The Report committee for Liming Luo

Certifies that this is the approved version of the following report:

Estimation of Population Sizes for the Jollyville Plateau Salamander (*Eurycea tonkawae*) Using a Mark-Recapture Method

APPROVED BY
SUPERVISING COMMITTEE:

Supervisor: ___________________________
Sahotra Sarkar

____
Thomas W. Pullum

Estimation of Population Sizes for the Jollyville Plateau Salamander

(*Eurycea tonkawae*) Using a Mark-Recapture Method

By

Liming Luo, B. S., M. S.

Report

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Dedication

To my parents Zhongfa Luo, Kanglin Wei and my husband Yiqing Wei

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I'm also grateful to my husband, Yiqing Wei, for his love and care to me. I'm indebted to my parents, who give me unconditional support and love.

Abstract

Estimation of Population Sizes for the Jollyville Plateau Salamander (*Eurycea tonkawae*) Using a Mark-Recapture Method

Liming Luo, M.S. Stat.

The University of Texas at Austin, 2010

Supervisor: **Sahotra Sarkar**

The Jollyville Plateau Salamander (JPS), *Eurycea tonkawae*, is a species of salamander endemic to Texas, the United States. It is a candidate for protection under the Endangered Species Act. This report assesses the JPS population abundances at Lanier Spring, Long Hollow Creek at Wheless Spring, and Ribelin Spring in Austin using a mark-recapture method. The maximum likelihood estimation method was used to obtain the population size estimates ($\hat{N}$) under two models, the M_0 model and the M_t model. The M_0 model assumes that every animal has the same capture probability in the population for each sampling period while the M_t model allows capture probabilities to vary by time. Simulations were performed by using an MCMC algorithm based on the M_0 model. Between 2007 and 2009, the population size estimates for JPS (>16mm snout-vent length, (SVL)) at Lanier Spring varied between 86 and 554 under the M_0 model, between 80 and 549 under the M_t model, and between 76 and 564 using MCMC

simulations. During 2007 monitoring periods, the population size estimates for JPS (>16mm SVL) at Ribelin Spring varied between 105 and 236 under the M_0 model, between 104 and 196 under the M_t model, and between 105 and 265 using MCMC simulations. During 2007 and 2008 monitoring periods, the population size estimates for JPS (>16mm SVL) at Wheless Spring varied between 368 and 1087 under the M_0 model, between 339 and 1075 under the M_t model, and between 411 and 1098 using MCMC simulations. Different estimation methods yielded consistent estimates. No clear population trends were detected due to the big fluctuations in estimates in this study.

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Chapter 1: Introduction

1.1 Introduction to the Jollyville Plateau Salamander

The Jollyville Plateau Salamander (JPS), *Eurycea tonkawae*, is a species of salamander in the Plethodontidae family. It was described by Chippindale in 2000 (Chippindale et al., 2000, Fig.1.1). So far, it is found to be endemic to Texas (Bowles et al., 2006).

Figure 1.1 Holotype of *Eurycea tonkawae*, adult female, TNHC 50952 (From Chippindale et al., 2000).

The Jollyville Plateau Salamander's natural habitats are freshwater springs and wet caves. It is found only on the Jollyville segment of the Edwards Plateau, Texas (Bowles et al., 2006). Its known range includes nine creek watersheds in northwestern Travis County and the border of Williamson County, including Bull, Brushy, Buttercup, Cypress, Lake, Long Hollow, Shoal, Walnut, and West Bull creeks (Chippindale et al., 2000, Herbez, 2005). The species is carnivorous and it consumes benthic macroinvertebrates, including a variety of snails (*Gastropoda*), seed shrimp (*Ostracoda*), copepods (*Copepoda*), flatworms (*Planaria*), and segmented worms (*Annelida*) (Davis et al., 2001). The relationships between the JPS and its predators are not well understood yet. Its predators may include freshwater sunfish, basses, crayfish, and some large invertebrates (Davis et al., 2001, Bowles et al., 2006).

1.2 JPS is a candidate for protection

The Jollyville Plateau Salamander faces the threat of decreasing populations due to ongoing rapid urbanization, according to environmentalists in the City of Austin (Bowles et al., 2006). It is currently a candidate for protection under the Endangered Species Act (the U.S. Fish and Wildlife Service, 2002, 2007a, 2007b). There are several reasons why the JPS is in danger. First, the distribution of this species is highly restricted. It is found in a very narrow geographic area. Its habitats are generally characterized by well-oxygenated water and proximity to springs, spring-fed streams and wet caves with a narrow temperature range (18-21ºC) and mostly neutral pH (Davis et al., 2001). The highly restricted distribution of this species may be explained by the fact that spring-associated *Eurycea* are dependent on the stable conditions of the spring systems, such as near constant water temperature, water flow, dissolved oxygen, and minimal substrate siltation (Tupa and Davis, 1976, Bowles et al., 2006). Also, the population sizes of the JPS are relatively small (Davis et al., 2001). It is generally agreed that the risk of extinction is higher for species with small geographic ranges and populations, because the influence of stochastic variation in demographic (reproductive and mortality) rates and environment can have a much greater impact on species with smaller populations than on species with larger populations (Soulé, 1983, Diamond, 1984).

