Decision theory in conservation biology: are there rules of thumb?

Application for 1999 NCEAS Centre Fellowship

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Summary

Ecological theory and complex, often spatially explicit, computer simulations are two ways in which ecologists have attempted to help managers solve conservation problems. Both methods have provided little guidance. Ecological theory is simple enough to be general, but lacks the constraints and trade-offs to be usefully applied in the real world. Complex computer simulations target specific ecosystems and problems (are not general), require many parameters that may be hard to estimate, and the robustness of the ensuing decisions may take years of simulating to evaluate. The primary purpose of this sabbatical will be to use existing work on the application of formal optimisation tools, like stochastic dynamic programming, to develop simple and robust "rules of thumb" for two major conservation problems, disturbance management and metapopulation management. In its grandest sense, I wish to outline a theory of applied conservation biology - something which I believe does not exist.

This research proposal arises from an NCEAS working group on population management held in August 1997 (Shea, Mangel and Possingham). Some ancillary projects initiated in the workshop need to be completed. In the July 1998 NCEAS proposal round I will apply for funds to reconvene parts of the population management workshop. My research will be split between the problem described above and tidying up ancillary projects from the working group.

Problem Statement

In August 1997 the Centre hosted a working group on population management (Shea, Mangel and Possingham). The purpose of the working group was to identify differences and commonalities between the three fields of population management: harvesting, conservation and pest management. One issue that emerged was the different extents to which each field uses decision theory tools. In harvesting the use of formal optimisation methods is commonplace (eg. Supriatna and Possingham 1998) while in conservation the use of any formal decision-making tools is rare (Maguire et al. 1987, Milner-Gulland 1997, Shea et al. submitted). The primary purpose of this sabbatical is to develop a theory of applied conservation using decision theory tools, in particular stochastic dynamic programming.

Conservation biology is one of the applied arms of ecology. Some of the major questions in nature conservation have only recently been posed. How big is a viable population? How big should a reserve be? How should we manage disturbances? Ever since these problems were posed ecologists have sought to use existing ecological theory and tools to solve them (MacArthur and Wilson 1967, Shaffer 1981). This attempt has often lead to embarrassing failure - as with the SLOSS debate. The failure can often be attributed to the fact that applied conservation problems like: Are habitat corridors useful? are not well posed from the perspective of a manager. The questions ignore constraints and trade-offs. Specifically, the question is not - Should we construct a habitat corridor? - but if we are constructing habitat should that be in the form of a corridor, a new patch of habitat, or should it be used to increase the size of one of the patches. In short, theory for nature conservation lacks an “economy” in the broadest sense of the word. (The idea of well-posed applied conservation problems is discussed in Possingham (1997) with respect to metapopulation management.) Let us now consider this issue in the context of managing disturbances, the issue that will be the focus of my sabbatical research.

We know that different species prefer different habitat types. Disturbances and succession change an area from one habitat type to another. Some species prefer early successional habitat, some mid and others “old-growth” habitat. How then should we manage a disturbance, like fire in a large natural area, for conservation? Eliminating fire will cause the demise of early successional species but uncontrolled fires will eliminate species that favour late successional habitat. There are two conventional approaches to this problem: “ecological theory”, and “simulate everything”.

The “ecological theory” approach seeks solutions to applied problems using very general models or principles. The intermediate disturbance principle (Lubchenco 1978) is one of the few general rules in ecology. It states that maximum species diversity occurs in places with intermediate levels of disturbance. The principle was never intended to guide management yet it is one of the few pieces of advice we can give on disturbance management. In the context of fire management it would imply that too many or too few fires is bad. The statement is of little use as a management prescription when we have explicit economic and biodiversity costs and benefits from different activities and outcomes. For example, putting a fire out or letting a fire burn each has associated economic biodiversity costs that depend explicitly on the state of the ecosystem.

The “simulate everything” approach attempts to incorporate as many biological processes as possible (eg. Fleming et al., 1994). There is an alarming increase in the number of very complex spatially explicit computer simulation models intended to help managers. Some of these target the issue of disturbance management. The models may include many species, many processes that have complex spatial and temporal drivers, and several site-specific management options. They are fun to play with and their construction may be enlightening to those involved, but in almost all cases it is hard to imagine how a manager would use these models to make real decisions, because of parameter and process uncertainty.

