

Conservation Management of Two Threatened Frog Species in South-Eastern New South Wales, Australia

David Hunter (BSc, MSc)

Institute for Applied Ecology
University of Canberra ACT 2601

Submitted in total fulfillment of the requirements of the degree Doctor of Philosophy
at the University of Canberra

June 2007

Abstract

The decline and extinction of amphibian species over the past three decades is widely acknowledged as one of the greatest biodiversity crises of modern time. Providing convincing data to support hypotheses about these declines has proved difficult, which has greatly restricted the development and implementation of management actions that may prevent further amphibian declines and extinctions from occurring. In this thesis, I present research that was undertaken as part of the recovery programs for the southern corroboree frog (*Pseudophryne corroboree*), and the Booroolong frog (*Litoria booroolongensis*); two species that underwent very rapid declines in distribution and abundance during the 1980's. More specifically, I investigated potential causal factors in the declines of both species using experimental and correlative studies, and examined the mechanisms by which one threatening process (chytridiomycosis) may be causing continued decline and extinction in *P. corroboree*. I also examined the implications of population dynamics for monitoring *L. booroolongensis*, and suggest a possible monitoring strategy that may reliably facilitate the implementation of recovery objectives for this species. I also tested one possible reintroduction technique aimed at preventing the continued decline and extinction of *P. corroboree* populations.

In Chapters 2 and 3, I present the results from a series of experiments in artificial enclosures designed to examine whether the tadpoles of *L. booroolongensis* are susceptible to predation by co-occurring introduced predatory fish species; brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), European carp (*Cyprinus carpio*), redfin perch (*Perca fluviatilis*), and mosquito fish (*Gambusia holbrooki*). I demonstrated that the tadpoles of *L. booroolongensis*, and a closely related species *Litoria lesueuri*, were palatable to non-native trout species, but not to two native predatory fish species, *Gadopsis bispinosus* and *Galaxias olidus*. A pond breeding frog species included in this experiment, *Limnodynastes tasmaniensis*, was palatable to both the native and non-native fish species. In a separate experiment I also demonstrated that the tadpole of *L. booroolongensis* is palatable to the three other introduced fish species examined in this study; *C. carpio*, *P. fluviatilis*, and *G. holbrooki*. In three of the experiments, the provision of rock within enclosures as a potential refuge habitat did not afford protection to *L. booroolongensis* tadpoles from

predation by any of the five introduced fish species examined. While all the introduced fish species tested here did consume *L. booroolongensis* tadpoles, the results also suggested that chemical unpalatability might afford some level of protection against some of these fish species. Firstly, the addition of alternative prey items in one of the experiments reduced the proportion of tadpoles consumed, suggesting that *L. booroolongensis* may not be a preferred prey item. Secondly, the proportion of tadpoles consumed varied greatly among the different fish species examined, suggesting differing levels of palatability. Overall, this study supports previous research in suggesting that chemical unpalatability may be an important strategy for the tadpoles of riverine frog species in south-eastern Australia to avoid predation by native fish species, and that this strategy is less effective against introduced fish species. While *L. booroolongensis* currently persists in streams inhabited by a number of introduced fish species, this study supports the likelihood that these species are having a negative impact on populations of *L. booroolongensis* in the wild.

In Chapter 4, I present the results of a study aimed at examining potential monitoring techniques for *L. booroolongensis*. The results of a mark-recapture exercise demonstrated that *L. booroolongensis* may exhibit large fluctuations in abundance from one year to the next, and through a prospective power analysis approach, I demonstrated that it would be difficult to confidently identify population trends of interest using either indices or estimates of abundance for this species. An assessment of the capacity to identify the presence or absence of *L. booroolongensis* using night-time spotlight surveys demonstrated the high detectability of this species using this technique, at both the scale of 300-meter sections of stream and individual breeding areas (typically less than 10-meters of stream). This study suggests that the monitoring objectives of the *L. booroolongensis* recovery program would be most effectively achieved using presence/absence surveys at different scales.

