October 2002

Adaptive Management: What Does it Mean and How Can it be Used in Fire Management?

R. J. Whelan
University of Wollongong, rob@uow.edu.au

Adaptive Management: What Does it Meant and How Can it be Used in Fire Management?

Abstract

'Adaptive Management' is becoming a frequently heard term but it is a much misunderstood concept. It does not mean that developments can go ahead and be 'adapted' if detrimental effects are discovered! Its greatest value is in defining an experimental approach to land management in situations where scientific knowledge is lacking but where immediate actions are required. This is especially important where doing nothing might conceivably be just as undesirable as applying any of the alternative management options. Given the lack of knowledge of fire responses of much of our native biota, adaptive management is clearly a sensible approach to deciding the fire regimes that might be applied in fire-prone landscapes. This paper identifies the main elements that are needed for incorporating good experiments into management: replication of sites, randomisation, and interspersion of treatments, monitoring and analysis of results, and communication of findings. The Illawarra Greenhood Orchid is used as a case study to illustrate that these elements can indeed be incorporated into fire management.

Keywords

fire, management, biodiversity, experiment

Disciplines

Life Sciences | Physical Sciences and Mathematics | Social and Behavioral Sciences

Publication Details

This paper was originally published as Whelan, RJ, Adaptive Management: What does it mean and how can it be used in fire management?, in Halse, S (ed) Bushfire: Managing the Risk, New South Wales Nature Conservation Council, Sydney, 2004.

Adaptive Management: What Does it Mean and How Can it be Used in Fire Management?

Professor Rob Whelan
Institute for Conservation Biology
University of Wollongong
NSW, 2522

rob_whelan@uow.edu.au

October 2002

Abstract

'Adaptive Management' is becoming a frequently heard term but it is a much misunderstood concept. It does not mean that developments can go ahead and be 'adapted' if detrimental effects are discovered! Its greatest value is in defining an experimental approach to land management in situations where scientific knowledge is lacking but where immediate actions are required. This is especially important where doing nothing might conceivably be just as undesirable as applying any of the alternative management options. Given the lack of knowledge of fire responses of much of our native biota, adaptive management is clearly a sensible approach to deciding the fire regimes that might be applied in fire-prone landscapes. This paper identifies the main elements that are needed for incorporating good experiments into management: replication of sites, randomisation, and interspersion of treatments, monitoring and analysis of results, and communication of findings. The Illawarra Greenhood Orchid is used as a case study to illustrate that these elements can indeed be incorporated into fire management.

> ADAPTIVE MANAGEMENT: *"The rigorous combination of management, research, and monitoring so that credible information is gained and management activities can be modified by experience. Adaptive policy acknowledges institutional barriers to change and designs means to overcome them."*
>
> <http://www.for.gov.bc.ca/hfp/amhome/amhome.htm>

Introduction

The concept of adaptive management was formally introduced into ecology in the late 1970s and it has been championed by Holling (1978), Walters (1986), Walters & Holling (1990) and Hilborn & Walters (1992). The term 'adaptive management' is now used often in the context of harvesting from natural systems (fisheries & forestry), land management, and even in relation to development applications for large-scale development projects. The concept is increasingly becoming part of the language of policy and environmental politics internationally and in Australia (Dovers & Mobbs 1997) yet it is widely misunderstood and frequently misused (Wilhere 2002). Nevertheless, applied properly, it offers a potentially powerful approach for improving our management of fire in an environment of uncertain knowledge. The aims of this paper are (i) to explore the use of the term 'adaptive management' and to clarify its definition, (ii) to assess how the approach might most effectively be used in fire management, and (iii) to present a case study illustrating how it can be used to improve fire management in relation to an endangered plant species.

Adaptive Management - Concept and Definition

Adaptive management is most important in situations in which some management action is essential but the scientific knowledge that is necessary for accurate predictions of the outcomes of particular management actions is scanty or completely lacking. Under such circumstances, the precautionary principle would suggest that action should be avoided until its likely effects can be predicted with some certainty. However, there are some situations in which delaying some form of management could itself have an ecologically deleterious effect and

others in which immediate action is imperative, despite the potential for detrimental consequences. These are the situations in which adaptive management is most frequently used, such as when economic pressures are driving the management: forestry and fisheries (Lee 1993, Lessard 1998). In these cases, the 'management' refers to the type and magnitude of harvesting, and the principal objective is sustainability of the resource. Clearly there is insufficient scientific knowledge on which to base predictions about, for example, what would happen to population sizes or age structures of fish populations if a particular fishing quota were applied. Likewise, the different impacts on biodiversity of a variety of forest harvesting management practices can not yet be accurately predicted (Canadian Ministry of Forests 2000a & b).

Adaptive management is a ***structured process of experimental management*** (Walters 1997). It offers the opportunity of 'learning by doing', thus permitting management (or resource exploitation) to go ahead, initially without sufficient scientific knowledge, in a way that generates the knowledge. Management is expected to be modified in response to the acquisition and interpretation of the new information.

There are many misapplications of the term 'adaptive management' (Halbert 1993, Walters 1997, Wilhere 2002), so it is important to recognise that this is a formal process with a number of essential components. Adaptive management is not simply 'willingness to change', 'flexible management' or 'trial-and-error', because these terms emphasise just a few components of the process. Willingness to change management and flexibility in management are crucial elements of adaptive management but they are useless without being based on well designed studies that test clearly stated questions. Wilhere (2002) argued that trial-and-error typically emphasizes the trial but neglects error detection, which entails costly monitoring. His assessment was that the approach of trial and error often leads to the implementation of a single policy that is assumed satisfactory until proven otherwise, and that 'casual observations, anecdotal reports, and unreplicated case studies lack statistically valid experimental design and are likely to yield unreliable information.'

The superiority of adaptive management over these alternatives is that the drivers for changing management are internal to the process (Wilhere 2002); it involves all the stakeholders and it combines data collection with decision-making about management. The Canadian Ministry of Forests (2000a) defines adaptive management as follows, and is applying it to determine the responses of biodiversity to various alternative forest harvesting management practices.

