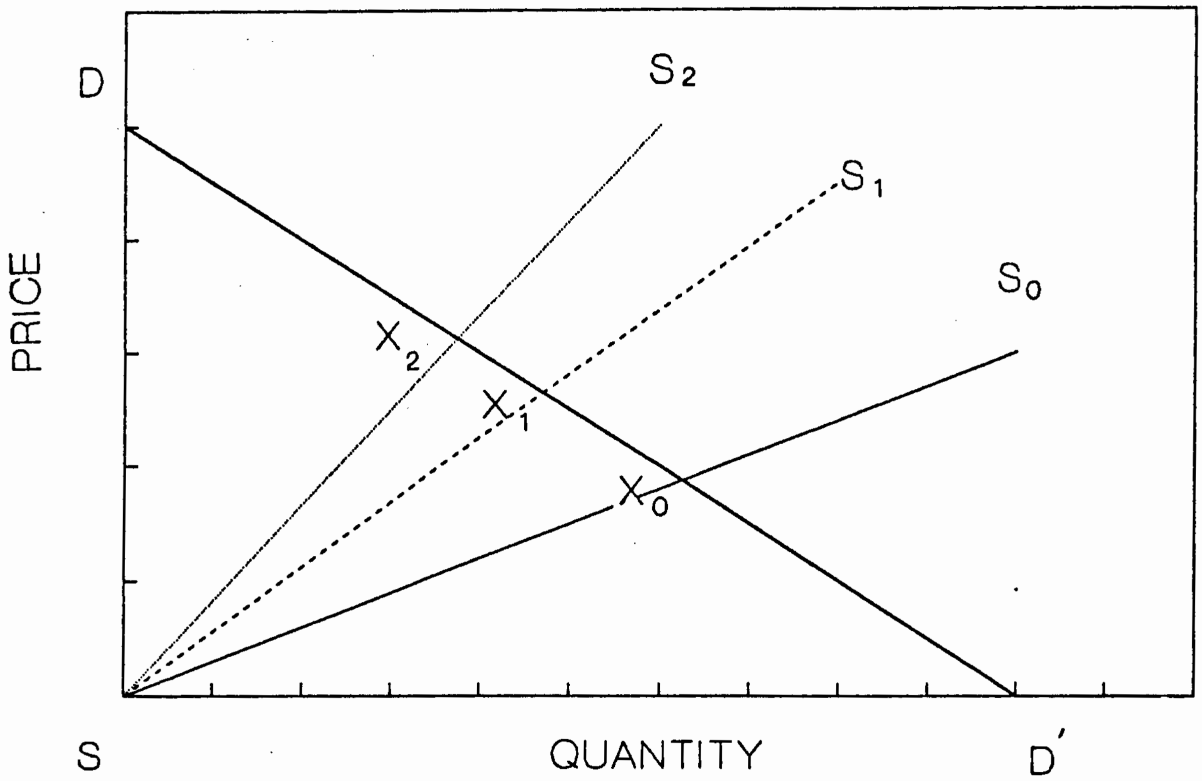


FIGURE 8-3. The supply-demand relationship showing the effects of three different estimates of production cost (SS_i for i = 0,1,2). Total respective profit is represented by the triangles DSX_i, showing lower profits with the inclusion external costs (i = 1 and 2), and hence with less appeal for economics of the invisible hand. (After Pearce 1988).

welfare, are usually carefully scrutinized by managers for the relationship between costs and benefits. One of the conceptual legacies of the era of classical political economy, however, is the notion that things are getting better all the time. Improvement of technological skills, refinement of processes, discovery of new resources (usually using new technologies), are all expected to make future generations wealthier than the present one. Such investment in future generations, it is argued (Barnett and Morse 1963 as cited in Goodland and Ledec 1987), should be made against a high *interest rate*. The concept of interest can be reversed to accommodate devaluation of current spending on projects with future benefits (Seneca and Taussig 1984). Most cost-benefit analyses by this means include devaluation of utility value according to a prescribed *discount rate*. A typical formula for discounting future value of a project is one used by the World Bank in its assessment of Net Present Value (NPV) (Goodland and Ledec 1987), and is as follows:

$$NPV = \Sigma(B_i - C_i)/(1 + r)^i$$

where B_i is total benefit at time i;
C_i is total cost at time i
and r is the discount rate.

The value of **r** used in project analyses, often taken to be the current interest rate , which Goodland and Ledec (1987) feel in many cases to be too high, and which therefore jeopardizes the conservation of resources for use by future generations. But long-term public benefit is poor collateral for committed creditors, and competitively funded projects tend therefore to have discount rates at or above the market interest rate.

Ecologists themselves are perhaps caught in a secondary dilemma. As most professional ecologists will affirm, they are not to be confused with the "green environmentalists" who are often heard vociferously denouncing many human practices under the banner of ecology. As pointed out by Fenchel (1987), ecology as a natural science is extremely limited in its ability to construct predictive models, and is concerned primarily with the elucidation of relationships between organisms and their environments in the natural world. He also claims that it has nothing directly to do with human values. This is the narrow and precise perspective of the natural scientist. The "greens" on the other hand are caught up in a milieu where pictures must be painted in the broad brushstrokes of political rhetoric, and scenarios of eco-disaster lose potency to motivate the languid masses towards some form of consciousness and action if they are cluttered with all the trappings and provisos of modern scientific rigour. Addressing a public meeting regarding the prospects for the conservation of biotic diversity and the preservation of a habitable human environment (see Huntley 1989 for the contents of the conference to which that talk was appended), Paul Ehrlich, himself a highly regarded academic ecologist, considered the most potent appeal he could make to the non-specialist audience, was for people to consciously spend ten minutes a day making the world a better place to live in. The desperation apparent in that call is also an indication of the size of the chasm between professional ecologists, who are supposedly in the best position to make educated guesses about the consequences of human attitudes toward the environment, and the society which votes in governments and constitutes the market upon which the patterns of resource-use depend.

Gross National Product as a measure of human and ecological good

One of the most widely used indicators of the well-being of an economy is the Gross National Product (GNP), an index which reflects total expenditure by government, consumers, and investors. Because it recognizes only market activity, GNP is not an appropriate measure of human welfare, especially in the developing third world, where economies are largely subsistence in nature (Goodland and Ledec 1987). Assuming that subsistence is closer to the ideal of a sustainable biophysical economy than is consumerism (a reasonable assumption since the use of non-renewable resources is minimized), it must be accepted that GNP is also a poor indicator of environmental well-being. At least 14 years earlier, Samuelson (1973) referred to similar objections to the shortcomings of GNP, and presented the concept of Net Economic Welfare (NEW), which took into account the negative affects of economic progress on the quality of human life. Goodland and Ledec's (1987) objection can be taken as an indication that this is probably still an unresolved issue. Furthermore, the concentration of economic analysis on market activity and monetary flow, rather than on resource distribution, utilization and conservation, draws no distinction between social goods and social evils. In this way we have a legacy of the "good" of expenditure on armaments manufacture, and the resulting awe-inspiring arsenals of the super-powers.

Another recognition of the shortcomings of the standard economic approach comes from the World Bank, which is involved in providing loans for the funding of many development projects in the developing world. In a recent address, the president of the institution conceded that the bank had previously overlooked environmentally sensitive issues by making decisions on purely economic grounds

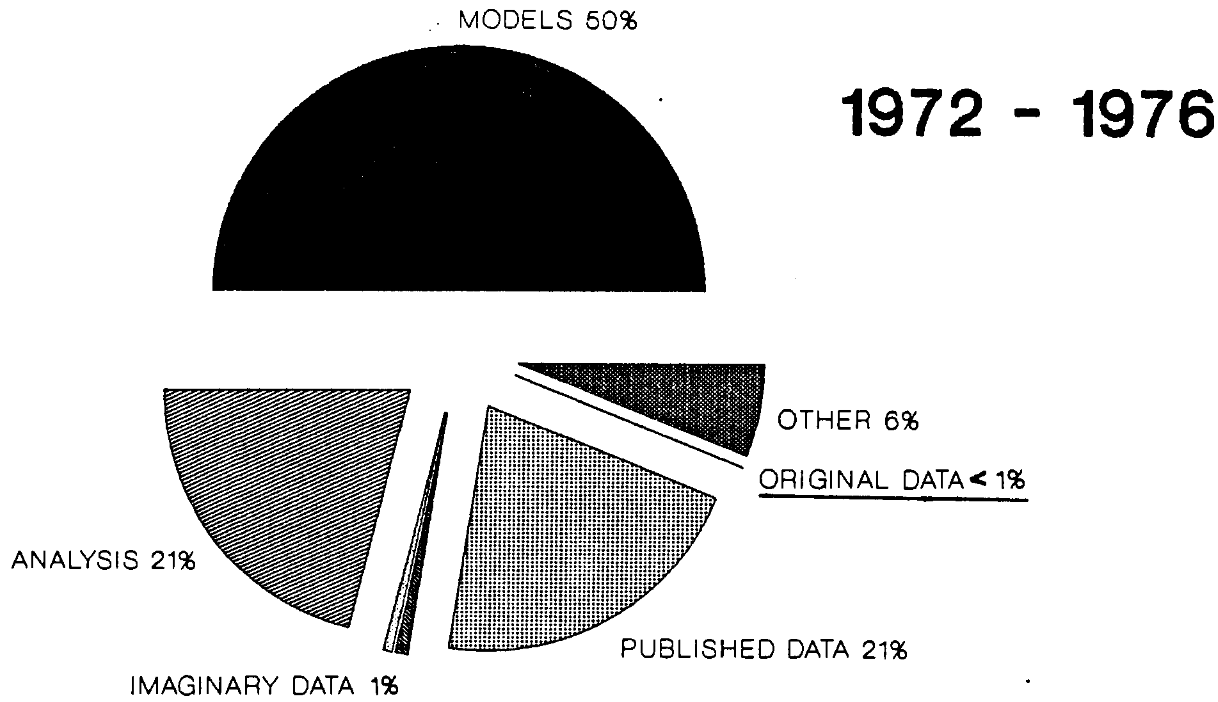
(Anderson 1987). It is true that such statements from the mainstream of applied economic thought are often diplomatic responses to pressures from the increasingly mobilized and influential environmental groups, but it gives reason to hope that the merging of the ecological and economic perspectives may have commenced.

Economics and the lack of empirical data

More direct indictments of modern economic thought and methodology have come from academics themselves. Nobel laureate Wassily Leontief, in a letter to *Science* in 1982 lamented the reluctance (or inability) of economists to generate empirical data upon which to base economic thinking (Leontief 1982; see Figure 8-4). And even if observed economic "facts" were more plentiful and easy to come by, there is some question as to whether the current body of economic theory is in a position to process them in a valid scientific manner. In a critique of modern theory and empirical research in economics, Eichner (1985) concluded that according to the standard tests which guide decisions about the validity of scientific theories - *viz.* **correspondence** (does the theory apply consistently to observable phenomena?), **comprehensiveness** (does the theory account for all of the observable phenomena?), and **parsimony** (does the theory have any elements which are redundant in describing observed phenomena?) - much economic theory does not warrant acceptance as "scientific". This is perhaps the crux of the misunderstanding across the looking glass barrier. The concept of a universal scientific methodology to act as a mechanical book of rules for solving problems has, in the face of modern scientific thinking, been abandoned (Lakatos 1970, in Hacking 1981), leaving the field open for alternative "logics of discovery". If these alternatives, applied to a common problem, produce different solutions, then economists and ecologists will not necessarily overcome the remaining problems through independent and uncoordinated normative procedures.

A rhetorical alternative

In a rejoinder to what he calls "modernism" in economics, McCloskey (1985) criticized what he perceived to be a slavish dedication to the "scientific" approach, and defended rhetoric as a valid medium for complex argument. It is, he claimed, also an important but rarely acknowledged component of all scientific enquiry. Ecologists, while rightfully and professionally honing the analytic tools of their science to cut clean and true, are also in part committing themselves to the specialist mode of cutting fine and narrow. It would seem that there is a need for a sub-



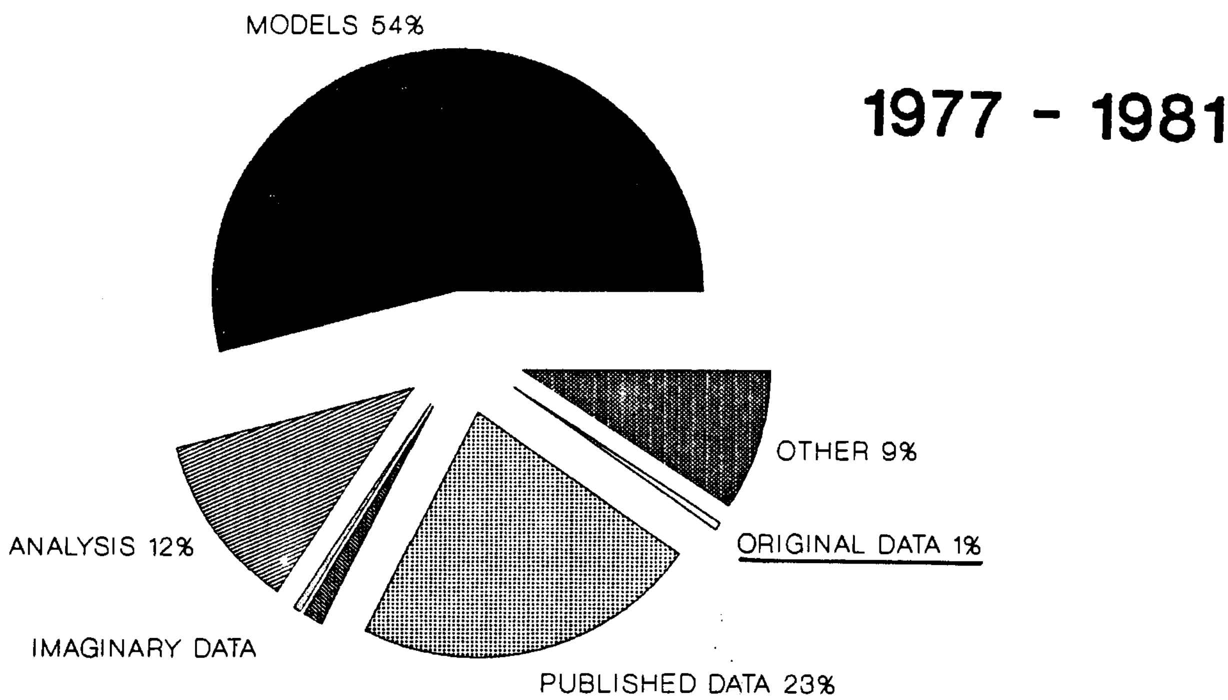


FIGURE 8-4. Leontief's analysis of categories of economic papers published in the *American Economic Review* between 1972 and 1981. The unlabelled segment clockwise from "imaginary data", is for "statistical methods". Attention is drawn to the proportion of papers based on "original data" (after Leontief 1982).

discipline of ecology to probe the questions raised in the sphere of human affairs, and to attempt their solution in within the framework of a sustainable and biophysically compatible economy.