In Chapter 5, I present the results of a field survey aimed at determining the current distribution and habitat requirements of *L. booroolongensis* in the South West Slopes region of New South Wales. Of the 163 sites I surveyed across 49 streams, I located *L. booroolongensis* along 77 of these sites from 27 streams. Based on population and habitat connectivity, this study identified 18 populations of *L. booroolongensis* that

are likely to be operating as independent populations. Twelve of these populations are not represented in conservation reserves, but rather occur along streams that flow through the agricultural landscape. A broad scale habitat analysis identified a positive relationship between extent of rock structures along the stream and the occurrence of *L. booroolongensis*, and a negative relationship between the proportion of canopy cover and this species' occurrence. At the breeding habitat scale, this study identified a positive relationship between the presence of breeding males and; number of rock crevices in the aquatic environment, extent of emergent rocks, and proportion pool. This analysis also detected a negative relationship between occupancy and water depth. These results confirm previous work suggesting the importance of rocky stream habitats to the persistence of *L. booroolongensis*, but also suggest how disturbance processes, such as increasing sedimentation and weed invasion, may reduce the suitability of rocky structures as breeding sites.

In Chapter 6, I investigated current levels of amphibian chytrid fungus (*Batrachochytrium dendrobatidis*) infection in corroboree frog populations, and used retrospective screening of museum specimens to assess the possibility that this pathogen was implicated in the initial decline of the corroboree frogs. Using histology, I did not detect any *B. dendrobatidis* infections in corroboree frog populations prior to their decline, however using the same technique, moderate levels of infection were detected in post-decline populations of both species. Real-time PCR screening of skin swabs identified much higher overall infection rates in post-decline populations of *P. corroboree* (between 44% and 59%), while significantly lower rates of infection were observed in *P. pengilleyi* populations (14%). These results suggest that the initial and continued decline of the corroboree frogs may well be attributed to the emergence of *B. dendrobatidis* in populations of these species.

In Chapter 7, I investigated how *B. dendrobatidis* may be causing the continued decline of *P. corroboree* through the presence of an abundant reservoir host for this pathogen. I found that populations of adult *C. signifera* in sub-alpine bogs carry high *B. dendrobatidis* infection rates (86%), but appear unaffected by this infection. An experiment involving the release of *P. corroboree* tadpoles into 15 natural pools resulted in metamorphs from seven of these pools testing positive for *B. dendrobatidis*, with all these individuals dying soon after metamorphosis. These

results support the possibility that *B. dendrobatidis* infection in *P. corroboree* populations is being facilitated by the presence of large numbers of infected *C. signifera* in the shared environment.

Chapter 8 presents the results of a population augmentation study for *P. corroboree*. I investigated the extent to which increasing recruitment to metamorphosis may result in population recovery in this species. This was undertaken by harvesting eggs from the field and rearing them through to mid stage tadpoles over the winter period prior to being released back to their natal ponds in spring. While I was able to increase recruitment to metamorphosis by an average of 20 percent, this did not result in a noticeable influence on the subsequent adult population size, as both manipulated and non-manipulated sites declined over the course of this study by an average of 80 percent. I observed a positive relationship between natural recruitment to a late tadpole stage and subsequent adult male population size, however there was considerable variation associated with this relationship. The relationship between recruitment and subsequent population size at the augmentation sites was consistent with the relationship observed at the non-manipulated sites. These results suggest that recruitment to metamorphosis may not be the most important life stage restricting the population recovery of *P. corroboree*, but that mortality during post-metamorphic stages may be more important in regulating current population size. Hence, further attempts to use captive rearing to increase *P. corroboree* populations in the wild should focus on the release of post-metamorphic frogs.

Overall, this thesis demonstrates the value of quantitative research to the implementation and progress of threatened species recovery programs. While this research will specifically contribute to the recovery programs for *L. booroolongensis* and *P. corroboree*, it more broadly contributes to the understanding and capacity to respond to the concerning levels of amphibian extinctions currently occurring throughout the world.