> *Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form – "active" adaptive management – employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed.*

Canadian Ministry of Forests (2000a) portrays their adaptive management process as a six-step cycle, and emphasizes that successful adaptive management requires managers to complete all six steps (Figure 1).

Figure 1 near here

Walters (1997) emphasised that the first step, 'assess problem', requires input from a range of sources or stakeholders, including scientists. It is critical that the issues and objectives are clearly defined, and desired outcomes are quantified. This is essentially a process of

articulating management actions and hypothesising (or ‘modelling’) possible outcomes based on the best, currently available knowledge.

The second step, ‘design’, also requires the input of scientists, so that a statistically valid experimental test of the alternative models can be achieved. Such a test requires (i) an appropriate spatial scale for each replicate treatment block, (ii) sufficient replication of each management ‘treatment’, (iii) interspersion of treatments, (iv) random allocation of treatments to each experimental block, and (v) appropriate measurements and time-span of monitoring (Green 1979, Underwood 1995).

Once the experiment is designed, the third step, ‘implement’, is the province of the manager. Possible constraints and catastrophes would hopefully have been foreseen in step 2, and responses to them identified in advance.

Monitoring, the fourth step, must be an integral part of implementation. Funding it must therefore be treated as an integral part of the whole process and not a separate budget item that can be pruned off if insufficient funds are available.

The fifth step, ‘evaluate’, again requires the input of scientists and managers together, because it includes both the statistical analysis of the results (produced by the monitoring program) and the assessment of the implications of the findings for management. It will lead directly on to the next cycle of experimental management, starting with the adjustment (step 6) of the management practices under question.

Applications to Fire Management

The challenge of managing fire regimes without compromising the conservation of biodiversity is highlighted with every major fire in Australia and in other fire-prone regions of the world (Keeley & Fotheringham 2001). The criticisms of the National Parks and Wildlife Service during and after the 2001-02 fires largely ignored the primary land management objective of the Service, which is the conservation of natural and cultural heritage (NPWS 2001; Whelan 2002a & b). Against this objective, this land management agency (and others) must design fire management actions that achieve the protection of life and property while not compromising the conservation objective.

Controlled fires have long been used for many purposes, including achieving ecological objectives as well as reducing fuel loads to limit intensity of subsequent wildfires (Whelan 1995, Fisher 1996). There are, however, many questions that have no answers or at best incomplete ones. How frequently do hazard-reduction burns have to be applied to achieve effective protection from a subsequent wildfire? How does this vary in different landscapes and climatic regions? How quickly do fuel loads build up in different vegetation types? Does this vary with the nature of the hazard-reduction burn that is applied? Does frequent hazard-reduction burning have detrimental effects on biodiversity? What fire frequency is critical in a particular area? How does season of burning affect biodiversity? How does season determine the effectiveness of hazard-reduction burning in reducing fuel loads?

Clearly, land management agencies cannot wait until the answers to these questions and others are known before applying the ‘perfect management action’. The main social pressure driving management of fire in areas with urban-bushland or agriculture-bushland interfaces is protection of life and property. Thus, there is a need to apply some form of fire management before we have detailed information about the likely impacts of any particular management

prescription on either of two principal objectives: (i) increasing our ability to control a wildfire threatening lives or property, and (ii) protecting biodiversity.

In relation to biodiversity conservation, there is considerable knowledge about the impact of too-frequent fires on some elements of biodiversity (Bradstock et al. 2002), in particular the obligate-seeder plant species (see Nieuwenhuis 1987, Morrison *et al.* 1995, Clarke & Knox 2002) and many cover-dependent animals (Catling 1991; Baker 2002). Many of the plants and animals that are listed under the NSW Threatened Species Conservation Act (TSCA) (1995) have these characteristics, and are potentially threatened by too-frequent fire. Indeed, the Scientific Committee has listed inappropriate fire regimes as a Key Threatening Process under the TSCA (NPWS 2002) and the Ecological Society of Australia (1999) identifies the biodiversity threats caused by too-frequent fires in its position statement on the use of fire in ecological management. However, there is insufficient knowledge of the precise fire responses of most plant or animal species to be able to predict, with any certainty, their individual responses to different fire return times in a particular vegetation type.

This scenario has all the ingredients that make adaptive management the most appropriate response. Can it be applied effectively? I argue here that it can be applied. Indeed, conducting large-scale fire ecology research studies will require close collaboration between researchers and managers. In the following section, I describe a situation in which we have integrated research and management in a small adaptive management project.

The Illawarra Greenhood Orchid - A Case Study

The Illawarra Greenhood orchid (*Pterostylis gibbosa*) is listed on the NSW Threatened Species Conservation Act, Schedule 1 as 'endangered'. The current ecological knowledge of this species is described in the draft Recovery Plan (NPWS 2002). The species is believed to have occurred from Parramatta to the Shoalhaven, but by the 1980s, few populations appeared to remain extant. Two of the most important populations occurred on land controlled by Transgrid, as part of an electricity supply substation. Early surveys estimated orchid numbers and annual flowering, and set up permanent quadrats for annual censuses. These early studies also identified grazing by rabbits and horses as potential threats to these two populations (Muston & Associates 1991). As a result, Transgrid removed horses that were being agisted and fenced the two sites to exclude rabbits. This in itself represents adaptive management at a simple level: (i) a potential problem was perceived, (ii) a simple response (fencing) was devised to address it, and (iii) monitoring was continued to test the effectiveness of the response. As Gill (1998) observed, even if a scientific management program cannot be applied, a manager can glean important information by careful observation, manipulation and careful monitoring of the effects of alternative treatments.

Establishment of the permanent quadrats and initial surveys at these two sites were completed as a small consultancy funded by Transgrid (Muston & Associates 1991), and the annual censuses are conducted by Graeme Bradburn of the Australian Native Orchid Society (ANOS). Further surveys and more detailed studies have been conducted by National Parks & Wildlife Service staff and by Environmental Science Honours students at the University of Wollongong (Dokonal 1996, Heylin 1997, Taylor 1998, Visman 2000).

These studies revealed that numbers of orchids remained static for several years (Fig. 2) but grass growth following removal of horse and rabbit grazing had permitted an increasing fire hazard and the potential for direct competition with orchids (Dokonal 1996; T. Chambers & G.