Fisheries modellers appear to have taken a more realistic approach to providing guidance to managers. They invariably begin with clear objectives, like minimising the chance of stock collapse while ensuring economic profitability. They are also aware of management constraints, like the ability to control the fishers through different policies, and they are aware of the limitations of their data. The population models are of low to moderate complexity and they invariably use explicit decision theory to find optimal management policies. The results of these formal analyses are then approximated by simple “rules of thumb” which are then tested for robustness. It is this general approach that I wish to apply to the management of disturbance.

Over the past two years my colleagues and I have begun developing a suite of models for optimal disturbance management (Possingham and Tuck 1997, Possingham and Tuck 1998, Richards, Possingham and Tizard, in prep). While these models and associated work on metapopulations (Possingham 1997) have shown the power of putting conservation problems into a stochastic dynamic programming framework the big step to generate rules of thumb remains undone. In each of these models we have been able to formally pose the conservation problem, define constraints and find the optimal state-dependent management strategy. What remains to be done is simplifying these rules so that any manager can apply them with confidence. Let me illustrate this research agenda with an example.

For fire management in a large park we set the biodiversity objective: each of the three major successional habitats in the park must cover at least 20% of the park (Richards, Possingham and Tizard, in prep). The states are defined so that key fauna and flora are adequately conserved if, and only if, the biodiversity objective is being met. A discrete-time Markov chain models the vegetation dynamics and stochastic dynamic programming is used to find the state-dependent strategy that maximises the proportion of time that the park meets our biodiversity objective. The vegetation model is simple and non-spatial. What I intend to do is to explore the model more fully, generate some rules of thumb, and then explore the robustness of these rules of thumb when the vegetation dynamics are made more complex (a semi-Markov process) and space is introduced in the model. A similar research agenda will be used to explore optimal fire management for a single threatened species (Possingham and Tuck 1998) and metapopulation management (Possingham 1997).

This research agenda presents some major challenges. Do robust rules of thumb exist for conservation managers? Can very simple population and ecosystem models be used to generate these rules? Does space matter?

Aside from main project described above I will work on ancillary projects, most of which have arisen from the population management workshop. I will not describe these projects in detail, but merely list them by project name and collaborator.

Ancillary projects

Unifying metapopulation and disturbance theory - with Priyanga Amarasekare (successful NCEAS postdoctoral associate applicant from fall 1998)

Decision theory for pest management - with Katriona Shea and Bill Murdoch

Applying optimisation and decision tools to reserve design - with Sandy Andelman and her working group

Analysis of time series data for determining minimum viable habitat areas - with Peter Karieva and others

Virtual ecology in action: matching observed patterns with model output - Andrew Tyre (applicant for NCEAS postdoctoral associate for 1999)

Rationale for NCEAS support

The NCEAS is the logical place to carry out this research program for the following reasons

1. The kind of work envisaged, which will involve large state-space stochastic dynamic programming problems, will require access to fast computers with large amounts of RAM such as those at the NCEAS.
2. The sabbatical proposal represents a logical continuation of the very successful Population Management Working Group. The NCEAS provides the unique opportunity to combine a sabbatical visit with a working group facilitating the existing collaborations between scientists associated with the NCEAS (see ancillary projects above).
3. I believe that the research agenda proposed here will precipitate a paradigm shift in conservation biology consistent with two broad aims of the NCEAS - cutting-edge analytical approaches, and developing novel ideas and theories.

Proposed activities and timetable

Organise workshop for January 1999	February-June 1998
Submit workshop proposal to NCEAS	July 1998
Centre Fellow	
at centre	December 14 1998 - April 17 1999
at centre	June 20 1999 - July 2 1999
Workshop (proposal to be submitted)	January 18-29 1999

Anticipated results and beneficiaries

I anticipate two main papers - one that generates and tests the robustness of rules of thumb for fire management, another for metapopulation management. These will be published in other forms to facilitate discussion in the conservation biology community and ultimate transfer to managers. Other publications will result from the ancillary projects identified above.

I typically attend about four conferences a year and deliver about 20 talks/seminars outside my normal lecturing duties. While at the Centre I will deliver several talks about this research agenda to universities, especially those on the west coast, and the ESA conference in July. However travel time will be generally minimised (day trips). In my last six months sabbatical I gave sixteen talks which was too many!