Acknowledgements

The research undertaken in this thesis was made possible through the provision of funding from the following organisations; Australian Research Council, NSW Department of Environment and Climate Change, University of Canberra, Co-operative Research Centre for Freshwater Ecology, NSW Fisheries, Murray Catchment Management Authority and Amphibian Research Center. I am indebted to staff in the NSW National Parks and Wildlife Service offices in Tumut and Khancoban for their efforts in assisting many aspects of this work. Chapters 6, 7 and 8 are the result of continued support and guidance by the Corroboree Frog Recovery Team.

I am very thankful to all those who provided me with field assistance and company throughout this research; Sean Doody, Michelle Walter, Rod Pietsch, Mike Smith, Lachlan Farrington, Alex Knight, Alex Quin, David Bourne, Martha Reese, Dieuwer Reynders, Russel Traher, David Judge, Rajani Rhy, Colin De Pagder, Craig Smith, Jessica Rossell, Michael McFadden, Yoko Shimizu, Ty Mathews and Jamie Molloy. Claire Steel is owed particular thanks for undertaking much of the husbandry for Chapter 7. I am particularly thankful to Mike Smith and Michael Scroggie for their assistance with the statistical analyses in Chapters 2 and 5. Jason Baldwin and Tony Day (NSW Fisheries) provided considerable assistance in many aspects of this project. I also thank Bob Faragher and Roy Witstanly (NSW Fisheries) for capturing the fish used in Chapter 3, and also Brian Free and the Tumut Acclimatisation Society for the use of their shed. Rick Speare and Diana Mendez undertook the histology and screening of specimens in Chapter 6, and provided much advice and comment on this chapter. I am particularly appreciative to all the property owners and managers I visited during the surveys in Chapter 5, who allowed me access through their land, and shared their wealth of knowledge about the streams in the South West Slopes region. Kylie Durrant and Cherie White provided much local knowledge and advice that greatly facilitated the surveys undertaken in Chapter 5. I also thank the following for fruitful advice and discussions at various stages through my thesis; Tony Tucker, Murray Evans, Sean Doody, Arthur Georges, Graeme Gillespie, Nick Clemann and Glen Johnson.

I am especially thankful to the following people for their contributions to this thesis and my capacity to undertake it. Firstly, I probably wouldn't have embarked on this project if it wasn't for the encouragement of Scott Keogh and Paul Doughty – unfortunately Plan A didn't quite work out. My supervisor Will Osborne provided constant support and advice during all phases/directions of my PhD work, and was particularly helpful during the final write-up. Michael Smith has been an invaluable source of support, advice and amusement during this thesis. I am particularly indebted to Mike Saxon and Rod Pietsch for their support as colleagues and supervisors during this research – they have definitely inspired me to keep pursuing a career in this field. I am greatly indebted to Gerry Marantelli for his innumerable contributions to this thesis and his tireless efforts in our broader endeavors - I hope one day we celebrate success! My family (Mum, Dad, Jonathan, Meggsie, Allie, Steven and Dorrie) provided much valuable support during periods when I was away from home.

The second half of my PhD journey has been a relatively painless exercise thanks to the love and fulfillment in my life from Dieuwer, Ollie and Manu. In addition to the direct support and sacrifices they made for my research, they importantly gave me the capacity to put this thesis into perspective.