Bradburn personal communications). Clearly management was needed; what form should it take?

Many terrestrial orchids are facilitated by fire, or can at least survive (e.g. Leigh *et al.* 1984, Fischer 1996). Others are damaged by fire (e.g. Barnett 1984). Season of burning may be crucial, as this species dies back to a subterranean tuber every summer, and flowers in spring (Visman 2000). Discussions at this 'Assess Problem' (refer to Fig.1) phase of the project included representatives of the land-owner, the NPWS, the University of Wollongong, and ANOS. The outcome was a 'Design' (see step 2 in Fig. 1) that included prescribed burning to be applied in summer, but to only to part of each of the two sites. The part of each site to be burned was to be in two blocks, separated from each other. Figure 3 summarises the design. The boundaries of the treatment blocks were determined by locations of orchids in the two plots, detailed in previous surveys of these two sites in 1993 (QEM 1994) and 1996 (Dokonal 1996), and by the locations of the permanent quadrats that had contained reasonable densities of orchids in 1999 (Bradburn & Tunstall 1999).

Figure 2 near here

Figure 3 near here

Three features of the design are particularly critical in conducting experiments: (i) replication of sites, (ii) replication of treatment blocks (burned vs. unburned) within each site (though two replicates at each of these levels is barely sufficient), and (iii) interspersion of the treatments. These and other important elements of experimental design are detailed in Quinn & Keough (2002) and Underwood (1996).

The fires were conducted on 16th December 1999 by the National Parks and Wildlife Service, on behalf of Transgrid. Initial monitoring of the effects of the fires was achieved by an undergraduate Honours project, supported by Transgrid (Visman 2000) and by ongoing censuses of permanent quadrats by Graeme Bradburn (personal communication). The results of the fire study are as follows:

1. Despite the best laid plans, most of the permanent, $1m^2$ quadrats set up, in random locations, in 1990, have contained no orchids over 12 years of monitoring. Few quadrats have contained the majority of the orchids each year (>160 orchids in the densest quadrat in 2001). Further, not all of the quadrats that contained orchids, in the two areas in each site identified for burning, actually burned, because the fires were patchy and, in Site 2, smaller in area than initially planned. This was because conducting prescribed fires in summer can be risky, especially where ground fuel loads are substantial, dry and well aerated, so these fires were conducted in still weather, early in the morning, with high fuel moisture, in order to ensure effective control. These factors have reduced the power of the monitoring program, and of the fire study.
2. In Site 1, 22 of the 53 permanent quadrats were burned; in Site 2, 20 of the 57 were burned. There were no orchids in most of these quadrats over the 12 years of monitoring.
3. Of the permanent quadrats that contained orchids in the burned areas (see Fig. 2), some were only partly burned. Detailed mapping of individual orchids and of the fires (Visman 2000) allowed us to classify whether the orchids had appeared in the burned or the unburned portion of the quadrat.

4. Numbers of orchids per quadrat did not differ between the year prior to the fire (1999) and the year after (2000), or between 1999 and 2001 (Figure 4). The diagonal line in each of these scatter-plots represents the line of no difference between the two years being compared.
5. The fires did not affect the average diameter of the orchid rosettes, overall (Figure 5), though there appeared to be a difference in the western half of Site 2. To construct Figure 5, permanent quadrats were classified as being in one of 4 'blocks' (a block being an adjacent burned and unburned site): Site 1 south, Site 1 north, Site 2 west and Site 2 east. Orchids in the permanent quadrats were classified as burned or unburned, recognising that some quadrats were only partly burned.
6. The burned quadrat in Site 2 west that produced all the orchids in this comparison was one of the few overall that had recruited many seedlings in each year spanning the fires (110 in 1999, 72 in 2000 and 121 in 2001; see Bradburn 2001) whereas the quadrats that happened to be unburned produced much less recruitment. Thus, the apparent difference in Site 2 west can be attributed to the fact that one of the burned quadrats happened to contain many seedlings whereas the unburned quadrats contained mostly adults. This result emphasises the need to measure appropriate parameters both before and after the experimental treatment. In this study, rosette diameters were not measured prior to burning.
7. Two of the quadrats that were partly burned contained relatively large numbers of plants (62 and 32), some of which were in each part of the quadrat. Table 1 shows that mean orchid diameter did not differ between the burned and unburned orchids in either of these quadrats.
8. Visman (2000) also found that, overall, the proportion of rosettes that flowered was much less in 2000 than in 1999 (11% vs. 34%) but that this drop was independent of burning. In 2000, the proportions flowering in burned and unburned quadrats (and portions of quadrats) were equivalent (12.5% for burned orchids and 10.5% for unburned).

Figure 4 near here

Figure 5 near here

Table 1 near here

In summary, this adaptive management study indicated that fires in the 1999-00 summer period, at the time of year when the orchids were present only as below-ground tubers, had little effect on either orchid numbers or rosette sizes (measured in June/July each year). Increases in numbers due to recruitment (Fig. 2), which were contributed by just a few of the permanent quadrats, appear to be quite independent of the fire treatment.

The study itself is not without flaws, from a scientific perspective. Treatments could not be allocated to plots truly at random, because safety considerations (both for firefighters and orchids!) required easy access to the burned plots. There were relatively few quadrats that contained orchids in each of the burned treatments, orchids were clumped in a very few quadrats, there were only two burned areas in each site, and only two site. Together, these characteristics of the design reduce its statistical power and our ability to generalize from the results. However, the effort that has been directed at the monitoring and other experimental studies, via student projects, is greater than most land managers would be able to mobilize.

Conclusions

Walters (1997) assessed the outcomes of 25 adaptive management programs in fisheries, in which he had been personally involved. Only seven of these resulted in experimental management studies. Of these, only two experiments were well enough designed to answer the questions being posed. In a similar vein, Wilhere (2001) surveyed a large number of 'Habitat Conservation Plans' that have been developed in the USA, and concluded that only 5% of these plans included monitoring that would be sufficient to evaluate the success of the plan's implementation.