Participants

Collaborators are listed under ancillary projects. The follow-on population management workshop for January 1999, that I will propose to the Center in July, will involve these people and others yet to be contacted. I anticipate about eight participants, slightly fewer than last time.

Budget

Travel	Foreign airfare	$1500	
Expenses	Visitor days (140 @ $63.25)		$8855

References

Fleming, D.M., DeAngelis, D.L., Gross, L.J., Ulanowicz, R.E., Wolff, W.F., Loftus, W.F. and Huston, M.A. 1994. ATLSS: Across-Trophic-Level System and simulation for freshwater wetlands of the everglades and big cypress swamp. National Biological Service Technical Report.

Lubchenco, J. 1978. Plant species diversity in a marine intertidal community: importance of herbivore food preference and algal competitive abilities. *The American Naturalist* 112:23-39.

Maguire, L.A., Seal, U.S. and Brussard, P.F. 1987. Managing critically endangered species: the Sumatran rhino as a case study. Pages 141-158 *in Viable Populations for Conservation*. Ed. M.E.Soule, Cambridge Univ Press, Cambridge.

Milner-Gulland, E.J. 1997. A stochastic dynamic programming model for the management of the saiga antelope. *Ecological Applications* 7:130-142.

Possingham, H. P. 1996. Decision theory and biodiversity management: how to manage a metapopulation. Pages 391-398 in *Frontiers of Population Ecology*. Eds. R.B. Floyd, A.W. Sheppard and P. Wellings, CSIRO Publishing, Canberra, Australia.

Possingham, H. P. 1997 State-dependent decision analysis for conservation biology. Pages 298-304 in *The ecological basis of conservation: Heterogeneity, ecosystems and biodiversity*. Eds S.T.A. Pickett, R.S. Ostfeld, M. Shachak, and G.E. Likens, Chapman and Hall, New York.

Possingham, H. P. and Tuck, G. 1997. Application of stochastic dynamic programming to optimal fire management of a spatially structured threatened species. Pages 813-817 in *Proceedings of MODSIM 97*. Eds. A.D. MacDonald and M. McAleer, Elsevier, London.

Possingham, H. P. and Tuck, G. 1998. Fire management strategies that minimise the probability of population extinction for mid-successional species. Pages xx-xx in *Statistics in Ecology and Environmental Monitoring*. Eds. D. Fletcher and B. Manly, University of Otago Press, Dunedin.

Richards, S.A., Possingham, H.P. and Tizard, J. (in prep). Succession management using optimal fire strategies.

Shaffer, M.L. 1981. Minimum population sizes for species conservation. *Bioscience* 31:131-134.

Shea, K. and NCEAS Working Group on Population Management. (submitted) Modelling for population management

Supriatna, A., and Possingham, H. P. 1998. Optimal harvesting for a predator-prey metapopulation. *Bulletin of Mathematical Biology* (in press).

Keywords

1. Organizational Focus
(pick 1)

__ Global
__ Ecosystem
__ Community
__ Meta-population
_X Population
__ Organismal
__ Cellular
__ Molecular

2. Regional Focus
(pick all that apply)

__ California
United States

__ Southwest

__ Northwest
__ Southcentral
__ Northcentral
__ Southeast
__ Northeast
__ Africa
__ Antarctic
__ Arctic
__ Asia
__ Australia/NZ
Canada

__ Central America
__ Europe
__ South America
_X Global

3. Ecological Theme
(rank up to 3)

__ amensalism
_1 biodiversity
__ biogeography
__ commensalism
__ community dynamics
__ competition
__ complex systems
__ dispersal
_2_ disturbance
__ ecological economics
__ evolution
__ genetics
__ global change
_3_ methodological innovation

__ microclimate

4. Taxonomic Group
(pick all that apply)

_X Plants
_X Invertebrates
__ insects
__ other terr. inverts
__ marine inverts
__ aquatic inverts
_X Vertebrates
__ mammals
__ birds
__ reptiles/amphibians
__ fish
__ Microbes
__ Fungi

5. Methods
(pick all that apply)

__ Statistical modeling
__ Numerical Analysis
_X Simulation model
__ Visualization
__ Meta-analysis
__ Classification and Mapping
_X Other _Optimisation_

