MONITORING FIRE-PRONE FLORA IN RESERVES FOR NATURE CONSERVATION

A. M. Gill

CSIRO Division of Plant Industry
GPO Box 1600
Canberra ACT 2601

A. O. Nicholls

CSIRO Division of Wildlife and Ecology
PO Box 84
Lyncham ACT 2602

SUMMARY

Monitoring is an important component of scientific management. It is the process of repeated assessment of the condition of a resource which, in this case, is the complement of vascular plant species of a conservation reserve. In this paper, monitoring is seen to be a process constrained in practice by the availability of staff, time and money and, therefore, one to be implemented in a minimal set of reserves, at a minimal set of sites, on a minimal set of species, for a minimal period of time for a minimal set of attributes. Reserves for priority monitoring are those with greatest departures from naturalness while sites for monitoring within reserves are here considered to be a minimal set chosen from those surveyed with restrictions made according to recent fire history, species composition and species responses to fires. Monitoring can be further reduced by choosing to assess a species at only one site although it may occur at many. The consequences of choices of sites and species are explored using minimal data set theory across a spectrum of circumstances varying from complete ignorance to moderate, but incomplete, knowledge. Every monitoring event should be a learning event so that as time proceeds there is even less to monitor. As an example, the available data for Nadgee Nature Reserve in south eastern New South Wales have been collated then analysed. It was assumed that the purpose of monitoring was to reveal the regenerative status of all plant species present so that planned fires may be initiated, or unplanned fires suppressed, according to current species condition. A total of 201 sites had been surveyed but only 72 were needed to incorporate all recorded plant species (601) at least once. For monitoring, only species with unknown regenerative mechanisms or longevity, and perennials with non-vegetative recovery mechanisms were considered; 389 species remained. Using only the "monitoring species", 65 sites were needed to record all of them at least once. The need for further work due to absence of data on one hand, and the tentative nature of much of the remainder on the other, is stressed.

INTRODUCTION

The world literature on the monitoring of vegetation in conservation areas is minuscule. Possible reasons for this are that monitoring is seen to be: an informal function of normal managerial action and not a topic needing research attention;

an unnecessary action for conservation reserves with natural ecosystems; a practice too difficult to implement; or, a program too expensive to run in terms of staff, finance and time. In this paper, the need for monitoring within the context of a scientific management program is explored and ideas for the design of a monitoring system in which costs are to be minimised are presented.

Scientific Management

A rational program for the implementation of scientific management in a conservation reserve will consist of the following elements:

(a) the establishment of aims and goals;

(b) an assessment of the resource (inventory and survey);

(c) a consideration of managerial problems and the operational tools to overcome them;

(d) the implementation of management; and

(e) the monitoring of the resource in terms of the aims of management.

For the purpose of this contribution, the aim of management is considered to be the maintenance of the total pool of vascular plants in a reserve in perpetuity. Other possible aims such as the extermination of alien species, the preservation of scenic beauty and historic relics, the maintenance of vegetation structure, the persistence of animal communities and the enhancement of recreational opportunity are not considered here despite the fact that they are of practical importance in many cases.

For many managers of Australian conservation reserves the major problem of management is, primarily, the control of unplanned fires, and secondly, the long-term biological consequences of measures taken to minimise the frequency, intensity and extent of such fires. The manager has a range of techniques suited to the solution of the problem such as prescribed fire and suppression strategies. If the manager knows the condition of the flora under his care - through monitoring - he can make decisions to prescribe fire or not, or to assign priorities for suppression operations to particular areas with confidence. In this paper, then, the need for, and the design of, a monitoring program is considered within the fire context. It is assumed, for current purposes only, that the problem is one of too frequent fires rather than one of an absence of fire and, as such, the manager has no need to consider the possibility of local extinctions due to the absence of fire.

Inventory, survey and monitoring are related. Inventories (check lists) represent the first step from ignorance towards knowledge. Surveys, which consist of site-specific data (of plant species lists in this case) represent another forward advance, but their completeness is a measure of the degree of advancement toward complete knowledge of the resource. Because monitoring is a process of checking or repeated assessment of condition, it relies on a knowledge base; an item cannot be monitored if it is not known that it exists. Australian conservation reserves have few inventories, fewer surveys and no formal systems of monitoring in place.

It could be asserted that monitoring is not necessary because natural ecosystems are self perpetuating. This may be the case but it is arguable that vegetation of any conservation reserve in Australia is in a completely natural state. Firstly, reserves often have artificial boundaries, and include roads, survey lines, even prospecting activity; secondly, reserves usually have introduced plants (including fungal diseases) and animals present; thirdly, reserves usually have changed fire regimes due to an historical shift from Aboriginal to European management and the changed cirumstances in the landscapes around reserves (eg farming) which affect ignition rates and extent of spread of fires; and, fourthly, changes may occur in regional water tables and salinity due to agriculture or urbanisation in areas around the reserve. It is a matter of observation that many reserves are greatly disturbed and not at all natural.