Second, ongoing rapid urbanization has negatively impacted the salamander habitat. The City of Austin scientists have been monitoring populations of the JPS since 1997 and have found that several of the long-term monitoring sites have experienced declines. The declines appear to be related to urban development. The study also found that some urban salamander sites were significantly contaminated by toxic compounds like DDT, chlordane, hexachlorobenzine, and diedrin (Davis et al., 2001). Although the relationship between salamander population declines and urbanization is still not clear, evidence shows that sites with the most urban development have the lowest abundance of salamanders. Figure 1.2 below shows the results from direct count surveys between 1997 and 2005 at Bull Creek Tributary 5. At the beginning of the study in 1997, Bull Creek Tributary 5 was still a rural area. Over the past ten years, it has experienced rapid development. It was found that conductivity, nitrate, and sodium increased significantly in this area (O'Donnell et al., 2005, 2006). Although the counts at Bull Creek Tributary 5 fluctuated from year to year, a declining trend was detected between 2002 and 2006 showing that counts were on average much lower than those from previous years.

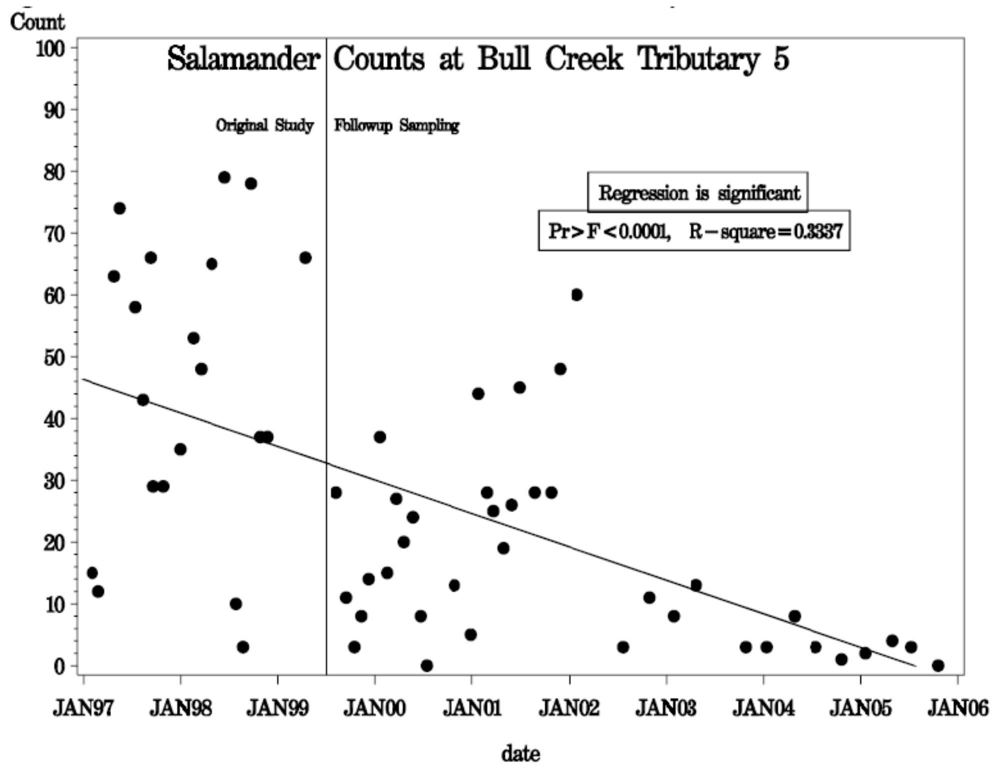


Figure 1.2 Direct count surveys between 1997 and 2006 at Bull Creek Tributary 7. Between 2002 and 2006, the counts were on average lower than those from previous years (From O'Donnell et al., 2006).

1.3 Conservation Status of the JPS

In 1995, the Aquatic Biological Assessment Team (ABAT) was commissioned by the City of Austin and the Texas Parks and Wildlife Department (TPWD) to evaluate the status of the Jollyville Plateau Salamander. In 1997 and 1998, a two-year intensive study was conducted to collect baseline information about the JPS. This study involved detailed analyses of habitat and water quality parameters and their relationship to salamander distribution and abundance (Davis et al., 2001, Bowles et al., 2006). Not surprisingly, preliminary results indicated an inverse correlation between the degree of urbanization and salamander abundance at spring outflows (Davis et al., 2001). In this two-year study, nine monitoring sites in three watersheds (Bull, Long Hollow, and Shoal) were established by direct count surveys. From 1999 to 2003, the City of Austin biologists continued to monitor salamander population sizes at some of these original monitoring sites with less frequency. To collect more information, including habitat conditions, seasonal variation in reproduction, and population trends, the City of Austin biologists expanded the monitoring survey to include all nine long-term monitoring sites as well as new sites in three other watersheds (Cypress Walnut and West Bull) beginning in 2004 (O'Donnell et al., 2005, 2006).

In 2007, the U.S. Fish and Wildlife Service (USFWS) issued a 90-day petition finding and a 12-month petition finding to determine whether the service will list the species as endangered. The 90 day finding listed the JPS as endangered under the Endangered Species Act of 1973, as amended (Act) (USFWS, 2007a). The 12-month finding described listing the species as endangered or threatened as "warranted but precluded (USFWS, 2007b)," which basically means that they know the species deserves status as endangered or threatened but that other candidate species have a higher priority based on the level of perceived threat and the availability of resources.