6. Research Application
(rank up to 3)

__ acid rain
__ agriculture
__ aquaculture
__ coastal resources
_1_ conservation
_2_ ecosystem management
__ energy
__ environmental policy
__ fisheries
__ forestry
__ global warming
__ human population
__ land management
__ ozone
__ pollution
__ reserve siting/design
__ restoration
__ toxicology
__ Other ________________

__ mutualism
__ nutrient cycling
__ paleoecology
__ plant-animal interactions
__ population dynamics
__ predator-prey interactions
__ primary production
__ soil processes
__ succession
__ parasitism
__ symbiosis
__ Other __________________

7. Biomes
(pick all that apply)

__ Marine
__ Benthic
__ Pelagic
__ Intertidal
_X_ Terrestrial
__ Forest
__ Grassland
__ Desert
__ Wetlands

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Born July 21st 1962 in Adelaide, Australia
Married to Karen Anne Fiegert on July 1st 1985
Son, Nicholas Lawrence, born July 27th 1989
Daughter, Alexandra Constance, born December 26th 1990

EDUCATION

1968-79	St. Peter's College, Adelaide, Australia.
1980-83	University of Adelaide, Australia. Majors: Biochemistry and Applied Mathematics B.Sc. (Hons.) 1st class, Applied Mathematics
1984-87	D.Phil., Oxford University, United Kingdom.

MAJOR PRIZES AND SCHOLARSHIPS

1984	Amir Hassan Abdi Prize for top Mathematics Honours student
1984	Rhodes Scholarship, Australia-at-large
1989	QEII Fellowship

ACADEMIC EMPLOYMENT

1987-88	**Post-doctoral Research Associate** with Jonathan Roughgarden in the department of Biological Sciences, Stanford University, USA.
1989	**Post-doctoral Research Fellow** with Ian Noble in the Ecosystem Dynamics Group, Research School of Biological Sciences, Australian National University.
1989	**Visiting Fellow** in the School of Biological Sciences, University of New South Wales.
1990	**QEII Fellow** in Ecosystem Dynamics Group, RSBS, Australian National University.
1991-93	**Lecturer** in the Department of Applied Mathematics, The University of Adelaide.
1994-95	**Senior Lecturer** in the Department of Applied Mathematics, The University of Adelaide.
1995-	**Professor** in the Department of Environmental Science and Management, The University of Adelaide.

CURRENT POSITIONS

Member - National Biodiversity Council
Member - SA National Parks Council

Member - Wildlife Advisory Committee (SA)
President of the Nature Conservation Society of South Australia
Head of Department of Environmental Science and Management
International Board of Govenors - Resource Modelling Association
Convener of A&NRS Faculty Information Technology Committee

RESEARCH PROGRAMS:

Optimal control problems in reserve design, biodiversity management, and fire regime management.

Population viability analysis (PVA) - including the development of ALEX - a software package that assesses the likelihood of animal extinctions for teaching, research, management and EIS.

Pollination ecology, metapopulation dynamics, bioeconomics,stochastic modelling, biodiversity and climate change, population dynamics of marine organisms, avian community ecology, edge effects and fragmentation, behavioural and population ecology of parasitoids.

POSTGRADUATE SUPERVISION (*principal supervisor)

PhD	Geoffrey Tuck*	1991 - 1994 (Bioeconomics)
	Jemery Day *	1991 - 1995 (Metapopulation dynamics)
	Shane Richards	1992 - 1996 (Larval distribution models)
	Ian Lundy*	1992 - 1997 (Population genetics)
	Ian Ball*	1994 - (Natural resource modelling)
	Asep Supriatna*	1994 - (Predator/prey harvesting)
	Jason Ting	1994 - (Management priorities in reserves)
	Stephen Ball	1995 - (Empirical metapopulation dynamics)
	Rick Southgate*	1995 - (Bilby Ecology)
	Andrew Tyre*	1996 - (Population scaling)
	Batbold Dorjughem*	1996 - (Biodiversity planning)
	Brett Bryan*	1996 - (Biodiversity planning)
	Janine Baker*	1997 - (Marine reserve design)
	Soolim Carney	1997 - (Impact of koalas on trees)
	Michael Harte	1997 - (Rock Lobster fisheries management)
	Fiona Fisher*	1998 - (Biodiversity)

