

A framework for the improved management of threatened species based on Population Viability Analysis (PVA)

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Considerable funding and effort is dedicated to the conservation and recovery of threatened species in Australia. We describe a series of five iterative steps that will improve the effectiveness of programmes for threatened species management. These steps are best integrated using Population Viability Analysis (PVA) in an approach to management where the key stages are completed concurrently. In this way management actions for the conservation of threatened species can be regularly assessed and upgraded as more information and improved computer simulation models become available.

INTRODUCTION

A LOT of the conservation effort in Australia is dedicated to preventing the extinction of threatened species (Australian National Parks and Wildlife Service 1989, 1992). Over the past 12 months the Endangered Species Programme co-ordinated by the Australian National Parks and Wildlife Service allocated five million dollars for the conservation and recovery of threatened species (Common and Norton 1992). At a State level, Victoria committed a total of \$653 000 in the 1991–1992 financial year to the implementation of management plans for the Helmeted Honeyeater *Lichenostomus melanops cassidix*, Leadbeater's Possum *Gymnobelideus leadbeateri* and the Eastern-barred Bandicoot *Paramelotes gunii* (Department of Conservation and Environment 1991).

Recent efforts to conserve and manage threatened species have concentrated on the development of species recovery plans and biological research. However, much of this work proceeds by the educated guesses of scientists and managers familiar with the target species and not through the objective assessment of alternative management options. In this paper we outline a more objective and efficient approach for managing threatened species based on a sequence of steps that are integrated using Population Viability Analysis (PVA).

Once a species has been identified as threatened, we argue that there are five tasks that need to be completed simultaneously within a programme for its recovery: (1) collating existing information on the species; (2) listing and costing management options; (3) ranking management options using PVA; (4) using sensitivity analysis

to test the ranking and guide future research; and (5) implementing the best option with repeated monitoring and re-evaluation of the programme. The use of PVA is fundamental to most of these steps, and we discuss some of the more valuable features of the technique for threatened species management. In this paper we define threatened species as those categorized by the I.U.C.N. as rare, vulnerable and endangered (Mace and Lande 1991).

WHAT IS POPULATION VIABILITY ANALYSIS (PVA)

Population Viability Analysis (PVA) is a process in which the likelihood that a population will become extinct is assessed, within a specified time and under particular circumstances (Shaffer 1981; Possingham 1991; Boyce 1992). This process often involves the use of mathematical models that are explored using computer simulation.

Although PVAs have probably been carried out on over 50 populations (Boyce 1992), the details of many studies are published in literature that is generally not accessible, while many others remain unpublished. Some overseas examples of the use of PVA are: work by Shaffer (1983) on the grizzly bear *Ursus arctos horribilis*, several papers and reports on the northern spotted owl *Strix occidentalis caurina* (e.g., Marcot and Holt-hausen 1987; Lande 1988; Thomas *et al.* 1990; Lamberson *et al.* 1992) and several reports and papers that use a PVA package called VORTEX to assess the viability of small populations (Lacy 1992).

Within Australia the application of PVA is advocated by a range of Australian Federal Government agencies responsible for sustainable natural resource management and the conservation

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of biodiversity (e.g., Ecologically Sustainable Development Working Group 1991; Resource Assessment Commission 1992). Possingham and Noble (1991) use PVA to examine the probability of persistence of the Powerful Owl *Ninox strenua* under different forest management scenarios in south-east New South Wales. Based on a range of biological data on the eastern barred bandicoot *Perameles gunnii* input to the PVA programme VORTEX, Lacy and Clark (1990) predict that the population of the species in western Victoria will be extinct within 25 years. Lindenmayer *et al.* (1991) explore the viability of Leadbeater's possum *Gymnobelideus leadbeateri* under several scenarios including climate change.

Measures other than the probability of extinction within a certain time can be used to assess population viability. The median time to extinction is the time at which there is a 50 per cent chance the population is extinct. Quasi-extinction (*sensu* Ferson and Burgman 1990) is the probability that a population will decline to a small number like twenty. Quasi-extinction is an important measure because little is known about the dynamics of very small populations and the associated decline of genetic diversity. As the conservation of small remnant populations can be very expensive (Menkhorst and Middleton 1991) measures of quasi-extinction can be used to help manage populations before they reach a minimum critical size.