FYNBOS, ECOLOGY, AND SOUTH AFRICAN SOCIETY

Education

This thesis has as focus the wildflower industry of the south-western Cape. In this chapter I have investigated what may seem like a side issue to many botanical researchers, but which I perceive as central to the issue of natural resource utilization, and hence pertinent to the overall theme. The commercial wildflower trade, which relies in part on preservation of the natural state of the veld, offers a good opportunity for studying the functionally common ground between commerce and conservation, even if the perceptions of its role are paradigmatically different. The area of common interest can, with co-operation of the parties involved, be extended to promote a common understanding of the motivations and aspirations of both. Although ecologists appeal to commercial practitioners to be more understanding of environmental issues, it is equally true that ecologists are often quite insensitive to the constraints imposed by real-world economics, and the broader social structures within which they are embedded. Before any real progress can be made in solving the "remaining environmental problems" (*sensu* Costanza and Daly 1987), those relatively alien concepts must be introduced into the ecological balance sheet. On the other hand there must also be an effort to make functional ecological concepts accessible to the commercial exploiter of natural systems, and more generally to the voting and consumerist public. Judging by the many well researched environmental documentaries which are screened on television, this appears to be happening in some parts of the developed world, where fierce competition in the media industries has discovered that environmental issues are profitable source material. (One point to Adam Smith.) Awareness of environmental problems such as pollution, ozone depletion, and endangered wildlife, and probably many more, has entered the consciousness, although perhaps not always the understanding, of those societies equipped with the educational infrastructure necessary for transmission of the information. In most of the underdeveloped countries, however, social issues are too pressing for people to be drawn spontaneously into addressing the apparently less immediate environmental crises, as perceived and described by first-world environmentalists. South Africa, by virtue of its widespread poverty (Wilson & Ramphele 1989) must qualify as such an underdeveloped country. Problems of habitat conservation are regarded by the major portion of the population as secondary to those of inadequate housing, poor education, and low wages. The only solution to this bias of concern, is to provide the materially poor and environmentally uninformed communities with adequate educational facilities. Through provision of access to the appropriate knowledge, participation in conservation issues can be encouraged. Environmental degradation and human poverty can in effect be viewed as interdependent and mutually re-inforcing phenomena. Huntley *et al.* (1989), in their recent evaluation of environmental scenarios for South Africa into the next century, recognize this link. Their outline includes as prerequisite for a solution, the restoration of fundamental democratic rights to allow participation of all citizens in social decision making processes[1]. For this reason, at the time of my writing this thesis chapter, the book stands as a notably progressive statement for a politically and ecologically viable future for South Africa. Of concern to me, however, is their starting point. They assume that the necessary conditions can only be met if accompanied by a sustained economic development involving private ownership of resources, and a free-market economy. They state as incontrovertible a mutually necessary relationship between sustained economic development and the maintenance of a healthy environment, dismissing socialism as contradictory to both. For two reasons I find this a disturbingly facile assessment of a complex situation. Firstly, in South Africa, where a long history of repression has fused the politics of struggle and survival with a suspicion of capitalist ideals, a glib rebuttal of socialism will understandably be interpreted as a reflection of capitalist self-interest. The emergent political power base in South Africa is entitled to a more studied response if it is to co-operate with a univeral solution to environmental problems. As stated by one of the co-authors in an earlier article (Siegfried 1989), "...the problem is scale dependent, requiring different approaches and solutions in different places and societies." Secondly, and more germane to the topic of this chapter, is the fact that an expanding economy must to some extent rely on an expanding resource base. With no assurances that the biophysical resource base for human survival can tolerate expansion of the

[1] Some apparently significant gestures towards negotiating a democratic basis for a future South Africa have been made by government in the recent past (as I do the final editing of this chapter). See world press February 2, 1990 and following weeks for details (GWD Feb 17, 1990).

economic one, it would seem prudent to seriously consider political philosophies which are based on human aspirations of co-operation (*cf.* Kaufmann 1987).

It is impossible to think of arriving at a reasonable working hypothesis without objective consideration of the full spectrum of political, and hence economic perspectives. Indications are that ecologists, who need to project their work into the public sphere for purposes of environmental management, also need to familiarize themselves with the political processes operating at all levels of human society, an important though often overlooked constituency of their discipline. In South Africa especially, where large disenfranchised populations of people are dependent on overloaded and under-subsidized education systems (Wilson & Ramphele 1989) for insights into the complex issues of nature conservation and resource utilization, the professional ecologist has a distinct obligation to communicate the specialized knowledge which he or she has derived from a more privileged background.

CONCLUSION

In the south-western Cape, the commercial fynbos wildflower industry exemplifies a user of a resource which is intrinsically linked to natural ecosystem processes. The component systems of the Fynbos Biome provide two identifiably important environmental services to the human communities of the area *viz.* the catchment of water for domestic, agricultural, and industrial consumption, and areas for recreational escape from urban environments. In addition they impart a unique natural beauty, which is a highly saleable commodity for the substantial tourism industry.

The wildflower industry is a direct user of this resource, and provides a reasonably predictable market for both formal and informal labour. It is therefore an important revenue earner for many of the economically depressed rural communities in the region. For these reasons the wildflower industry is pivotal in the development of a land-use strategy which can address the questions of ecosystem conservation.

CHAPTER 9
SYNTHESIS AND CONCLUSIONS

An important theme underlying this project is the urgent need for us to review the manner in which we use natural resources. The work has centred on the Fynbos Biome, with particular emphasis on mountain fynbos vegetation. In the Fynbos Biome as a whole, there are other components, such as the lowland vegetation types (Jarman 1986), whose conservation status is more tenuous than that of the mountain regions. (Hilton-Taylor and Le Roux (1989) report that mountain fynbos, Veld Types 69 and 70 according to the classification of Acocks (1953), enjoys permanent conservation of more than 15% of its area, while for coastal fynbos and coastal renosterveld, Veld Types 47 and 46 respectively, this figure is less 5%.) The contribution which this volume hopes to make, is not to analyze the conservation of the wildflower resource *per se*, but rather to focus on processes implicit in the development of conservation strategies.

At the primary ecological level (*sensu* Fenchel 1987) there is much work to be done in unravelling the biophysical relationships which are cardinal to the maintenance of the systems. But the work presented here suggests that wider human issues are also important in applying ecological principles to the management of land-use. My thesis, *sensu lato*, is that the detailed knowledge of natural systems generated by ecologists is not fully realized, and is often in danger of being subverted, when it is not linked to the decision-making processes of the users, and the policy-making processes of the managers. I propose that there are conceptual discontinuities which inhibit the flow of knowledge, and therefore co-operation, between ecological researchers and these other agents of land-use management. The nature of these discontinuities, which are largely economic, is analyzed in Chapter 8. It is at the interfaces between the respective areas of expertise that work needs to be done if integrated strategies are to be developed. This wildflower project may be regarded as a relatively uncomplicated case-study, where the discontinuities are not pronounced (as might be the case in strip mining for kaolin, coal, or tar-sands). The principle parties involved in the analysis are: fynbos ecologists, commercial wildflower producers, and nature conservationists.

I have attempted in this document to run a thread through the full spectrum of considerations recognized as part of the problem, from the ecophysiological requirements of cultivated floricultural species, to the historical and philosophical obstacles to effective land-use management. The major conclusions of the work performed are outlined below.

THE WILDFLOWER INDUSTRY AS A USER OF FYNBOS SYSTEMS

Management of the production site under marginal cultivation

Sustainable management of a natural resource is an ideal which implies that one has quantitative knowledge of a threshold below which the intensity of utilization must be kept. This threshold must also accommodate variabilities of demand and resource regeneration to accommodate worst case scenarios. In the wildflower industry, which has a large potential resource in the extensive surviving natural vegetation of the mountain fynbos (Moll and Bossi 1984), marginal cultivation is the leading edge of its expansion towards such a threshold. Individual production sites (such as those simulated by the experimental sites of this volume) are largely experimental with respect to detailed knowledge of the plant/site interactions at the microenvironmental level. Chances of success at these sites are dependant on foresight and experience of the producer, and basic available knowledge of the ecosystem type and the autecology of the species being cultivated. Development of a production site *de novo* should anticipate failure, be it for either economic or ecological reasons. The transformation process must therefore optimize chances of the system's recovery in the event of abandonment. This implies a knowledge of system resilience to the particular disturbance imposed during preparation. Some results which contribute to a knowledge base for modelling of the relevant processes were obtained during the course of this study.

The experimental work carried out (see Chapters 3 to 7) shows that natural mountain fynbos systems annexed for the production of indigenous floricultural species, are probably altered for at least the next generation of their fire driven life-cycle (Kruger and Bigalke 1984). The long-term ramifications of these effects were not specifically addressed, and little information regarding the "old-field" recovery of disturbed fynbos systems is available. Acquisition of such information needs to be placed on the fynbos research agenda. Given that our predictive skills as ecologists are limited (Fenchel 1987), and that the conservation of biotic diversity and the associated habitats is of high priority (Huntley 1989), then it is important that annexation of natural land for the production of wildflowers be done with circumspection.

The disturbance of topsoil by tillage was shown to alter both the physical processes of water and energy transfer (Chapter 4), and the community structure of the natural vegetation which re-established itself on this soil (Chapter 5). Equally important was the confirmation of one of the desired benefits of cultivation to *some* species, *viz*. improved growth on soil prepared by the conventional agricultural practice of tilling. However, the implications are complex. Firstly, the response, both in terms of growth and ecophysiological behaviour, was not uniform between species (see Chapters 5 to 7). It is important therefore that careful consideration be given to the ecological requirements of target species before application of a technique such as tilling, a practice which this study has shown can be responsible for a significant decline in the richness and diversity of the natural vegetation (Chapter 5). The ecological requirements of cultivated species may range from the specific water and energy regimes needed for seed germination, seedling establishment and plant growth, to the likelihood of creating an environment favourable for pest organisms such as leaf-feeders, stem and shoot borers, or pathogenic fungi (Coetzee *et al*. 1989).

Once it has been established that tillage is an appropriate method of land preparation for the species to be cultivated, the specific method of strip tillage should be employed both for control of soil erosion, and for the maintenance of species diversity (results from this study). These strips, however, should not then be used later as service alleys during maintenance and harvest in such a way as to reduce their effectiveness as refugia for components of the natural vegetation.

The requirements for ecosystem maintenance and economic viability should be a matter of open dialogue, and constant review, amongst ecologists and commercial producers, as it is already between horticulturalists and producers. This places an onus on ecologists concerned with conservation management to initiate research programmes to address the effects of anthropogenic disturbance on fynbos systems. It also implies making of the available ecological expertise accessible to the commercial production sector, a process which has to some extent already been initiated (Greyling and Davis 1989).

Management of the fynbos resource

In the first two chapters I adopted a broader perspective of the wildflower industry in relationship to its fynbos resource. From the review of laws which govern the behaviour of wildflower producers, it appears that the machinery of legislation (conceding that it originated in times when conservation issues were less pressing, and ecological knowledge was less complete than the present), has led to a confusing *status quo*. There are obvious difficulties in reconciling the existing legal framework, with both commercial expectations, and with the ecologically sound management of land-use (see Chapter 1). A solution would be facilitated if the interfaces between the three spheres of **commercial production, conservation legislation** and **ecological research** were structured to allow for the efficient flow of information and ideas between them. One of the riders to this suggestion is the need for environmental scientists to get directly involved in the political processes implicit in the exchange of ideas across ideological and conceptual barriers.

The regional effects of land transformation, marginal cultivation, and to a lesser extent veld harvesting, is not fully known. But their cumulative effect on the functional quality of fynbos ecosystems - such as the maintenance of water catchments for the provision of the conservatively estimated 21.9 x 10^6 m^3 of water used by Cape Town households for domestic purposes each year (Davies and Day 1986) - needs to be carefully considered. Landowning wildflower producers need to be aware of their own contributions to the way in which natural systems function, but they also need access to advice on a co-operative basis, and economic incentives to conserve, as has been suggested by McDowell (1986a; 1986b). The communication links between the various agents of ecosystem utilization, management, and understanding need to be particularly efficient if laws and strategies are to be able to track the ever-expanding awareness of ecosystem function. The role of feedback mechanisms, discussed in Chapters 1 and 2, which might facilitate this tracking, also needs urgent consideration.

THE WIDER CONTEXT

A perspective of land-use management which I have attempted to develop in this treatise includes an outline of the framework within which the floricultural user of fynbos veld operates. It also broaches the economic and philosophical influences which are active in this South African industry. As I have suggested in Chapter 8, human utilization of natural resources has grown into a process well removed from the biophysical basis of existence. That removal, however, is inseparable from the many unique characteristics of our species which make abstract thought and its attendant facilities possible - *cogito ergo sum*. Therefore the answers to the following questions I believe are neither obvious nor necessarily negative: "Does the European urban dweller *need* a bouquet of fynbos foliage and inflorescences on the hall table to alleviate the oppression of a relentless winter, air pollution, and the fear of muggers?"; "Does the South African wildflower exporter *need* the profits which his industry earns him?". Simpler to answer would be: "Does the piece-work labourer who harvests material from the veld for the trade referred to above, *need* his earnings to feed and clothe his family in the economically depressed community within which they live?"

The process of industrialization, followed by the intensifying waves of technological wizardry (a latter day product at which I am bashing out these letters into binary code), has eroded the understanding of biophysical reality for most of the materially privileged citizens of the developed world. But now, in the last decade of the twentieth century, as the depletion of resources becomes apparent, and global systems show signs of stress, this awareness is returning via the mass media as a vicarious understanding of the human place in the biosphere. The wildflower industry as I have attempted to present it - even though I am not partial to captive inflorescences - is a link to our biophysical past, and a real part of human ecology in the Fynbos Biome of the present.

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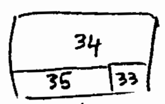
APPENDIX I