These findings are cause for pessimism in relation to adaptive management. However, these detailed analyses allow us to investigate the possible reasons for failure and learn from them in designing a better application of adaptive fire management. Most of the management issues in Walters' analysis related to commercial enterprises, such as fisheries. He identified several main classes of impediment to successful adaptive management programs:

(i) Problems with the initial modelling phase (from 'Assess Problem' to 'Design' in Figure 1), in which increasingly complex modelling is substituted for prediction and field studies designed to test the predictions;

(ii) Costs of monitoring in large-scale management experiments, where managers tend to reduce the size of the experiment (compromising replication and therefore power) rather than integrating the funding for research and monitoring into the overall management program, or looking for and supporting innovative ways of achieving adequate monitoring;

(iii) Risks of particular outcomes to stakeholders, where a particular outcome (or an experimental treatment) is likely to have an economic impact (for the commercial partner) or an unpalatable biodiversity impact (e.g. reduction in numbers of a threatened species);

(iv) Self-interest of research and management organisations, in which the design of the research and monitoring is determined more by the past practices, expertise, and reward systems of the researchers and managers than by a dispassionate assessment of the hypotheses advanced and the methods needed to test them;

(v) Fundamental differences in ecological values, producing very different opinions on the nature of the ecological outcome of the management that is acceptable.

Several of these problems are potential impediments to effective adaptive management of fire regimes in NSW, and some are not. In fire management on protected lands, biodiversity conservation is clearly stated as the primary management objective and there are no commercial interests (NPWS 2001). Thus, it should be relatively easy for stakeholders to agree on the nature of the questions that need to be addressed. However, the need to protect lives and property in neighbouring lands provides the potential for clashes of ecological values, in assessing what level of reduction in biodiversity or alteration to ecological processes in the protected lands would be 'acceptable' in achieving protection.

The issue of self-interest of researchers or managers has the potential to hijack experimental designs and monitoring programs. As Walters (1997) stated, a cooperative approach at the very start of an adaptive management project is the best protection against this problem.

The issue of adequate funding of monitoring in an adaptive management program is currently, in my view, the greatest threat to effective adaptive management. Monitoring of the Illawarra Greenhood Orchid has been possible because of the time contributed gratis by students in Environmental Science at the University of Wollongong and by members of the Australian Native Orchid Society. Monitoring of Ground Parrot and Eastern Bristlebird responses to fire has been possible because of extensive volunteer input coordinated by Birds Australia (Baker & Whelan 1994; Whelan & Baker 1999) and by a large-scale PhD project (Baker 1997) respectively. It is doubtful whether any of these would have been achieved if the full cost of monitoring, even of these relatively small-scale studies, had to be borne totally by the management agency; it is much more likely that the monitoring would have been seen as a 'research component', which would have been pruned from the management budget, thus converting true adaptive management into a 'trial-and-error', in which the trial is established but assessment of the error neglected.

Our challenge is therefore to achieve the following (see Figure 6): (i) Commitment from the stakeholders to cooperate in getting the goals and objectives of an adaptive management program right; (ii) Commitment from managers to apply the experiment as designed; (iii) Commitment from funding agencies to guarantee adequate support for monitoring as an integrated component of the program; (iv) Input of scientists, especially in the design and analysis phases; (v) A process for recording and disseminating the results of the program.

Figure 6 near here

Acknowledgements

I thank Honours students in the University of Wollongong Environmental Science Program over the years (Zoran Dokonal, Elisa Heylin, Inger Taylor and Karen Visman) for their work on *Pterostylis gibbosa*. Ros Muston initiated our interest in *Pterostylis gibbosa* and Tom Chambers (Transgrid) has continued the funding for management and monitoring of its populations. Graeme Bradburn (and other members of the Aust. Native Orchid Society) has generously contributed his expertise and assistance; without him the *Pterostylis gibbosa* project would not have been achievable. Thanks to Louise Meades for commenting on a draft of this paper.

Bibliography

Baker, J.R., 1997, The decline, response to fire, status and management of the Eastern Bristlebirds. *Pacific Conservation Biology,* Vol. 3, pp 235-243.

Baker, J.R., 2002, ??? title??? In: Halse, S. (Ed.) *Bush Fire: Managing the Risk.* The Nature Conservation Council of NSW, Sydney, pp. ??-??.

Baker, J. & Whelan, R.J., 1994, Detecting long-term population trends in the ground parrot. *Emu,* Vol. 94, pp 300-304.

Barnett, J.M., 1984, The initial effects of fire on orchids in a Stringybark forest. *Victorian Naturalist,* Vol. 101, pp 188-190.

Bradburn, G., 2001. *2001 Census of* Pterostylis gibbosa *(Illawarra Greenhood Orchid, Transgrid: Yallah Site.* Report to Transgrid and NPWS.

Bradburn, G. & Tunstall, R., 1999, *1999 Census of* Pterostylis gibbosa *(Illawarra Greenhood Orchid, Transgrid: Yallah Site.* Report to Transgrid and NPWS.

Bradstock, R.A., Williams, J. & Gill, A.M. (Eds), 2002, *Flammable Australia: Fire Regimes and Biodiversity of a Continent.* Cambridge University Press, Cambridge.

Canadian Ministry of Forests, 2000a, <http://www.for.gov.bc.ca/hfp/amhome/amhome.htm> (accessed 11th July 2002).

Canadian Ministry of Forests, 2000b, <http://www.for.gov.bc.ca/hfp/amhome/SUMMARY/Donna.htm> (accessed 11th July 2002).

Catling, P., 1991, Ecological effects of prescribed burning practices on the mammals of southeastern Australia. In: Lunney, D. (Ed.) *Conservation of Australia's Forest Fauna.* Royal Zoological Society of NSW, Mosman, pp 353-363.

Clarke, P., & Knox, K.J.E., 2002, Post-fire response of shrubs in the tablelands of eastern Australia: do existing models explain habitat differences? *Australian Journal of Botany,* Vol. 50, pp 53-62.

Dokonal, Z., 1996, *Identifying Factors Affecting the Distribution and Abundance of the Endangered Illawarra Greenhood Orchid,* Pterostylis gibbosa. B. Env. Sci. (Hons) Thesis, University of Wollongong.