1.4 Goals of the study described in this report

Beginning in 2007, mark-recapture surveys were conducted to better estimate the population sizes of the JPS at three sites, Lanier Spring, Long Hollow Creek at Wheless Spring, and Ribelin Spring. The original purpose of the mark-recapture surveys was to assess the potential impact of a proposed water treatment plant (WTP4) at the Bull Creek watershed. In 2007, the City Council of Austin decided to move WTP4 out of the Bull Creek watershed to an alternate site; so, documenting the effect of WTP4 on JPS populations became unnecessary. However, the mark-recapture surveys can still provide critical information about JPS population sizes. In the past, all monitoring was conducted by periodically searching salamanders and recording all the observations in a given area. However, this method cannot serve well to estimate population size since it usually is not possible to obtain a complete count of a natural population of animals. Mark-recapture is a method commonly used in ecology to estimate population size. It allows for estimation of capture probability, and thus gives much more accurate estimation of population. In this study, my goal is to use different statistical approaches to analyze the mark-recapture data, estimate the salamander population sizes and detect the population trends at these sites.

Chapter 2: Methods

2.1 Closed population mark-recapture model

2.1.1 The origin and basic idea

Mark-recapture is a method commonly used in ecology to estimate population size. It can be traced back to 1802, when Pierre Laplace used a capture-recapture type of approach to estimate the size of the population of France (Cochran, 1978, Stigler, 1986). In the mark-recapture method, a number of individuals in a natural population are captured and marked, and then returned to that population. Some of them are subsequently recaptured in the next visit, which is the basis for estimating the size of the population at the time of marking and release. The basic principle under the method is that if a proportion of the population was marked and returned to the original population and then, after complete mixing, when a second sample is taken, the proportion of marked individual in the second sample will stay the same as was marked initially in the total population (Amstrup et al., 2005).

The origin of mark-recapture methodology is the Lincoln-Petersen method. The method assumes that the studied population is "closed," which means that no individuals die, are born, move into the study area (immigrate), or move out of the study area (emigrate) between two occasions. Assume:

$\widehat{N}_p$ = the estimate of total population size

n_1 = the total number of animals captured and marked in the first sample

n_2 = the total number of animals captured in the second sample

m_2 = the number of animals captured on the first visit that were then recaptured in the second sample

If both samples were properly collected, the proportion of marked individuals that are caught (m_2 / n_2) in the second sample should be equal to the proportion of the marked animals (in the first sample) in the population (n_1 / N). Rewriting the equation $\frac{m_2}{n_2} = \frac{n_1}{N}$ allows us to estimate the population size with:

$$\widehat{N}_p = \frac{n_1 n_2}{m_2} \tag{1}$$

This is the well-known Petersen-Lincoln estimator (Amstrup et al., 2005).

Although the mark-recapture method is widely used in ecology, it can also apply in a much wider range of domains, such as sociology, demography, finance and marketing.

2.1.2 Model types

For the most restrictive closed population mark-recapture model, five assumptions are necessary: (1) the population is closed; (2) marks are not lost or overlooked during the experiment; (3) all marks or tags are correctly noted and recorded at each trapping occasion; (4) capture and marking do not affect the survival and capture probability of the animal, and all individuals in the population have a constant and equal probability of capture on each trapping occasion (Otis et al., 1978); (5) the marked and unmarked animals are completely mixed. Otis et al (1978) suggested three sources of variation in capture probabilities: (1) capture probabilities vary from occasion to occasion; (2) capture probabilities vary due to behavioral response with recapture probabilities either greater (trap happy) or less than initial capture probabilities (trap shy); (3) capture probabilities vary by individual animal because of inherent differences among individuals (Otis et al., 1978). They proposed a suite of eight models for the estimation of the size of closed populations. These eight models are described in Table 2.1.

Table 2.1 Eight closed-population models described by Otis et al.

Otis notation	**Description**
$\mathbf{M_0}$	Costant *p* : capture probabilities are constant
$\mathbf{M_t}$	Time varying *p* : capture probabilities vary with time or trapping occasion
$\mathbf{M_b}$	Behavioral response: capture probabilities vary due to behavioral response
$\mathbf{M_h}$	Heterogeneous *p*: capture probabilities vary by individual animal
$\mathbf{M_{tb}}$	Capture probabilities vary by time and by behaviroal response
$\mathbf{M_{th}}$	Capture probabilities vary by time and by individual animal
$\mathbf{M_{bh}}$	Capture probabities varied by individual animal and by behavioral response to capture
$\mathbf{M_{tbh}}$	Capture probabilites vary by time, behavioral response to capture, and individual animal

2.2 Maximum likelihood estimation (MLE) by program MARK

In this report, several methods were used to estimate salamander abundance at each site. The program MARK (White and Burnham, 1999) was used to calculate the maximum-likelihood estimators under two models, the M_0 model and the M_t model. In program MARK, the capture history of each captured individual is expressed as a series of 0's and 1's, which 0's indicate noncaptures and 1's indicate captures.

(1) the M_0 model

The M_0 model assumes that every animal in the population has the same capture probability for each sampling period in the study. The model has been studied by Darroch (1958), Otis, Burnham, White and Anderson (1978).

The probability distribution of the set of possible capture histories $\{X\omega\}$ for the M_0 model is given by (Darroch, 1958):

$$P[\{X_\omega\} \mid N, p] = \frac{N!}{\left[\prod_\omega X_\omega!\right](N - M_{t+1})!} \times p^{n^c} (1-p)^{kN - n^c} \quad (2)$$

where

M_{t+1} = the number of different animals captured in the experiment

n^c = the number of capture in the experiment

(2) the M_t model

With the M_t model, capture probabilities vary with time or trapping occasion. A basic assumption in the M_t model is that all animals have the same probability of capture at each sampling occasion.