Source code of the wildflower harvesting simulation, VELDFLOW, described in CHAPTER 2. It was written in True BASIC version 2.01 (True BASIC Inc., Hanover, New Hampshire), under site licence at the University of Cape Town. Some graphics output routines have not been completed for this version of the programme, resulting in some apparent redundancies in the code.

```
900  ! VELDFLOW - A PROGRAMME TO SIMULATE UTILIZATION OF NATURAL
901  !POPLATIONS OF FYNBOS PLANT SPECIES BY THE WILDFLOWER INDUSTRY
902  ! AND TO ANTICIPATE JEOPARDY TO THEIR WELL-BEING BY SELECTIVE
904  ! HARVESTING
1030
1040 !                        GEORGE DAVIS,
1041 !                        EXPERIMENTAL ECOLOGY UNIT
1042 !                        NATIONAL BOTANIC GARDENS/
1050 !                              BOTANICAL RESEARCH INSTITUTE
1060 !                        c/o DEPARTMENT OF BOTANY
1070 !                        UNIVERSITY OF CAPE TOWN
1080 !                        PRIVATE BAG, RONDEBOSCH 7700
1090 !                        TEL: 650-3486
1100 !
1110 !
1120 !           WRITTEN IN TRUE BASIC (R) (UNDER UCT SITE LICENCE)
1130
1140  CLEAR
1150 ! CALL READTEXT_EXTERNAL("README1.PRN",30)
1160  OPEN #88: PRINTER
1170
1180   LET TIMESTART$ = TIME$
1190 !SETTING INITIAL CONDITIONS AND PROGRAM PREREQUISITES
1200 !DIMENSION STATEMENTS
1210        DIM DISTRIB(20,52)                   ! 52 WEEKS
1220        DIM SPNAME$(20)
1230        DIM SPID(22)
1240        DIM SPDISTRIB(104)                   ! 2 YEARS TO COVER ALL FLOWERING
1250        DIM WEEKLABUND(52)
1260        DIM TRAVLCOST(52,10)                 ! 10 TYPES OF PRODUCE
1270
1280        DIM ACTUAL_RESPONSE(20)
1290        DIM ANNUAL_LOAD(20)
1300        DIM ANNUAL_VALUE(20)
1310        DIM COUNTYPE(10)
1320        DIM DEMAND_TYPE(10)
1330        DIM END_PUBERTY(20)
1340        DIM EXPLOIT(20)
1350        DIM EXPLOIT_WEEK(20)
1360        DIM EXPLOIT_WEEK_NOM(20)
1370        DIM EXPLOIT_YEAR(20)
1380        DIM EXPLOIT_YEAR_DENOM(20)
1390        DIM EXPLOIT_YEAR_NOM(20)
1400        DIM FETCH(21,4)
1410        DIM HARVEST_LEVEL(20)
1420        DIM IMPACT(20)
1430        DIM LIFE_EARN(20)
1440        DIM MARKET_DEMAND(53,10)
1450        DIM MATURITY_FACTOR(20)
1460        DIM NATURAL_YIELD(20)
1470        DIM PICK_LIMIT(20)
1472        DIM AGE_YIELD(20)
1480        DIM PLANT_YIELD(20)
1490        DIM POP_SIZE(20)
1500        DIM POP_START(20)
1510        DIM RELPOP_SIZE(20)
1520        DIM RESPONSE_FACTORS(20,4)
1530        DIM SEEDSTORED(20)
1540        DIM SEEDSTORE_START(20)
1550        DIM SEEDSTORE(25,20)
1560        DIM SENESCENCE_FACTOR(20)
1570        DIM SORT_MATRIX(20,5)
1580        DIM START_PUBERTY(20)
1590        DIM START_SENESCENCE(20)
1600        DIM STORY$(100)
1610        DIM TOTAL(20)
1620        DIM WEEKVALUE(52,10)
1630        DIM YIELD_FACTOR(20)
1640        DIM SPNUMBER(20)
1650        DIM SPTYPE(20)
1660        DIM DESIRE(20)
1670        DIM FLOWER_ON(20)
1680        DIM FLOWER_OFF(20)
1690        DIM SPECIES_ID(20)
1700        DIM POP_ID(20)
1710        DIM ROUTE(20)
1720        DIM MARKET_PRICE(20)
1730        DIM DISTANCE(20)
1740        DIM MASS_LEFT(20)
1750        DIM TOTAL_POTL_MASS(20)
1760        DIM MASS_RETREIVED(20)
1770        DIM VALUE_RETRIEVED(20)
1780        DIM FETCH_COST(20)
1790        DIM EXPLOITED_FULLY(20)
1800        DIM GOT_ALL_WE_CAN(20)
1810        DIM PROFIT(25)
1820        DIM SPP_GROSS_PROFIT(20)
1830
1840
1850
1860 !SETTING INITIAL PARAMETER VALUES
1870
1880          LET PAYLOAD=750                   !SIZE OF TRUCK
1890          LET TRAVLRATE=.5                  !COST OF TRANSPORT RANDS/km
1900          LET THRESHOLD_WORTH = 1.01          !1.1 IMPLIES 10% PROFIT MARGIN
1910          LET IMAGE1$ = ">#########"
1920          LET IMAGE2$ = ">######.##"
1930          LET IMAGE3$ = ">###.#"
1940          LET STORYLINES = 1
1950
1960          LET YEAR = 0
1970          LET LEGIT_PICK = 0
1980          LET LIFETIME = 20
1990          LET CHANGING_MARKET = 0
2000          LET STORYFILE$ = "SIDELINE"     !1   THESE INPUT FILES  EXPECTED
2010          LET SPP$ = "SPPCHARS.PRN"       !1   IN SAME DIRECTORY AS MODEL
2020          LET POP$ = "POPCHARS.PRN"       !1      .......ditto..........
2030          LET VELDOUT1$ = "VELDOUT1.PRN"   !2   THESE OUTPUT FILES CAN BE
2040          LET VELDOUT2$ = "VELDOUT2.PRN"   !2   DIRECTED AT WILL DURING
2050          LET VELDOUT3$ = "VELDOUT3.PRN"   !2   THESE OUTPUT FILES CAN BE
2060          LET VELDOUT4$ = "VELDOUT4.PRN"   !2   DIRECTED AT WILL DURING
2070          LET VELDOUT5$ = "VELDOUT5.PRN"   !2   THESE OUTPUT FILES CAN BE
2080          LET VELDOUT6$ = "VELDOUT6.PRN"   !2   DIRECTED AT WILL DURING
2090          LET RESOURCE$ = "RESOURCE.PRN"   !2   EXECUTION OF THE PROGRAMME
2100          LET DETAILS$  = "DETAILS.PRN"    !2   EXECUTION OF THE PROGRAMME
2110          LET GRAPHICS = 0
2120          LET CHANGE_PARAM = 121
2130          LET COLOURYEAR = 0
2140          LET OVERHEADFACTOR = 1
2150
2160
2170             LET DIAGNOSE = 0
2180             LET TRACE = 1
2190             LET TRACE_COSTIT_LOOP = 0
2200             LET TRACE_COSTIT_WEEK = 0
2210             LET WEEK_DETAIL = 0
2220             LET WEEK_HOLD = 0
2230             LET DONT_STOP = 1
2240             LET DISK$ = "C:\GEOWORK\TRASHOUT\"
2250             LET RESOURCE_CALC = 0
2260
2270
2280 !#################################################################
2290
2300 !MAIN PROGRAMME
2310
2320     LET YEAR = 0
2330      FOR N = 1 TO 20
2340          LET ANNUAL_VALUE(N) = 0
2341             LET PLANT_YIELD(N) = 0
2342             LET AGE_YIELD(N) = 0
2350      NEXT N
2360
2370    CALL WINDOWS
2380
2390    CALL SETUP
2400
2410  LET DETAILS$ = DISK$ & DETAILS$
2420     OPEN #21: NAME DETAILS$, ORGANIZATION TEXT, CREATE NEWOLD
2430     ERASE #21
2440     SET #21: MARGIN 200
2450
2460
2470  LET VELDOUT1$ = DISK$ & VELDOUT1$
2480     OPEN #15: NAME VELDOUT1$, ORGANIZATION TEXT, CREATE NEWOLD
2490     ERASE #15
2500     SET #15: MARGIN 200
2510
2520  LET VELDOUT2$ = DISK$ & VELDOUT2$
2530     OPEN #16: NAME VELDOUT2$, ORGANIZATION TEXT, CREATE NEWOLD
2540     ERASE #16
2550     SET #16: MARGIN 200
2560
2570  LET VELDOUT3$ = DISK$ & VELDOUT3$
2580      OPEN #17: NAME VELDOUT3$,ORGANIZATION TEXT, CREATE NEWOLD
2590      ERASE #17
2600      SET #17: MARGIN 200
2610
2620  LET VELDOUT4$ = DISK$ & VELDOUT4$
2630      OPEN #18: NAME VELDOUT4$,ORGANIZATION TEXT, CREATE NEWOLD
2640      ERASE #18
```

```
2650      SET #18: MARGIN 200
2660
2670  LET VELDOUT5$ = DISK$ & VELDOUT5$
2680     OPEN #19: NAME VELDOUT5$, ORGANIZATION TEXT, CREATE NEWOLD
2690     ERASE #19
2700     SET #19: MARGIN 200
2710
2720  LET VELDOUT6$ = DISK$ & VELDOUT6$
2730     OPEN #20: NAME VELDOUT6$, ORGANIZATION TEXT, CREATE NEWOLD
2740     ERASE #20
2750     SET #20: MARGIN 200
2760
2770 CALL SETUP_PRINT    !WRITE INITIAL PARAMETER SETTINGS TO
2780                         ! FILE "LIFESUMM.PRN"
2790
2800      IF TRACE > 0 THEN
2810        LET GRAPHICS = 0
2820
2830        WINDOW #0
2840        CLEAR
2850        CALL WINDOWS2
2860      END IF
2870
2880 CALL SELECT    ! SELECTS SPP FOR ANALYSIS BY COMPARING INVENTORY
2890                   ! FILE "SPPCHARS.PRN" WITH REQUEST FILE "POPCHARS.PRN"
2900
2910
2920            PRINT "PLEASE BE PATIENT, CALCULATING THE RESOURCES"
2930              CALL SOUNDIT
2940
2950 CALL RESOURCESET    ! CALCULATES DISTRIBUTION OF MATERIAL
2960       CALL RESOURCEOUT   ! RECORDS THESE DISTRIBUTIONS IN "RESOURCE.PRN"
2970
2980       DO WHILE YEAR <= LIFETIME + 1
2990
3000
3010 CALL CONNECTIT        ! CONNECTS ANNUAL CYCLES BY ADJUSTING
3020                             ! POPULATION SIZE, PLANT YIELD, AND/OR
3030                             ! MARKET DEMAND
3040
3050      IF YEAR = LIFETIME THEN EXIT DO
3060      IF STOPPIT = 1 THEN EXIT DO
3070
3080 CALL COSTIT         ! THE ECONOMIC HEART OF THE PROGRAMME
3090
3100
3110      LET COLOURYEAR = ABS(COLOURYEAR - 1)
3120
3130        FOR N = 1 TO SPTOTAL
3140          LET LIFE_EARN(N) = LIFE_EARN(N) + ANNUAL_VALUE(N)
3150        NEXT N
3160
3170         LET YEAR = YEAR + 1
3180         LET REPEATNOT = 0
3190
3200 LOOP   ! LIFETIME
3210
3220 CALL LIFE_REPORT
3230
3240          CLOSE #15
3250          CLOSE #16
3260          CLOSE #17
3270          CLOSE #18
3280          CLOSE #19
3290          CLOSE #20
3300          CLOSE #21
3310
3320
3330
3340       LET TIMEFINISH$ = TIME$
3350
3360      WINDOW #35
3370
3380              PRINT "SHOW'S OVER, FOLKS"
3390           PRINT "TIME START:  ";TIMESTART$
3400           PRINT "TIME END:    ";TIMEFINISH$
3410
3420
3430 STOP
3440
3450 !###################################################################
3460
3470 !THE INTERNAL SUBROUTES
3480
3490 !SUB SETUP
3500
3510  SUB SETUP
3520
3530 DO WHILE CHANGE_PARAM = 121 OR CHANGE_PARAM = 89
3540
3550   WINDOW #31
3560   CLEAR
3570        PRINT
3580        PRINT "THE INITIAL PARAMETERS:"
3590        PRINT "  (where binary: 1 = YES; 0 = NO)"
3600        PRINT
3610        PRINT  " 1. PAYLOAD           = "; PAYLOAD;" kg"
3620        PRINT  " 2. TRAVLRATE         = "; TRAVLRATE;" R/km"
3630        PRINT  " 3. VALUE/COST RATIO  = "; THRESHOLD_WORTH
3640        PRINT  " 4. GRAPHICS          = "; GRAPHICS
3650        PRINT  " 5. TRACE             = "; TRACE
3660        PRINT  " 6. DONT_STOP         = "; DONT_STOP
3670        PRINT  " 7. OUTPUT DISK       = "; DISK$
3680        PRINT  " 8. LIMITS OBSERVED?  = "; LEGIT_PICK
3690        PRINT  " 9. LIFETIME OF MODEL = "; LIFETIME;" YEARS"
3700        PRINT  "10. CHANGING_MARKET   = "; CHANGING_MARKET
3710        PRINT
3720        PRINT " SEE 'README.PRN' FOR DETAILS"
3730        PRINT
3740        PRINT "RUN STARTED AT:  "; TIME$
3750        PRINT "             ON:  "; DATE$
3760        PRINT
3770        PRINT "DO YOU WANT TO CHANGE"
3780        PRINT " ANY OF THESE? (Y/N)"
3790
3800             DO
3810  !#####     GET KEY CHANGE_ASK
3820              LET CHANGE_ASK = 78
3830               IF CHANGE_ASK <= 127 THEN EXIT DO
3840             LOOP
3850
3860   IF CHANGE_ASK = 78 OR CHANGE_ASK = 110 THEN EXIT DO
3870
3880      IF CHANGE_ASK = 121 OR CHANGE_ASK = 89 THEN
3890
3900       INPUT PROMPT "NUMBER ABOVE: ":PARAM_CHANGE
3910        IF PARAM_CHANGE = 1 THEN
3920          INPUT PROMPT "THE NEW VALUE FOR PAYLOAD IS: ": NEW
3930           LET PAYLOAD = NEW
3940        ELSE IF  PARAM_CHANGE = 2 THEN
3950          INPUT PROMPT "THE NEW VALUE FOR TRAVLRATE IS: ": NEW
3960           LET TRAVLRATE = NEW
3970        ELSE IF  PARAM_CHANGE = 3 THEN
3980          INPUT PROMPT "THE NEW VALUE FOR VALUE/COST IS: ": NEW
3990         LET  THRESHOLD_WORTH = NEW
4000        ELSE IF  PARAM_CHANGE = 4 THEN
4010            PRINT "GRAPHICS DEVELOPMENT HELD OVER"
4020            CALL HOLDIT
4030        ELSE IF  PARAM_CHANGE = 8 THEN
4040           LET LEGIT_PICK = ABS(LEGIT_PICK - 1)
4050        ELSE IF  PARAM_CHANGE = 9 THEN
4060          INPUT PROMPT "THE NEW VALUE FOR LIFETIME IS: ": NEW
4070           LET LIFETIME = NEW
4080        ELSE IF  PARAM_CHANGE = 5 THEN
4090           LET TRACE = ABS(TRACE - 1)
4100        ELSE IF  PARAM_CHANGE = 6 THEN
4110           LET DONT_STOP = ABS(DONT_STOP - 1)
4120          ELSE IF PARAM_CHANGE = 7 THEN
4130           INPUT PROMPT "DISK FOR OUTPUT (DRIVE colon) ":DISK$
4140        ELSE IF PARAM_CHANGE = 10 THEN
4150           LET CHANGING_MARKET = ABS(CHANGING_MARKET - 1)
4160        ELSE
4170          PRINT "NO OTHER CHANGES BUILT IN YET"
4180        END IF
4190
4200     END IF
4210
4220  LOOP
4230
4240    WINDOW #32
4250  END SUB    !SETUP
4260 ! ###################################################################
4270 SUB SETUP_PRINT
4280
4290
4300 ! THE SAME SUMMARY OF START PARAMETERS WRITTEN TO THE DETAILS FILE
4310
4320
4330       PRINT #21:  "FILE 'LIFESUMM.PRN'"
4340       PRINT #21:
4350       PRINT #21: "THE INITIAL PARAMETERS:"
```

```
4360      PRINT #21
4370      PRINT #21: " PAYLOAD           = "; PAYLOAD;"   kg"
4380      PRINT #21: " TRAVLRATE         = "; TRAVLRATE;"   R/kg"
4390      PRINT #21: " VALUE/COST RATIO  = "; THRESHOLD_WORTH
4400      PRINT #21: " LIMITS OBSERVED?  = "; LEGIT_PICK;"   (1=Y;0=N)"
4410      PRINT #21: " LIFETIME OF MODEL = "; LIFETIME;"   YEARS"
4420      PRINT #21:
4430      PRINT #21: "RUN STARTED AT:  "; TIME$
4440      PRINT #21: "             ON:  "; DATE$
4450      PRINT #21:
4460      PRINT #21:
4470
4480 END SUB     !SETUP_PRINT
4490    !*********************************************************************
4500 SUB WINDOWS
4510
4520 !SUB WINDOWS                 INTERNAL SUBROUTINE FOR ORGANIZATION