The probability of extinction and/or quasi-extinction is usually derived from a Monte Carlo simulation of an array of interacting processes that may influence populations of animals. Most programmes for PVA typically emphasize those processes considered to have the greatest impact on the probability of extinction, including estimates of the life-history and demographic parameters of a species, the frequency and relative impact of catastrophes on populations and a range of potentially significant environmental and genetic factors.

Despite all these studies, only a few have explicitly and adequately used PVA to choose between different management options. The most celebrated example is that of the northern spotted owl, where Thomas *et al.* (1990) use PVA, to choose critical areas that would support about 20 pairs each and ensure landscape management that reduces dispersal mortality (a significant threatening process for this population).

PVA AND THREATENED SPECIES MANAGEMENT

There are two broad objectives in threatened species management. A short-term objective is to minimize the probability that the target species will become extinct. A longer term objective is to ensure that the species retains its potential for

evolutionary change without intensive management. Notably, few species recovery programmes have such a long-term focus. PVA can assist in realizing both these objectives. Within this context, the approach can be used to address three aspects central to threatened species management: design of programmes for further research; compilation of lists of threatened species; and identification and assessment of management options.

Planning research and data collection

The most important data for applied species conservation are those necessary to assess the relative viability of the species and to list and rank management options. PVA may reveal that population viability is insensitive to particular parameters. Consequently, it may be unnecessary to expend additional effort and resources to obtain better estimates of those parameters. Research should be targeted at those factors identified by PVA as having a potentially significant impact on extinction probability or the ranking of management options.

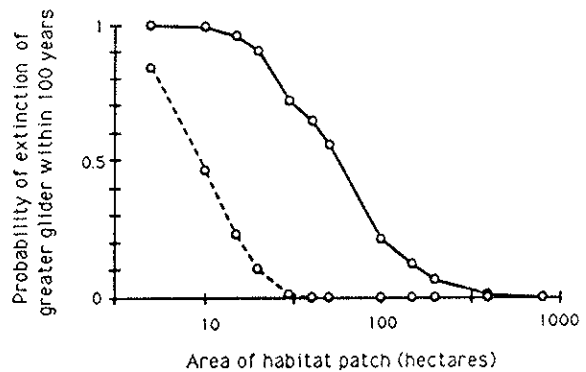


Fig. 1. Output from the programme for PVA, ALEX, showing the predicted probability of persistence of the greater glider *Petauroides volans* in patches of different sized high quality habitat with (—) or without (---) owl predation.

Figure 1 shows that the viability of a population of greater gliders *Petauroides volans* in optimal habitat is very sensitive to whether or not there is owl predation (Noble and Possingham 1991). Figure 2 shows that the viability of a southern brown bandicoot population in a forest block in the south-east of SA is relatively insensitive to the probability of adult dispersal (Possingham *et al.* 1993).

Listing of threatened species

Lists of threatened species are becoming increasingly important in the development of policies and legislation for the conservation of threatened species. PVA can provide an objective mechanism to assess the vulnerability of a species

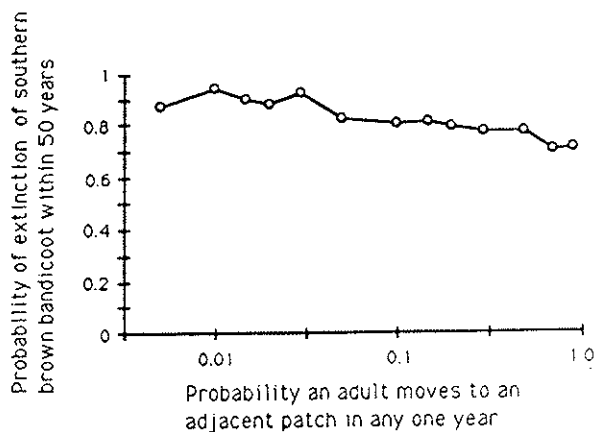


Fig. 2. Viability over 100 years of the southern brown bandicoot *Isoodon obseleus* in Honan's scrub in the SE of SA as a function of the probability that adult females move between adjacent forest compartments in any year.

to extinction (Mace and Lande 1991) and, in turn, to compare it to other taxa believed to be threatened. This ranking can be used with other criteria such as cultural significance (Davis *et al.* 1992) and taxonomic uniqueness (Faith 1992) to set priorities for species conservation programmes.

Although the task of assessing the viability of large lists of species using computer models is currently too great, Belovsky (1987) has used empirical observations and mathematical models to estimate minimum viable population sizes for many North American mammals.