The probability distribution of the set of possible capture histories {Xω} for the M_t model is given by (Otis et al., 1978):

$$P[\{X_{\omega}\} \mid N, p] = \frac{N!}{\left[\prod_{\omega} X_{\omega}!\right](N - M_{t+1})!} \times \prod_{j=1} P_j^{n_j} (1 - p_j)^{N - n_j} \tag{3}$$

where

M_{t+1} = the number of different animals captured in the experiment

n_j = the number of animals caught on the j^{th} occasion.

Computer simulation shows that if the probabilities of capture *p* are, on the average, close to 0.1 or larger, the bias of N_t is not significant.

2.3 Bayesian Estimation by a Markov Chain Monte Carlo (MCMC) method

For many animal mark-recapture data analyses, MLE has been one of the most preferred methods. However, Bayesian analysis is gaining popularity in the statistical modeling community. It allows one to incorporate information from previous similar studies, obtain probability regions for parameters, and obtain estimation in complex models via simulation (Robert, 2001). MCMC is a technique where a Markov chain is constructed that has its limiting stationary distribution as the posterior distribution of interest (Gilks et al., 1996). Bayesian analysis of the M_0 model is achieved by using a method of “data augmentation” (Tanner and Wong, 1987, Royle et al., 2007), which allows for a straightforward implementation in the software WinBUGS (Gilks et al., 1994, Lunn et al., 2000). In practice, Bayesian analysis of population size is difficult because the population size is unknown, which makes the dimension of the parameter space unfixed. Therefore, a function of the unknown index is obtained in some cases. This can be overcome by the method of data augmentation that provides for an efficient Bayesian implementation (Royle et al., 2007). Under the data augmentation approach, the observed data set is augmented with a fixed, known number, say $M - n$, of all-zero capture histories and the resulting augmented dataset (of size M) is modeled as a zero-inflated version of the complete-data model where the unknown multinomial index is replaced by the zero-inflation parameter (Royle et al., 2007). As long as M is sufficiently large, this yields a natural and noninformative prior for the population size.

Assume:

N = the population size

y_i = the detection frequency

Z_i = the latent indicator variable with "1" for observed and "*NA*" for unobserved

P = the capture probability

T = the number of occasions

ψ = the probability that an element of the augmented population (of size M) is a member of the sampled population (of size N)

After augmentation, the data consist of:

(1) the n observed detection frequencies $y_1, y_2, \ldots, y_n$;

(2) zero pseudo-operations ($y_{n+1} = 0$, $y_{n+2} = 0, \ldots, y_M = 0$) introduced for estimation by data augmentation;

(3) a set of latent indicator variables $\{Z_i\}_{i=1}^{M}$ that are observed ($Z = 1$) for $i = 1, 2, \ldots, n$ and unobserved ($Z = NA$) for $i = n+1, \ldots, M$.

For each Z_i, $Z_i \sim$ Bernoulli (ψ), and then $N = \sum_{i=1}^{M} Z_j$ (Royle, 2009). For each y_i, $[yi \mid p] \sim$ Binomial(T, $p*Z_i$). By the data augmentation method, estimation and inference are straightforward using conventional MCMC methods. MCMC simulations were performed in WINBUGS. WINBUGS code is provided in Appendix A.

2.4 Study area

This study included 3 monitoring areas.

(1) Bull Creek Mainstem, Lanier Spring

Lanier Spring lies along the main stem of Bull Creek. The creek channel is predominantly riffle habitat with sand, gravel, and cobble substrate at this site (O'Donnell et al., 2008). Based on the preliminary data obtained in 2005, the JPS population at this site appeared to be increasing. A robust JPS population may exist here by a cursory survey on the Lanier tract along the tributary on July 11, 2005 (O'Donnell et al., 2005).

(2) Bull Creek Tributary 8, Lower Ribelin

Ribelin Spring was discovered during reconnaissance surveys along Bull Creek Tributary 8 in early 2007 (O'Donnell et al., 2008). The creek channel is predominantly bedrock covered with little loose rock and plant substrate at this site.

(3) Wheless Spring

Wheless Spring became a long-term monitoring site in 1997 (Davis et al., 2001). The creek is almost entirely bedrock covered with a mixture of soil, cobble, gravel and boulders. The JPS has been found along much of the creek with relatively large population size.

These three sites were selected because a water treatment plant (WTP4) was proposed to be built in the Bull Creek watershed. The City Council wanted to assess the potential impact of WTP4 on JPS populations. Lanier Spring and Ribelin Spring were below the former WTP4 site. Wheless Spring was a control site. However, in 2007, the City Council voted to move WTP4 out of the Bull Creek watershed to an alternate site. Documenting the effects of WTP4 was no longer necessary.

A map of these 3 survey sites is provided in Appendix B.

2.5 Field methods

Multiple sampling events were conducted in three consecutive days. The short interval was chosen to satisfy the assumption of "closed population" (no births and deaths, no immigration and emigration). To inhibit horizontal salamander movement, minnow seines were placed across the width of the stream at the boundaries of each survey site. To verify the inhibition of movement, searches for marked animals were conducted above and below the seines. Only the JPS greater than 16 mm snout-vent length (SVL) were collected for mark-recapture. Juveniles shorter than 16mm were not included in the mark-recapture data because they are too small to safely and reliably apply a mark (O'Donnell et al., 2008).

The mark-recapture experiment was conducted once a month from May through October 2007 at Ribelin Spring. Between March 2007 and October 2007, the experiment was conducted once a month at Lanier Spring and Wheless Spring. After October 2007, the experiment continued to be conducted at these two sites but on a less frequent basis due to time and labor constraint.