Honours	1991	Anna Ting, Richard Webster, Louise Emmerson
	1992	Catherine Thomas, Janet Collier, Joseph Askew
	1993	Maureen Goldfinch, Sandra Jackson, John Priest
	1994	Joslin Moore, Joanna Chessel, Wendy Stubbs
	1995	Juliette Woods, Natasha Garrett, Janet Matthews, David Gobbett
	1996	Gary Luck, Jason White, Paul Thomas
	1997	Daniel Stokes, Catherine Corrie, David Matthews, John Lorke
	1998	Matt Turner, Anne Koerber

TEACHING

1986-87	Tutor in Finals **Probability** and **Random Processes**, Demonstrator in **Preliminary Statistics**, and Teaching Assistant in **Non-parametric Statistics** at Oxford University.
1988	Teaching Assistant for **Principles of Ecology** at Stanford University.

1989	Lecturer for the third year course **Population and Community Ecology** at UNSW, Sydney campus.
1990	Six lectures on **Community Ecology** for the Zoology Department, ANU; two lectures on **Biomathematics** in the School of Mathematical Sciences, ANU.
1991	Lecturer for **Optimisation III**, **Mathematics I**, **Mathematical Biology III** and **Linear Programming II** at The University of Adelaide.
1992-95	Lecturer for **Mathematics I, Scientific Computing I**, **Mathematical Biology III, Biomathematics I** (for Agricultural Science students) and **Conservation Biology** (Graduate Diploma in Ecology and Management).
1996	Lecturer for **Conservation Biology III (12)**, **Community Ecology II (6)**, **Population Ecology II (9)**, **Mathematical Biology III (12)**, and **Agriculture, Environment and Society I (3)**.
1997-98	Lecturer for **Conservation Biology III (12)**, **Environmental Biology I (9)**, **Mathematical Biology III (3-12)**, **Environment and Society I (8)**.

REVIEWER FOR THE FOLLOWING JOURNALS

American Naturalist, Ecology, Theoretical Population Biology, Ecological Modelling, Pacific Conservation Biology, Australian Journal of Ecology, Australian Journal of Botany, Australian Journal of Zoology, Wildlife Research, Journal of Australian Marine and Freshwater Research, Australian Journal of Applied Mathematics (Series B), Biological Conservation, Environmental Modelling, PNAS, Journal of Animal Ecology, Animal Conservation, Royal Society - Biological Sciences, Biological Conservation, Conservation Biology and others.

RESEARCH GRANTS AND CONSULTANCIES **1993 onwards**

1993	Reserve design consultancy: DASET - $2 250
1993	Recovery plan for Leadbeaters Possum (with D. Lindenmayer) - $60 000.
1994	Small ARC, *Modelling of Water Quality in Boston Bay* (with B.J. Noye) - $16 000
1994 - 95	Adelaide University URS grant on *Stochastic modelling* - $40 000
1994 - 95	Small ARC, *Algorithms for reserve design problems* - $16 000
1995	*Owl PVA* consultancy with NSW NPWS/SFNSW - $15 000
1995 - 97	Large ARC (with Mike Keller, Crop Protection) - $177 000
1995 - 96	*Linking PVA and GIS* - Forestry CANADA - $6 500
1995	ANU collaboration grant (with D. Lindenmayer) - $2 000
1995 - 96	ANCA tree hollow consultancy (with D. Lindenmayer) - $22 000
1996	ANU collaboration grant (with D. Lindenmayer) - $2 000
1996	ANCA PVA consultancy (with D. Lindenmayer) - $28 000
1996	WCF (SA) - orchid pollination ecology - $3 000
1997	Koala management model - $12 000 (DENR, SA)
1997 - 98	Advice on fauna and flora conservation - Environment Australia - $20 000
1997 - 99	Large ARC (with Ian Noble, IAS - ANU) - $115 000
1997 - 99	Large ARC (with Mike Bull, Flinders) - $235 000

1997 - 99	ARC Collaborative (with David Lindenmayer, IAS - ANU) - $180 000
1997 - 99	APA-I - Koala Management (with David Paton) - $60 000
1998	Small ARC - $10 000
1998	Small ARC (with Mike Keller) - $10 000
1998 - 00	APA-I - Lobster Fisheries (with Greg van Gaans) - $60 000