Ranking management options

The most important use of PVA is to guide threatened species management by estimating the extinction probability associated with different management options. The approach can be used to predict the likely response of a species to management actions such as re-introduction, captive breeding (Lacy *et al.* 1990), prescribed burning (Possingham *et al.* 1993), timber harvesting (Possingham and Noble 1991), the

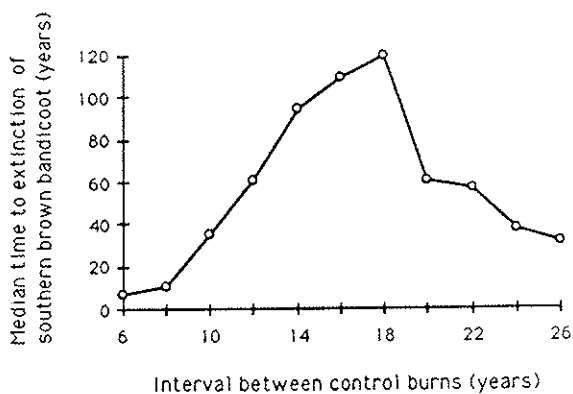


Fig. 3. Viability over 100 years of the southern brown bandicoot *Isoodon obseleus* in Honan's scrub in the SE of SA as a function of interval between control burns for those compartments scheduled for control burning.

acquisition of a network of reserves (Thomas *et al.* 1990) and the implementation of wildlife corridors.

Thomas *et al.* (1990) use a spatially explicit PVA model to determine the optimal size of Habitat Conservation Areas for the northern spotted owl. For single species reserve design it is useful to know the relationship between the size of a patch of habitat and the viability of a population within that patch (Fig. 1).

A PVA of a population of southern brown bandicoots in Honan's scrub (a forest reserve in south east South Australia) suggests that the optimal interval between control burns for this species is about eighteen years (Fig. 3, Possingham *et al.* 1993).

STEPS FOR THREATENED SPECIES MANAGEMENT

A sequence of five main steps for threatened species management is outlined in Figure 4. These are treated in more detail below. Where urgent action is required, management strategies may need to be implemented before several of the steps are initiated. However, the success of each step will largely depend on the success of the others in the sequence. The most effective threatened species management programmes are most likely to be those where the processes of data collection, computer simulation modelling, on-ground management and monitoring are integrated.

Step 1. Collate existing information on a species

Before gathering new information on a species it is essential to assemble existing data. Even though there will be uncertainty about the value of many parameters, it is worthwhile attempting a PVA because the process of assembling input data for analysis will focus future research by highlighting gaps in existing knowledge.

If adequate information exists for the target species, then a first step is to determine if it is threatened. PVA can be used to quantify the probability of extinction for a range of time frames (e.g., 100–200 years). Different species can be ranked according to their extinction probability (and other PVA outputs). We believe that there should be an attempt to quantify the probability of extinction as one means of setting priorities.

Step 2. Generate, list and cost management options

The process of generating, listing and then costing management options is often forgotten in the conservation of threatened species. For some species there may be no practical management options that can be funded in the foreseeable

future, regardless of the conservation status of that species. An option like maintaining a species in long-term captive breeding programmes may be unacceptable. In these cases, further research may be pointless unless it might lead to alternative management options. It appears inevitable that some species will be lost irrespective of the management action that is taken. A risk analysis framework can be useful at this step (Maguire 1991).

Step 3. Assess each management option using PVA

PVA generates predictions of trends in population behaviour and dynamics in response to various influences and the interactions between

such factors. The relative effects of key parameters on the viability of a species to extinction can be quantified for any time frame and spatial scale. Thus, management options can be ranked according to their impact on the viability of populations of organisms.

Step 4. Sensitivity analyses

Estimates of population viability will be sensitive to the parameters input to the programme used for PVA at all stages in the sequence of steps for threatened species management. As the values for given attributes are varied, there will be changes in the predicted probability of extinction. Large changes in some parameters may have a