The Monitoring Problem

The monitoring "problem" is seen here to be one of too many reserves with too many items to monitor with too few staff, too little money and too little time (after Gill 1986). The "solution" then is to choose, by establishing priorities, a minimal set of reserves (eg on the basis of lack of naturalness), a minimal number of sites within a reserve, and a minimal set of items to monitor for a minimal period of time. The establishment of detailed priorities for the monitoring of named reserves is not considered here but, in general, the reserves most open to artificial influences - whether from management or other sources - may be given greatest priority. Thus, small reserves near cities set in agricultural contexts may be chosen first while large remote reserves may be given lowest priority. Most attention is given below to the questions relating to the numbers of sites to be monitored, the numbers of plant species to monitor, the period of time for which to monitor, and the attributes of species which should be observed.

Monitoring may be seen as a process through which knowledge grows. As a consequence, the intensity and purpose of monitoring should change through time. If everything is known, monitoring is unnecessary; if nothing is known, inventory and survey are needed first. Monitoring, then, is a process which is most effective when knowledge is incomplete, a ubiquitous circumstance in Australian conservation reserves. Thus, this study utilises incomplete data bases.

Minimal Sites

Preliminary analyses have been carried out on a data set consisting of presences and absences of plant species for 201 sites in Nadgee Nature Reserve in south eastern New South Wales (NSW). A map of the vegetation is given by Fox (1978). The sites were chosen originally as trapping sites for small mammals (30 sites) and as track-identification sites for animals (or "sand plots", 106 sites). The remainder were chosen by Gilmour (1983) as part of a vegetation survey (65 sites). Different plot sizes were used to assess the floristic composition of the vegetation, plots being 400 m2 for the sand plots, 700 m2 for the mammal survey (PC Catling, personal communication) and dimensionless for the vegetation survey (Gilmour 1983). The vegetation varied from wet sclerophyll forest to heath and included floristic elements as diverse as *Atriplex, Callitris, Ficus* and *Cyathea*. Two severe fires have swept the area in the past fifteen years, one in

1972 (Fox 1978) and one in 1980. The area has been relatively well studied particularly in relation to animals, heathlands and fires (eg Newsome *et al* 1975, Recher *et al* 1975, Fox 1978, Posamantier *et al* 1981). The data-set chosen was considered to represent the current state of knowledge of the floristics of this relatively well-known reserve and to be typical of the most likely way that site-specific data banks will accumulate for nature conservation reserves in general.

After cross-referencing the species lists for synonyms with the help of floras (Beadle *et al* 1976, Burbidge and Gray 1970, Willis 1962, 1972) and a checklist for NSW (Jacobs and Pickard 1981) they were subject to minimal common set analysis (Margules *et al* 1988). This analysis chooses the minimal number of sites, from all those available, which collectively include all species of the total set. Having achieved this with the total data set - the current state of knowledge - the numbers of sites available for analysis were randomly reduced to indicate the consequences of having a poorer data base on which to work. With fewer sites sampled, of course, there would be fewer species known to occur on the reserve. Four runs of the analyses were made to indicate the variation expected with a different sequence of sites being dropped in each series.

The analyses (Figure 1) show that of the 201 sites recorded, only 72 were needed to record all species. As the number of sites available decreased, so too did the minimal number of sites to just include all species. When only eleven sites were left, all were needed to represent the species complement. However, with only eleven sites the number of species present was down to between 169 and 290 out of the original 601 (Figure 1b). Extrapolation of Figure 1b suggests that further survey will reveal further species so the number of sites for a minimal set will grow.

If any of the sites of the data set are not fire prone they can be "removed" from the list for the purposes of monitoring described earlier. To decide fire proneness, any site which burned in either of the severe fires of 1972 and 1980 was included while any site which was untouched by both events was considered not to be fire prone. Of the 201 sites, only three were unburned in either 1972 or 1980. The elimination of these three sites reduced the size of the minimal data set to 71 sites (Table 1) and 578 species. Note that only one of the three sites not fire prone had been included by the minimal common set analysis.

Table 1
Numbers of observations of presence (i.e. the sum of species numbers for all sites) which would be required in a monitoring program of the 201 recorded sites at Nadgee Nature Reserve, NSW, given the criteria shown.