The mark-recapture experiment was conducted by Nathan Bendik and his colleagues. Nathan Bendik is an environmental scientist for the City of Austin working on issues related to the study and conservation of Austin's endemic salamanders, with a specific emphasis on the JPS.

Chapter 3: The Data

The data contain the capture history of each salamander captured at Lanier Spring, Long Hollow Creek at Wheless Spring, and Ribelin Spring. During the study, a total of 4373 salamanders (>16mm SVL) were captured and marked. 956 recaptures were observed. Table 3.1 - Table 3.3 give a summary of the number of salamanders captured and re-captured at each site between 2007 and 2009.

Table3.1 Mark/recapture data between 2007 and 2009 at Lanier Spring

	No. of capture and recapture			*No.* of recapture	
Date	day 1	day2	day3	day2	day 3
3/19-3/21/07	89	65	50	25	26
4/16-4/18/07	63	69	45	23	28
5/14-5/16/07	50	65	37	15	18
6/11-6/13/07	35	47	23	7	6
7/9-7/11/07	28	18	14	9	6
8/13-8/15/07	19	18	21	5	6
9/10-9/12/07	42	22	47	4	18
10/8-10/10/07	53	52	29	23	12
3/11-3/13/08	88	98	82	48	56
3/17-3/19/09	127	89	91	30	46
6/10-6/12/09	134	104	98	30	33

Table3.2 Mark/recapture data in 2007 at Ribelin Spring

	No. of capture and recapture			*No.* of recapture	
Date	day 1	day2	day3	day2	day 3
5/14-5/16/2007	45	31	6	9	0
6/11-6/13/2007	24	24	32	7	10
7/9-7/11/2007	23	27	20	6	9
8/13-8/15/2007	49	37	34	10	15
9/10-9/12/2007	46	24	30	10	11
10/8-10/10/2007	69	46	39	17	22

Table3.3 Mark/recapture data between 2007 and 2008 at Wheless Spring

	No. of capture and recapture			*No.* of recapture	
Date	day 1	day2	day3	day2	day 3
3/10-3/12/2007	60	55	77	9	2
4/23-4/25/2007	177	121	115	19	45
5/21-5/23/2007	174	120	118	29	41
6/18-6/20/2007	103	83	111	19	26
7/16-7/18/2007	147	153	134	28	49
8/20-8/22/2007	183	104	101	16	29
9/18-9/20/2007	117	99	63	36	24
10/15-10/17/2007	115	37	50	9	22
3/24-3/25/2008	101	59	34	9	16

Chapter 4: Results

4.1 Population size estimates obtained by the maximum likelihood method

Population size estimates ($\hat{N}$) in the program MARK were obtained by the method of maximum likelihood estimation (MLE) under the M_0 model and the M_t model. The results are shown in Table 4.1 - Table 4. 3.

Table 4.1 Maximum likelihood estimates of the population size ($\hat{N}$) under the M_0 model and the M_t model at Lanier Spring

	M_0		M_t	
Date	$\hat{N}$	s.e.	$\hat{N}$	s.e.
3/19-3/21/07	245.375	22.28935	239.2026	21.22414
4/16-4/18/07	181.3209	15.01827	179.0493	14.59324
5/14-5/16/07	215.446	26.81199	210.1402	25.6896
6/11-6/13/07	240.3968	41.77217	235.6587	41.53102
7/9-7/11/07	86.17326	22.70967	80.25274	20.42057
8/13-8/15/07	108.3149	23.1907	108.6183	23.44504
9/10-9/12/07	172.3028	23.40741	167.7	22.5532
10/8-10/10/07	153.699	16.1104	149.9518	15.38789
3/11-3/13/08	194.2859	8.405218	193.8635	8.334491
3/17-3/19/09	374.2196	28.04253	369.2234	27.34387
6/10-6/12/09	554.985	51.77145	549.8378	51.04046

Table 4.2 Maximum likelihood estimates of the population size ($\hat{N}$) under the M_0 model and the M_t model at Ribelin Spring

	M_0		M_t	
Date	$\hat{N}$	s.e.	$\hat{N}$	s.e.
5/14-5/16/2007	235.3453	66.56373	196.8938	52.73666
6/11-6/13/2007	113.8427	19.35363	112.7719	19.0516
7/9-7/11/2007	105.3529	16.68122	104.8298	16.54632
8/13-8/15/2007	167.3861	19.96613	165.8575	19.66886
9/10-9/12/2007	143.2355	21.46068	138.2174	20.22365
10/8-10/10/2007	182.1906	18.76586	176.9774	17.73705

Table 4.3 Maximum likelihood estimates of the population size ($\hat{N}$) under the M_0 model and the M_t model at Wheless Spring

	M_0		M_t	
Date	$\hat{N}$	s.e.	$\hat{N}$	s.e.
3/10-3/12/2007	1086.945	302.2764	1075.293	298.6824
4/23-4/25/2007	781.767	60.10504	754.0067	59.47579
5/21-5/23/2007	756.9727	69.26	740.615	67.58514
6/18-6/20/2007	598.8094	53.34419	614.9973	71.06678
7/16-7/18/2007	716.0588	51.13174	711.2667	50.80005
8/20-8/22/2007	1007.339	105.3149	973.9113	101.1892
9/18-9/20/2007	401.7403	35.96374	388.4766	33.39477
10/15-10/17/2007	367.5121	38.71284	338.7154	34.65846
3/24-3/25/2008	408.0352	38.53225	391.9224	36.35419

4.2 Population size estimates obtained by MCMC simulations

MCMC simulations were performed using the program WINBUGS under the noninformative prior $N \sim$ uniform (1, 5000). For each simulation, four chains were run and the performance of the simulation was assessed by checking the posterior density plot, Gelman-Rubin statistic and autocorrelation of variables. The results are shown in Table 4.4 - Table 4.6.