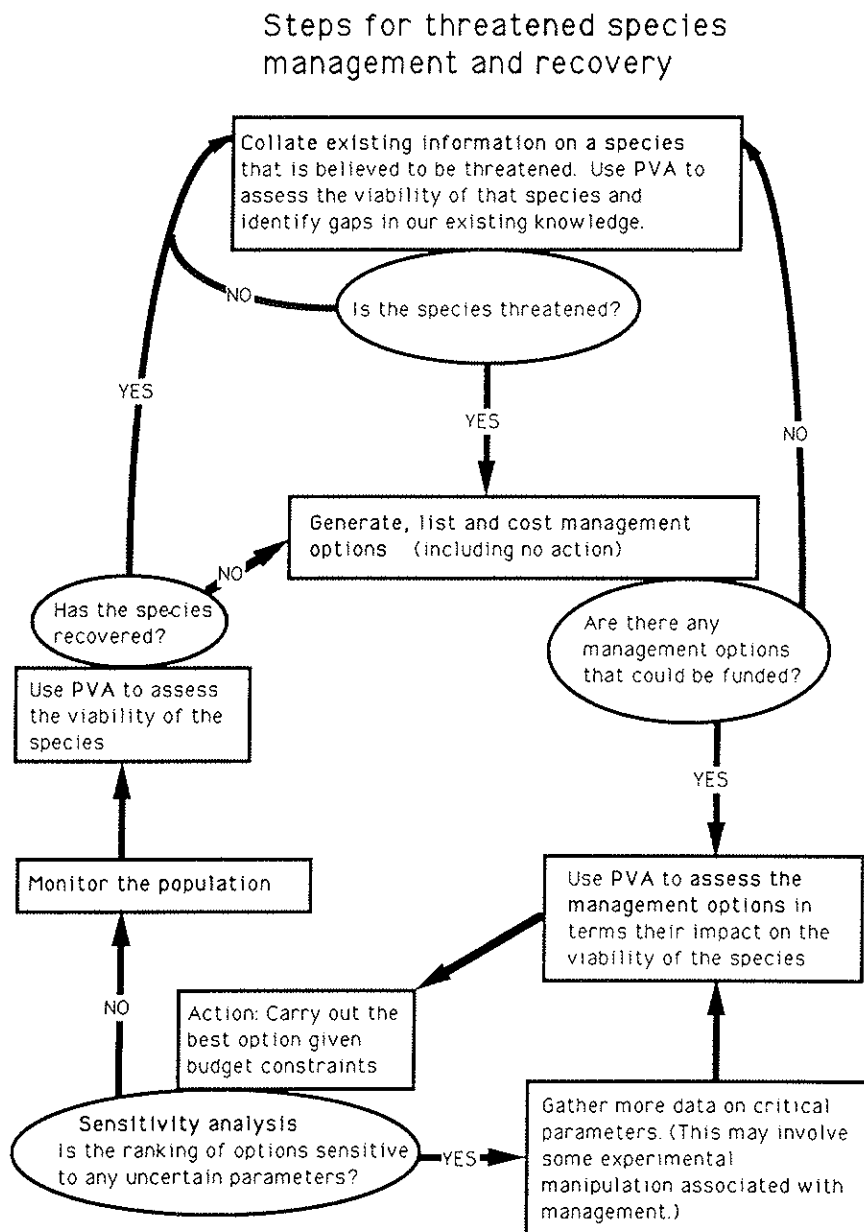


Fig. 4. Key steps and iterative framework for threatened species management and species recovery programmes.

minimal effect on the probability of extinction (Fig. 2). Conversely small variations in other factors may have considerable impact on extinction probability (Figs 1 and 3) and PVA should be used to carefully assess the response of the population to these critical attributes. This process is termed sensitivity analysis and it is an important procedure for assessing and ranking management options for a threatened species programme. This is because for wildlife management, the most important consideration may not be the absolute extinction probability but the extinction probability *relative* to those derived for other management options. Furthermore, most options for conservation will be relatively insensitive to realistic variations in many parameters input to PVA.

Step 5. Monitor the population

Monitoring is a critical component of any programme for the management of threatened species. It is essential for any recovery programme and must not be viewed as second-rate science or management practice (Common and Norton, in press). Field-based monitoring should be coupled with on-going sensitivity analyses using PVA. Thus, as further information on key life-history attributes or other population parameters become available, programmes for PVA can be refined and the more comprehensive dataset subjected to re-analysis. The procedure for coupling data collection, ongoing analyses and the regular re-assessment of management options is termed "adaptive management" (Holling 1978). Such an approach is valuable as it allows management actions to be relaxed if the target species recovers and is no longer threatened. Resources can then be re-allocated to the conservation of other taxa of higher priority.

DISCUSSION

The use of PVA offers a wide range of benefits for programmes designed to ensure the conservation of threatened species. Some of the most important of these are allied to the quantitative and objective nature of the technique (Lindenmayer and Possingham 1991; Lindenmayer *et al.*, in press). Its application can help place a quantitative value on the impact of proposed resource development and exploitation activities. PVA can also help overcome the problems associated with the subjective judgements made by wildlife biologists and managers who may have predetermined opinions about the conservation status of, and management strategies for populations they know well. Although we have emphasized the role of PVA in the management of threatened species, the approach can also provide information that is valuable for the conservation of other organisms that are not threatened, but which may be important for ecosystem function (Norton and Possingham 1991).