Dovers, S.R. & Mobbs, C.D., 1997, An alluring prospect? Ecology, and the requirements of adaptive management. In: Klomp, N. & Lunt, I. (Eds) *Frontiers in Ecology: Building the Links.* Elsevier, Oxford, pp 39-52.

Ecological Society of Australia, 1999, *Position Statement: The Use of Fire in Ecological Management*. <http://life.csu.edu.au/esa/esaPSfire.html#Future> (accessed 15th July 2002).

Fisher, J.T., 1996, Fire in flora and fauna management. In: *Fire and Biodiversity: The Effects and Effectiveness of Fire Management.* Dept. of Environment, Sport and Territories, Canberra, pp 241-246.

Gill, A.M. (1998), Monitoring for biodiversity in fire-prone areas. In: *Fire Management, Presented Papers, Natural Resource Management Workshop, Rockhampton, Qld,* Department of the Environment. (Pages unnumbered).

Green, R.H., 1979, *Sampling Design and Statistical Methods for Environmental Biologists.* Wiley, New York.

Halbert, C.L., 1993, How adaptive is adaptive management? Implementing adaptive management in Washington State and British Columbia. *Reviews in Fisheries Science,* Vol. 1, pp 261-283.

Heylin, E., 1997, *Study of the Rare and Endangered Illawarra Greenhood Orchid,* Pterostylis gibbosa. B. Env. Sci. (Hons) Thesis, University of Wollongong.

Hilborn, R. and Walters. C.J., 1992, *Quantitative Fisheries Stock Assessment and Management: Choice, Dynamics and Uncertainty.* Chapman & Hall, New York.

Holling, C.S. (Ed.), 1978, *Adaptive Environmental Assessment and Management*. Wiley, New York.

Keeley, J.E. and Fotheringham, C.J., 2001, History and management of crown-fire ecosystems: A summary and response. *Conservation Biology,* Vol. 15, pp 1561-1567.

Lee, K.N., 1993, *Compass and Gyroscope: Integrating Science and Politics for the Environment*. Island Press, Washington, DC.

Leigh, J.H., Boden, R., and Briggs, J., 1984, *Extinct and Endangered Plants of Australia.* MacMillan, Melbourne.

Lessard, G., 1998, An adaptive approach to planning and decision-making. *Landscape and Urban Planning,* Vol. 40, pp 81-87.

Morrison, D.A., Cary, G.J., Pengelly, S.M., Ross, D.G., Mullins, B.J., Thomas, C.R. and Anderson, T.S., 1995, Effects of fire frequency on plant species composition of sandstone communities in the Sydney region: inter-fire interval and time-since-fire. *Australian Journal of Ecology,* Vol. 20, pp 239-247.

Muston and Associates, 1991, *Plan of Management for the Rare and Endangered Illawarra Greenhood Orchid (*Pterostylis gibbosa*) on Property Owned by the Electricity Commission of NSW at Yallah.*

Nieuwenhuis, A., 1987, The effect of fire frequency on the sclerophyll vegetation of the West Head, New South Wales. *Australian Journal of Ecology*, Vol. 12, pp 373-385.

NPWS, 2001, *NSW National Parks and Wildlife Service Corporate Plan.* NPWS, Hurstville, NSW.

NPWS, 2002, *Draft Recovery Plan for the Illawarra Greenhood Orchid.* <http://www.npws.nsw.gov.au/news/recovery_plans/PgibbosaDraftPlan.pdf> (accessed 30th August 2002).

QEM, 1994, *Conservation Research Statement and Species Recovery Plan for the Endangered Illawarra Greenhood Orchid,* Pterostylis gibbosa *R. Br.: Draft Report.* Australian Nature Conservation Agency, Canberra.

Quinn, G. and Keough, M., 2002, *Experimental Design and Data Analysis for Biologists*. Cambridge University Press, Cambridge.

Taylor, I., 1998, *Study of Herbivory and Pollination in the Endangered Illawarra Greenhood Orchid,* Pterostylis gibbosa. B. Env. Sci. (Hons) Thesis, University of Wollongong.

Threatened Species Conservation Act (TSCA) (1995). <http://www.austlii.edu.au/au/legis/nsw/consol_act/tsca1995323/>

Underwood, A.J., 1995, Ecological research and (and research into) environmental management. *Ecological Applications,* Vol. 5, pp 232-247.

Underwood, A.J., 1996, *Experiments in Ecology*. Cambridge University Press, Cambridge.

Visman, K.N., 2000, *The Effects of Fire on the Rare and Endangered Illawarra Greenhood Orchid,* Pterostylis gibbosa. B. Env. Sci. (Hons) Thesis, University of Wollongong.

Walters, C.J., 1986, *Adaptive Management and Renewable Resources.* McMillan, New York.

Walters, C.J., 1997, Challenges in adaptive management of riparian and coastal ecosystems. *Conservation Ecology* [online], Vol. 1, <http://www.consecol.org.vol1/iss2/art1>

Walters, C.J. & Holling, C.S., 1990, Large-scale management experiments and learning by doing. *Ecology,* Vol. 71, pp 2060-2068.

Whelan, R.J., 1995, *The Ecology of Fire*. Cambridge University Press, Cambridge.

Whelan, R.J., 2002a, Don't fight fire with fire. *Nature,* Vol. 416, p 15 [March 7].

Whelan, R.J., 2002b, Managing fire regimes for conservation and property protection: an Australian response. *Conservation Biology* (in press).

Whelan, R.J. and Baker, J.R., 1999, Fire in Australia: coping with variation in ecological effects of fire. In: Sutton, F., Keats, J., Dowling, J. and Doig, C. (eds), *Protecting the Environment, Land, Life and Property. Proceedings of the Bushfire Management Conference.* NSW Nature Conservation Council, Sydney, pp. 71-79.

Wilhere, G.F., 2002, Adaptive management in habitat conservation plans. *Conservation Biology,* Vol. 16, pp 20-29.

Table 1: Comparison on mean rosette diameters of orchids in burned vs. unburned parts of two partly burned quadrats. These means did not differ significantly.