4530                              ! OF OUTPUT TO THE STARTING SCREEN
4540
4550      CLEAR
4560       OPEN #30: SCREEN 0, .49, 0, 1
4570       OPEN #31: SCREEN .01, .489, .01, .99    ! LHS FOR TEXT
4580       OPEN #32: SCREEN .5, 1, 0, 1     ! RHS FOR PIX WHEN READY
4590
4600       WINDOW #30
4610       SET WINDOW  0, 100, 0, 100
4620       BOX LINES  0, 100, 0, 100
4630
4640       WINDOW #31
4650       SET WINDOW 0, 100, 0, 100
4660       SET CURSOR  1, 1
4670
4680
4690   END SUB    ! WINDOWS 1
4700
4710 !***************************************************************
4720
4730 !SUB WINDOWS2
4740
4750 SUB WINDOWS2                 ! FOR OUTPUT OF THE TRACER (TRACE = 1)
4760
4770
4780   OPEN #33: SCREEN .75, 1, 0, .249 ! TIMER WINDOW
4790    WINDOW #33
4800     SET WINDOW 25, 125, 0, 100
4810
4820      PLOT TEXT, AT 50,65:"the weeks"
4830      PLOT TEXT, AT 50,15:"  fly by"
4840     BOX ELLIPSE 30,120,5,95
4850      BOX KEEP 30,120,5,95 IN BOX$
4860
4870   OPEN #34: SCREEN 0,1,.26,1     ! DATA SCREEN
4880     SET WINDOW 0,100,0,100
4890    OPEN #341: SCREEN 0,1,.250,.259 ! SEPARATE WINDOWS
4900     SET WINDOW 0,1,0,1
4910     PLOT LINES: 0,0;1,0
4920
```




```
4930   OPEN #35: SCREEN 0,.749,0,.249  ! INTERACTION WINDOW + STORYLINE
4940      SET WINDOW 0,100,0,100
4950
4960   END SUB          ! WINDOWS2
4970 ! ****************************************************************
4980 !SUB SELECT
4990 SUB SELECT
5000
5010
5020     !      ROUTINE TO SELECT THE RELEVANT SPECIES FOR THIS ANALYSIS  -
5030     !      UP TO 20 SPECIES ALLOWED IN ASCENDING ORDER, READ IN FROM
5040     !      FILE "POPCHARS.PRN" TOGETHER WITH THE EXTRINSIC FACTORS WHICH
5050     !      DESCRIBE THE ATTRIBUTES OF THE POPULATIONS UNDER CONSIDERATION
5060     !
5070     !      THIS READING IN OF INFORMATION DESCRIBING THE POPULATIONS
5080     !      AVAILABLE TO THE PRODUCER ASSUMES THAT THE SPECIES CONSIDERED
5090     !      ARE A SUBSET OF "SPPCHARS.PRN" (FILE OF INTRINSIC SPECIES
5100     !      CHARACTERISTICS) WHICH HAS THE SAME SEQUENCE - THEREFORE
5110     !      PLEASE SORT BOTH FILES ACCORDING TO THE SAME KEYS
5120
5130
5140
5150      OPEN #2: NAME SPP$, ACCESS INPUT
5160      OPEN #3: NAME POP$, ACCESS INPUT
5170
5180
5190    ! READING THE HEADER LINE FROM EACH DATA FILE
5200          LINE INPUT #2: S$
5210          LINE INPUT #3: P$
5220
5230
5240      LET  N=0
5250      LET  M=0
5260      LET  K=0
5270
5280   IF DIAGNOSE > 0 THEN
5290   WINDOW #34
5300    PRINT "HERE IS A LIST OF SPECIES AVAILABLE TO INCLUDE IN THE ANALYSTS AT;"
5310    PRINT "        THIS TIME - MORE CAN BE ADDED IF DESIRED TO FILES 'SPPNAMES.PRN'"
5320    PRINT "    AND 'SPPCHARS.PRN'.THE INTRINSIC PARAMETERS DESCRIBED ARE:"
5330    PRINT "            T=TYPE (1=SHOWY, 2=FLOWERED SHOOTS, 3=GREENS); "
5340    PRINT"             CD=COMMERCIAL DESIREABILITY; Y=YIELD/PLANT/YEAR;"
5350    PRINT"               ON=WEEK FLOWERING STARTS; OFF=WEEK FLOWERING STOPS; "
5360    PRINT"                E=ENDANGERED STATUS"
5370    PRINT "ID#","SPECIES","T","CD","Y","ON","OFF","E","TD#"
5380   END IF
5390
5400       DO WHILE MORE #3                    !LOOP1 START
5410
5420          LET N=N+1
5430          LET K=K+1
5440
5450
5460          LINE INPUT #3: P$
5470             LET SPPOP = VAL(P$[1:9])
5480
5490             LET SPNUM = 999
```

```
5500
5510
5520
5530   DO WHILE ABS(SPPOP-SPNUM) > 0    ! LOOP2 START
5540
5550     LINE INPUT #2: S$
5560
5570      LET SPNUM = VAL(S$[1:9])
5580      LET SPNAM$ = S$[10:36]
5590
5600
5610   LOOP                              ! LOOP2 END
5620
5630    LET N = N+1
5640
5650        LET    SPNAME$(N) = SPNAM$          ! PLACED IN "SPPCHARS.PRN"
5660        LET SPNUMBER(N)    = SPNUM          ! = VAL(S$[1:9])
5670        LET SPTYPE(N)      = VAL(S$[37:45])  !  TYPE
5680        LET DESIRE(N)      = VAL(S$[46:54])  !  DESIRE
5690    LET NATURAL_YIELD(N) = VAL(S$[55:63])   !  YIELD
5700        LET FLOWER_ON(N)   = VAL(S$[64:72])  !  FLOWON
5710        LET FLOWER_OFF(N)  = VAL(S$[73:81])  !  FLOWOFF
5720        LET PICK_LIMIT(N)  = VAL(S$[82:90])  !  PRESCRIBED PICKING LEVEL %
5730
5740   !     LET    SPNAMES(N) = SPNAM$          ! PLACED IN "SPPCHARS.PRN"
5750   !     LET RESOURCE(N,1) = SPNUM            ! = VAL(S$[1:9])
5760   !     LET RESOURCE(N,2) = VAL(S$[37:45])   !  TYPE
5770   !     LET RESOURCE(N,3) = VAL(S$[46:54])   !  DESIRE
5780   !     LET RESOURCE(N,4) = VAL(S$[55:63])   !  YIELD
5790   !     LET RESOURCE(N,5) = VAL(S$[55:63])   !  YIELD
5800   !     LET RESOURCE(N,6) = VAL(S$[64:72])   !  FLOWON
5810   !     LET RESOURCE(N,7) = VAL(S$[73:81])   !  FLOWOFF
5820   !     LET RESOURCE(N,8) = VAL(S$[82:90])   !  PRESCRIBED PICKING LEVEL %
5830
5840        LET RESPONSE_FACTORS(N,1) = VAL(S$[91:99])
5850        LET RESPONSE_FACTORS(N,2) = VAL(S$[100:108])
5860        LET RESPONSE_FACTORS(N,3) = VAL(S$[109:117])
5870        LET RESPONSE_FACTORS(N,4) = VAL(S$[118:126])
5880
5890        LET START_PUBERTY(N)     = VAL(S$[127:135])
5900        LET END_PUBERTY(N)       = VAL(S$[136:144])
5910        LET START_SENESCENCE(N)  = VAL(S$[145:153])
5920        LET SENESCENCE_FACTOR(N) = VAL(S$[154:162])
5930
5940
5950        LET SPECIES_ID(N)  = VAL(P$[1:9])     !  SPECIES ID
5960        LET POP_ID(N)      = VAL (P$[10:18])  !  POPULATION ID
5970        LET POP_SIZE(N)    = VAL(P$[19:27])   !  POPULATION SIZE (# plants)
5980        LET ROUTE(N)       = VAL(P$[28:36])   !  ROUTE # (viz direction)
5990        LET DISTANCE(N)    = VAL(P$[37:45])   !  DISTANCE TO POPULATION (km)
6000        LET MARKET_PRICE(N)= VAL(P$[46:54])   !  MARKET PRICE FOR THIS SPECIES
6010       LET HARVEST_LEVEL(N)= VAL(P$[55:63])   !  CHOSEN HARVESTING LEVEL
6020
6030
6040 !       LET EXTRINSIC(N,1) = VAL(P$[1:9])     !  SPECIES ID
6050 !       LET EXTRINSIC(N,2) = VAL (P$[10:18])  !  POPULATION ID
6060 !       LET EXTRINSIC(N,3) = VAL(P$[19:27])   !  POPULATION SIZE (# plants)
```

```
6070 !        LET EXTRINSIC(N,4) = VAL(P$[20:36])   !  ROUTE # (viz direction)
6080 !        LET EXTRINSIC(N,5) = VAL(P$[37:45])   !  DISTANCE TO POPULATION (km)
6090 !        LET EXTRINSIC(N,6) = VAL(P$[46:54])   !  MARKET PRICE FOR THIS SPECIES
6100 !        LET EXTRINSIC(N,7) = VAL(P$[55:63])   !  CHOSEN HARVESTING LEVEL
6110 !
6120
6130      LOOP                                ! LOOP1 END
6140
6150      LET SPTOTAL=N
6160
6170       CLOSE #2
6180       CLOSE #3
6190
6200
6210
6220     IF TRACE > 0 THEN
6230                     WINDOW #34
6240                      SET ZONEWIDTH 20
6250                        CLEAR
6260                 PRINT "CHECKING THE SET OF SELECTED SPECIES AS SPECIFIED IN "
6270                  PRINT"     FILE 'POPCHARS.PRN' FOR:"
6280                PRINT "SPECIES",
6290         PRINT USING">##########":"YIELD(kg)","POP_SIZE","PICK_LMT%","HARV_LVL%"
6300               PRINT
6310
6320                       FOR N = 1 TO SPTOTAL
6330                       PRINT SPNAME$(N)[1:10],
6340                         PRINT USING ">#####.###": NATURAL_YIELD(N);
6350         PRINT USING ">##########":POP_SIZE(N),PICK_LIMIT(N),HARVEST_LEVEL(N)
6360
6370                       NEXT N
6380     END IF
6390      END SUB                     !SELECT
6400
6410  !#######################################################################
6420 !SUB RESOURCESET
6430
6440  SUB RESOURCESET    ! DISTRIBUTION OF FLOWERING MATERIAL THE GAUSSIAN WAY
6450
6460     FOR N=1 TO SPTOTAL
6470
6480         LET FLOWON=FLOWER_ON(N)
6490         LET FLOWOFF=FLOWER_OFF(N)
6500         LET ACTUAL_RESPONSE(N) = 100
6510
6520            IF FLOWOFF < FLOWON THEN LET FLOWOFF = FLOWOFF + 52
6530
6540          LET FLOWPERIOD=FLOWOFF-FLOWON
6550
6560          LET SIGMA = FLOWPERIOD/8      ! FOUR STANDARD DEVIATIONS
6570                                        ! EACH SIDE OF MEAN FOR 100%
6580
6590             LET X = - FLOWPERIOD/2
6600
6610
6620     FOR W=FLOWON TO FLOWOFF
6630
6640      LET SPDISTRIB(N)=(1/(SQR(2*PI)*SIGMA))*EXP(-(X^2)/(2*(SIGMA^2)))
6650               ! PROPORTION OF THE POPULATION IN
6660               ! FLOWER AT THIS TIME (WEEK W) - THE NORMAL DISTRIB
6670
6680                 LET X = X + 1
6690
6700                 LET WW=W
6710
6720                 IF WW>52 THEN LET WW = WW - 52
6730
6740             LET DISTRIB(N,WW) = SPDISTRIB(N) !DISTRIBUTION OF THE MASS OF FLOWERING MATERIAL
6750
6760            NEXT W
6770
6780        NEXT N
6790
6800       END SUB  !RESOURCESET
6810    !#######################################################################
6820 !SUB CONNECTIT
6830     SUB CONNECTIT
6840
6850    !  THIS IS WHERE THE ANNUAL CYCLE RETURNS TO...
6860
6870
6880    ! ADJUSTING THE RESOURCE TO REFLECT THE
6890    ! IMPACT OF UTILIZATION FROM LAST YEAR
6900
6910      IF YEAR > 0 THEN
6920 !CALL ADJUST_IMPACT
6930       CALL
ADJUST_IMPACT(POP_SIZE,PLANT_YIELD,RESPONSE_FACTORS,ACTUAL_RESPONSE,PICK_LIMIT,EXPLOIT_YEAR,SPTOTAL)
6940                                ! AN EXTERNAL SUBROUTINE
6950
6960
6970    ELSE
6980           FOR N = 1 TO SPTOTAL
6990             LET POP_START(N) = POP_SIZE(N)
7000             LET SEEDSTORE_START(N) = POP_SIZE(N) * PLANT_YIELD(N) .
7010           NEXT N
7020     END IF
7030
7040
7050     !  MATURITY FACTOR LOOP WHICH SETS THE PRODUCTIVITY
7060     !  RELATIVE TO THE STAGE OF DEVELOPMENT OF THE PLANT
7070
7080              FOR N = 1 TO SPTOTAL
7090                 IF YEAR < START_PUBERTY(N) THEN
7100                 LET MATURITY_FACTOR(N) = 0    ! THAT IS THE POPULATION
7110                                               ! IS PRE-REPRODUCTIVE
7120                  ELSEIF YEAR < END_PUBERTY(N) THEN
7130                       LET MATURITY_FACTOR(N) = (YEAR - START_PUBERTY(N))/(END_PUBERTY(N)-
START_PUBERTY(N))
7140                       ELSEIF YEAR < START_SENESCENCE(N) THEN
7150                         LET MATURITY_FACTOR(N) = 1
7160                     ELSE
7170             LET MATURITY_FACTOR(N) = MATURITY_FACTOR(N) * (SENESCENCE_FACTOR(N)/100)
7180                 END IF
7190
7200    NEXT N
7210
7220     FOR N = 1 TO SPTOTAL
7230        LET RELPOP_SIZE(N) = (POP_SIZE(N)/POP_START(N))*100
7231         LET AGE_YIELD(N) = NATURAL_YIELD(N) * MATURITY_FACTOR(N)
7240         LET PLANT_YIELD(N) = NATURAL_YIELD(N) * ACTUAL_RESPONSE(N)/100 * MATURITY_FACTOR(N
7250      NEXT N
7260
7270         CALL YEAR_REPORT      !WRITE THE ANNUAL STATE OF AFFAIRS TO FILES
7280
7290    IF TRACE > 0 THEN
7300       CALL YEAR_PRINT          !WRITE THE ANNUAL STATE OF AFFAIRS TO SCREEN
7310       LET CHANGE_SWITCH = 1
7320      IF DONT_STOP = 1 THEN
7330       ELSE
7340        LET CHANGE_NOT = 0
7350         DO WHILE CHANGE_SWITCH = 1
7360           WINDOW #35
7370           CLEAR
7380           PRINT "** DO YOU WISH TO CHANGE ANY OF THE PARAMATERS? (Y/N) "
7390              CALL SOUNDIT
7400            DO
7410             GET KEY CHANGEIT
7420             IF CHANGEIT <= 127 THEN EXIT DO
7430            LOOP
7440
7450             IF CHANGEIT = 121 OR CHANGEIT = 89 THEN
7460               LET CHANGE_NOT = CHANGE_NOT + 1
7470               CALL CHANGE_PARAMS
7480               CALL YEAR_PRINT
7490              ELSE
7500               LET CHANGE_SWITCH = 0
7510               EXIT DO
7520             END IF
7530
7540         LOOP  ! CHANGE_SWITCH
7550
7560     ! NOW ALSO GIVE THE CHANCE TO CHANGE VALUES OF THE INITIAL VARIABLES
7570
7580
7590       LET CHANGE_SWITCH = 1
7600        LET CHANGE_NOT = 0
7610        DO WHILE CHANGE_SWITCH = 1
7620           WINDOW #35
7630           CLEAR
7640           PRINT "** DO YOU WISH TO CHANGE ANY OF THE INITIAL VARIABLES? (Y/N) "
7650              CALL SOUNDIT
7660            DO
7670             GET KEY CHANGEIT
7680             IF CHANGEIT <= 127 THEN EXIT DO
7690            LOOP
7700
7710             IF CHANGEIT = 121 OR CHANGEIT = 89 THEN
7720               LET CHANGE_NOT = CHANGE_NOT + 1
7730               CALL SETUP
7740               CALL YEAR_PRINT
```

```
7750             CLEAR
7760            ELSE
7770             LET CHANGE_SWITCH = 0
7780
7790           END IF
7800
7810        LOOP  ! CHANGE_SWITCH
7820
7830     !    IF CHANGE_NOT > 0 THEN CALL
7840 !YEAR_LPRINT
7850
7860       END IF  ! DONT_STOP
7870
7880   END IF     ! TRACE > 0
7890
7900
7910    FOR N = 1 TO SPTOTAL
7920       LET ANNUAL_VALUE(N) = 0
7930     NEXT N
7940
7950
7960 ! SETTING UP THE MARKET DEMAND MATRIX, EITHER FOR THE FIRST TIME,
7970 ! OR MODIFYING IT FOR CHANGED MARKET CONDITIONS SINCE LAST YEAR
7980:
7990     IF YEAR = 0  OR CHANGING_MARKET = 1 THEN
8000
8010 CALL READ_DEMAND(MARKET_DEMAND,YEAR)
8020
8030       LET CHANGING_MARKET = MARKET_DEMAND(53,1)
8040     END IF
8050
8060
8070        WINDOW #35