CONFERENCE PAPERS AND WORKSHOPS 1992 onwards

**** indicates all costs covered, boldface - overseas***

1992*	**Feb**	**New Zealand**	**The impact of climate change on biodiversity**
1992	**Aug**	**Hawaii**	**Ecological Society of America, Fire and flammability**
1992	Sep	Roseworthy	Ecological Soc of Aust., Barnacle population dynamics
1993	Feb	Adelaide	Applied Mathematics Conference, Population cycling
1993*	July	Sydney	NSW NPWS conference, Demystifying PVA
1993	July	Adelaide	Australian Operations Research Society, Reserve Design
1993	July	Adelaide	Applied Control Theory Workshop
1993	Sep	Canberra	Ecological Society of Australia
1993*	Dec	Perth	International Society of Ecological Modelling conference
1994	**Study Leave**		**Invited talks at Leiden, Imperial College, Oxford, Cambridge, Sheffield, Bristol, Princeton, Colorado, Georgia, Stanford, San Diego.**
1994*	**July**	**San Diego**	**Pacific Coast Resource Modelling Conference**
1994	Sep	Alice Springs	ESA symposium organiser - Ecological Modelling
1994*	Oct	Melbourne	Biodiversity and Fire
1994*	Dec	Canberra	International Forest Ecology Meeting
1995	Feb	Bussellton	Applied Mathematics Conference
1995*	Apr	Canberra	The Nicholson Meeting, Frontiers of Population Ecology
1995*	**May**	**New York**	**Sixth Cary conference on Linking Ecology and Conservation- Institute of Ecosystem Studies**
1995*	June	Perth	Requirements for reservation in south-western Australia
1995*	Oct	Canberra	Bioregionalisation
1996*	Jan	Sydney	DFA Forest workshop
1996*	**Feb**	**California**	**NCEAS conference on Spatio-temporal modelling**
1996*	**May**	**California**	**Ecological Economics conference**
1996*	**June**	**Dunedin**	**Statistics and Ecological Monitoring**
1996	July	Townsville	Ecological Society of Australia conference
1997*	**August**	**California**	**Population modelling workshop**
1997*	Sept	Wollongong	Allan Sefton Memorial Lecture
1997*	Sept	Albury	Limnological conference

1997*	Sept	Adelaide	ANZAAS
1997*	Dec	Adelaide	Biometrics conference
1997	Dec	Hobart	MODSIM
1997	Dec	Hobart	International RMA conference
1998*	Feb	Gold Coast	Applied Maths Conference
1998	July	Sydney	Conservation Biology

Publication summary (DEETYA counted)

	1994	1995	1996	1997	1998	1999
International refereed journals	10	11	4	1	4+	
Local refereed journals (eg AJB, SAO)	3			1		
Books	1					
Refereed Conference Proceedings	3		2	6		
Book Chapters		1	3	2	1+	
Total	17	12	9	10	5+	

Numerous (about 50) publications in non-refereed publications like Environment SA, Habitat, Xanthopus, Newsletters of clubs and societies

PUBLICATIONS - 1992-PRESENT

Possingham, H. P. 1992. The role of population viability in forest management. Pages 35-39 in *Issues in Forest Management* ed. Dan Lunney, Surrey-Beatty, Sydney.

Possingham, H. P., I. Davies, I. R. Noble and T. W. Norton. 1992. A metapopulation simulation model for assessing the likelihood of plant and animal extinctions. *Mathematics and Computers in Simulation* 33:367-372.

Possingham, H. P. 1992. Habitat selection by two species of nectarivore: habitat quality isolines. *Ecology* 73:1903-1912.

Lindenmayer, D. W., Possingham, H. P. and Norton, T. W. 1993. An approach for determining wildlife metapopulation viability using GIS to couple habitat models and forest resource data. Pages 529-539 in *Proceedings of GIS'93 Symposium*, Vancouver, Canada.

Possingham, H. P. 1993. The impact of elevated CO_2 on biodiversity: a population-dynamic perspective. *Australian Journal of Botany* 41:11-21.

Possingham, H. P., Day, J., Goldfinch, M. and Salzborn, F. 1993. The mathematics of designing a network of protected areas for conservation. Pages 536 - 545 in the *Proceedings of the 12th Australian Operations Research Conference*. Decision Sciences, Tools for Today, eds. D. Sutton, E. Cousins and C. Pearce, ASOR, Adelaide.