PVA is a single species approach to conservation biology. However, suitable management strategies for many species may also conserve a wide range of other organisms. For example, appropriate forest management practices for Leadbeater's possum will assist the survival of the greater glider and other fauna dependent on trees with hollows (Lindenmayer 1992). However, a management regime for the conservation of a particular organism is unlikely to be appropriate for every species. Given this, together with the impossibility of completing PVA for all taxa, the identification of those species best targeted for PVA is crucial. Some important target organisms for analysis include:

- i. *Well studied species*. These are valuable to assess because the accuracy of predictions from PVA are dependent on the accuracy of the data used to run the model. Analyses of these species can be used to develop, test and validate various components of programmes used for PVA.
- ii. *Keystone species*. These are organisms that are important to a number of other species or critical for ecosystem function.
- iii. *Indicator species*. These are easily censused species that are sensitive to changes in the environment such as some invertebrates.
- iv. *Threatened species*.
- v. *Species of special cultural value*.

Programmes for use in PVA

There is a range of models for use in PVA (Lindenmayer *et al.* 1991). Three that are currently available include VORTEX (Lacy 1992), ALEX (Possingham *et al.* 1991) and RAMAS/Space (Akçakaya and Ferson 1992). These are presently being compared in a detailed assessment of key models for use in the assessment of population vulnerability. This will assist users to decide which programme is best suited to the analyses and management of the target species. For example, for a very small, isolated population, the impacts of inbreeding depression and genetic drift may be important and the use of the programme VORTEX may be most appropriate. Conversely, the analysis of metapopulation dynamics involving the examination of numerous sub-populations of varying size may be better completed using ALEX or RAMAS/Space. In other cases, the development of new programmes for PVA may be required to meet the needs of a particular species management problem. This approach was adopted for PVA of the Helmeted Honeyeater (Menkhorst and Middleton 1991).

Finally, although PVA is useful for enhanced threatened species management, its application *must* be accompanied by serious attempts from Government agencies to stem the loss of biodiversity

and address major conservation issues and threatening process such as vegetation clearance, over-grazing and inappropriate forestry practices (Norton and Lindenmayer 1991; Common and Norton 1992).

ACKNOWLEDGMENTS

We thank Mr. Russell James from the Endangered Species Unit of the Australian National Parks and Wildlife Service for access to unpublished reports on species recovery programmes. We are grateful to Dr. M. Burgman for discussions about the computer model presently being designed for PVA of the Helmeted Honeyeater. Two referees made many useful comments.