	Burned part		*Unburned part*	
	Diameter (mm)	*n*	*Diameter (mm)*	*n*
Quadrat 1	22.7 ± 2.55	13	20.6 ± 1.30	49
Quadrat 2	27.5 ± 2.71	25	28.9 ± 3.84	7

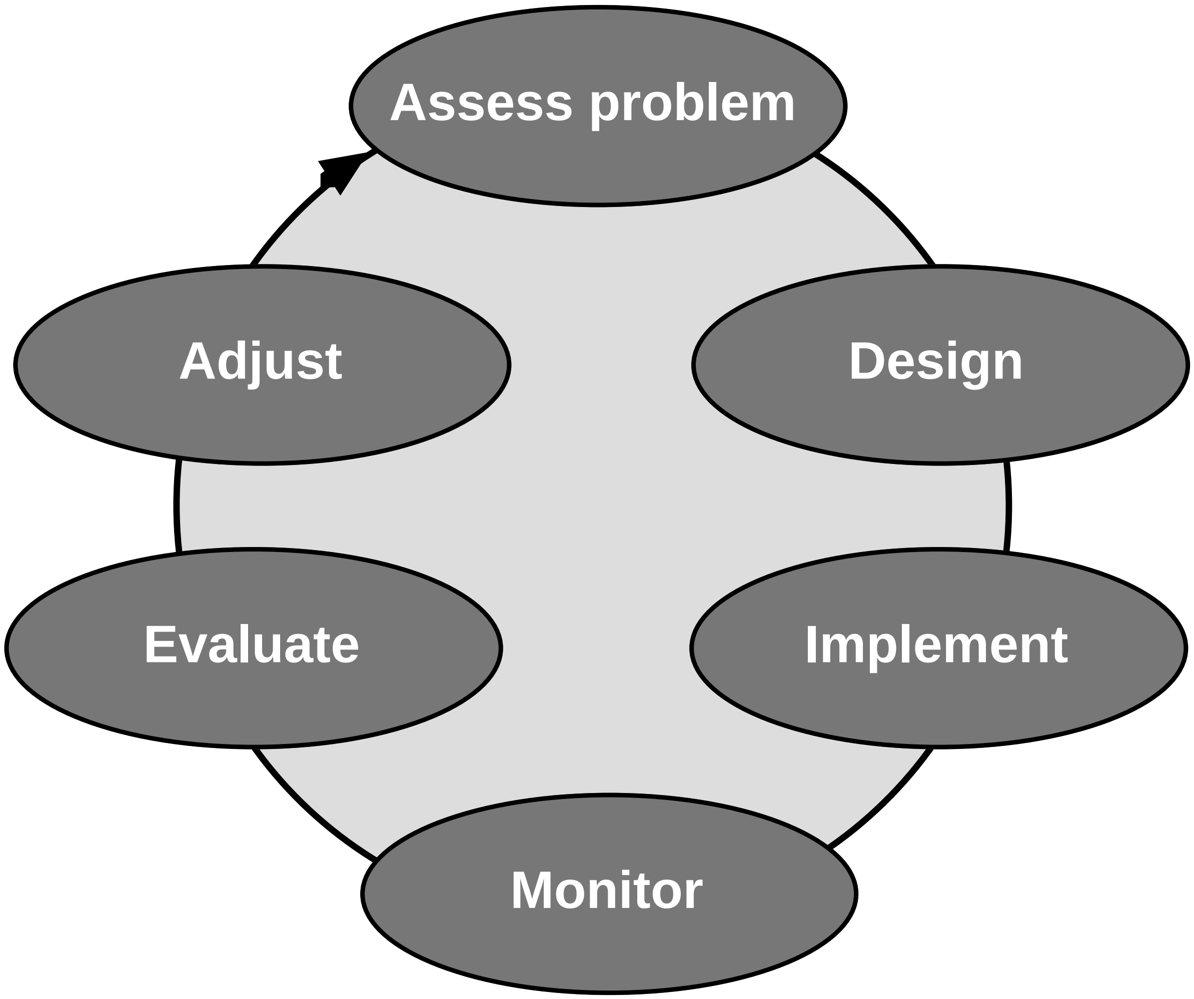

Figure 1: Six-step cycle defining the adaptive management process, as used by the Canadian Ministry of Forests (2000a)

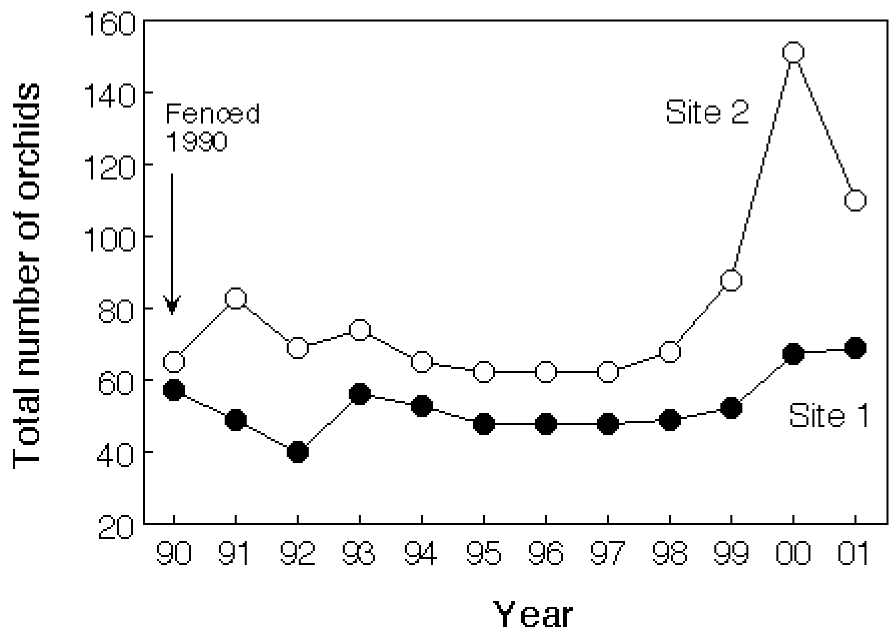

Figure 2: Trends in total numbers of mature orchid plants in all permanent quadrats in Sites 1 & 2, based on annual censuses in June/July each year. Mature plants are classified as those with >2 leaves in the rosette. Experimental fires were applied in December 1999. Note that numbers remained static for 10 years after fencing of the sites to exclude horses and rabbits.

