POPULATION ANALYSIS OF CHRYSINA WOODII (COLEOPTERA: SCARABAEIDAE) IN THE DAVIS MOUNTAINS OF WEST TEXAS

A Thesis

Presented to the

Faculty of the College of Graduate Studies and Research

Angelo State University

In Partial Fulfillment of the

Requirements for the Degree

MASTER OF SCIENCE

by

TIMOTHY GLENN MADDOX

August 2017

Major: Biology

POPULATION ANALYSIS OF CHRYSINA WOODII (COLEOPTERA:

SCARABAEIDAE) IN THE DAVIS MOUNTAINS OF WEST TEXAS

by

TIMOTHY GLENN MADDOX

APPROVED:

Dr. Ned E. Strenth

Dr. Ben R. Skipper

Dr. Nicholas J. Negovetich

Dr. Karl J. Havlak

June 26, 2017

APPROVED:

Dr. Susan E. Keith

Dean, College of Graduate Studies and Research

ACKNOWLEDGEMENTS

I would like to thank my graduate advisor and mentor Dr. Ned E. Strenth for encouraging me to follow my interests, as well as his moral support, and assistance in the field and lab. I would also like to thank the other members of my committee whose help has been invaluable: Dr. Ben R. Skipper for his impeccable reviewing skills as well as general problem solving and expert advice regarding Program MARK and GIS; Dr. Nicholas J. Negovetich for his statistical advice and Program MARK assistance; and lastly Dr. Karl J. Havlak who has been very flexible schedule and willingness to help wherever he was needed. I would also like to thank Texas Parks and Wildlife including, Wanda Olszewski, Nicolas Havlik, David Riskind, and Mark Lockwood for allowing me to work in the Davis Mountain State Park and providing permits. A special thanks to Kelly Bryan for his advice on finding beetles. I would also like to thank Angelo State for accepting me into graduate school and providing research scholarships and funding.

Lastly, a tremendous thanks to my field crew who helped me scour the mountains for beetles as well as keeping me company, and Mary Jones who has offered much help both in and out of the field. My most sincere thanks to Kaitlynn Marie LeBrasseur, whose unyielding support has made this publication possible, and to my parents who have endured my bizarre fascination with creepy crawlies and who have supported me every step of the way through my college career. Lastly, I would like to thank the Biology department at Angelo State University that made me feel at home, and I will always appreciate my family who share my interests in the living world.

ABSTRACT

This study examined the seasonal dynamics of a population of Wood's jewel scarab inhabiting the primitive equestrian site located in the Davis Mountain State Park of west Texas. Mark and recapture techniques were conducted on adults of *Chrysina woodii* from July 2015 to October 2016 to determine population size, sex ratios, survival rates and dispersal capabilities. Population estimates and survival rates were estimated for both sexes using the POPAN Jolly-Seber model and the Cormack-Jolly Seber model in Program MARK. Beetles were determined to be highly mobile, capable of traveling between sites along the length of Limpia Creek. During peak activity in July and August, an estimated ~1900 (827-4874 ±95% CI) adult *C. woodii* travel through the primitive site during 2015 and ~ 2100 (527- 8389 ±95% CI) for the 2016 season. Sex ratios appear skewed with more males captured than females, and survival rates did not vary drastically between sexes.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Jewel scarabs belong to a group of 113 described species of New World rutelinid beetles that range from South America through Mexico into the southwestern United States (Moore et al. 2017). This group of leaf-chafing beetles exhibits its highest species diversity in Latin and Central America where they inhabit tropical rainforests of moderate to high elevations surrounded by deserts or scrublands (Hawks 2002). Four species of *Chrysina* are currently reported from the southwestern United States, these are: *C. woodii, C. lecontei, C. beyeri, and C. gloriosa*. Published literature relative to these four species is somewhat limited. This general lack of published information appears to be related to the fact that members of this genus are not considered agricultural pests or medically important disease vectors and are restricted in their distribution to the somewhat remote region of the desert southwest. Most of the related published references instead is focused on the polarizing nature of the elytra (Del Rio et al. 2016). These four species of *Chrysina* are all limited to the higher elevations of mountains in the southwestern United States and are thought to represent Pleistocene relics that have adapted to more arid conditions and are now isolated on scattered peaks within the deserts of Arizona, New Mexico and west Texas (Young 1957).