Criteria	Number of Sites	Number of Species	Number of Observations of Presence
1. All sites and species	201	601	7257
2. All species, minimum sites	72	601	2798
3. Minimum sites, minus non-fired sites	71	578	2674
4. As for (3) above but species observed once only	71	578	578
5. As for (3) above but for species other than ferns, annuals, biennials and known vegetative regenerators	65	389	1431
6. As for (5) above but species observed only once	65	389	389

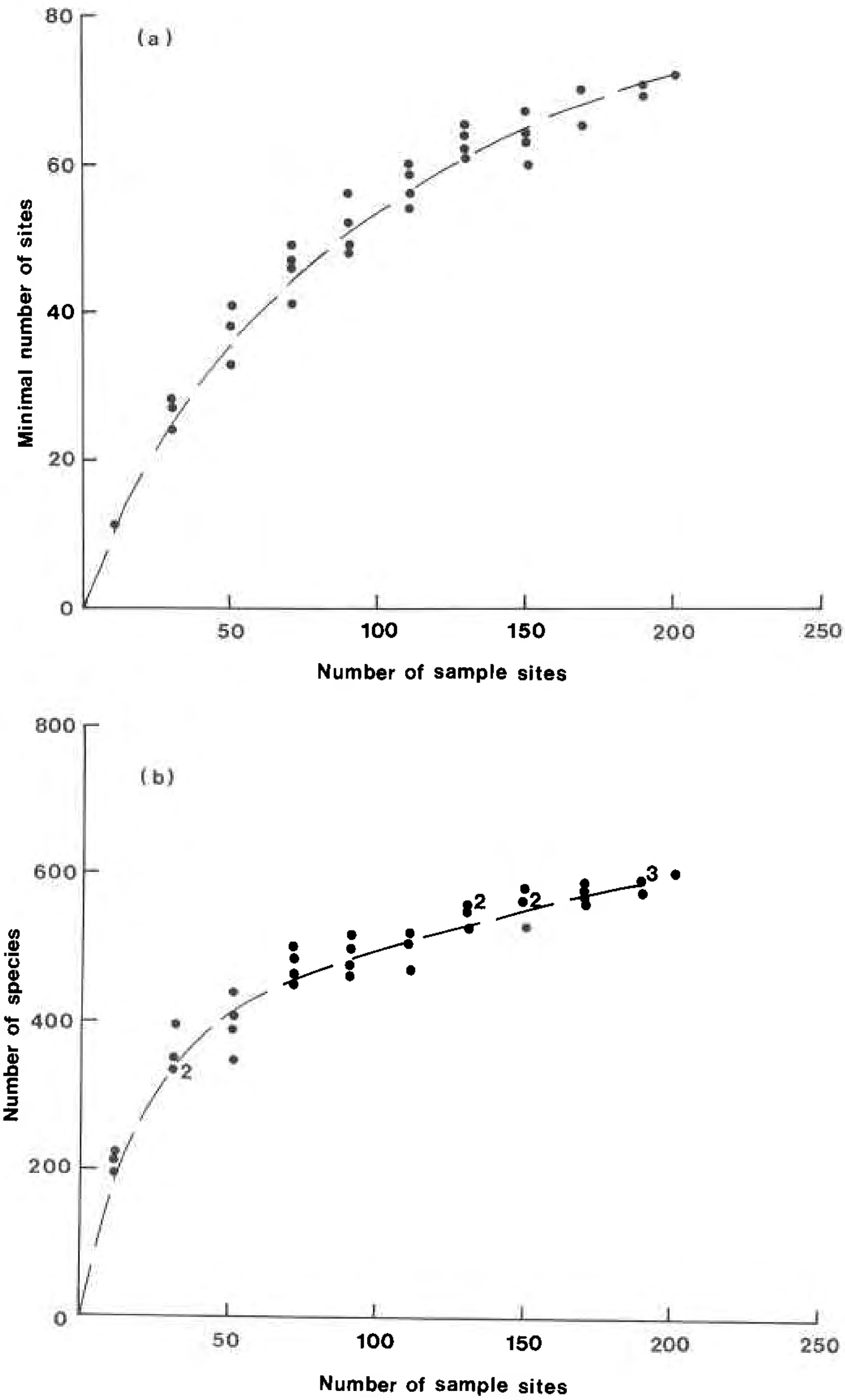

FIGURE 1
Analysis of data from plant species surveys for Nadgee Nature Reserve, NSW, to show the effect of random deletions of sites from the 201 presently recorded on (a) the minimal number of sites necessary to record each species at least once; and (b) the number of species present in the data set. The dashed lines were fitted by eye.

Minimal Species

A priority for species monitoring can be established on the basis of what is known of plant species responses to fires in general and what is known of the responses of those species in the data set in particular; ie we can give priority to those species we regard as being the most vulnerable to local extinction and those for which we have no information. To achieve this priority we can follow the path of selective elimination of species from the data set, according to current knowledge, until only the most vulnerable class is left along with those with unknown properties.

Consider that a severe fire has passed through the whole reserve (as it did in 1972). What we may expect is the early appearance of some annuals, some biennials and some fire ephemerals which we can assume will set seed within a short time and, therefore, be able to persist beyond a further fire. We can drop these species from the monitoring program. Other species will have various mechanisms of vegetative recovery such that most of the original population will survive or, if regenerating from spreading rhizomes, stolons or roots, even expand their populations; these species may be regarded as relatively secure. However, such species should not be regarded as totally secure in all circumstances because frequent repeated fires can decimate their populations (Grano 1970), sometimes (as in the case of mallee eucalypts), in an interaction with season of fire occurrence (Noble *et al* 1984). Also likely to be secure are ferns which have such light propagules, *viz* spores, that their return to a site, even if fire sensitive, seems assured. There is very little information available on the fire responses of ferns, however.