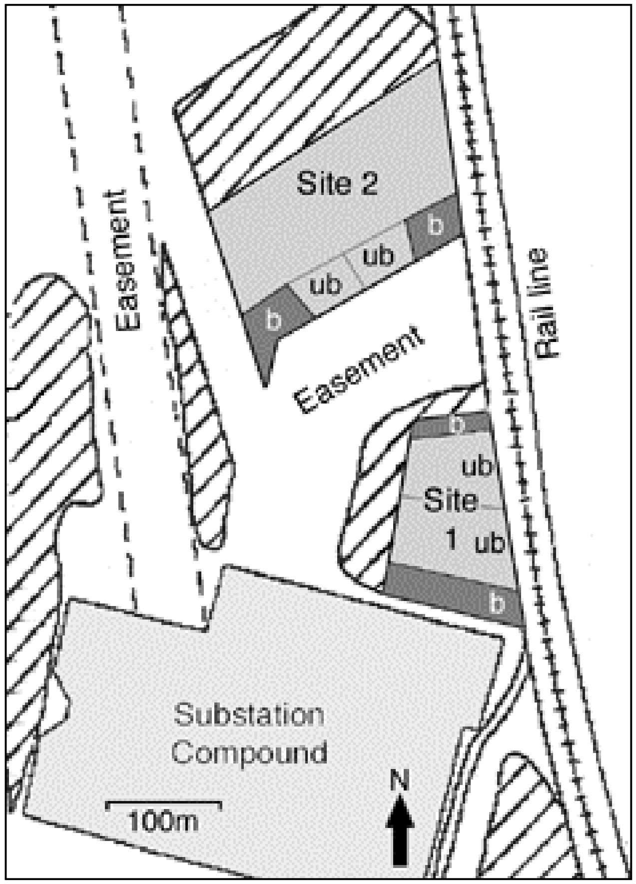

Figure 3: Study area for *Pterostylis gibbosa* showing remnant vegetation (hatched), two fenced sites (Site 1 and Site 2), and burned (b) and unburned (ub) treatments. Access for fire control constrained burned areas to edges of each site.

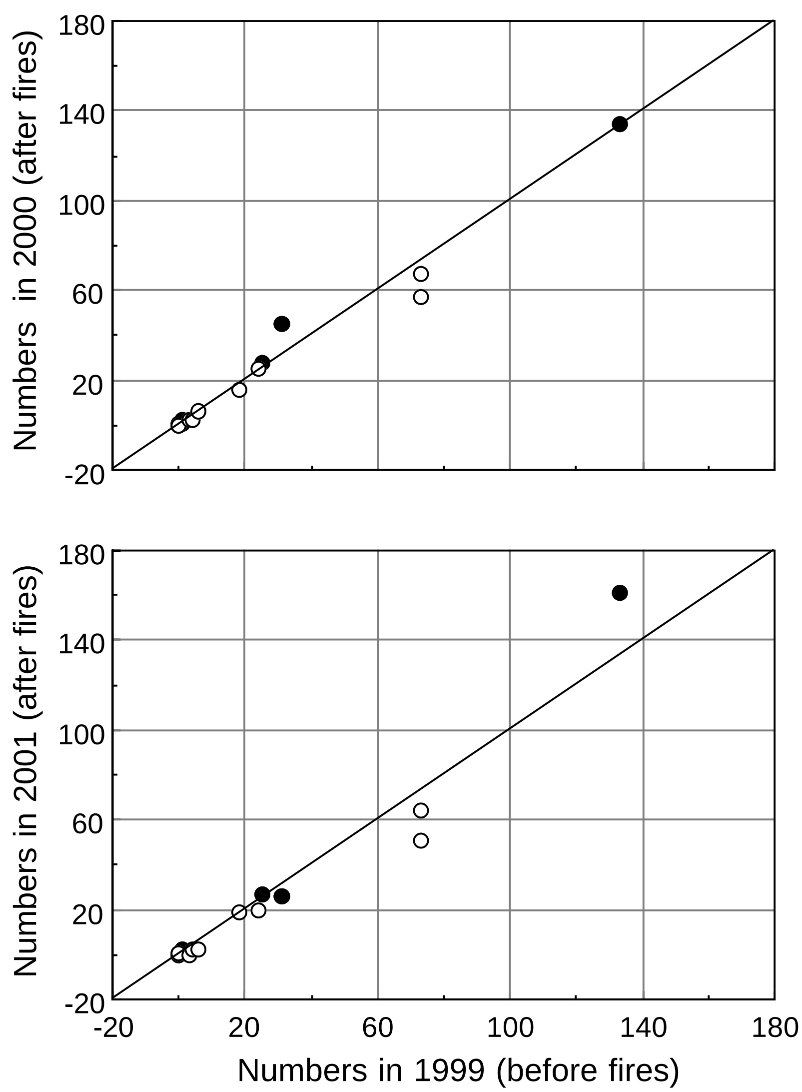

Figure 4: Relationship between numbers of orchids in 1999 (before fires) and numbers in 2000 (after fires) for those quadrats that had orchids in any year during the 12 years of the study. Each point represents a single quadrat: dark symbols are burned quadrats, open symbols are unburned. A point falling on the diagonal line represents a quadrat with equal numbers in 1999 and 2000.