Possingham, H. P., Lindenmayer, D. W., and Norton, T. W. 1993. The role of PVA in endangered species management. *Pacific Conservation Biology* 1:39-45.

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Environmental Systems, eds. Jakeman, A.J., Beck, B. and McAleer, M. Elsevier, Amsterdam.

Goldingay, R. and Possingham, H. P. 1993. Population viability analysis of small populations of the gliding marsupial, *Petaurus australis*. Pages 609-614 in *Proceedings of the 11th Biennial Conference on Modelling and Simulation*.

Possingham, H. P. and Gepp, B. 1993. Assessment of management options for the southern brown bandicoot *Isoodon obesulus* in South Australia using Population Viability Analysis. Pages 633-638 in *Proceedings of the 11th Biennial Conference on Modelling and Simulation*.

Tuck, G. and Possingham, H. P. 1994. Optimal harvesting strategies for a metapopulation. *Bulletin of Mathematical Biology* 56:107-127

Possingham, H. P., S. Tuljapurkar, M. Wilks and J. Roughgarden. 1994. Population cycling in space-limited organisms subject to density-dependent predation. *The American Naturalist* 143: 642-661

Lindenmayer, D. B. and Possingham, H. P. 1994. *The Risk of Extinction: Ranking management options for Leadbeater's possum using population viability analysis.* Centre for Resource and Environmental Studies, Canberra, 254pp.

(Book taunched by Federal Environment Minister in January 1995)

Richards, S.R., Possingham, H.P. and Noye, B.J. 1995. Larval dispersion along a straight coast with tidal currents: complex distribution patterns from a simple model. *Marine Ecology Progress Series* 122:59-71.

Possingham, H. P., Comins, H. N, and Noble, I. R. 1995. The fire and flammability niches in plant communities. *Journal of Theoretical Biology* 174:97-108.

Bull, M. and Possingham, H. P. 1995. A model of parapatry. *The American Naturalist* 145:935-947.

Lindenmayer, D.W. and Possingham, H. P. 1995. Modelling the impacts of wildfire on the metapopulation behaviour of the Australian arboreal marsupial, Leadbeater's possum, *Gymnobelideus leadbeateri*. *Forest Ecology and Management* 74:197-222.

Possingham, H. P. and Davies, I. 1995. ALEX: A population viability analysis model for spatially structured populations. *Biological Conservation*. 73:143-150.

Southgate, R. and Possingham, H. P. 1995. Population viability analysis of the Greater Bilby, *lagotis macrotis*. *Biological Conservation*. 73:151-160.

Goldingay, R. and Possingham, H. P. 1995. Area requirements for viable populations of the Australian gliding marsupial, *Petaurus australis*. *Biological Conservation*. 73:161-167.

Lindenmayer, D. W., Burgman, M., Akçakaya. R., Lacy, R. and Possingham, H. P. 1995. Computation and understanding in modelling metapopulations: a review of three generic computer models - ALEX, RAMAS/Space and VORTEX. *Ecological Modelling* 82:161-174.

Lindenmayer, D.W. and Possingham, H. P. 1995. Modelling the viability of metapopulations of the endangered Leadbeater's possum in south-eastern Australia. *Biodiversity and Conservation* 4:984-1018.

Lindenmayer, D.W. and Possingham, H. P. 1995. The conservation of arboreal marsupials in the montane ash forests of the central highlands of Victoria, South-Eastern Australia. VII. Modelling the persistence of Leadbeater's possum in response to modified timber harvesting practices. *Biological Conservation* 73:239-257.

Day, J. R. and Possingham, H. P. 1995. A stochastic metapopulation model with variability in patch size and position *Theoretical Population Biology* 48:333-360

Possingham, H. P. 1995. The practical application of Population Viability Analysis for conservation planning. Pages 292-299 in *Conserving Biodiversity: threats and solutions* Eds R. A. Bradstock, T. D. Auld, D. A. Keith., R. T. Kingsford, D. Lunney and D. P. Sivertsen. Surrey Beatty & Sons, Sydney.

Lindenmayer, D.W. and Possingham, H. P. 1996. Modelling the inter-relationships between habitat patchiness, dispaersal capability and metapopulation persistence of the endangered species, Leadbeater's possum, in south-eastern Australia. *Landscape Ecology* 11:79-105

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