Table of Contents

Abstract.....	I
Acknowledgements	V
Table of Contents	VI
List of Tables	X
List of Figures.....	XI
Chapter 1	1
Introduction.....	1
1.1 Amphibian Declines.....	1
1.1.1 The Global Amphibian Decline Phenomena	1
1.1.2 Causal Factors of Recent Amphibian Declines	2
1.1.3 Conservation Management of Threatened Amphibian Species.....	3
1.1.4 Management Response to Recent Amphibian Declines	4
1.2 Study Species 1; The Booroolong Frog (<i>Litoria booroolongensis</i>).....	6
1.2.1 General Description	6
1.2.2 Distribution and Habitat.....	7
1.2.3 Life History and Demography	9
1.2.4 Decline and management.....	9
1.3 Study Species 2; The Southern Corroboree Frog (<i>Pseudophryne corroboree</i>)	10
1.3.1 General Description	10
1.3.2 Distribution and Habitat.....	11
1.3.3 Life History and demography	13
1.3.4 Decline and management.....	14
1.4 Research Objectives.....	16
Chapter 2	17
Experimental Examination of the Potential for Three Non-Native Fish Species to Prey on the Tadpole of the Endangered Booroolong Frog (<i>Litoria booroolongensis</i>)	17
2.1 Introduction.....	17
2.2 Methods.....	19
2.2.1 Obtaining Tadpoles and Fishes.....	19
2.2.2 Experimental Apparatus and Design	19
2.2.3 Statistical Analysis.....	20
2.3 Results.....	21
2.4 Discussion.....	25

Chapter 329

An Experimental Examination of the Propensity for Introduced Trout to Prey on the Tadpole of the Endangered Booroolong Frog (*Litoria booroolongensis*)29

3.1 Introduction..... 29
3.2 Methods..... 32
 3.2.1 Fish and Tadpole Study Species 32
 3.2.2 Obtaining Experimental Tadpoles and Fish..... 33
 3.2.3 Experimental Apparatus and Design 34
 3.2.4 Statistical Analysis..... 36
3.3 Results..... 37
3.4 Discussion 40

Chapter 443

Evaluating Monitoring Strategies for the Endangered Booroolong Frog (*Litoria booroolongensis*)43

4.1 Introduction..... 43
4.2 Methods..... 46
 4.2.1 Study Area 46
 4.2.2 Mark-Recapture 48
 4.2.3 Presence/Absence Surveys..... 48
 4.2.4 Statistical Analysis..... 49
4.3 Results..... 51
 4.3.1 Population Size Estimates..... 51
 4.3.2 Capacity to Detect Population Trends 55
 4.3.3 Presence/Absence Surveys..... 55
4.4 Discussion 59
 4.4.1 Temporal Trends in Abundance..... 59
 4.4.2 Trends in Detection Probabilities..... 60
 4.4.3 Using Abundance Estimates to Detect Population Trends 60
 4.4.4. Detecting Population Trends Using Presence/Absence Surveys 61
 4.4.5 Recommendations for Monitoring *L. booroolongensis* 63

Chapter 565

Survey, Habitat Assessment and Conservation of the Endangered Booroolong Frog (*Litoria booroolongensis*) on the South West Slopes of New South Wales.65

5.1 Introduction..... 65
5.2 Methods..... 66
 5.2.1 Study Area, Site Selection and Survey Methods 66
 5.2.2 Regional Habitat Use 67
 5.2.3 Within-Breeding Habitat Use 68
 5.2.4 Statistical Analysis..... 70