Table 4.4 MCMC estimates of the population size ($\hat{N}$) at Lanier Spring

Date	$\hat{N}$	s.e.
Mar. 2007	250.4	15.95
Apr. 2007	185.1	27.79
May. 2007	219.9	73.95
Jun. 2007	289.4	14.3
Jul. 2007	76.29	26.46
Aug. 2007	102.6	29.69
Sep. 2007	179.6	17.6
Oct. 2007	157.6	8.651
Mar. 2008	195.9	28.93
Mar. 2009	379.3	53.43
Jun. 2009	564.4	15.95

Table 4.5 MCMC estimates of the population size ($\hat{N}$) at Ribelin Spring

Data	$\hat{N}$	s.e.
May 2007	265.4	86.04
Jun. 2007	121.1	22.4
Jul. 2007	105.9	21.21
Aug. 2007	183.1	27.55
Sep. 2007	152.3	25.32
Oct. 2007	187.2	20.2

Table 4.6 MCMC estimates of the population size ($\hat{N}$) at Wheless Spring

Date	$\hat{N}$	s.e.
Mar. 2007	1198	293.2
Apr. 2007	850.5	85.56
May-07	768.4	71.53
Jun. 2007	630.6	76.83
Jul. 2007	771.5	67.64
Aug. 2007	1096.0	145.2
sep. 2007	411.4	38.8
Oct. 2007	425.9	62.74
Mar. 2008	496.7	86.2

Chapter 5: Discussion and Conclusion

5.1 Estimation of population size

Population size estimation is an important aspect of many ecological studies and wildlife management programs. In this report, a mark-recapture method was used to get better estimation of the population sizes for the JPS at three monitoring sites in Austin. The maximum likelihood method and MCMC simulations were used to analyze the mark-recapture data. The population size estimates were obtained under two models, the M_0 model and the M_t model. Between 2007 and 2009, the population size estimates for the JPS (>16mm SVL) at Lanier Spring varied between 86 and 554 under the M_0 model, between 80 and 549 under the M_t model, and between 76 and 564 using MCMC simulations. During 2007 monitoring periods, the population size estimates for the JPS (>16mm SVL) at Ribelin Spring varied between 105 and 236 under the M_0 model, between 104 and 196 under the M_t model, and between 105 and 265 using MCMC simulations. During 2007 and 2008 monitoring periods, the population size estimates for the JPS (>16mm SVL) at Wheless Spring varied between 368 and 1087 under the M_0 model, between 339 and 1075 under the M_t model, and between 411 and 1098 using MCMC simulations. These estimates provide "snapshots" of the JPS populations between 2007 and 2009 at these monitoring sites, and thus give some useful information about the JPS populations.

As shown in Fig. 5.1- Fig 5.3, there is no significant difference among the estimates obtained by different methods. During the study, a total of 4373 salamanders were captured and marked. Only 15 confirmed violations of closure were found due to horizontal movement at three sites. This implies the "closed population" assumption, which is of fundamental importance, was satisfied. The M_t model allows capture probabilities to vary by time. However, the difference between the MLE estimates under the M_0 model and the M_t model is not significant, which implies the variation of capture probabilities in different sampling periods was not significant and didn't have a significant effect on the population size estimation. If the data fit the model well, the estimates obtained by the MLE method and MCMC simulations should be consistent. As shown in Fig. 5.1 - Fig 5.3, the MCMC and MLE estimates are not significantly different from each another, indicating the M_0 model is appropriate for this study.