In this analysis, if a species often recovers vegetatively but a large proportion of the population has been observed to die in severe fires, (such as the *Cassia eremophila* A Cunn ex Vogel of the semi arid region, Wilson and Mulham 1979), then it should remain in the monitoring set for the time being. In following this particular step-wise process of elimination, we would expect to eliminate vascular plants in a series from those with very short primary juvenile periods such as annuals and some fire ephemerals, through to biennials and further fire ephemerals then to species with secondary juvenile periods (ie the time from the fire to first flowering in vegetatively regenerating plants, Gill 1975) which are mostly short also. Many vegetatively regenerating woody species begin to flower two or three years after fire.

Using the floras for the Australian Capital Territory (Burbidge and Gray 1970), the Sydney region (Beadle *et al* 1976) and Victoria (Willis 1962, 1972) each species was assigned its appropriate classification for life cycle (annual, biennial, perennial) and origin (native, alien) where recorded. If not specifically stated, an "unknown" designation was applied. Fire responses were assigned, where known, on the basis of personal observations or observations of those who have worked in similar vegetation types elsewhere along the New South Wales and Victorian coasts. If different observers found different responses for the same species in different areas then the species was retained as one for monitoring. It is important to note that the information obtained is not the result of deliberate systematic observation of species responses at Nadgee but is from scattered geographic sources and from casual observation at Nadgee and elsewhere (see Table 2 for details). Perhaps, like the site-specific species lists, this is the way information is gradually compiled by managers and, as such, is typical of the information is gradually compiled by managers and, as such, is typical of the limited data available to a reserve manager. We emphasise that our purpose here is to illustrate how such a data base can be used to assist in the design of a monitoring program.

The results from Nadgee (Table 2) reveal a considerable level of ignorance in relation to longevity and fire responses. Of the native species, a very large proportion were perennials of which most were species which regenerate vegetatively after fire. A quarter of the aliens were annuals or biennials whereas only about three per cent of native species occurred in these categories. If ferns, annuals, biennials and the vegetative regenerators among the perennials are overlooked for the purposes of monitoring then the species data set is reduced by about one third.

Table 2

Numbers of species in various longevity, fire-persistence and origin classes for the Nadgee Nature Reserve species list. Observations of fire-persistence were made by various people at various locations: *viz*, the senior author at Nadgee and on the southern tablelands of NSW; DH Benson (1985) near Sydney; M Fox (personal communication) at Myall Lakes National Park, NSW; F Ingwersen (1977) at Jervis Bay Nature Reserve; P Stricker (personal communication) at Royal National Park, NSW; and M Wark *et al.* (1987) near Angelsea, Victoria.

Species class	Natives	Aliens	Unknown origin	Total
Ferns	41	0	2	43
Annuals	15	6	1	22
Biennials	3	2	0	5
Perennials with				
• vegetative regeneration	122	3	0	125
• seed only regeneration	68	5	0	73
• unknown responses	234	9	7	250
Longevity unknown, not ferns	69	5	9	83

Minimal Time, Minimal Attributes

By tackling which attributes of a species should be priority monitored, the minimal time for monitoring can be assessed. There are two aspects to this. Firstly, there is the time spent at a site on each occasion when monitoring. Secondly, there is the duration of years over which monitoring should take place.

The time spent in monitoring the desired attributes of a population will depend on some inherent characteristics of that population. Monitoring a species with high ground cover and many individuals would be much more efficient than monitoring one with a very low cover and a few individuals only. Thus, in setting up a monitoring program it may be desirable to choose sites where a species is obvious, if possible, rather than those where it is obscure. This is something we have not been able to take into account here because of the absence of information.

By recording some measure of performance, such as abundance or cover, the observer may not only discover trends but also know whether or not the species is going to be hard to detect. For small plants, abundance and cover are going to be related but for big plants, like mature trees, a few individuals may provide a high cover. Because big plants are going to be more fire resistant than small plants of the same species in most cases, and because the recording of big plants as having one individual in a plot is not very meaningful, it is considered that the single best estimate of vegetative performance is cover. A cover value has the most information content for the time spent in its determination; an ocular estimate of percentage cover or an assessment of a species as having "low", "medium" or "high" cover may be sufficient.

While the most pertinent reproductive measure to record may be seed production, such a conclusion raises the difficulty of how frequently monitoring should be carried out within a year because of the variation between species in reproductive phenology. No systematic information is available for Nadgee Nature Reserve but for the perennials being considered here it is likely that flowering takes place for most species in spring while fruit maturation may cover a much longer period of time. So, while seed production may be the most pertinent measure to record, flowering is considered to be the more practical because not only is its appearance more likely to be confined in time than fruit development, its presence assists in the detection of uncommon species and the flowers themselves are diagnostic for species identification.