The primary focus of this study will be on the population dynamics of *Chrysina woodii* (Horn 1885) from the Davis Mountains of west Texas. *Chrysina woodii* (Horn 1885) is a moderately sized species of scarab with a body length ranging from 25 to 35 millimeters and is morphologically distinct from *C. lecontei* and *C. gloriosa*.

The Coleopterists Bulletin

It is similar in overall size and appearance to *C.beyeri* but is distinguishable from all other North American *Chrysina* by the presence of cobalt blue tarsi and elongated tarsal claws; *C. beyeri* has uniformly purple legs and tarsi/tarsal claws.

The precise location of the type locality for *C. woodii* remains in question. Skinner (1905) lists both El Paso, Texas and where “Tornillo Creek meets the Great Bend of the Rio Grande” in what is now Big Bend National Park both as the possible type localities. Following its original description, only three specimens have been reported to have been collected from the Big Bend region; these are currently deposited in the Texas A&M Insect Collection and the Big Bend National Park collection dating from 1928 and 1937, respectively. Most of the reported collection localities in Texas are from the Davis Mountains (Jeff Davis Co.) or Guadalupe Mountains (Culberson Co.) The overall distribution of this species in Texas, New Mexico and adjoining Mexico as well as the designation of the original type locality are not within the scope of this study.

Chrysina woodii is a diurnal leaf chafer that can be regularly observed in select areas of the Davis Mountains in west Texas from June through early October. Adults may be seen feeding on *Juglans microcarpa*. This rather small deciduous tree is known by several common names including: Texas walnut, Texas black walnut, little walnut, little black walnut or Stewart's little walnut (Tirmenstein 1990). Individual beetles tend to spend most of their time grasping the underside of branches and leaves, only flying when disturbed or searching for females. This species is reported to feed on a limited number of additional host plants. Fullington (1979) reported observations of this species feeding on an unidentified species of *Quercus* in the Guadalupe Mountains of Culberson County in west Texas. Other than the previous note by Fullington (1979), there has been no additional published reports or remarks on the populations of *C. woodii* within its range in Texas. Fullington (1979) stated that “care should be exercised in protecting these species” over concerns that populations could be depleted quickly. This current study represents the first to estimate survival rate and the population size of *C. woodii* in the Davis Mountains State Park with special attention to the areas that exhibit an abundance of the host plant *J. microcarpa*. This study will utilize mark and recapture methods to assess the number of individuals that can be found within the Davis Mountains State Park primitive site. This study site was selected due to the limited amount of human traffic and the greater abundance of walnut trees which serve as a refuge for *C. woodii*. This study will provide a baseline population estimate for future research in tracking population levels of *C. woodii* in the Davis Mountains State Park of west Texas as well as monitoring the number of individuals in the park.

MATERIALS AND METHODS

Site determination. The primary area of interest for this study was the Davis Mountains State Park primitive site due to the greater concentrations of the host plant along Limpia Creek. The primitive site was surveyed for areas that had the greatest density of *J. microcarpa*. It was determined that the host plant grows within close proximity to the beds of Limpia Creek that run through the entirety of the primitive site. Three sites within the primitive site of the state park were identified based on the presence of the host plant with ≥ 40 individuals of varying size. Site 1 was established directly across from the parking area of the primitive site and consisted of 47 walnut trees that ranged from 1.5-6 meters in height. This site covered 2.35 hectares and extended 258 meters along Limpia Creek which varies by width along the length of the site. Site 2 was established 0.87 kilometers west from Site 1 and Site 3, and contained 49 walnut trees covering 1.2 hectares and extended 286 meters along Limpia Creek with varying width. Site 3 was the last and smallest site to be added. It was designated as the junction where Keesey Creek meets Limpia Creek and had the highest density of host plants with 55 trees in 0.24 hectares and extending over 90 meters along both creeks. Due to the flooding conditions of Limpia Creek during the winter months, each site lost several trees, however new walnut growth was observed in Site 3 during 2016. Very few host plants and beetles were found within the primary portion of the state park, that contains the Indian Lodge as well as the main office, therefore this area was not included in the formal survey.