8080
8090   !  CALL READTEXT_STORY(STORY$,YEAR,LIFETIME,STORYLINES,LINES_IN)
8100                                  ! TELL THE STORY
8110     PRINT USING "###": YEAR;
8120     PRINT USING "######.#":
PLANT_YIELD(7),NATURAL_YIELD(7),EXPLOIT_YEAR_NOM(7),EXPLOIT_YEAR_DENOM(7),EXPLOIT_YEAR(7),SEEDSTORED(7
)
8130
8140     END SUB   !CONNECTIT
8150  ! ####################################################################
8160 !SUB RESOURCEOUT
8170
8180   SUB RESOURCEOUT
8190
8200    !  FINISHED COMPUTING THE RESOURCE MATERIAL FROM AVAILABLE DATA
8210    !  NOW  WRITE THIS
8220    !  INFORMATION (DISTRIB(I,J)) TO A FILE FOR OUTSIDE USE
8230   LET RESOURCE$ = DISK$ & RESOURCE$
8240    OPEN #11: NAME RESOURCE$, ORGANIZATION TEXT, CREATE NEWOLD
8250
8260         ERASE #11
8270         LET MARJIN11 = (SPTOTAL + 4) * 9
8280         SET #11: MARGIN MARJIN11
8290
8300          PRINT #11, USING "RESOURCE MASS (kg) FOR YEAR NUMBER ###: ":YEAR
8310          PRINT #11
8320          PRINT #11: "OUTPUT FILE CREATED ON ";DATE$;" (YYYYMMDD)  AT  ";TIME$
8330          PRINT #11
8340          PRINT #11: "CODES FOR THE SPECIES USED ARE:"
8350           FOR N = 1 TO SPTOTAL
8360              PRINT #11:SPECIES_ID(N);" IS ";SPNAME$(N)
8370             NEXT N
8380         PRINT #11
8390
8400           PRINT #11, USING IMAGE1$: "WEEK";
8410
8420         FOR N=1 TO SPTOTAL
8430           LET TOTAL(N)=0
8440           PRINT #11, USING IMAGE1$: SPNUMBER(N);
8450         NEXT N
8460         PRINT #11
8470         FOR M=1 TO 52
8480             PRINT #11, USING IMAGE1$: M;
8490                FOR  N=1 TO SPTOTAL
8500                  PRINT #11, USING IMAGE2$: DISTRIB(M,N);
8510                  LET TOTAL(N) = TOTAL(N) + DISTRIB(M,N)
8520                NEXT N
8530               PRINT #11:""    ! MAYBE PUT IN WEEKLY VALUES HERE
8540             NEXT M
8550          PRINT #11
8560
8570        PRINT #11, USING IMAGE1$: "TOTAL:";
8580         FOR N=1 TO SPTOTAL
8590            PRINT #11, USING IMAGE1$: TOTAL(N);
8600         NEXT N
8610          PRINT #11: ""
8620          CLOSE #11
8630
8640
8650       END SUB
8660
8670       !###############################################################
8680 !SUB COSTIT              THIS IS THE HEART OF THE PROGRAM
8690 ! WHERE ALL OF THE WEEKLY  !  BUSINESS IS CONDUCTED, AND DECISIONS MADE ABOUT WHAT IS  !
PROFITABLE AND WHAT ISNT
8700
8710
8720  SUB COSTIT
8730
8740  !  SEE HOW MANY OF EACH TYPE OF PRODUCT THERE IS
8750
8760            FOR K = 1 TO 10
8770              LET COUNTYPE(K) = 0
8780            NEXT K
8790
8800
8810  FOR N = 1 TO SPTOTAL
8820              LET LOOKTYPE = SPTYPE(N)
8830               IF LOOKTYPE = 1 THEN
8840                  LET COUNTYPE(1) = COUNTYPE(1) + 1
8850               ELSEIF LOOKTYPE = 2 THEN
8860                  LET COUNTYPE(2) = COUNTYPE(2) + 1
8870                ELSEIF LOOKTYPE = 3 THEN
8880                  LET COUNTYPE(3) = COUNTYPE(3) + 1
8890                ELSE
8900                   PRINT "MORE THAN 3 TYPES?"
8910                END IF
8920
8930         LET EXPLOIT_YEAR(N) = 0
8940         LET EXPLOIT_YEAR_NOM(N) = 0
8950         LET EXPLOIT_YEAR_DENOM(N) = 0
8960         LET ANNUAL_LOAD(N) = 0   ! AND CLEARING CHECKING ARRAY
8970         LET SPP_GROSS_PROFIT(N) = 0
8971
8980    NEXT N
8990
9000      LET YEARVALUE_ALL = 0
9010      LET YEARCOST_ALL = 0
9020      LET YEARPROFIT=0
9030
9040
9050 ! THE WEEKLY CYCLE, WHICH IS THE FUNDAMENTAL MODULE
9060
9070
9080 FOR WEEK=1 TO 52   !================================###
9090
9100     IF REPEATNOT = 0 THEN
9110      IF  KEY INPUT THEN
9120           GET KEY CHANGEIT
9130           GET KEY STOPPITASK
9140            LET REPEATNOT = 1
9150           IF CHANGEIT = 67 OR CHANGEIT = 99 THEN LET DONT_STOP = ABS(DONT_STOP-1)
9160           IF STOPPITASK = 83 OR STOPPITASK = 115 THEN LET STOPPIT = 1
9170      END IF
9180     END IF
9190
9200   !  WINDOW #33
9210   ! CLEAR
9220   ! SET WINDOW 50, 100, 50, 100
9230   ! PRINT "YEAR #: "; YEAR
9240   ! PRINT "WEEK #: ";WEEK
9250   ! PRINT "TIME: ";TIME$
9260   ! WINDOW #32
9270      CALL FREEZIT_OPTION      ! PRESSING F OR f WILL INVOKE HOLDIT2
9280
9290        LET ALPHAWEEK = (WEEK/52)*2*PI
9300        LET ALPHAFLOODWK = ((WEEK - 0.5)/52)*2*PI
9310        LET XTIMEWEEK = 75 + 45*(SIN(ALPHAWEEK))
9320        LET YTIMEWEEK = 50 + 45*(COS(ALPHAWEEK))
9330        LET XTIMEWEEKFLD = 75 + 22*(SIN(ALPHAFLOODWK))
9340        LET YTIMEWEEKFLD = 50 + 22*(COS(ALPHAFLOODWK))
9350
9360
9370       WINDOW #33
9380
9390       IF COLOURYEAR = 1 THEN
9400         SET COLOR 0
9410       END IF
```

```
9420        IF WEEK = 1 THEN PLOT LINES:75,50;75,95
9430           PLOT LINES: 75,50;XT)NEWEEK,YT)NEWEEK
9440        SET COLOR 1
9450
9460     FOR T = 1 TO 10
9470          LET WEEKVALUE(WEEK,T) = 0
9480          LET TRAVLCOST(WEEK,T) = 0
9490      NEXT T
9500
9510  LET WEEKVALUE_ALL = 0
9520  LET WEEKCOST_ALL = 0
9530  LET COSTVALUE_ALL = 0
9540
9550
9560
9570
9580  ! RESETTING THE PART OF THE MATRIX NEEDED FOR THIS WEEK'S CALCS.
9590
9600        FOR N = 1 TO SPTOTAL
9610
9620                LET MASS_LEFT(N)        = 0
9630                LET TOTAL_POTL_MASS(N) = 0
9640                LET MASS_RETREIVED(N)  = 0
9650                LET VALUE_RETRIEVED(N) = 0
9660                LET FETCH_COST(N)       = 0
9670                LET EXPLOITED_FULLY(N) = 0
9680                LET GOT_ALL_WE_CAN(N)  = 0
9690
9700
9710        NEXT N
9720
9730      WINDOW #34
9740
9750      FOR N = 1 TO SPTOTAL
9760         LET  LOADN = DISTRIB(N,WEEK) * POP_SIZE(N) * PLANT_YIELD(N)
9770
9780                LET ANNUAL_LOAD(N) = ANNUAL_LOAD(N) + LOADN
9790
9800                       ! MASS AVAILABLE (kg) THIS WEEK -
9810                       ! ENTER AMOUNT INTO KEF. AND CALC.CELLS
9820                       ! EITHER WITH IMPOSED LEGAL LIMIT, (A)
9830                       ! OR CHOOSING OWN LEVEL  (C)
9840
9850       IF LEGIT_PICK = 1 THEN              !.....................!
9860              ! ?????? AND HARVEST_LEVEL(N) < 100 THEN???????
9870        IF HARVEST_LEVEL(N) < PICK_LIMIT(N)  THEN   !..................2
9880           LET MASS_LEFT(N) = LOADN * HARVEST_LEVEL(N)/100 ! C
9890          ELSE
9900           LET MASS_LEFT(N) = LOADN * PICK_LIMIT(N)/100 ! A
9910         END IF            !.........................................2
9920       ELSE
9930          LET MASS_LEFT(N) = LOADN * HARVEST_LEVEL(N)/100
9940                                                          !C REGARDLESS
9950      END IF      !.........................................!
9960
9970      LET TOTAL_POTL_MASS(N) = LOADN   !SET REFERENCE
9980
9990            LET EXPLOIT_WEEK(N) = 0
10000            LET EXPLOIT_WEEK_NOW(N) = 0
10010
10020
10030
10040          NEXT N
10050
10060
10070 !GET HOLD OF THE MARKET DEMANDS (IN kg) FOR THE THREE CLASSES
10080     ! OF PRODUCE:  1. = PROTEAS + OTHER SHOWY STUFF
10090     !              2. = GREENS
10100     !              3. = EVERLASTINGS (FOR NOW WE'LL ASSUME THAT THE
10110     !                              THE PRODUCER CAN SELL ALL OF 3)
10120     !
10130
10140
10150      LET DEMAND_TYPE(1) = MARKET_DEMAND(WEEK,1)     ! PROTEA_DEMAND
10160      LET DEMAND_TYPE(2) = MARKET_DEMAND(WEEK,2)     ! GREENS-DEMAND
10170      LET DEMAND_TYPE(3) = MARKET_DEMAND(WEEK,3)     ! SEWEJAARTJIE_DEMAND
10180
10190
10200
10210 ! LOOKING AFTER THE PROTEAS+, GREENS, AND EVERLASTINGS IN TURN -----------
10220 !  DOING THE CALCULATIONS BY TYPE SO AS TO RELATE TO THE MARKET DEMAND
10230
10240   FOR T = 1 TO 3                   !THREE IS THE NUMBER AT THIS TIME
10250
10260  IF DIAGNOSE = 1 THEN PRINT "DEALING WITH TYPE ";T;" FOR WEEK "; WEEK; "."
10270
10280     LET VIABLES_DONE = 0
10290     LET VIABILITY_INDEX = 0
10300     LET COUNTDONE = 0
10310
10320 !THIS LOOKS AT UNCOLLECTED MATERIAL FROM EACH POPULATION OF THIS TYPE
10330   !            IN TURN AND ASSESSES THE PROFITABILITY OF RETRIEVAL
10340
10350    LET NN = 0
10360
10370
10380    DO WHILE  DEMAND_TYPE(T) > 0 AND VIABILITY_INDEX < 1   ! --------LOOP START
10390
10400   LET NN = NN + 1
10410
10420         FOR I = 1 TO SPTOTAL
10430            FOR J = 1 TO 5
10440             LET SORT_MATRIX(I,J) = 0
10450
10460           NEXT J
10470           NEXT I
10480
10490
10500
10510    LET COUNTDONE = 0
10520
10530     FOR N = 1 TO SPTOTAL      ! -------------------------------N
10540
10550     LET VIABLY_DONE = 0
10560    LET EXPLOIT_N = 0
10570
10580
10590  IF SPTYPE(N) = T  THEN                               ! JUMP TO END AND DO NEXT N
10600                                                       ! IF WRONG TYPE
10610
10620     IF GOT_ALL_WE_CAN(N) = 0  THEN                    ! AVOID SPECIES WE'VE
10630                                                       ! VIABLY USED ALREADY
10640
10650      IF MASS_LEFT(N) <= 0 THEN                        ! JUMP TO END
10660                                                       ! AND DO NEXT N
10670
10680        LET VIABLY_DONE = 1                            ! IF NOTHING FLOWERING
10690                                                       ! BUT MUST COUNT
10700                                                        ! VIABLY_DONE
10710
10720        ELSE        ! CALCULATE THE LOAD
10730
10740         IF  MASS_LEFT(N) > DEMAND_TYPE(T) THEN
10750
10760           IF DEMAND_TYPE(T) > PAYLOAD THEN          ! DEMAND
10770
10780             LET LOADOUT = PAYLOAD
10790              ELSE
10800                LET LOADOUT = DEMAND_TYPE(T)
10810              END IF
10820
10830          ELSEIF MASS_LEFT(N) > PAYLOAD THEN
10840            LET LOADOUT = PAYLOAD
10850
10860          ELSE
10870              LET LOADOUT = MASS_LEFT(N)              ! MASS_AVAILABLE
10880              LET EXPLOIT_N = 1
10890
10900   END IF
10910
10920
10930        ! AND THE SUBSEQUENT CALCULATIONS AND SETTINGS
10940            LET VALUE = LOADOUT * MARKET_PRICE(N)  ! PRICE
10950            LET COST  = DISTANCE(N) * TRAVLRATE
10960
10970
10980            LET VALUE_COST = VALUE/COST
10990
11000             IF VALUE_COST >= (THRESHOLD_WORTH * COST) THEN
11010
11020               LET SORT_MATRIX(N,1) = N
11030               LET SORT_MATRIX(N,2) = LOADOUT
11040               LET SORT_MATRIX(N,3) = COST
11050               LET SORT_MATRIX(N,4) = VALUE_COST
11060               LET SORT_MATRIX(N,5) = EXPLOIT_N
11070
11080             ELSE
11090               LET VIABLY_DONE = 1
11100
11110             END IF
11120
```

```
11130        END IF                              !JUMPS HERE FOR NO FLOWERING
11140
11150        END IF                              !  JUMPS HERE IF POPULATION
11160                                                ! VIABLY UTILIZED
11170
11180        END IF                              ! JUMPS HERE FOR WRONG TYPE
11190
11200
11210
11220       LET COUNTDONE = COUNTDONE + VIABLY_DONE
11230
11240      NEXT N
11250
11260      SET ZONEWIDTH 4
11270
11280   IF DIAGNOSE = 1 THEN
11290               PRINT " ------------------SORT_MATRIX BEFORE SORT"
11300                     FOR LOOKYLOOK = 1 TO 5
11310                      FOR N = 1 TO SPTOTAL-1
11320                       PRINT SORT_MATRIX(N,LOOKYLOOK),
11330                       NEXT N
11340                       PRINT SORT_MATRIX(SPTOTAL,LOOKYLOOK)
11350                      NEXT LOOKYLOOK
11360    END IF
11370
11380
11390   !$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
11400 CALL SORTIT(SORT_MATRIX,SPTOTAL,5,4,0)
11410   !$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
11420
11430       IF DIAGNOSE = 1 THEN
11440                 PRINT " ------------------SORT_MATRIX AFTER SORT"
11450                    FOR LOOKYLOOK = 1 TO 5
11460                     FOR N = 1 TO SPTOTAL-1
11470                      PRINT SORT_MATRIX(N,LOOKYLOOK),
11480                      NEXT N
11490                      PRINT SORT_MATRIX(SPTOTAL,LOOKYLOOK)
11500                     NEXT LOOKYLOOK
11510         END IF
11520
11530
11540 !NOW WORK OUT THE ATTRIBUTES OF THE MOST PROFITABLE LOAD (ASSUMING ONLY
11550   ! ONE POPULATION VISITED - COMBINED OUTINGS CONSIDERED TOO COMPLEX AT
11560   ! THIS STAGE AND LEFT AS BASELLA TO THE OPERATOR)
11570
11580
11590   LET CHOSEN_POPULATION = SORT_MATRIX(1,1)
11600
11610  IF CHOSEN_POPULATION = 0 THEN
11620
11630    IF DIAGNOSE = 1 THEN
11640      PRINT "NOTHING THIS WEEK THANK YOU VERY MUCH"
11650    END IF
11660
11670  ELSE
11680    ! ADJUST MASS AVAILABLE :
11690       LET MASS_LEFT(CHOSEN_POPULATION) = MASS_LEFT(CHOSEN_POPULATION) - SORT_MATRIX(1,2)
11700
11710    ! ADJUST THE TOTAL MASS RETRIEVED THIS WEEK AND OF THIS TYPE:
11720       LET MASS_RETREIVED(CHOSEN_POPULATION) = MASS_RETREIVED(CHOSEN_POPULATION) +