In pursuing a minimal number of species to monitor, various species were dropped from the program at the outset because they were considered to be more tolerant of fires than the remainder. As monitoring proceeds, however, further species could be dropped from the program on the basis that their regenerative status had become adequate to ensure their persistence in the event of another fire occurrence. To explore the question, then, of the duration in years that a species should be monitored, attention is focussed on what is perhaps the group of plants most vulnerable to extinction, viz fire-sensitive shrubs with seed held only on the plant, and not at all in the soil.

It is a matter of simple logic that a fire-sensitive species without a seed store in the soil cannot survive two fires within the juvenile period of the species at that site unless unburned mature specimens remain nearby to disperse seed onto the site. The minimum requirement for survival of such species, then, is that the juvenile period be exceeded without fire.

While no data are available for Nadgee species, juvenile periods for some fire sensitive species in the sclerophyllous vegetation on nutrient-poor sandstone of the Sydney region have been recorded (Benson 1985). Half of the 33 species examined in the Sydney region had juvenile periods of four to five years as assessed by observations on tagged seedlings but precocious plants of the same species nearby had juvenile periods of only one to three years. The longest juvenile periods of six to nine years were found in seven species but these periods varied somewhat between sites. Two of the species in the Sydney study also occur at Nadgee, viz *Xanthosia tridentata* DC with a juvenile period of six years and *Hakea teretifolia* (Salisb) J Britt with a juvenile period of seven.

The behaviour of species in the Sydney area or elsewhere provides a guide to behaviour at the particular site for investigation, but caution in interpretation is necessary. For example, while *H. teretifolia* had a maximum observed juvenile period of seven years at Sydney (Benson 1985), the species at Nadgee eight years after fire had abundant seed, perhaps an unlikely occurrence for the first year after flowering, and also showed substantial fire resistance with up to 70 per cent of stems resprouting (AM Gill, personal observation). In Benson's (1985) study the minimum juvenile period of *H. teretifolia* was six years for tagged specimens but as little as two years for precocious plants. There may thus be considerable variation in behaviour within and between populations.

Fire sensitive species burned soon after their first flowering will have little regeneration post-fire because not all flowering in the first year leads to fruit production (Benson 1985, Wark *et al* 1987), fruit maturation may take a year, relatively few plants may set seed initially, and many years may be necessary before seed production is sufficient to restore the population after a fire (Gill and McMahon 1986). Given that it is desirable for a suitable seed store to be built up for regeneration before further burning takes place, monitoring may continue until this is observed or, alternatively, certain rules-of-thumb may be followed as a practical approach to management, not only for species whose seed store can be observed on the plant, but for all species.

Two rules-of-thumb are that seed production will be adequate when 50 per cent or more of the plants present have become reproductive (Van Wilgen 1980), or when a number of years has elapsed that is at least equal to twice the juvenile period observed. (These two guidelines are not mutually exclusive because the determination of the juvenile period will depend on a certain proportion of the plants first flowering rather than on the behaviour of isolated precocious plants.)

Research on a fire sensitive shrub with canopy-stored seed in north western Victoria, and south eastern South Australia, *Banksia ornata* F Muell, has shown that the species there has a juvenile period of five to seven years (Specht *et al* 1958, Figure 1; Gill and McMahon 1986). The time to more than 50 per cent of the population flowering was between seven and eleven years and the estimated time for sufficient seed to be accumulated to reproduce the population - given certain qualifications - was sixteen years (Gill and McMahon 1986). From this isolated example, doubling the juvenile period (eight to fourteen years) gave a more appropriate result than the time to 50 per cent of the population being reproductive (seven to eleven years).

Until further data become available it is suggested that a doubling of the general juvenile period of the species observed at the monitoring site be used as the guide to when the species is likely to be able to replace itself to prefire abundance levels. Of course, exceptions are to be expected.

Practical Monitoring

One further step remains in the sequential investigation into a monitoring scheme for the flora of a nature conservation area. To recapitulate previous steps: firstly, the number of surveyed sites necessary to just include all species at least once was determined; secondly, a number of steps were followed to reduce monitoring sites and species to a minimum, viz by considering only fire-prone sites, only one site per species, and only the most vulnerable species or those with unknown sensitivities; and, thirdly, a minimal number of attributes to be recorded for a minimal time was suggested. As a result of the second series of steps the "minimum number of sites" determined by the first step can be further reduced. Therefore, a second minimal common set analysis was conducted on the initial Nadgee data set with three sites removed because they were considered not to be fire prone, with all ferns, annuals and biennials removed, and with all fire-resistant perennials removed. The result was that of the 201 sites of the original surveys only 65 needed to be monitored according to the rules adopted here; 389 species were present (Table 1, Figure 2).