Figure 5.1 Comparison of population size estimates at Lanier Spring

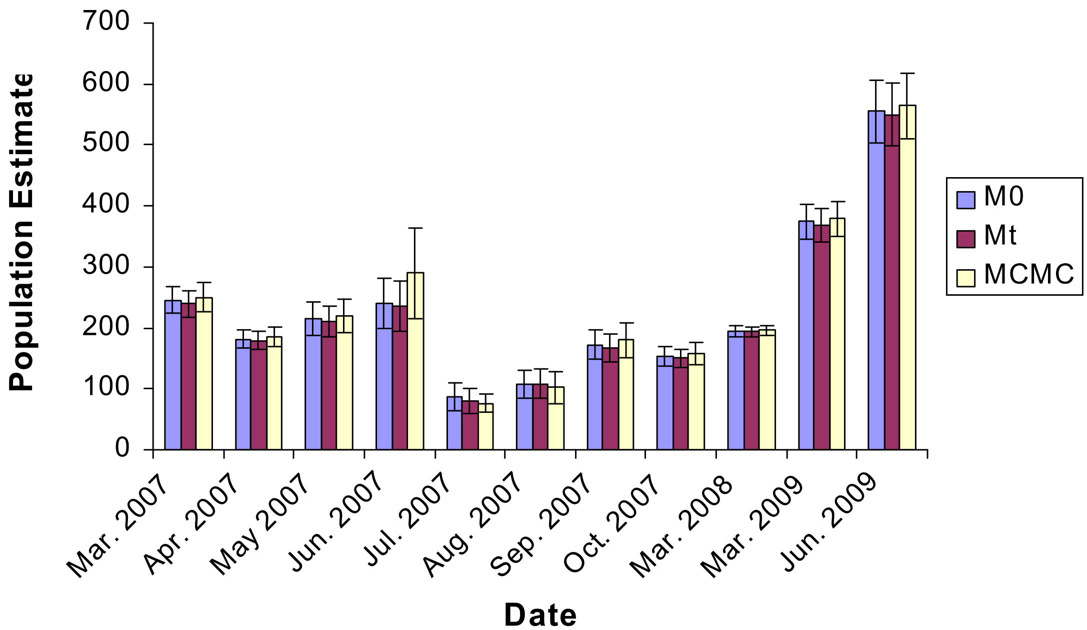


Figure 5.2 Comparison of population size estimates at Ribelin Spring

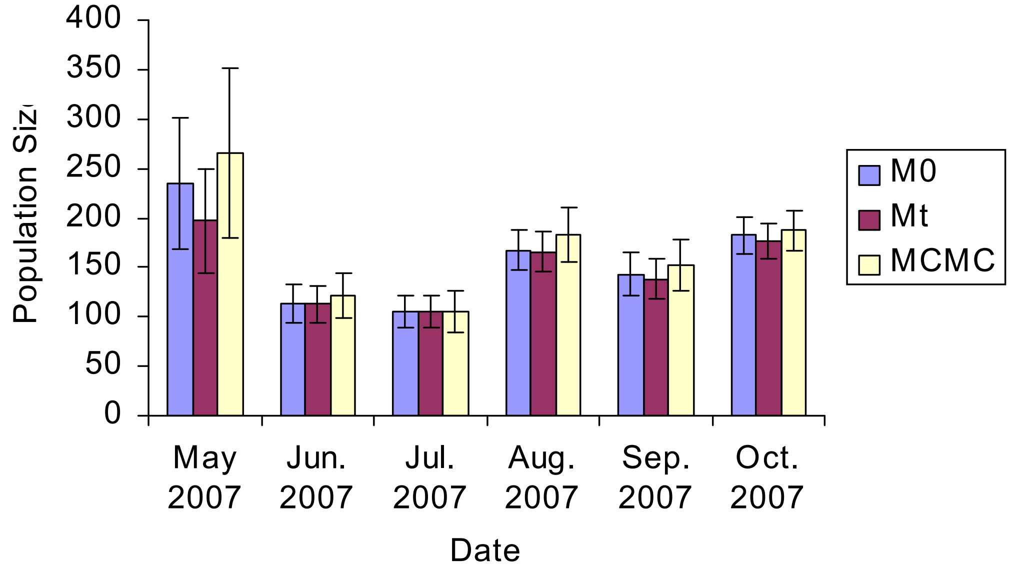
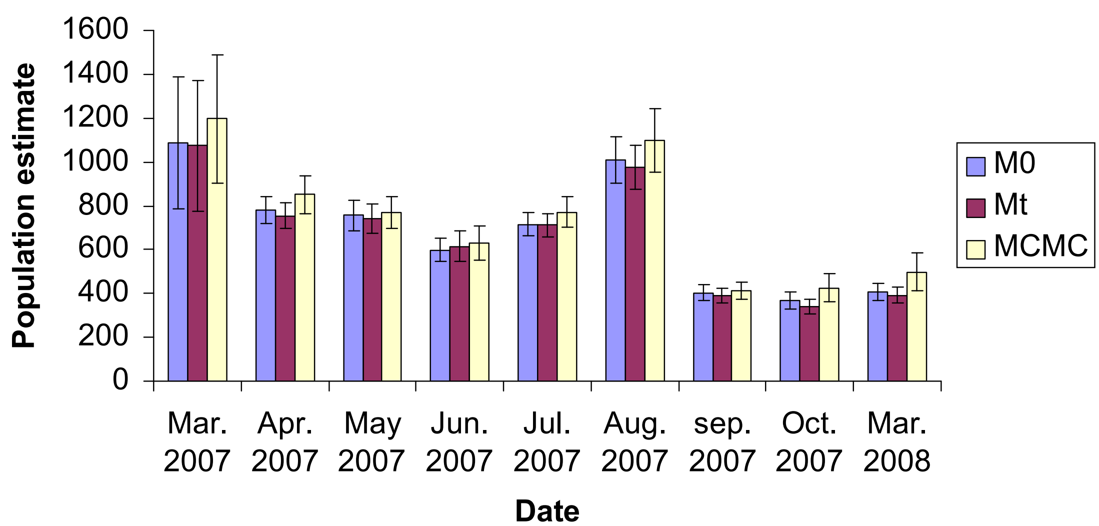