Host plant marking. Once sites were identified in the primitive site, each individual host plant within the site was marked using flagging for visibility. Tags were placed above areas on the host plant that had signs of high water levels or catch from previous flooding in an effort to increase the longevity of the flagging. Unique identification numbers were assigned to each tree and marked on both sides of the flagging using black permanent marker. In addition to marking the host plants with flagging, a Garmin 64st personal Global Positioning System unit was used to record the coordinates of each tree and to create a digital map for a reference in case flagging was lost. Coordinates were recorded from the base of each tree to ensure the most accurate location. Some host plants were found to be in close proximity of each other to the extent where foliage from both trees was indistinguishable from each other. In such cases, both trees were considered as one tree and only assigned a single identification number. Flagging was replaced at the start of the 2016 season or remarked for clarity and trees that were washed away were not used in the following season.

Beetle Capture and Marking. Marking trips consisted of two survey days for each of the three sites. Survey times were not standardized and occurred depending on the time of arrival or the weather conditions at the time. In instances of moderate to heavy rain, surveys were delayed until rain slowed or stopped. Surveying began at either end of the site depending on point of entry, and a thorough sweep through all marked trees in the site commenced with a maximum allotted time of two hours per site. For the 2015 mark-recapture period five marking occasions over 3 months beginning on July 30th to September 29th were carried out in intervals of 6, 20, 13, and 13 days, respectively. For the 2016 season, surveys were conducted every 14 days, beginning June 4th and ending October 23rd, and were significantly more standardized.

Host plants were inspected from the base of the trunk to the top of the canopy and circled a minimum of two times to search for the beetles. This degree of searching was required due to the fact that the beetles are somewhat cryptic in coloration. Additional care is required when searching for beetles during times of bright sunlight (e.g., mid-day) due to the iridescence blurring the margins of the beetles within their host plant as opposed to early morning or evening where the iridescence is more distinct. Beetles were captured by hand, net, or net attached to a telescoping pole to ensure that all beetles present on the tree were capable of being caught. Beetles that were startled and dropped from the trees were located if possible on the ground, and attempts were made to capture all beetles that flew from the trees once disturbed. Beetles could be easily collected from trees with the use of nets or bare hands, and only a small percentage of beetles were able to evade capture via flight and not be collected for marking. Beetles that were observed hovering around a host plant were captured and considered to be collected from that tree. Beetles that avoided capture and flew from the tree were pursued and if captured were also considered to be collected from the tree they were occupying. If a large number of beetles were collected from one tree, they were housed in a mesh laundry bag. The bag was made from a cloth like material that allowed the beetles to easily grasp the edge of the bag to minimize escape behaviors and minimize stress to the beetles as well as allowing for maximum ventilation to ensure beetles did not overheat and die in confinement.

Initial marking attempts used acrylic paint to uniquely mark beetles on their underside, however, due to the ineffective adherence of acrylic paint, all data from June and a considerable amount of data from July was considered lost. Beginning on July 30th 2015, a new marking method incorporating a handheld soldering iron was utilized (Currie 2016). Individuals of *C. woodii* once captured, had sex determined by looking at the last abdominal segment and anus (McMonigle 2006) and were then marked with a handheld battery powered soldering iron with each being given a unique identification number noting site number and beetle number (Fig. 1). Beetles were carefully marked on their elytra ensuring that excessive force was not used to prevent damage to the underlying wings or softer portions of the abdomen. Once beetles were marked, the mark was inspected for legibility then beetles were released at the site of capture. Beetles captured in 2016 were distinguished from beetles captured in 2015 by a unique mark preceding the unique identification number (Fig. 1). Beetles that immediately left their host plant and flew to the next available host plant were not noted if collected again in the same survey period as beetles were observed to flee to the nearest plant, host or otherwise. When observed copulating, the identityof both primary partners were made, excluding additional individuals that were attempting copulation at the same time. In addition to copulation, females who exhibited sign of digging (black scratches on head and elytra, or presence of soil) were noted to determine when egg laying occurs. Only specimens that were found alive were considered for this study. It is advised when marking this particular species, to be mindful of the elongated tarsi found in the genus *Chrysina*, wearing gloves or proper holding technique will prevent the hook like tarsi from piercing the skin. It is also noted that *C. woodii* regurgitate walnut leaves in a black liquid that will irritate open wounds.

Survival estimates. Survival rates for beetles were estimated with Program MARK using the Cormack Jolly-Seber (CJS) model. The CJS models utilizes apparent survival and capture probability to estimate the survival rate for beetles and allows survival estimates to vary by sex and time. Models were adjusted using ĉ-hat measure of dispersion that was acquired from running 500 replicates of the Bootstrap Goodness of Fit test within Program MARK on the fully saturated model $\{\Phi(t*sex)\rho(t*sex)\}$.