5.3 Results.....	71
5.3.1 Survey Results	71
5.3.2 Broad Habitat Associations.....	74
5.3.3 Breeding Habitat Associations.....	74
5.4 Discussion	81
5.4.1 Distribution and Conservation Status of the Booroolong Frog on the SWS	81
5.4.2 Broad Habitat Associations.....	82
5.4.3 Breeding Habitat Associations.....	83
5.4.4 Conclusions and Management Recommendations	84
 Chapter 6	 87
 Presence of the Amphibian Chytrid Fungus (<i>Batrachochytrium dendrobatidis</i>) in Threatened Corroboree Frog Populations in the Australian Alps	 87
6.1 Introduction.....	87
6.2.1 Study Species	89
6.2.2 Field Sampling.....	89
6.2.3 Histology and screening of toe material	90
6.2.4 Statistical Analysis.....	90
6.3 Results.....	91
6.4 Discussion.....	97
6.4.1 Distribution and Levels of Infection in Extant Corroboree Frog Populations.....	97
6.4.2 Presence of the Amphibian Chytrid Fungus pre and post decline	98
6.4.3 Disease hypothesis and the decline of the Corroboree Frogs	100
 Chapter 7	 102
 Significance of Reservoir Hosts in Amphibian Declines caused by the Amphibian Chytrid Fungus (<i>Batrachochytrium dendrobatidis</i>).....	 102
7.1 Introduction.....	102
7.2 Methods.....	104
7.2.1 Study Sites and Species	104
7.2.2 Swabbing Adult <i>C. signifera</i>	105
7.2.3 Field Reintroduction/Infection Experiment	107
7.2.4 PCR Screening for <i>B. dendrobatidis</i> Infection	109
7.2.5 Statistical Analysis.....	109
7.3 Results.....	111
7.4 Discussion	117
7.4.1 Infection of <i>P. corroboree</i> with <i>B. dendrobatidis</i>	117
7.4.2 Implications for the <i>P. corroboree</i> Recovery Program	119
7.4.3 Reservoir Hosts and Frog Declines Due to <i>B. dendrobatidis</i>	120
7.4.4 Conclusions and Further Research.....	121

Chapter 8	123
Augmenting Recruitment to Metamorphosis Fails to Increase the Size of Breeding Populations of the Critically Endangered Southern Corroboree Frog (<i>Pseudophryne corroboree</i>)	123
8.1 Introduction.....	123
8.2 Methods.....	125
8.2.1 Study Species	125
8.2.2 Study Area	125
8.2.3 Egg Collections and Captive Rearing.....	126
8.2.4 Comparing Field Survivorship to Metamorphosis.....	128
8.2.5 Assessment of Tadpole Recruitment at Non-Manipulated Sites	129
8.2.6 Monitoring Breeding Population Size	130
8.2.7 Screening for Amphibian Chytrid Fungus Infection	131
8.2.8 Statistical Analysis.....	131
8.3 Results.....	133
8.4 Discussion.....	140
8.4.1 The Influence of Increased Recruitment on Adult Population Size	140
8.4.2 Demographic Failure and Causal Factors of Decline	141
8.4.3 Future Directions for Reintroducing <i>P. corroboree</i>	142
Chapter 9	145
General Synopsis and Implications for Threatened Frog Recovery Programs	145
9.1 Monitoring Amphibian Populations	145
9.2 Causal Factors of Amphibian Declines.....	146
9.3 Amphibian Reintroduction Programs	148
9.4 Management Solutions to Recent Amphibian Declines	150
References.....	152

List of Tables

Table 2.1. Deviance Information Criteria for the five Bayesian logistic regression models examined.	23
Table 4.1. The nine most parsimonious Jolly-Seber models, ranked according to their Akaike’s Information Criterion (AIC) values, used to examine the relationship between sex (s), year (t), and population (g) on survivorship (ϕ) and probability of detection (p) in three <i>L. booroolongensis</i> populations.....	52
Table 4.2. Model averaged estimates for the parameters of male and female <i>L. booroolongensis</i> capture probability and survivorship. These averages are based on the top nine Jolly-Seber models and associated AICc Weights presented in Table 4.1	52
Table 4.3. Posterior distributions for site occupancy model parameters fitted to the repeated surveys of <i>L. booroolongensis</i> breeding habitat during the breeding period (male surveys), and immediately after the breeding period (tadpole and metamorph surveys).....	58
Table 5.1. Summary of <i>L. booroolongensis</i> populations in the South West Slopes region for estimated length of stream occupied (E.L.O.), and estimated proportion of each population represented in conservation reserves.	73
Table 6.1. Results for the histological screening of individual <i>P. corroboree</i> and <i>P. pengilleyi</i> across populations before and after observed decline in these species	92
Table 6.2. Results for the Amphibian Chytrid Fungus sampling undertaken across remnant <i>P. corroboree</i> populations in 2005 and 2006. Note - The calculation for proportion positive and 95% credible intervals (95%CI) excluded inhibited samples.	94
Table 6.3. Results for the Amphibian Chytrid Fungus sampling undertaken across <i>P. pengilleyi</i> populations in 2006. Note - The calculation for proportion positive and 95% credible intervals (95%CI) excluded inhibited samples.	95
Table 7.1. Results from the swabbing and PCR screening of adult <i>C. signifera</i> for <i>B. dendrobatidis</i> infection.	112
Table 8.1. Number of tadpoles released at sites where recruitment to metamorphosis was augmented.....	137
Table 8.2. Comparison of the candidate models for the removal sampling of <i>P. corroboree</i> tadpoles. Models are ranked according to their AICc – Akaike’s Information Criterion, values.....	137
Table 8.3. Model averaged estimates for the parameters of capture probability during the first census and total tadpole abundance for the removal sampling of <i>P. corroboree</i> tadpoles. These averages are based on the four models and associated AICc Weights presented in Table 8.2.	137