While the task of monitoring for plant species appears large for Nadgee as outlined here with 389 species-observations to be made for cover and flowering (equal to twice the number of species-observations) in the early years after fire, in practice a manager setting up a monitoring scheme would initially spend time assessing fire response types so as to reduce the numbers of species to consider in his monitoring program. Furthermore, it is unlikely that the manager would always be faced with monitoring the whole of the fire-prone portion of the reserve as assumed here because, in practice, only burned areas would receive attention and such areas are often only a portion of the fire-prone area. If canopies of trees were not killed, the species represented would not be monitored and, as species reached their juvenile periods - which are mostly short - monitoring of these species would cease. As monitoring observations decreased, the manager may pay more attention to the accumulating fuel quantity and the chances of fire in relation to the "vulnerable" period for the community - which can be defined as double the juvenile period of the species with the longest juvenile period. The manager may find that conservation groups could relieve him of some of the monitoring activity.

Practical issues like how to record, store and retrieve the data have not been considered here. For research purposes, photographs have proven particularly useful in some cases such as at Koonamoore Vegetation Reserve in South Australia (Hall *et al* 1964) and in Kosciusko National Park in New South Wales (Wimbush and Costin 1979). Hopkins *et al* (1987) have included photo points in their general monitoring system for reserves in Western Australia.

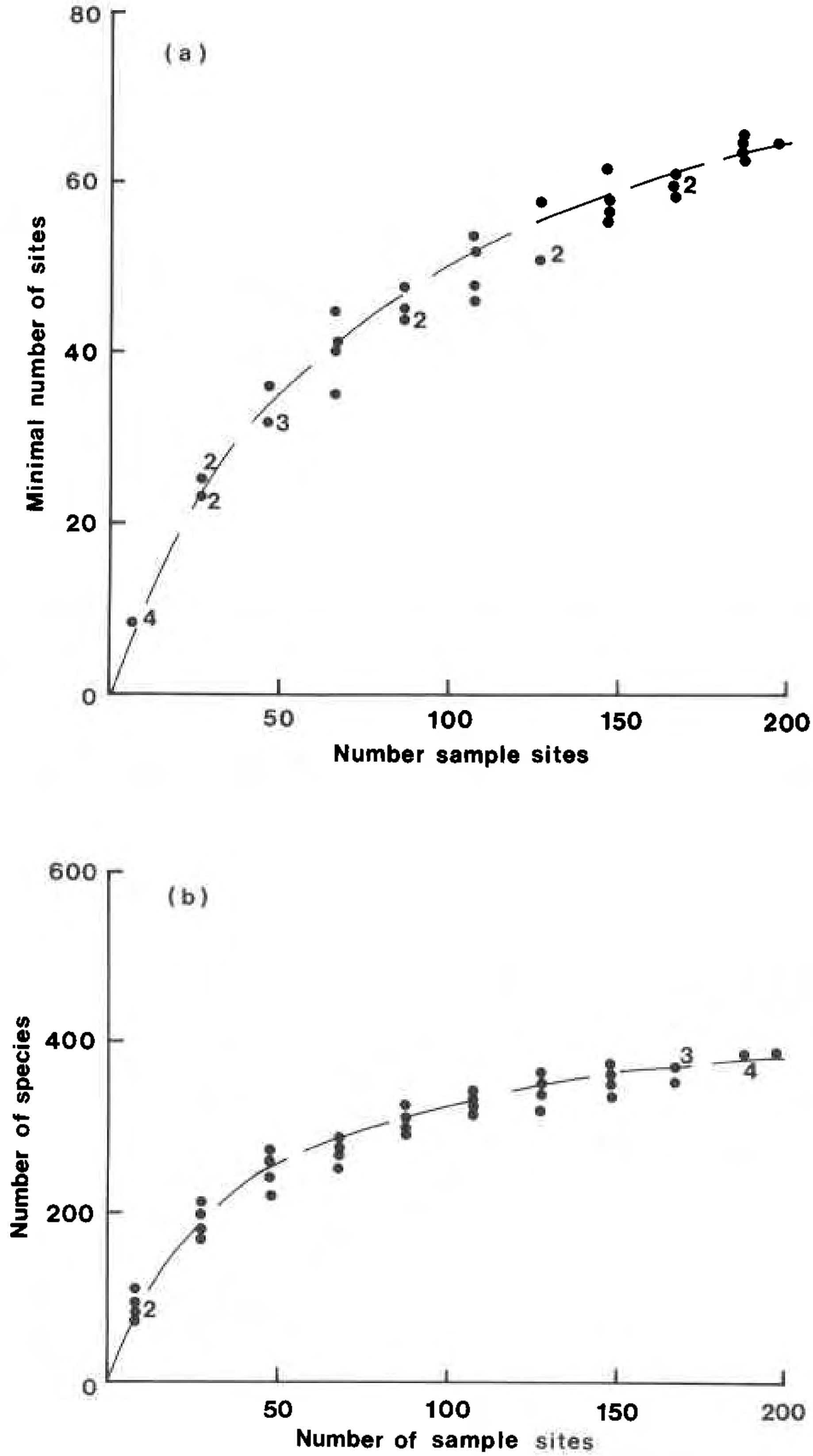

FIGURE 2

Analysis of data from plant species surveys for Nadgee Nature Reserve, NSW, to show the effect of random deletions of sites from the 198 fire-prone sites present when species are excluded from monitoring according to longevity, life cycle and vegetative persistence through a fire event: (a) on the minimal number of sites necessary to record each species at least once; and (b) on the number of species present in the data set.