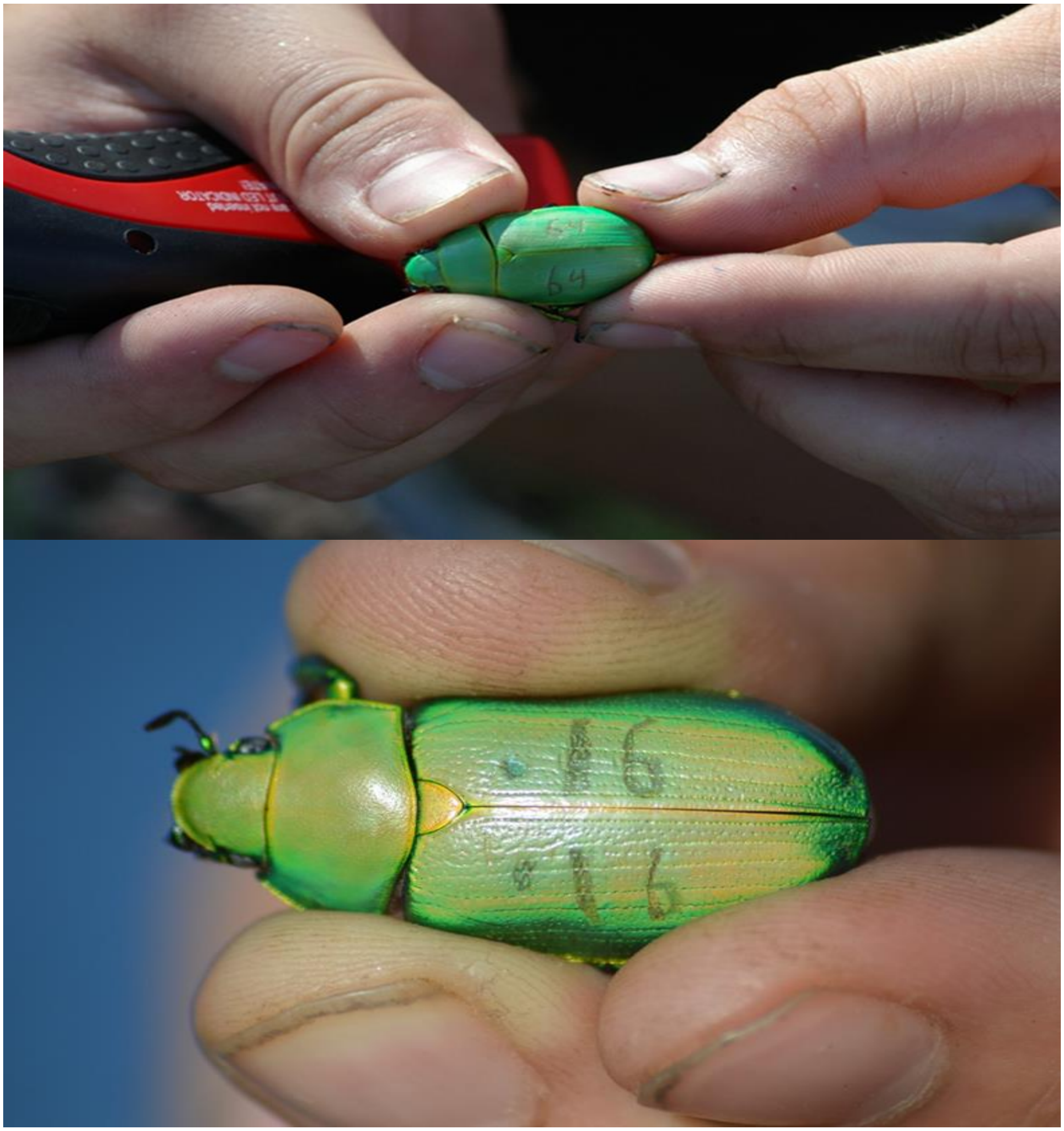


Fig. 1. **Top.** Individuals of *C.woodii* demonstrating the unique identification numbers engraved onto the elytra via handheld soldering iron. **Bottom.** Specimen of *C. woodii* marked during the 2016 marking season with dot to separate years. Photos by Ned E. Strenth.