SORT_MATRIX(1,2)
11730
11740    ! ADJUST THE TOTAL COST OF RETRIEVAL FOR THIS WEEK
11750       LET FETCH_COST(CHOSEN_POPULATION)  = FETCH_COST(CHOSEN_POPULATION) + SORT_MATRIX(1,3)
11760
11770    ! THE VALUE OF THIS WEEK'S HAUL = LOAD * PRICE
11780       LET VALUE_RETRIEVED(CHOSEN_POPULATION) = VALUE_RETRIEVED(CHOSEN_POPULATION) +
(SORT_MATRIX(1,2) * MARKET_PRICE(CHOSEN_POPULATION))
11790
11800       LET ANNUAL_VALUE(CHOSEN_POPULATION) = ANNUAL_VALUE(CHOSEN_POPULATION) +
(SORT_MATRIX(1,2)*MARKET_PRICE(CHOSEN_PUPULATION))
11810
11820     ! looking LET ANNUAL_VALUE(CHOSEN_POPULATION) =  ANNUAL_VALUE(CHOSEN_POPULATION) +
(SORT_MATRIX(1,2)*MARKET_PRICE(CHOSEN_POPULATION))
11830
11840
11850     ! REGISTERING THIS SPECIES' EXPLOITATION FOR THIS WEEK
11860       LET EXPLOITED_FULLY(CHOSEN_POPULATION) = SORT_MATRIX(1,5)
11870
11880
11890   LET EXPLOIT_WEEK_NOM(CHOSEN_POPULATION)  = EXPLOIT_WEEK_NOM(CHOSEN_POPULATION) +
SORT_MATRIX(1,2)
11900
11910
11920    ! UPDATE THE SUMMARY OF THE WEEK'S WORK FOR THIS TYPE:
11930    !     TYPES KEPT SEPARATE TO AID ANALYSIS  LATER
11940
11950      LET WEEKVALUE(WEEK,T) =  WEEKVALUE(WEEK,T) +  VALUE_RETRIEVED(CHOSEN_POPULATION)
11960      LET TRAVLCOST(WEEK,T) =  TRAVLCOST(WEEK,T) +  FETCH_COST(CHOSEN_POPULATION)
11980
11990   END IF
12000
12010 !COUNTING WHAT PROPORTION OF THE SET OF POPULATIONS OF THIS TYPE
12020   ! HAVE BEEN VIABLY DONE
12030
12040      LET VIABILITY_INDEX = COUNTDONE / COUNTYPE(T)
12050
12060    ! TOWARDS SATISFACTION OF MARKET DEMAND:
12070       LET DEMAND_TYPE(T) = DEMAND_TYPE(T) - SORT_MATRIX(1,2)
12080
12090
12100  !  CALL HOLDIT
12110
12120 LOOP     !-----------------------------------------------LOOP
12130
12140
12150 !$$$$  IF TRACE_COSTIT_LOOP = 1 THEN  PRINT "FINISHED WITH TYPE  ";T
12160
12170     LET VIABILITY_INDEX = 0
12180
12190
12200      LET WEEKVALUE_ALL = WEEKVALUE_ALL + WEEKVALUE(WEEK,T)
12210      LET COSTVALUE_ALL = COSTVALUE_ALL + TRAVLCOST(WEEK,T)
12220
12230    NEXT T
12240
12250       ! ---------------------------------------------------$$$
12260 !COMPUTE THE LEVEL OF EXPLOITATION OF EACH POPULATION THIS WEEK
12270   ! WEEK, AND TO KEEP THINGS TOGETHER, STORE IN V_C_MATRIX(*,9)
12280   ! THIS FIGURE IS THE % OFFTAKE FROM THE RESOURCE MATERIAL -
12290   ! ALSO SET UP BACKGROUND FOR EXPLOIT_YEAR(*) FOR FILE OUTPUT WHICH
12300   ! IS THE ANNUAL EXPLOITATION
12310
12320   FOR N = 1 TO SPTOTAL
12330    IF TOTAL_POTL_MASS(N) > 0 THEN
12340    LET EXPLOIT_WEEK(N) = (100*(EXPLOIT_WEEK_NOM(N) / TOTAL_POTL_MASS(N)))
12350    ELSE
12360     LET EXPLOIT_WEEK(N) = 0
12370    END IF
12380
12390   LET EXPLOIT_YEAR_NOM(N) = EXPLOIT_YEAR_NOM(N)  +  EXPLOIT_WEEK_NOM(N)
12400   LET EXPLOIT_YEAR_DENOM(N) = EXPLOIT_YEAR_DENOM(N) +  TOTAL_POTL_MASS(N)
12410
12420   NEXT N
12430
12440      LET YEARVALUE_ALL = YEARVALUE_ALL + WEEKVALUE_ALL
12450      LET YEARCOST_ALL = YEARCOST_ALL + COSTVALUE_ALL
12460      LET YEARPROFIT = YEARPROFIT + YEARVALUE_ALL - (OVERHEADFACTOR*YEARCOST_ALL)
12470
12480
12490     IF WEEK_HOLD = 1 THEN CALL HOLDIT
12500
12510 NEXT WEEK    ! ===========================================$$$
12520
12530
12540   LET  YEARPLUSONE = YEAR + 1
12550
12560  FOR N = 1 TO SPTOTAL-1
12570    IF EXPLOIT_YEAR_DENOM(N) > 0 THEN
12580     LET EXPLOIT_YEAR(N) =  100*(EXPLOIT_YEAR_NOM(N)/EXPLOIT_YEAR_DENOM(N))
12590    ELSE
12600      LET EXPLOIT_YEAR(N) = 0
12610   END IF
12620
12630   LET SEEDSTORE(YEAR+1,N) = ((100 - EXPLOIT_YEAR(N))/100) * POP_SIZE(N) * PLANT_YIELD(N)
12640   LET SEEDSTORED(N) = SEEDSTORE(YEAR+1,N) !FOR THE MEANTIME
12650
12660   NEXT N
12670
12680    IF EXPLOIT_YEAR_DENOM(SPTOTAL) > 0 THEN
12690     LET EXPLOIT_YEAR(SPTOTAL) =  100*(EXPLOIT_YEAR_NOM(SPTOTAL)/EXPLOIT_YEAR_DENOM(SPTOTA
12700    ELSE
12710      LET EXPLOIT_YEAR(SPTOTAL) = 0
12720      END IF
12730
12740
12750      LET SEEDSTORE(YEAR+1,SPTOTAL) = ((100 - EXPLOIT_YEAR(SPTOTAL))/100) * POP_SIZE(SPTOT/
PLANT_YIELD(SPTOTAL)
12760      LET SEEDSTORED (SPTOTAL) = SEEDSTORE(YEAR+1,SPTOTAL)
12770
12780      LET PROFIT(YEAR+1) = YEARPROFIT
```

```
12790
12800      END SUB              !COSTIT
12810
12820
12830   ! ==========================================================================
12840
12850 !SUB YEAR_REPORT
12860
12870
12880  SUB YEAR_REPORT
12890
12900      SET #15: ZONEWIDTH 6
12910       IF YEAR = 0 THEN
12920          PRINT #15
12930          LET PROFIT_START = (YEARVALUE_ALL - YEARCOST_ALL)
12940
12950         PRINT #15: "FILE #15   -   PLANT_YIELD"
12960         PRINT #16: "FILE #16   -   AGE_YIELD"
12970
12980
12990              PRINT #17: "FILE #17  -  SEEDSTORED"
13000              PRINT #18: "FILE #18  -  EXPLOIT_YEAR"
13010
13020
13030              PRINT #19: "FILE #19  -  POP_SIZE"
13040              PRINT #20: "FILE #20  -  ANNUAL_VALUE"
13050
13060          PRINT #15: "                                                  "
13070          PRINT #15: "                                                  "
13080          PRINT #16: ""
13090          PRINT #16: ""
13100          PRINT #17: "                                                  "
13110          PRINT #17: "                                                  "
13120          PRINT #18: ""
13130          PRINT #18: ""
13140          PRINT #19: "                                                  "
13150          PRINT #19: "                                                  "
13160          PRINT #20: ""
13170          PRINT #20: ""
13180
13190      END IF
13200
13210      PRINT #15, USING "###":YEAR;
13220      PRINT #16, USING "###":YEAR;
13230
13240           PRINT #17, USING "###":YEAR;
13250           PRINT #18, USING "###":YEAR;
13260
13270           PRINT #19, USING "###":YEAR;
13280           PRINT #20, USING "###":YEAR;
13290
13300
13310       FOR N = 1 TO SPTOTAL
13320              PRINT #15, USING IMAGE20: PLANT_YIELD(N);
13330              PRINT #16, USING IMAGE20: AGE_YIELD(N);
13340
13350
13360                         PRINT #17, USING IMAGE20: SEEDSTORED(N);
13370                         PRINT #18, USING IMAGE20: EXPLOIT_YEAR(N);
13380
13390                         PRINT #19, USING IMAGE20: POP_SIZE(N);
13400                         PRINT #20, USING IMAGE20: ANNUAL_VALUE(N);
13410         NEXT N   !&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
13420
13430
13440     PRINT #15
13450     PRINT #16
13460     PRINT #17
13470     PRINT #18
13480     PRINT #19
13490     PRINT #20
13500
13510   IF PROFIT_START = 0 THEN
13520     LET REL_PROFIT = 999
13530     ELSE
13540     LET REL_PROFIT = 100 * (YEARVALUE_ALL - YEARCOST_ALL)/PROFIT_START
13550
13560   END IF
13570  END SUB      ! YEAR_REPORT
13580
13590 !##########################################################################
13600 !SUB LIFE_REPORT      ....WHICH TAGS A BIT ONTO "LIFESUMM.PRN"
13610
13620     SUB LIFE_REPORT
13630
13640    PRINT #15: ""
13650    PRINT #15: ""
13660    PRINT #15: ""
13670    PRINT #15: ""
13680    PRINT #15: "A SUMMARY OF THE SEEDSTORES THROUGH THE YEARS"
13690    PRINT #15: ""
13700        WINDOW #34
13710
13720               PRINT #15, USING "#####": "YEAR";
13730           FOR N = 1 TO SPTOTAL-1
13740                PRINT #15, USING IMAGE10: SPNUMBER(N);
13750           NEXT N
13760               PRINT #15, USING IMAGE10: SPNUMBER(SPTOTAL)
13770         PRINT #15: ""
13780
13790        LET TIMEORIGIN = 0
13800               PRINT #15, USING "#####": TIMEORIGIN;
13810           FOR N = 1 TO SPTOTAL-1
13820                PRINT #15, USING IMAGE20: SEEDSTORE_START(N);
13830           NEXT N
13840               PRINT #15, USING IMAGE20: SEEDSTORE_START(SPTOTAL)
13850
13860
13870         FOR ANNUALCOUNT = 1 TO LIFETIME
13880               PRINT #15, USING "#####": ANNUALCOUNT;
13890
13900           FOR N = 1 TO SPTOTAL
13910                PRINT #15, USING IMAGE20: SEEDSTORE(ANNUALCOUNT,N);
13920
13930           NEXT N
13940
13950               PRINT #15, USING IMAGE20: PLANT_YIELD(N),POP_SIZE(N)
13960
13970          NEXT ANNUALCOUNT
13980
13990      END SUB
14000  ! ##########################################################################
14010 !SUB YEAR_PRINT
14020
14030  SUB YEAR_PRINT       ! PRINT ANNUAL SUMMARY TO SCREEN
14040   WINDOW #34
14050    CLEAR
14060     PRINT "YEAR ";YEAR,"TOTAL GROSS PROFIT = R";YEARVALUE_ALL
14070      IF YEAR < 1 THEN
14080         PRINT "AT THE START OF THE EXERCISE, THE SITUATION WAS AS FOLLOWS:"
14090        ELSE
14100          PRINT "AFTER ";YEAR;" YEAR(S) THE FOLLOWING WAS THE SITUATION:"
14110       END IF
14120
14130    PRINT USING ">###";".",".",".",".",".";
14140    PRINT USING ">########";"A","B",".","C","D","E"
14150    PRINT USING ">###";"REF",".";        !4 + 4
14160   PRINT USING ">###########";"SPNAME";  !12
14170   PRINT USING ">#######": "POP","YIELD","EXPLT","LEGAL","HARVST","MKTVAL","GROSS"
14180   PRINT USING ">###";".",".",".",".",".";  !20
14190   PRINT USING ">#######": "(plts)","(kg/pl)","(%tot)","LVL%","LVL%","(R/kg)","PROFIT"
14200
14210   FOR N=1 TO SPTOTAL
14220      PRINT USING "####": N,".";
14230      PRINT USING ">###########": SPNAME$(N)[1:11];
14240      PRINT USING "########": POP_SIZE(N);
14250      PRINT USING "#####.##": PLANT_YIELD(N);
14260      PRINT USING "########": EXPLOIT_YEAR(N),PICK_LIMIT(N),HARVEST_LEVEL(N);
14270      PRINT USING "#####.##": MARKET_PRICE(N),ANNUAL_VALUE(N)
14280
14290     NEXT N
14300
14310
14320      PRINT "TO CHANGE THE STOP/DONT_STOP TOGGLE PRESS 'C' TWICE"
14330      PRINT "SIMILARLY, TO STOP THE PROGRAM PRESS 'S' TWICE"
14340
14350
14360  END SUB     !YEAR_PRINT
14370  !##############################################################
14380 !SUB CHANGE_PARAMS
14390
14400  SUB CHANGE_PARAMS   ! OPPORTUNITY TO ALTER THE STATE OF AFFAIRS
14410             PRINT
14420                PRINT "WHICH OF THEM? (ONE AT A TIME PLEASE)"
14430                INPUT PROMPT "ENTER COLUMN (A - F):  ":COLCHANGE$
14440                INPUT PROMPT  "ENTER REF #:  ":ROWCHANGE
14450                INPUT PROMPT "WHAT'S THE NEW VALUE?  ":NEWVALUE
14460
14470
14480          IF ORD(COLCHANGE$) = 65   OR ORD(COLCHANGE$) = 97   THEN   ! A
14490               LET POP_SIZE(ROWCHANGE) = NEWVALUE
```

```
14500
14510          ELSEIF ORD(COLCHANGE$) = 66   OR ORD(COLCHANGE$) = 98   THEN
14520            LET PLANT_YIELD(ROWCHANGE) = NEWVALUE
14530
14540          ELSEIF ORD(COLCHANGE$) = 67   OR ORD(COLCHANGE$) = 99   THEN
14550            LET PICK_LIMIT(ROWCHANGE) = NEWVALUE
14560
14570          ELSEIF ORD(COLCHANGE$) = 68   OR ORD(COLCHANGE$) = 100  THEN
14580            LET HARVEST_LEVEL(ROWCHANGE) = NEWVALUE
14590
14600          ELSEIF ORD(COLCHANGE$) = 69   OR ORD(COLCHANGE$) = 101  THEN
14610            LET MARKET_PRICE(ROWCHANGE) = NEWVALUE
14620
14630             ELSE
14640          PRINT "INCORRECT COLUMN ENTRY - TRY AGAIN"
14650        END IF
14660
14670       END SUB   !CHANGEPARAMS
14680 !################################################################
14690
14700     END       !OF INTERNAL SUBROUTINES
14710
14720  ! ==================================================================
14730
14740  ! ==================================================================
14750 !EXTERNAL SUBROUTINES
14760 !SUB SORTIT (SORTMAT(,), ROWS,COLS,KEY,UPDOWN)
14770   SUB SORTIT (SORTMAT(,), ROWS,COLS,KEY,UPDOWN)   ! SORTING A  MATRIX WITH UP
14780                                                   ! TO 20 COLUMNS
14790
14800    DIM TEMP(500)
14810
14820      ! SORTING THE POPULATIONS INTO DESCENDING ORDER WITH RESPECT TO
14830      ! THEIR DISTNACE FROM HOME BASE
14840      !  PLUS OTHER  APPLICATIONS.
14850
14860      !  - A BUBBLE SORT
14870
14880     IF UPDOWN = 0  THEN                           !DESCENDING ORDER
14890
14900       LET SWOP = 1
14910
14920    DO WHILE SWOP =1
14930
14940         LET SWOP=0
14950
14960              FOR I = 1 TO ROWS
14970
14980
14990           IF SORTMAT(I,KEY) < SORTMAT(I+1,KEY) THEN
15000
15010
15020                 FOR J = 1 TO COLS
15030                   LET TEMP(J) = SORTMAT(I,J)  !
15040      NEXT J
15050
15060
15070                 FOR J = 1 TO COLS
15080                   LET SORTMAT(I,J) = SORTMAT(I+1,J) !
15090      NEXT J
15100
15110                 FOR J = 1 TO COLS
15120                   LET SORTMAT(I+1,J) = TEMP(J) !
15130      NEXT J
15140
15150               LET SWOP = 1
15160
15170       END IF
15180
15190       NEXT I
15200
15210     LOOP
15220
15230     ELSE                                      !    ASCENDING ORDER
15240
15250       LET SWOP = 1
15260
15270     DO WHILE SWOP =1
15280
15290          LET SWOP=0
15300
15310               FOR I = 1 TO ROWS