REFERENCES

- Akçakaya, H. R. and Ferson, S., 1992. RAMAS/Space. Applied Biomathematics. Setauket, New York.
- Australian National Parks and Wildlife Service, 1989. An Australian National Strategy for the Conservation of Species and Habitats Threatened with Extinction. Australian National Parks and Wildlife Service, Canberra.
- Australian National Parks and Wildlife Service, 1992. Annual Report 1991-1992. Australian National Parks and Wildlife Service: Canberra.
- Belovsky, G. E., 1987. Extinction models and mammalian persistence. Pp. 35-57 in *Viable Populations for Conservation* ed by M. E. Soulé. Cambridge University Press, Cambridge.
- Boyce, M. S., 1992. Population viability analysis. *Ann. Rev. Ecol. Syst.* 23: 481-506.
- Common, M. S. and Norton, T. W., 1992. Biodiversity: its conservation in Australia. *Ambio* 21: 258-65.
- Common, M. S. and Norton, T. W., (in press). Biodiversity, natural resource accounting and ecological monitoring. *Ambio*.
- Davis, A., Bellingham, M. and Malloy, J., 1992. What goes into the ark. *Forest and Bird* 23: 38-41.
- Department of Conservation and Environment, 1991. Annual Report. 1990-1991. Department of Conservation and Environment: Victoria.
- Ecologically Sustainable Development Working Group, 1991. Final Report — Forest Use. November 1991. Australian Government Publishing Service, Canberra.
- Faith, D. P., 1992. Conservation evaluation and phylogenetic diversity. *Biol. Conserv.* 61: 1-10.
- Ferson, S. and Burgmann, M. A., 1990. The dangers of being few: demographic risk analysis for rare species extinction. Pp. 129-32 in *Ecosystem Management: Rare Species and Significant Habitats* ed by R. S. Mitchell, C. J. Sheviak and D. J. Leopold. New York State Museum Bulletin 471.
- Holling, C. S., (ed), 1978. Adaptive environmental assessment and management. International Series on Applied Systems Analysis 3. International Institute for Applied Systems Analysis. John Wiley and Sons, Toronto.
- Lacy, R. C., 1992. VORTEX — a model for use in population viability analysis. *Wild. Res.* 20: (in press).
- Lacy, R. C. and Clark, T. W., 1990. Population viability assessment of the eastern barred bandicoot in Victoria. Pp. 131-45 in *Management and Conservation of Small Populations* ed by T. W. Clark and J. H. Seebeck. Chicago Zoological Society, Chicago.
- Lacy, R. C., Flesness, N. R. and Seal, U. S., 1990. Puerto Rican parrot population viability analysis. Report to the U.S. Fish and Wildlife Service. Captive Breeding Specialist Group, Species Survival Commission, IUCN, Minnesota.
- Lamberson, R. H., McKelvey, R., Noon, B. R. and Voss, C., 1992. A dynamic analysis of northern spotted owl viability in a fragmented forest landscape. *Conserv. Biol.* 6: 505-12.
- Lande, R., 1988. Demographic models of the northern spotted owl (*Strix occidentalis caurina*). *Oecologia* 75: 601-07.
- Lindenmayer, D. B., 1992. The ecology and habitat requirements of arboreal marsupials in the montane ash forests of the Central Highlands of Victoria. A summary of studies. Value Adding and Silvicultural Systems Programme. VSP Report No. 6. Native Forest Research, Melbourne.
- Lindenmayer, D. B. and Possingham, H. P., 1991. Population Viability Analysis as a tool in wildlife conservation. *Agricultural Systems in Information Technology Newsletter* 3: 45-46.
- Lindenmayer, D. B., Thomas, V. C., Lacy, R. C. and Clark, T. W., 1991. Population viability analysis (PVA): the concept and its applications, a case study of Leadbeater's Possum, *Gymnobelideus leadbeateri* McCoy. FTC91/18 Resource Assessment Commission, Forest and Timber Inquiry, Canberra.
- Lindenmayer, D. B., Clark, T. W., Lacy, R. C. and Thomas, V. C., (in press). Population viability analysis as a tool in wildlife management: a review with reference to Australia. *Environ. Management*.
- Mace, G. M. and Lande, R., 1991. Assessing extinction threats: towards a re-evaluation of I.U.C.N. threatened species categories. *Conservation Biology* 5: 148-57.
- Marcot, B. G. and Holthausen, R., 1987. Analyzing population viability of the spotted owl in the Pacific Northwest. *Transactions of the North American Wildlife and Natural Resources Conference* 52: 333-47.
- Maguire, L. A., 1991. Risk analysis for conservation biologists. *Conserv. Biol.* 5: 123-25.
- Menkhorst, P. and Middleton, D., 1991. The Helmeted Honeyeater Recovery Plan: 1989-1993. Department of Conservation and Environment, Victoria.
- Norton, T. W. and Possingham, H. P., 1991. Modelling the population viability of forest biota: a case study using the Australian arboreal marsupial folivore, *Petauroides volans* (Kerr). Pp. 442-47 in *Proceedings 9th Biennial Conference on Modelling and Simulation*. Simulation Society of Australia, Brisbane.
- Norton, T. W. and Lindenmayer, D. B., 1991. Integrated management of forest wildlife: towards a coherent strategy across State borders and land tenures. Pp. 237-44 in *Conservation of Australia's Forest Fauna* ed by D. Lunney. The Royal Zoological Society of NSW, Sydney.
- Possingham, H. P., 1991. The role of population viability analysis in forest management. Pp. 35-40 in *Conservation of Australia's Forest Fauna* ed by D. Lunney. The Royal Zoological Society of NSW, Sydney.
- Possingham, H. P., Gepp, B. and Herbert, A., 1993. The application of population viability analysis to habitat management for the southern brown bandicoot in South Australia. Report to SA Woods and Forests.
- Possingham, H. P. and Noble, I. R., 1991. An evaluation of population viability analysis for assessing the risk of extinction. Research consultancy for the Resource Assessment Commission, Forest and Timber Inquiry, Australian Government Printing Office, Canberra.