List of Figures

Figure 1.1. Distribution of <i>Litoria booroolongensis</i> in relation to major water catchments in New South Wales. Locality records are based on NSW Wildlife Atlas records.....	8
Figure 1.2. The distribution of the two corroboree frog species, <i>P. corroboree</i> and <i>P. pengilleyi</i> , in relation to nature conservation reserves in south-eastern New South Wales.....	12
Figure 2.1. Posterior distributions from the Bayesian logistic regression analysis. The point is the mean and the error bars are 95% credible intervals.....	22
Figure 2.2. Summary of total number of prey items not recovered for the different treatments in this experiment (mean and 95% credible intervals).....	24
Figure 3.1. Posterior distributions from the Bayesian logistic regression model comparing the proportion of three tadpole species surviving in the presence of three fish species. The points represents the mean and error bars represent the 95% credible intervals.....	38
Figure 3.2. Posterior distributions from the Bayesian logistic regression model comparing the proportion of <i>L. booroolongensis</i> tadpoles surviving in the presence of wild versus hatchery reared <i>S. trutta</i> with rock and no-rock treatments. The points represents the mean and error bars represent the 95% credible intervals.....	39
Figure 3.3. Posterior distributions from the Bayesian logistic regression model comparing the proportion of <i>L. booroolongensis</i> tadpoles surviving in the presence of adult <i>O. mykiss</i> when rock is provided and not provided. The points represents the mean and error bars represent the 95% credible intervals.....	39
Figure 4.1. Map of study site localities. Solid squares are the localities of areas where mark-recapture was undertaken, while solid circles are the localities where an assessment of presence/absence surveys was undertaken.	47
Figure 4.2. Annual population estimates for adult male and female <i>L. booroolongensis</i> from mark-recapture, for a) the Brungle Creek transect, and b) the Mountain Creek (Mo) and Goobragandra River (Go) transects. The point is the mean estimate and the error bars are the upper and lower 95 percent confidence limits.....	53
Figure 4.3. Annual population indices for adult male and female <i>L. booroolongensis</i> from raw counts, for a) the Brungle Creek transect, and b) the Mountain Creek (Mo) and Goobragandra River (Go) transects. The point is the mean estimate and the error bars are the upper and lower 95 percent confidence limits.....	54
Figure 4.4. Power to detect a population decline for <i>L. booroolongensis</i> using, a) mark-recapture population estimates, and b) raw counts of frogs along the 500-metre transect.	56