The CJS model is used to calculate the survival rate (Phi, Φ) and recapture probability (ρ). To determine which model best fit the 2015 data, all possible models for the dataset were set up manually using the Parameter Index Chart in Program MARK and correctly labeled based off of the variables of each model. Once all models were created and run, models were ranked by ΔQAICc and AICc weight to show which model fit the data best. Once the best fit model was selected, the adjusted ΔQAICc weight was estimated by applying the average ĉ-hat score for our fully saturated model where time and sex were both factors of survivability and recapture probability (Φ(t*sex)ρ(t*sex)). The interval survival rates will be reported by estimate and ± 95% CIs that vary by collecting intervals for 2015 and are bi-weekly for 2016. In addition to survival rates, the CJS model calculated the recapture rate for both seasons.

Populations estimate. Program MARK (White and Burnham 1999) was utilized to estimate the population for the three sites by occasion within the primitive site of the state park for both years. Within MARK, the POPAN model (Schwarz and Arnason 1996), which is a parameterization of the Jolly-Seber model, was used to estimate the abundance of this open population. POPAN estimates apparent survival or Phi (Φ), the capture probability (ρ), the probability of entry into the population (pent) and the super population (N) to generate estimates. Parameters could be either time-dependent or time-independent and vary by sex. A model with the parameters Φ(t*sex)ρ(t) would be interpreted as apparent survival varying by both time and sex, while the capture probability varying by time but not sex. The link functions for each parameter were specified according to (Tikkamäki and Komonen 2011) and resulted in both apparent survival (Φ) and capture probability (ρ) were set using the logit link function, probability of entry (pent) were set using the Mlogit1link function and the super population (N) was set using the log link function. Data from all three sites were combined for the 2015 and 2016 population estimates. Models were selected by their ΔAICc and AICc weight to determine which model best fit the data. Models with a ΔAICc of ≤ 2 were considered to be supported by the data and be competitive (Burnham and Anderson 2003).

RESULTS

Marking and Recapture. Marking took place over the course of 16 marking trips (Table 1) from July 2015 to October 2016 and resulted in 1024 marked individuals of *C. woodii*. The marking period for 2015 lasted from July 30th to September 27th over the course of 5 marking occasions and resulted in a total of 418 unique adult beetles being marked and 71 total recaptures for roughly a 17% recapture rate (Fig. 3). The 2016 marking period lasted from June 4th to October 23rd and resulted in the marking of 606 unique individuals (455 males, 155 females) with 62 total recaptures for a 10% recapture rate (Fig. 3) over 11 marking occasions. July and August were found to be the peak months for abundance with the greatest number of adult beetles marked in the Davis Mountains State Park primitive site for both years and with a sizable number of beetles marked in September as well. Adult beetles were observed to die around mid to late October as indicated by the abundance of carcasses around the host plants. In addition to marking beetles, observations for the 2016 year regarding copulation and evidence of digging in females were noted. A total of 19 observations of copulation occurred July-September and 17 females covered in soil from egg laying activities were observed from August to September (Fig. 2).

Survival Estimates. For the 2015 survival rate estimate, 16 models were evaluated utilizing Program MARK and the Cormack-Jolly Seber (CJS) live recapture model with live release. Models were adjusted using the average ĉ-hat (2.58) from 500 replicates of the Bootstrap Goodness of Fit test within MARK. Of the 16 models, only two were found to be competitive (Table 2) with a ΔQAICc $\leq$ 2.00 (Burnham and Anderson 2003). Due to the delayed sexing and lower sample size, estimates for each occasion could not be determined for female *C. woodii*. Our resulting survival rates from our best fit model give an estimate of

97% (82-99, ±95% CI) survival rates for males, and a 94% (90-97, ±95% CI) survival rate for the beetles with a unknown sex for intervals of 6, 20, 13 ,13 days respectively.