Figure 5.3 Comparison of population size estimates at Wheless Spring



5.2 Estimation of population trend

Another important issue for wildlife management is to understand the actual dynamics and long-term status of the population. A multi-year monitoring effort is needed to get this approach. It is important that any monitoring design be standardized so that the same methodology is used in each period (Mulders et al., 2007). As shown in Fig. 5.1, the population size seemed to be increasing between July 2007 and June 2009 at Lanier Spring. There was no clear trend detected at Ribelin Spring. The population size may remain unchanged at this site (Fig.5.2). At Wheless Spring, except for July and August in 2007, the population size seemed to decrease over time (Fig.5.3). However, big fluctuations in estimates were observed in different periods. Several possible reasons may explain these fluctuations. (1) The weather and seasonality have considerable influence on the number of captures (Anderson, 2001). For example, heavy rainfall may result in lower numbers of both initial captures and recaptures. The aquifers upon which the JPS depends are generally small and localized, and thus are very susceptible to seasonal change (Chippindale et al., 2000). Furthermore, reproduction and recruitment may influence the population size estimation too. Only the JPS greater than 16 mm SVL were collected for mark-recapture. However, juveniles could be recruited into the size classes that are large enough to mark in a few months. This was most pronounced at Wheless Spring, which had the largest numbers of small juveniles and thus had highest counts in summer (O'Donell et al., 2008, Table 3.3). (2) Immigration and emigration may occur between different experimental periods (Smith and Petranka 2000, Hyde and Simons, 2001). At Lanier Spring and Wheless Spring, suitable surface habitat extends both above and below the study areas, which allows animals move horizontally beyond the survey area between different experimental periods. By contrast, the habitat at Ribelin Spring is bounded by stream segments of bedrock, which makes the survey area discrete. The estimates at Ribelin Spring were less fluctuated from month to month compared to the ones at Lanier Spring and Wheless Spring, indicating temporary migration may have effects on the population size estimation. (3) Unequal amount of effort was given in searching animals in different periods, which would be erroneously interpreted as population change. During different study periods, the experiment was conducted by different people and the number of people was not fixed also, which may result in the variation of the number of salamanders captured and the capture probabilities. To get a better idea about the population trends, experiments should be conducted in a more controlled way with the same methodology and equal amount of effort for each sampling period.

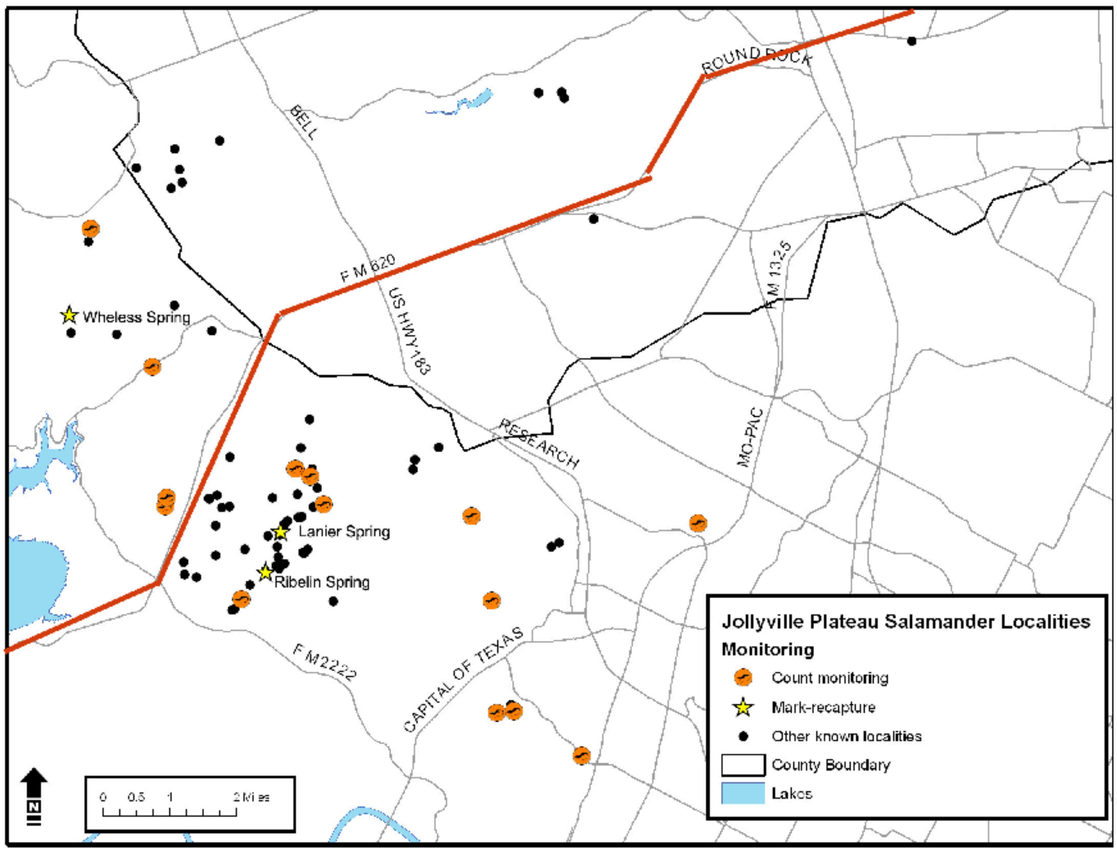
Appendix A

Winbugs code for the M_0 model

```
model
{
psi~dunif(0,1)
p~dunif(0,1)
for(i in 1:M){
   z[i]~dbin(psi,1)
  mu[i]<-z[i]*p
  y[i]~dbin(mu[i],T)
}
 N<-sum(z[1:M])
}
```

Appendix B

Location of *Eurycea tonkawae* monitoring sites, Travis County



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VITA

Liming Luo was born in Guangxi, China. She received the degree of Bachelor of Science from the Southwest University in 1998. In September 1998, she entered the graduate school at the Chinese Academy of Sciences in Wuhan. She received the degree of Master of Science in Botany in 2001 and was awarded excellent graduate in the year. Between 2001 and 2004, she was a scientist associate in the Wuhan Botanic Garden, the Chinese Academy of Sciences. In 2004, she entered the graduate school at the University of Texas at Austin. During the graduate program, she served as a teaching assistant in the School of Biological Sciences and as a research assistant for Dr. Herrin in the Section of Molecular Cell and Developmental Biology.

Permanent Address: 2501 Lake Austin Blvd. Apt. E212, Austin, Texas, 78703

This Master's report was typed by the author.