15320
15330            IF SORTMAT(I,KEY) < SORTMAT(I+1,KEY) THEN
15340
15350                 FOR J = 1 TO COLS
15360                   LET TEMP(J) = SORTMAT(I,J)  !
15370     NEXT J
15380
15390                 FOR J = 1 TO COLS
15400                   LET SORTMAT(I,J) = SORTMAT(I+1,J) !
15410     NEXT J
15420
15430                 FOR J = 1 TO COLS
15440                   LET SORTMAT(I+1,J) = TEMP(J) !
15450     NEXT J
15460
15470               LET SWOP = 1
15480
15490       END IF
15500
15510       NEXT I
15520
15530     LOOP
15540
15550    END IF
15560
15570    END SUB      ! SORTIT
15580  ! ################################################################
15590
15600 !SUB READ_DEMAND(MARKET(,),YEAR)
15610
15620  SUB READ_DEMAND(MARKET(,),YEAR)
15630
15640  IF YEAR < 1 THEN
15650     LET MARKET_FILE$ = "MARKET1.PRN"  ! TO GET THE BALL ROLLING
15660  ELSE
15670    PRINT "WHERE DO WE FIND THE NEW"
15680    INPUT PROMPT "MARKET DEMAND DATA? (FILENAME) ": MARKET_FILE$
15690  END IF
15700
15710   OPEN #4: NAME MARKET_FILE$, ACCESS INPUT
15720
15730            ! CAN WE HAVE THE FILENAME AS A VARIABLE DEPENDING ON YEAR?
15740
15750                     ! GETTING INFORMATION REGARDING THE DEMANDS
15760                     ! FOR THE VARIOUS TYPES OF MATERIAL FROM THE
15770                     ! MARKET DEMAND FILE "MARKETy.PRN" FOR YEAR y
15780
15790
15800     LINE INPUT #4: HEAD$
15810       FOR N = 1 TO 52
15820         LINE INPUT #4: NS$
15830           LET MARKET (N,4) = VAL(NS$[1:12])     ! WEEK NUMBER
15840                ! - SOMETHING UP WITH MARGIN IN TFERRING FROM LOTUS +3 COLS
15850           LET MARKET (N,1) = VAL (NS$[13:21])  ! DEMAND FOR TYPE 1
15860           LET MARKET (N,2) = VAL(NS$[22:30])   ! DEMAND FOR TYPE 2
15870           LET MARKET (N,3) = VAL(NS$[31:39])   ! DEMAND FOR TYPE 3
15880       NEXT N
15890
15900       IF YEAR < 1 THEN
15910       INPUT #4: NS$
15920        ELSE
15930        LET MARKET (53,1) =  VAL(NS$[1:9])  ! 1 = YES, 0 = NO:
15940       END IF                  ! TO "IS IT A CHANGING MARKET?
15950                                           ! FROM YEAR TO YEAR ?
15960
15970     END SUB
15980
15990  ! ################################################################
16000
16010 !SUB ADJUST_IMPACT
16020  SUB ADJUST_IMPACT(POP(),YIELD(),FACTOR_RESPOND(,),RESPOND_ACTUAL(),LIMIT(),EXPLOITED(),TOTAL)
16030   DIM START(20,5)
16040   DIM STOP(20,5)
16050
16060
16070   IF DIAGNOSIS > 0 THEN
16080
16090     FOR N = 1 TO TOTAL
16100      PRINT N,
16110      FOR NN = 1 TO 3
16120       PRINT FACTOR_RESPOND(N,NN),
16130       NEXT NN
16140       PRINT FACTOR_RESPOND(N,4)
16150      NEXT N
16160
16170   CALL HOLDIT
16180
16190     FOR N = 1 TO TOTAL
16200      LET START(N,1) = POP(N)
```

```
16210       LET START(N,2) = RESPOND_ACTUAL(N)
16220       LET START(N,3) = LIMIT(N)
16230       LET START(N,4) = EXPLOITED(N)
16240       LET START(N,5) = YIELD(N)
16250      NEXT N
16260       END IF
16270
16280
16290 ! ASSUME THAT EXPLOITATION CAN ACT IN ONE OF TWO WAYS:
16300 !      1. BY KILLING PLANTS AND REDUCING POPULATION
16310 !      2. BY RREDUCING YIELD OF INDIVIDUAL PLANTS
16320
16330 !   ADJUST BY ASSUMING THAT ANYTHING OVER RECOMMENDED YIELD
16340 !   WILL REDUCE THE POPULATION BY A FACTOR PROPORTIONAL TO
16350 !   THAT EXCESS
16360 !
16370       FOR N = 1 TO TOTAL
16380       IF EXPLOITED(N) > LIMIT(N) THEN
16390         LET EXCESS = EXPLOITED(N) - LIMIT(N)    ! THESE ARE %'s IN MAIN
16400         LET POP(N) = POP(N) * (1 - (EXCESS/(100-LIMIT(N))))
16410       END IF
16420
16430      NEXT N
16440
16450      FOR N = 1 TO TOTAL
16460
16470        IF EXPLOITED(N) = 0 THEN
16480         LET RESPOND_ACTUAL(N) = 100
16490
16500         ELSEIF EXPLOITED(N) < 25 THEN
16510               LET RESPOND_ACTUAL(N) = FACTOR_RESPOND(N,1)
16520
16530          ELSEIF EXPLOITED(N) < 50 THEN
16540           LET RESPOND_ACTUAL(N) = FACTOR_RESPOND(N,2)
16550
16560
16570         ELSEIF EXPLOITED(N) < 75 THEN
16580           LET RESPOND_ACTUAL(N) = FACTOR_RESPOND(N,3)
16590
16600           ELSEIF EXPLOITED(N) > 75 THEN
16610             LET RESPOND_ACTUAL(N) = FACTOR_RESPOND(N,4)
16620
16630            ELSE
16640             PRINT "SOMETHING WRONG IN EXTERNAL SUBROUTINE 'ADJUST'"
16650
16660          END IF
16670
16680             NEXT N
16690
16700
16710    IF DIAGNOSIS > 0 THEN
16720
16730     FOR N = 1 TO TOTAL
16740       LET STOP(N,1) = POP(N)
16750       LET STOP(N,2) = RESPOND_ACTUAL(N)
16760       LET STOP(N,3) = LIMIT(N)
16770       LET STOP(N,4) = EXPLOITED(N)
16780        LET STOP(N,5) = YIELD(N)
16790       NEXT N
16800
16810    CLEAR
16820
16830    FOR N = 1 TO TOTAL
16840
16850    PRINT "","SPECIES","POPULATN","RESPONSE","LIMIT","%EXPLOIT","YIELD"
16860
16870      PRINT
16880       PRINT "BEFORE:",N,
16890         FOR PARAM = 1 TO 5
16900         PRINT START(N,PARAM),
16910         NEXT PARAM
16920        PRINT
16930       PRINT "AFTER:",N,
16940         FOR PARAM = 1 TO 5
16950         PRINT STOP(N,PARAM),
16960         NEXT PARAM
16970        PRINT
16980
16990      CALL HOLDIT
17000
17010       NEXT N
17020
17030      CALL HOLDIT
17040
17050  END IF
17060
17070  END SUB
17080
17090  ! ##################################################################
17100 !SUB HOLDIT
17110
17120   SUB HOLDIT      ! A UTILITY SUBROUTINE TO PAUSE EXECUTION
17130    PRINT
17140    PRINT "################ PRESS ANY KEY TO CONTINUE"
17150     CALL SOUNDIT4
17160         DO
17170      GET KEY WAITT
17180           IF WAITT <= 127 THEN EXIT DO
17190          LOOP
17200         END SUB
17210
17220  ! ##################################################################
17230 ! SUB HOLDIT2
17240
17250   SUB HOLDIT2      ! A UTILITY SUBROUTINE TO PAUSE EXECUTION
17260                    !  NO PRINT
17270         DO
17280           GET KEY WAITT
17290           IF WAITT <= 127 THEN EXIT DO
17300          LOOP
17310         END SUB
17320
17330  ! ##################################################################
17340 !SUB FREEZIT_OPTION
17350
17360   SUB FREEZIT_OPTION     ! A UTILITY SUBROUTINE TO FREEZE FROM KEYBOARD
17370                          ! FREEZES OPERATION WITH 'f' OR 'F'
17380    IF KEY INPUT THEN
17390       GET KEY FREEZE
17400
17410         IF FREEZE = 70 THEN
17420           CALL HOLDIT2
17430          END IF
17440
17450         IF FREEZE = 102 THEN
17460           CALL HOLDIT2
17470          END IF
17480
17490         END IF
17500
17510         END SUB
17520
17530  !##################################################################
17540 !SUB READTEXT_STORY
17550
17560 SUB READTEXT_STORY(STORY$(),YEAR,LIFETIME,STORYLINES,LINES_IN)
17570
17580                   ! TO PICKUP A TEXT FILE AND WRITE IT TO THE SCREEN
17590                   ! IN BLOCKS OF 'NUMBER_LINES' LINES
17600
17610           LET TEXTFILE$ = "SIDELINE."
17620           LET NUMBER_LINES = 4    !THESIZE OF THE WINDOW WHERE IT GOES
17630
17640       CLEAR
17650
17660      IF YEAR = 0 THEN
17670
17680      OPEN #52: NAME TEXTFILE$, ACCESS INPUT
17690
17700
17710         LET LINES_IN = 1
17720          DO WHILE MORE #52
17730           LINE INPUT #52: TEXT$
17740           LET STORY$(LINES_IN) = TEXT$
17750           LET LINES_IN = LINES_IN + 1
17760         LOOP
17770
17780     END IF
17790    IF STORYLINES < LINES_IN THEN
17800     LET LINES_NOW = 1
17810
17820            DO WHILE  LINES_NOW <= 4
17830             PRINT STORY$(STORYLINES)
17840             LET LINES_NOW = LINES_NOW + 1
17850             IF STORYLINES = LINES_IN THEN EXIT DO
17860             LET STORYLINES = STORYLINES + 1
17870           LOOP    ! NEXT LINE
17880     END IF        ! WHILE MORE IN THE FILE
17890
17900          IF YEAR = LIFETIME   THEN
17910            PRINT " .......sorry out of time, remainder available in ";TEXTFILE$
```

```
17920           CALL HOLDIT
17930          ELSE
17940            IF STORYLINES = LINES_IN THEN PRINT  ".....and that's the end of organized
entertainment"
17950          END IF
17960
17970
17980        END SUB     ! READTEXT_INTERNAL
17990  !****************************************************************
18000 !SUB READTEXT_EXTERNAL
18010 SUB READTEXT_EXTERNAL (TEXTFILE$,NUMBER_LINES)
18020
18030                    ! TO PICKUP A TEXT FILE AND WRITE IT TO THE SCREEN
18040                    ! FOR INFO PANELS MAINLY
18050
18060      OPEN #51: NAME TEXTFILE$, ACCESS INPUT
18070       CLEAR
18080         DO WHILE MORE #51
18090           LET LINE = 1
18100
18110           DO WHILE  LINE <= NUMBER_LINES
18120
18130           LINE INPUT #51: TEXT_INPUT$
18140            LET NEW_PAGE1 =   ORD(TEXT_INPUT$[1:1])
18150            LET NEW_PAGE2 =   ORD(TEXT_INPUT$[16:16])
18160
18170              IF NEW_PAGE1 = 45 AND NEW_PAGE2 = 45 THEN EXIT DO
18180              IF NEW_PAGE1 = 95 AND NEW_PAGE2 = 95 THEN EXIT DO
18190
18200               PRINT TEXT_INPUT$
18210            IF NOT(MORE #51) THEN EXIT DO
18220            LET LINE = LINE + 1
18230
18240            LOOP    ! MAXIMUM LINES
18250
18260        IF NOT(MORE #51) THEN EXIT DO
18270
18280
18290                    CALL HOLDIT
18300           CLEAR
18310
18320        LOOP      !TILL FILE FINISHED
18330
18340         CLOSE #51
18350
18360        CALL HOLDIT
18370        END SUB     ! READTEXT
18380  !****************************************************************
18390 !SUB SOUNDIT
18400
18410
18420    SUB SOUNDIT        ! TO DRAW ATTENTION TO THE FACT THAT A RESPONSE
18430                        ! IS REQUIRED FROM THE USER
18440       LET SOUND$ = "T5000 ML O3 C1 C+1 D1 D+1 E2"! D+1 D2 D+1 E1 F1 F+1 G1 G+1 A1  A+1 D2 A+1
A2 A+1 B1 C3"
18450       PLAY SOUND$
18460      END  SUB      !SOUNDIT
```

```
18470  !****************************************************************
18480 !SUB SOUNDIT2
18490
18500
18510    SUB SOUNDIT4       !JUST MUSIC
18520
18530
18540      LET SOUND1$ = "T1000 ML O3 R12 A4" & "B-2 A4 G1 F1 G5 R1 A2"
18550      LET SOUND2$ = ">C2 <B-4 A1 G1 B-5 R1 >C2" & "F2 E4 D1 C1 D8"
18560      LET SOUND3$ = "R12 E4" & "G2 F4 E1 D1 E4 F4" & "C3 R1 C4 <F4 G4"
18570      LET SOUND4$ = "A8 >C1 <B1 B1 A4 R1" & "G4 G+1 A1 A+1 B1 >C4 R2 <A2"
18580      LET SOUND1A$ = "B-2 A4 G1 F1 G5 R1 A2"
18590      LET SOUND2A$ = ">C2 <B-4 A1 G1 B-5 R1 >C2" & "F2 E4 D1 C1 D8"
18600      LET SOUND5$ = "G2 F4 E1 D1 E4 F4" & "C3 R1 C4 <F4 G4"
18610      LET SOUND6$ = "F16" & "F5 R1 C2 E-2 G2 F+3 R1"
18620
18630
18640
18650       LET ITAGAINSAM$ =  SOUND1$  ! & SOUND2$ & SOUND3$ & SOUND4$
18660       LET ITAGAINSAM2$ =  SOUND1A$ & SOUND2A$ & SOUND5$ & SOUND6$
18670
18680       PLAY  ITAGAINSAM$
18690     !  PLAY  ITAGAINSAM2$
18700
18710
18720
18730     END  SUB      !SOUNDIT2
18740
18750  !****************************************************************
18760
18770 SUB SOUNDIT3       !JUST MUSIC
18780
18790
18800      LET SOUND1$ = "T200 MN MD O3 D8 A8 G4 > G4 E8 D8 E8 G8 < D4 D8 A8 D4 D8 A8"
18810      LET SOUND2$ = "G4 > G4 E8 D8 E8 G8 < A4 A8 G8 A8 > C8 < D8 A8 G4 > G4 E8 D8 E8 G
18820      LET SOUND3$ = "< D4 D8 A8 D4 > D4 E4 R8 D8 E4 E8 F+8 G8 E8 D8 < D8 A4 A8 D8" ! C
PATTERN
18830      LET SOUND4$ = "G8 A8 D8 > C8 D8 < G8 D8 G8 D4 D8 A8 D4 D8 A8 G8 A8 D8 > C8 D8 <
18840      LET SOUND5$ = "A4 A8 G8 A8 > C8 < D8 A8 G8 A8 D8 > C8 D8 < G8 D8 G8 "
18850      LET SOUND6$ = "D4 D8 A8 D4 > D4 E4 R8 D8 E4 E8 F+8 G8 E8 D8 < D8 A4 R6 G8 8"
18860
18870
18880       LET REEL$ =  SOUND1$ & SOUND2$ & SOUND3$ & SOUND4$ & SOUND5$ & SOUND6$
18890
18900       PLAY  REEL$
18910
18920     END  SUB      !SOUNDIT3
18930
18940  !****************************************************************
18950 SUB SOUNDIT14       !CHROMATIC SCALE
18960
18970
18980      LET SOUND1$ = "T9000 MN MD O1"
18990      LET SOUND2$ = "C C+ D D+ E F F+ G G+ A A+ B >"
19000      LET SOUND3$ = "C C+ D D+ E F F+ G G+ A A+ B >"
19010      LET SOUND4$ = "C C+ D D+ E F F+ G G+ A A+ B >"
19020      LET SOUND5$ = "C C+ D D+ E F F+ G G+ A A+ B >"
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19030      LET SOUND6$ = "C C+ D D+ E F F+ G G+ A A+ B >"
19040      LET SOUND7$ = "C B B- A A- G G- F E E- D D- <"
19050      LET SOUND8$ = "C B B- A A- G G- F E E- D D- <"
19060      LET SOUND9$ = "C B B- A A- G G- F E E- D D- <"
19070      LET SOUND10$ = "C B B- A A- G G- F E E- D D- <"
19080      LET SOUND11$ = "C B B- A A- G G- F E E- D D- <"
19090
19100
19110       LET SCALE$ =  SOUND1$ & SOUND2$ !& SOUND3$ & SOUND4$ & SOUND5$ & SOUND6$ & SOUND
SOUND8$ & SOUND9$ & SOUND10$ & SOUND11$
19120
19130       PLAY  SCALE$
19140
19150     END  SUB      !SOUNDIT4
19160
19170 !****************************************************************
```