DISCUSSION

The manager may wish to monitor many other ecosystem components than the floristic one. Structural features of plant communities, numbers of animals and extent of erosion are a few of the many possibilities. Each of these may be regarded as a target for monitoring (Gill 1982) in that the process is aimed at a particular component of the environment. Another aspect of monitoring is to continually look for unexpected changes in non-target components; comparing sequential images from remote sensing devices is an example.

In this contribution we have used minimal common data set analysis for determining the number of sites at which monitoring should take place. The method also had value in pointing to the need for further survey. Use of such analyses for the design of monitoring programs can be an on-going procedure as different combinations of sites are affected by unplanned or management fires from time to time.

Only the simplest of classifications of fire responses was used here due to the general lack of information. It has rudiments of the classification of Gill (1981) and lacks the relative sophistication of the classification of Noble and Slatyer (1980) which requires a knowledge of conditions of establishment (tolerant/intolerant) and critical life stages (time to reproductive maturity, longevity of the species population and the time to reach local extinction - including soil-stored seed) as well as the method of persistence through a fire event. A computer package designed to assist observers to record fire responses of plant species has been written by Noble (1985) using an "expert system" approach. The sequence used here to eliminate species from the monitoring program is not necessarily one that would be universally chosen. However, it does reflect the process envisaged for the design of a monitoring program. Species considered to have a high certainty of survival were eliminated from the program while those of uncertain or potentially vulnerable status were retained. The sequence used may be different in other areas, eg where season-of-burning may have an important effect.

No special attention was given to alien species in the analysis. However, many managers may wish to monitor such populations carefully in order to devise ways of controlling their growth and spread.

The methods used here could be incorporated into the various systems of geographical data basing and process modelling that are becoming more and more widely used in Australian landscapes (Kessell *et al* 1980, Davis *et al* 1985, Thackway *et al* 1985). These systems already include ways of recording fire events and site data such as species lists. The addition of a monitoring subroutine to these packages would augment their value.

CONCLUSION

Monitoring is rarely practised in Australian conservation reserves. Part of the reason for this is that too few staff, too little money and too little time are available. The methods presented here should enable managers to design a cost-efficient strategy for the monitoring of plant species persistence in perpetuity given sequences of either unplanned or management fires. Perhaps the greatest need in many reserves is for a survey of the flora and determination of the way species persist through a fire event. Monitoring will then reveal critical periods such as the times to first flowering and seed set.

ACKNOWLEDGEMENTS

The dedication of Ms Astrida Mednis, New South Wales National Park and Wildlife Service (NPWS), to the collation and checking of the Nadgee species list, along with the information sought for each of these species, was much appreciated. Many people, mentioned in the text, provided unpublished information and to them goes special thanks. In particular, Mr Peter Catling provided unpublished species lists for 136 sites at Nadgee. Mr Roger Good (NPWS) and Mr A.J.M. Hopkins (Western Australian Department of Conservation and Land Management) provided welcome encouragement.

REFERENCES

Beadle, N.C.W., Evans, O.D. and Carolin, R.C. (1976). *Flora of the Sydney Region* A.H. and A.W. Reed, Sydney.

Benson, D.H. (1985). Maturation periods for fire sensitive shrub species in Hawkesbury sandstone vegetation. *Cunninghamia* 1 pp 339-49.

Burbidge, N.T. and Gray, A.M. (1970). *Flora of the Australian Capital Territory* Australian National University Press, Canberra.

Davis, J.R., Hoare, J. and Nanninga, P. (1985). The GEOKAK fire behaviour and fire effects expert systems. In *Towards an Expert System for Fire Management at Kakadu National Park* (Eds J. Walker, J.R. Davis and A.M. Gill) pp 153-68. Technical Memorandum 85/2. CSIRO, Division of Water and Land Resources, Canberra.

Fox, A.M. (1978). The '72 fire of Nadgee Nature Reserve. *Parks and Wildlife* 2(2) pp 5-24.

Gill, A.M. (1975). Fire and the Australian flora : a review. *Australian Forestry* 38 pp 4-25.

Gill, A.M. (1981). Coping with fire. In *The Biology of Australian Plants* (Eds J.S. Pate and A.J. McComb) pp 65-87. University of Western Australia Press, Nedlands.

Gill, A.M. (1982). Priorities for research and monitoring in mallee and heath lands of conservation reserves in north western Victoria. In *Fire Ecology in Semi-arid Lands* (Eds A. Heislers, P. Lynch and B. Walters) National Parks Service, Victoria and CSIRO, Division of Land Resources Management, Deniliquin.

Gill, A.M. (1986). Research for the Fire Management of Western Australian State Forests and Conservation Reserves. Western Australian Department of Conservation and Land Management Technical Report 12.