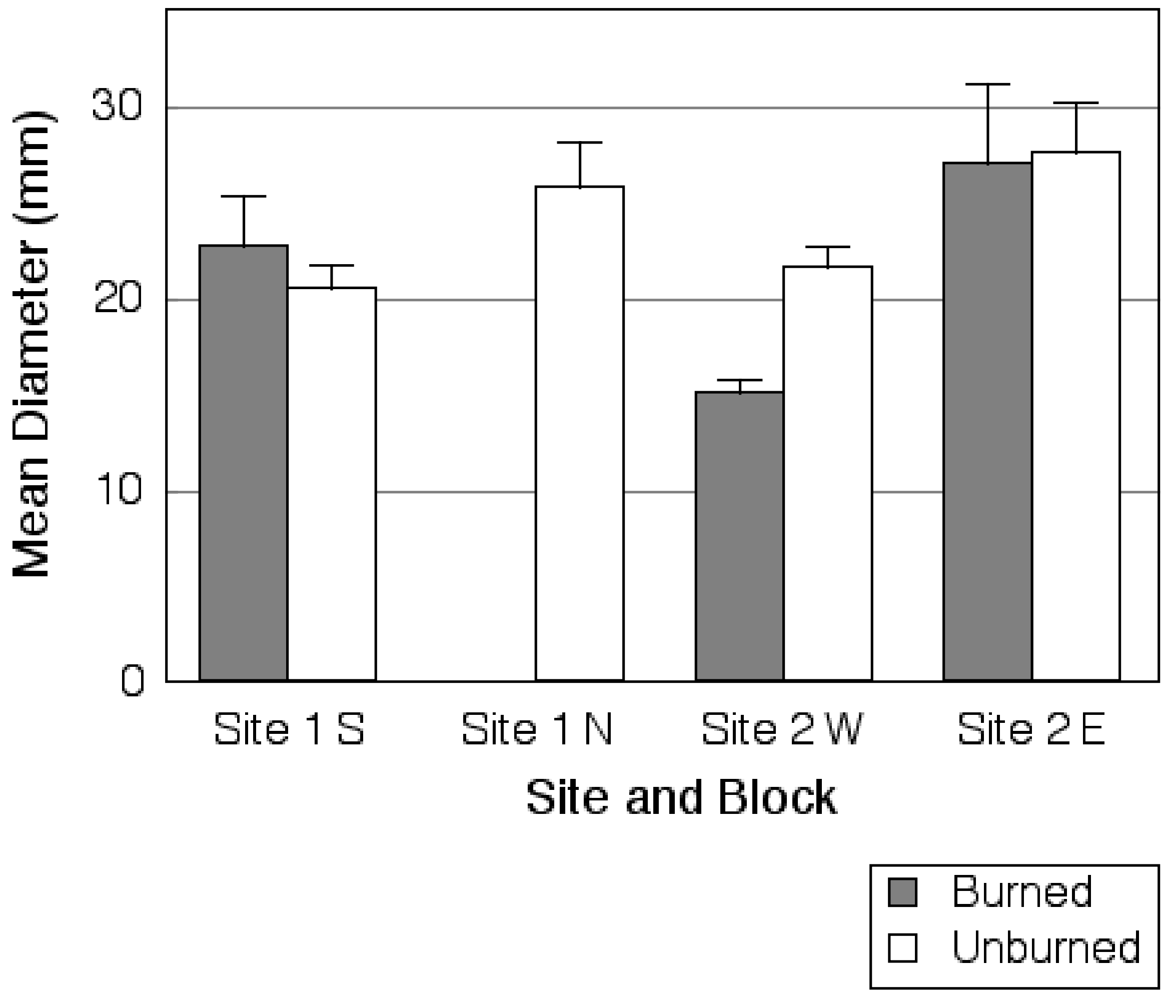

Figure 5: Comparisons of mean diameter of orchids in burned and unburned permanent quadrats in each 'block' (burned plus unburned pair) in Site 1 and in Site 2. (Note: there were no orchids in any of the burned quadrats in the northern burn in Site 1).

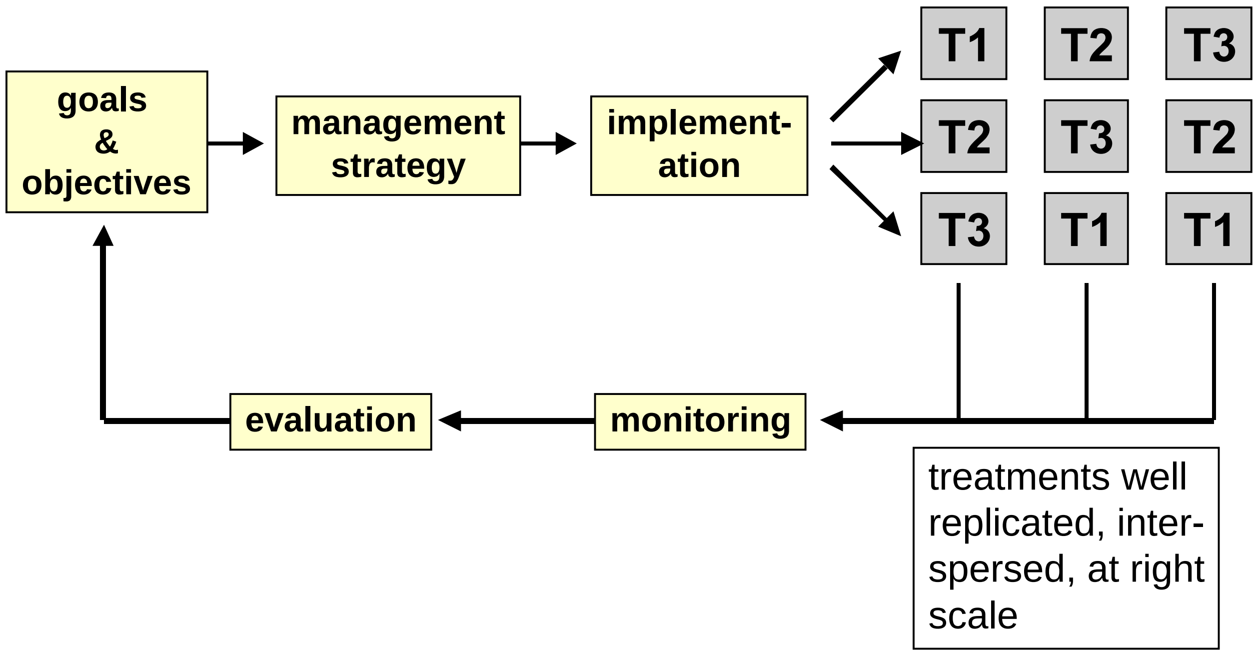

Figure 6: Adaptive management scheme, in which all elements need to be completed successfully to achieve an effective outcome. Modified from Lessard (1998).