APPENDIX II

Reprint of a short communication published in Bothalia 17(1), 1987 (Davis 1987) which describes the prominent environmental feature of wind at the Highlands study site. Reference is made to this Appendix in Chapters 3 and 4.

PERFORMANCE OF A LABORATORY-CONSTRUCTED ANEMOMETER UNDER SUMMER FIELD CONDITIONS ON A MOUNTAIN FYNBOS EXPERIMENTAL SITE

The consumer-oriented electronics industry has developed extremely rapidly over the past decade and has provided many beneficial side-effects for experimental scientists. A development of particular interest to environmental researchers is the advent of a new generation of relatively inexpensive solid-state data-loggers. This type of apparatus, which uses the same technology as that of the popular digital microprocessor industry, makes continuous monitoring of environmental parameters at remote sites feasible for even modestly funded studies. The analogue sensors needed to provide the logging device with input information, however, do not usually arise from similar high-volume production lines, and very often constitute the most costly part of any data monitoring system. This article intends to illustrate the idea that inexpensive, laboratory-constructed transducers can play an important role in optimizing the potential benefits of modern data-logging equipment.

During 1985, an experimental study plot was established in an area of natural mountain fynbos at an altitude of 375 m in the Highlands State Forest Reserve in the south-western Cape, on a site which had been cleared by burning in February of that year. Since the wind, especially the forceful summer 'south-easter', is a dominant feature of the regional climate, and one to which the vegetation is probably adapted in many respects (see Boucher 1972), it was decided to dedicate one channel of an on-site logger to measuring wind-speed at the site. The most economical and convenient means of achieving this was to construct a three-cup anemometer similar to that described by Unwin (1980), but using a small 3 VDC electric motor as a voltage generator in place of an electronic pulse counter. Investment in the instrument comprised less than R15,00 in component parts and approximately one working-day for assembly and calibration, whereas the cost of an imported commercial anemometer of similar design (Didcot DWR/201G) was cited as more than R2 000,00 at the time of writing.

The cup wheel was constructed from half table tennis balls, 2 mm brazing rod, microjet irrigation fittings, and epoxy resin (see Figure 4). Output from this generator was adjusted via a half-bridge resistance circuit to provide the logger with a signal in the correct range of 0 to 2 000 mVDC. Although it is reported (Woodward & Sheehy 1983) that anemometers using this principle of signal generation have a relatively high detection threshold (up to 2 m.s^{-1}), this shortcoming was not considered a hindrance to the measurement of maxima, and the approximation of mean windspeeds for the expected seasonal windy conditions. The length of the arm (47 mm) relative to the cup radius (17 mm) was close to the ratio of 2,5 recognized as a reasonable compromise between sensitivity and linear response (see Grace 1977). In the field, the device was mounted with the cups 1,5 m above the ground.

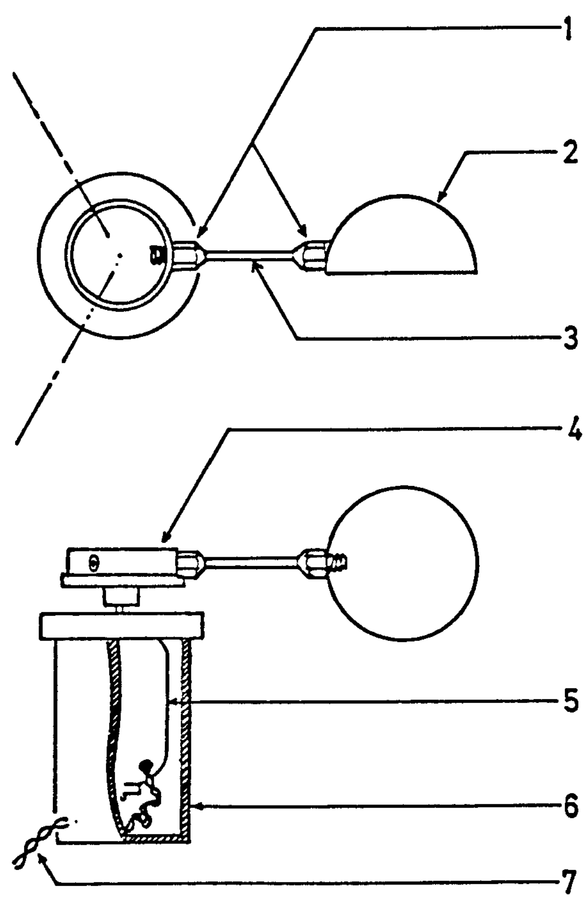

FIGURE 4.—Construction of the D.C. generator anemometer. Component parts were assembled as indicated in the above sketch, with slow-setting epoxy resin as a joining and sealing medium. The parts labelled are: 1, microjet irrigation couplers; 2, half table tennis ball; 3, brazing rod; 4, plastic vial lid; 5, electric motor; 6, plastic film cannister; and 7, electric leads to monitoring circuitry. Scale is provided by the table tennis ball which has a diameter of 34 mm.

The instrument was calibrated on a windless day by mounting it 0,5 m above the roof of a car, and driving at constant speeds between 20 and 80 km.h^{-1} (5,6 and 22,2 m.s^{-1}) while measuring the output on a digital voltmeter (Fluke, model 73). Accuracy (± 5 %) of the car's speedometer was checked within the calibration range by timing displacement over measured distances. Further comparisons were made *in situ* in the field with an adjacently mounted totalizing anemometer (S.I.A.P., model 1220) over 30-minute periods on a windy day (Figure 5). This latter set of measurements implied a reliable detection threshold of approximately 2 m.s^{-1}.

During the measurement period (November 15, 1985 to March 13, 1986), output from the anemometer was measured once per minute, and processed by inbuilt data-logger software to provide a mean windspeed value for every three-hour interval, as well as the maximum single value recorded during each day. Information is summarized in Figures 6 & 7 for the full period, a time of year when the south-east wind is common. From Figure 6 it can be seen that on only one day during the trial period did air movement remain below the reliable detection threshold for the full 24-hour period, while an overall maximum windspeed of 16,1 m.s^{-1} was recorded on November 18. The three-hour mean values have been combined for the whole measurement period, and plotted in Figure 7 to indicate the diurnal pattern of air movement. The site may not be subject to the full force of the south-easter, as it is approximately 75 to 125 m lower than a ridge two kilometres distant to the south and south-east. Records of windspeed at D. F. Malan Airport indicate that gusts of 28 m.s^{-1} may be experienced on the Cape Flats between November and March (Weather Bureau 1960).

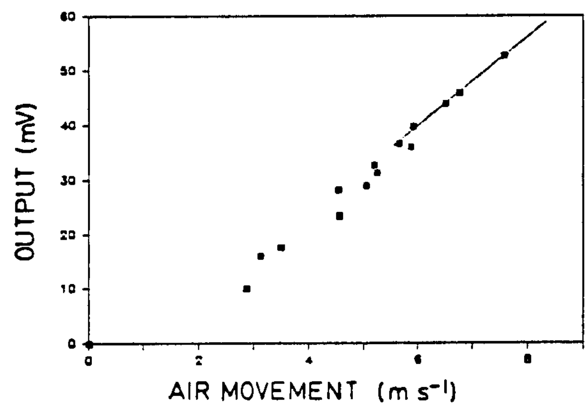

FIGURE 5.—Calibration of the D.C. generator anemometer. The solid line (Y = 8.121X − 8.895; r^2 = 0.9997) represents in part the calibration of the device against a car speedometer for five values between 5,6 and 22,2 m.s^{-1} (values beyond 8 m.s^{-1} are not shown). Solid points compare mean output to mean windspeed as measured at the study site by an adjacently mounted totalizing anemometer over 30-minute periods.

Although a quantitative measurement of accuracy has not been made on the instrument, both the linearity of the calibration and the favourable comparison with a commercial anemometer suggest that the recorded measurements of air movement at the study site are accurate within the limits outlined above. Other more sensitive devices of sophisticated design for windspeed measurement (see Rosenberg 1974) can be constructed for interfacing with a data-logger. Practical designs for transducers to measure other environmental parameters are also readily available from the literature—see Chapter 8 of Woodward & Sheehy (1983) for a useful list of references. Apart from their benefit as instruments of opportunistic data capture, relatively cheap laboratory-constructed transducers can be left unattended with less anxiety at remote stations where pervasive human vandalism is frequently a threat.

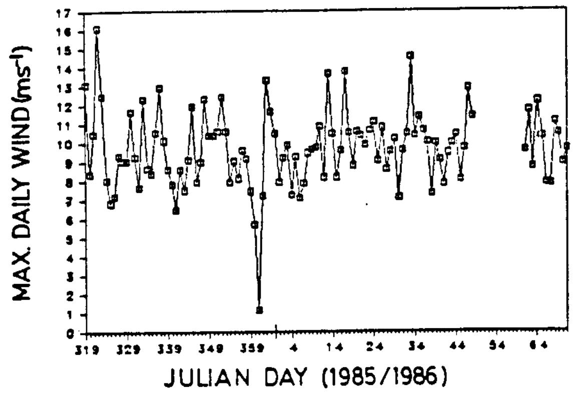

FIGURE 6.—Maximum daily windspeeds measured at the Highlands study-site. The gap starting at day 49 (Feb. 18, 1986) indicates a period of missing data owing to a problem with programmable memory space in the recording device.

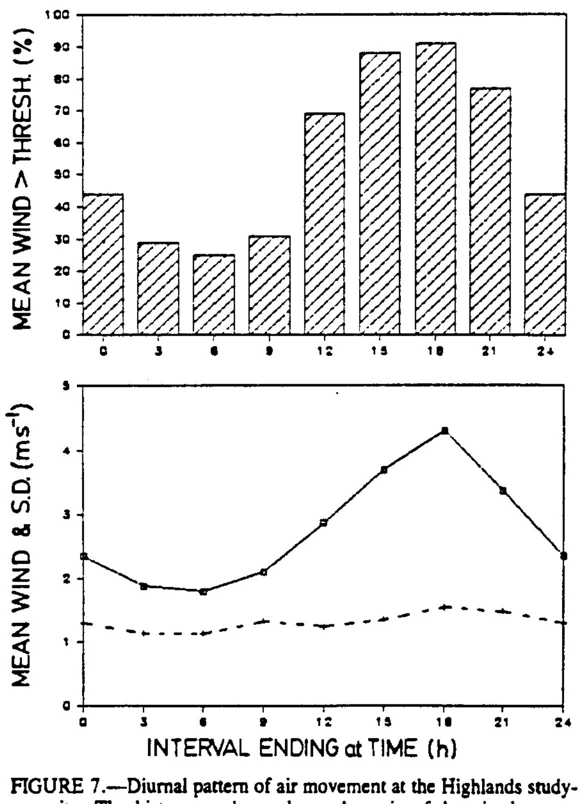

FIGURE 7.—Diurnal pattern of air movement at the Highlands study-site. The histogram above shows the ratio of days in the measurement period when the mean measured wind-speed during the relevant time interval was above 2 m.s^{-1}. Below is the overall mean windspeed, including calms, for each time interval (solid line), and the associated standard deviation of each (broken line).

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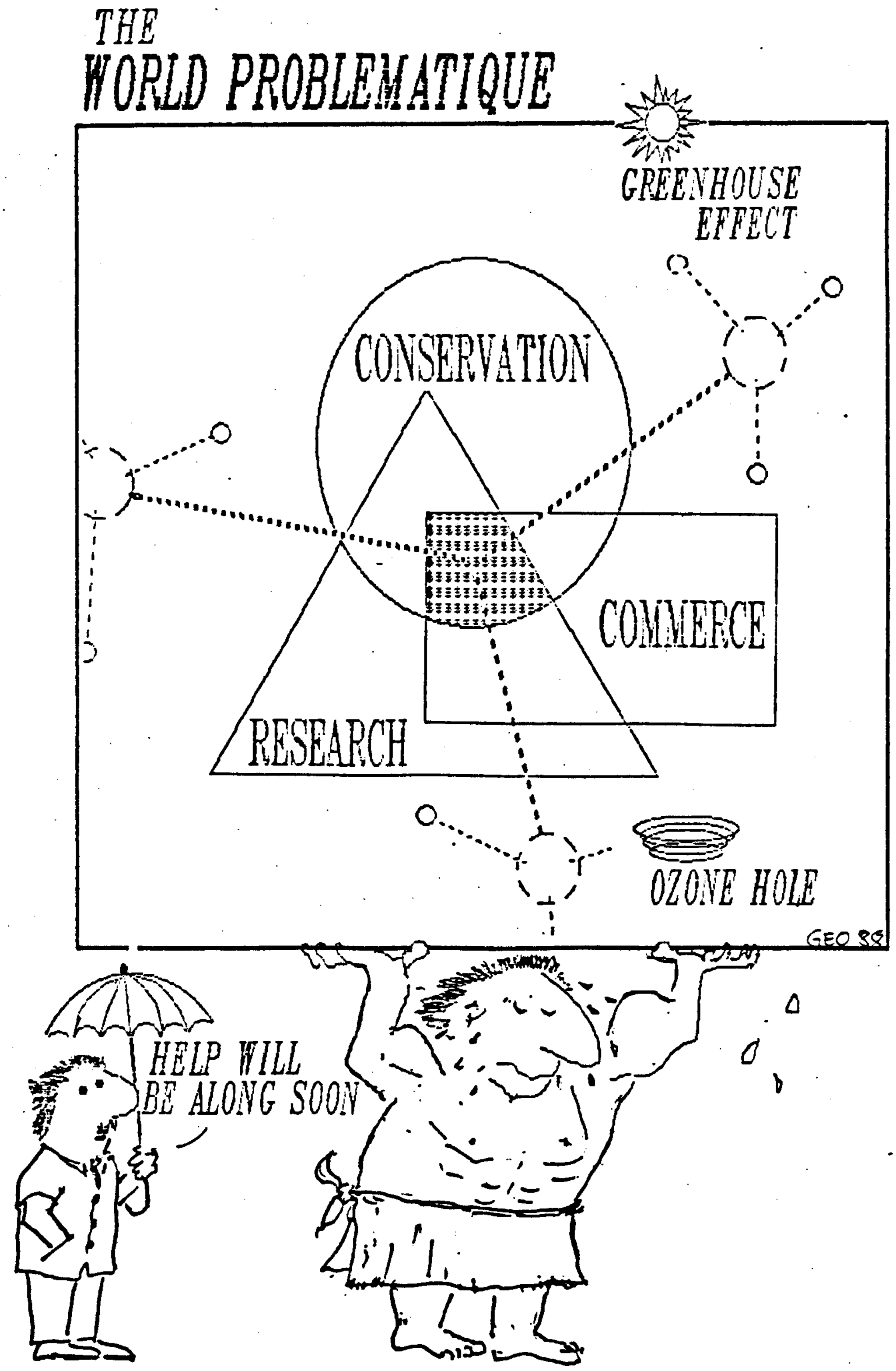
G. W. DAVIS



— one thing leads to another . . . . .