Gill, A.M. and McMahon, A. (1986). A post-fire chronosequence of cone, follicle and seed production in *Banksia ornata. Australian Journal of Botany* 34 pp 425-33.

Gilmour, P. (1983). A Survey of Vegetation of Nadgee Nature Reserve. Report to New South Wales National Park and Wildlife Service (unpublished).

Grano, C.X. (1970). Eradicating understory hardwoods by repeated prescribed burning. United States Department of Agriculture Forest Service Research Paper SO-56 11 pp.

Hall, E.A.A., Specht, R.L. and Eardley, C.M. (1964). Regeneration of the vegetation on Koonamoore Vegetation Reserve 1926-1962. *Australian Journal of Botany* 12 pp 205-64.

Hopkins, A.J.M., Brown, J.M. and Goodsell, J.T. (1987). A monitoring system for use in the management of natural areas in Western Australia. In *Nature Conservation : The Role of Remnants of Native Vegetation* (Eds D.A. Saunders, G.W. Arnold, A.A. Burbidge and A.J.M Hopkins) pp 337-9. Surrey Beatty and Sons, Sydney.

Ingwersen, F. (1977). Vegetation Development after Fire in Jervis Bay Territory. MSc Thesis, Australian National University, Canberra.

Jacobs, S.W.L. and Pickard, J. (1981). *Plants of New South Wales. A Census of the Cycads, Conifers and Angiosperms* National Herbarium of New South Wales, Sydney.

Kessell, S.R., Good, R.B. and Potter, M.W. (1980). Computer modelling in natural area management. *Australian National Parks and Wildlife Service Special Publication* No 9 45 pp.

Margules, C.R., Nicholls, A.O. and Pressey, R.L. (1988). Selecting networks of reserves to maximize biological diversity. *Biological Conservation* 43 pp 63-76.

Newsome, A.E., McIlroy, J.C. and Catling, P. (1975). The effects of an extensive wildfire on populations of twenty ground vertebrates in south-east Australia. *Proceedings of the Ecological Society of Australia* 9, pp 107-23.

Noble, I.R. (1985). Fire effects, vital attributes and expert systems. In *Towards an Expert System for Fire Management at Kakadu National Park* (Eds J. Walker, J.R. Davis and A.M. Gill) pp 96-102. Technical Memorandum 85/2. CSIRO, Division of Water and Land Resources, Canberra.

Noble, I.R. and Slatyer, R.O. (1980). The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. *Vegetation* 43 pp 5-21.

Noble, J.C., Harrington, G.N. and Hodgkinson, K.C. (1984). The ecological significance of irregular fire in Australian rangelands. In Rangelands : A Resource Under Siege. Proceedings of the Second International Rangelands Congress Adelaide May 1984 pp 577-80. Australian Academy of Science, Canberra.

Posamantier, H.G., Clark, S.S., Hain, D.L. and Recher, H.F. (1981). Succession following wildfire in coastal heathland (Nadgee Nature Reserve NSW). *Australian Journal of Ecology* 6 pp 165-75.

Recher, H.F., Lunney, D. and Posamentier, H. (1975). A grand natural experiment. The Nadgee wildfire. *Australian Natural History* 18 pp 154-63.

Specht, R.L., Rayson, P. and Jackman, M.E. (1985). Dark Island heath (Ninety-mile Plain, South Australia) VI. Pyric succession : changes in composition, coverage, dry weight and mineral nutrient status. *Australian Journal of Botany* 6 pp 59-88.

Thackway, R., Myers, K. and Malafant, K. (1985). Kakadu Ecological Data Base (KEDABA). In *Towards an Expert System for Fire Management at Kakadu National Park* (Eds J. Walker, J.R. Davis and A.M. Gill) pp 104-16. Technical Memorandum 85/2. CSIRO, Division of Water and Land Resources, Canberra.

Van Wilgen, B.W. (1980). Some effects of fire frequency on fynbos at Jonkershoek, Stellenbosch, South Africa. MSc Thesis, University of Cape Town.

Wark, M.C., White, M.D., Robertson, D.J. and Marriott, P.F. (1987). Regeneration of heath and heath woodland in the north-eastern Otway Ranges following the wildfire of February 1983. *Proceedings of the Royal Society of Victoria* 99, pp 51-88.

Willis, J.H. (1962). *A Handbook to Plants in Victoria. I. Ferns Conifers and Monocotyledons.* Melbourne University Press, Melbourne.

Willis, J.H. (1972). *A Handbook to Plants in Victoria. II. Dicotyledons.* Melbourne University Press, Melbourne.

Wilson, A.D. and Mulham, W.E. (1979). A survey of the regeneration of some problem shrubs and trees after wildfire in Western New South Wales. *Australian Rangelands Journal* 1 pp 363-8.

Wimbush, D.J. and Costin, A.B. (1979). Trends in vegetation at Kosciusko II. Subalpine range transects, 1959-1978. *Australian Journal of Botany* 27 pp 789-831.