Figure 4.5. Power to detect a population increase for <i>L. booroolongensis</i> using, a) mark-recapture population estimates, and b) raw counts of frogs along the 500-metre transect.	57
Figure 5.1. Map of the South West Slopes region of New South Wales showing survey localities and sections of stream likely to support extant populations of <i>L. booroolongensis</i> . Crosses are survey sites where <i>L. booroolongensis</i> was not located. Closed triangles are sites where <i>L. booroolongensis</i> was located. Shaded sections of the landscape are areas of conservation reserves while shaded sections of stream are areas where <i>L. booroolongensis</i> is expected to occur based on the survey results and presence of suitable habitat.	72
Figure 5.2. Beta values and 95% confidence intervals (CI) for each regional predictor variable. Intercept values have been omitted to improve resolution.	75
Figure 5.3. Fitted curves for probability of occupancy versus (a) cobble bank length, (b) Bedrock length and (c) percentage canopy cover. Dashed lines indicate 95% credible intervals.	76
Figure 5.4. Beta values and 95% credible intervals (CI) for each among bedrock habitat predictor variable.	77
Figure 5.5. Fitted curves for the relationship between expected occupancy and (a) the number of crevices, (b) pool length and (c) water depth in the bedrock habitat. Dashed lines indicate 95% credible intervals.	78
Figure 5.6. Beta values and 95% credible intervals (CI) for each among cobble habitat predictor variable.	79
Figure 5.7. Fitted curves for the relationship between expected occupancy and (a) emergent rock, (b) the number of crevices, (c) the number of pools and (d) water depth in the cobble habitat. Dashed lines demark 95% credible intervals.	80
Figure 6.1. Location of sites sampled for <i>B. dendrobatidis</i> infection in <i>P. corroboree</i> and <i>P. pengilleyi</i> populations. Arrows point to sites where positive infection was recorded.	96
Figure 7.1. Location of sites where swabbing of <i>C. signifera</i> was undertaken (closed circles and triangles) and where <i>P. corroboree</i> tadpoles were returned to natural and artificial pools (closed circles).	106
Figure 7.2. Post metamorphic survivorship from the Bayesian logistic regression for the tadpoles from artificial tubs and natural pools within each of the five experimental sites. The points represents the mean and error bars represent the 95% credible intervals.	114
Figure 7.3. Results of the Bayesian logistic regression analysis for (a) tadpole survivorship from release to collection, (b) survivorship from collection to post metamorphosis, and (c) postmetamorphic survivorship. The points represents the mean and error bars represent the 95% credible intervals.	115

Figure 7.4. Results of the Bayesian nested ANOVA for (a) development stage, and (b) body length at the point of tadpole collection. Points represents the mean and error bars represent the 95% credible intervals. Note, the infection status of the natural pools was not incorporated into the analysis, but is presented for visual comparison..... 116

Figure 8.1. Location of population augmentation sites (closed triangles) and control sites where no augmentation and tadpole surveys were undertaken (closed circles).127

Figure 8.2. Survival from egg to metamorphosis for field clutches (closed squares) and captive reared clutches (closed triangles). The point is the mean, box is the 75% confidence limits and the error bars are the 95% confidence limits. The closed circles are outliers and crosses are extreme values. 134

Figure 8.3. Difference in survival from egg to metamorphosis between field and captive reared clutches. The point is the mean and the error bars are the 95% credible intervals..... 134

Figure 8.4. Difference in time to metamorphosis (number of days) between clutches left in the field and captive reared clutches. The point is the mean and the error bars are the 95% credible intervals..... 135

Figure 8.5. Number of days to metamorphosis after the start of December for field clutches (closed squares) and captive reared clutches (closed triangles). The point is the mean, box is the 75% confidence limits and the error bars are the 95% confidence limits. The closed circles are outliers..... 135

Figure 8.6. Level of decline relative to the number of males observed in 1999 at sites where recruitment to metamorphosis was augmented (closed triangles) and control sites where recruitment to metamorphosis was not manipulated (closed squares). The point is the mean, box is the 75% confidence limits and the error bars are the 95% confidence limits. The closed circles are outliers and crosses are extreme values... 138

Figure 8.7. Relationship between the number of tadpoles and subsequent number of breeding males across non-manipulated sites (closed circles) for male counts during 2004 and 2005. The dotted lines are the 95% credible intervals for this relationship. The number of males relative to tadpoles released at the augmentation sites has been presented on these graphs for visual comparison (closed triangles)..... 139