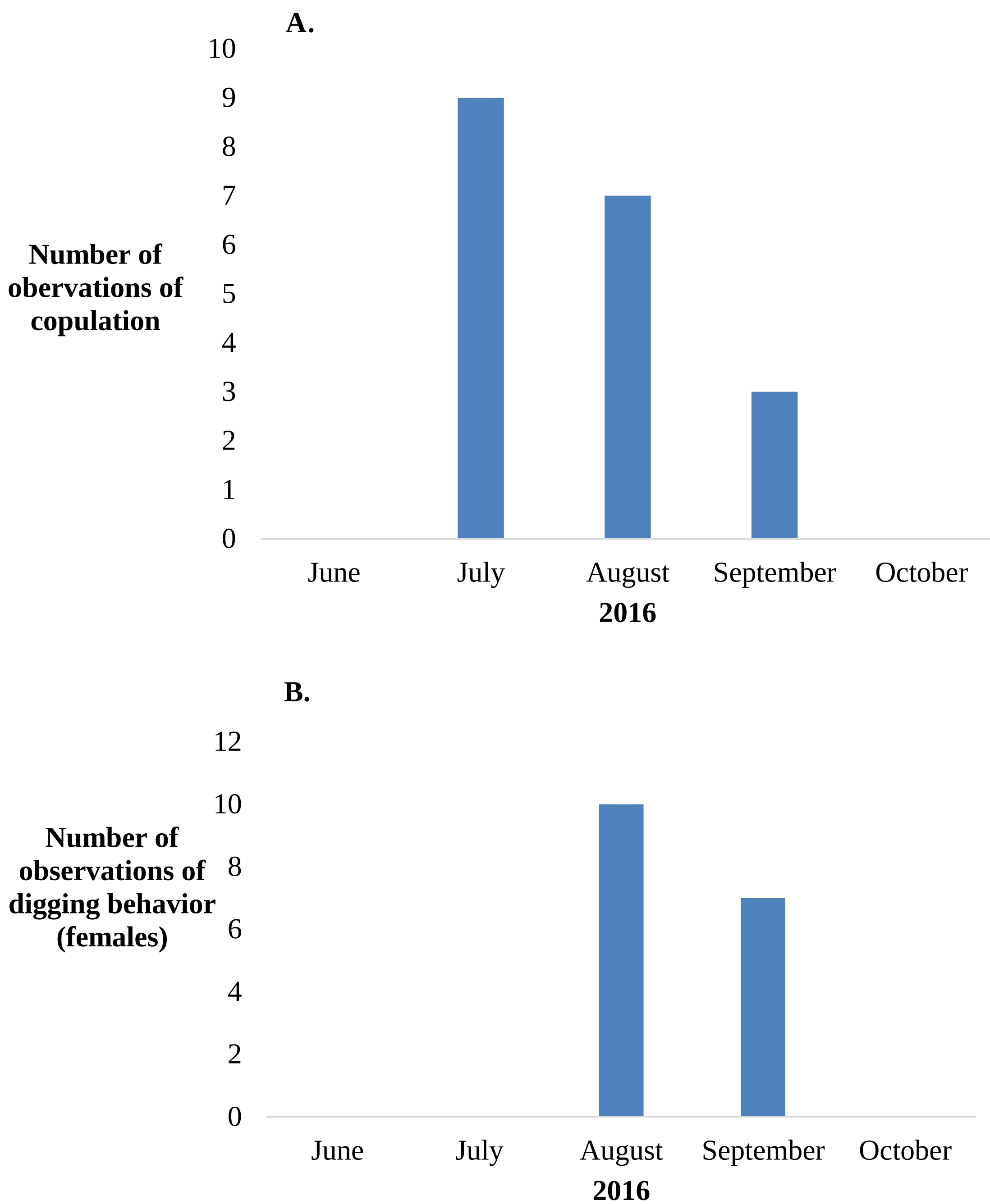
To estimate the survival rates in 2016, the same 16 models were utilized in Program MARK using the CJS model. Models were adjusted using the average ĉ-hat (2.42) from 500 replicates of the Bootstrap Goodness of Fit test within MARK. Of the 16 models, four were found to have a ΔQAICc of less than 2.00 and were considered competitive (Table 2). The most supported model for the 2016 data set was also Φ (.*sex) ρ(.). The survival rate for males within the three sites was estimated to be 95% (91-97, ±95%CI) and for females 90 (82-96, 95% CI) for a period of 14 days.

Population Estimation. The estimated number of *C. woodii* increase over the course of June and the greatest number of adults was estimated in July and August. During the peak of activity, an estimated ~1900 (827-4874 ±95% CI) adult *C. woodii* pass through the primitive area (Table 5). For population estimation of the 2015 data set, only one model had a ΔAICc of ≤ 2.00 and two additional models had ΔAICc values between 3.0 and 4.0 (Table 4). The top model of the 2015 data set was Φ(t*sex)p(t*sex)pent(t)N(sex) which allowed apparent survival (Φ) vary by time (t) and sex, probability of capture (ρ) vary by time and sex and probability of entry (pent) vary by time but not sex.

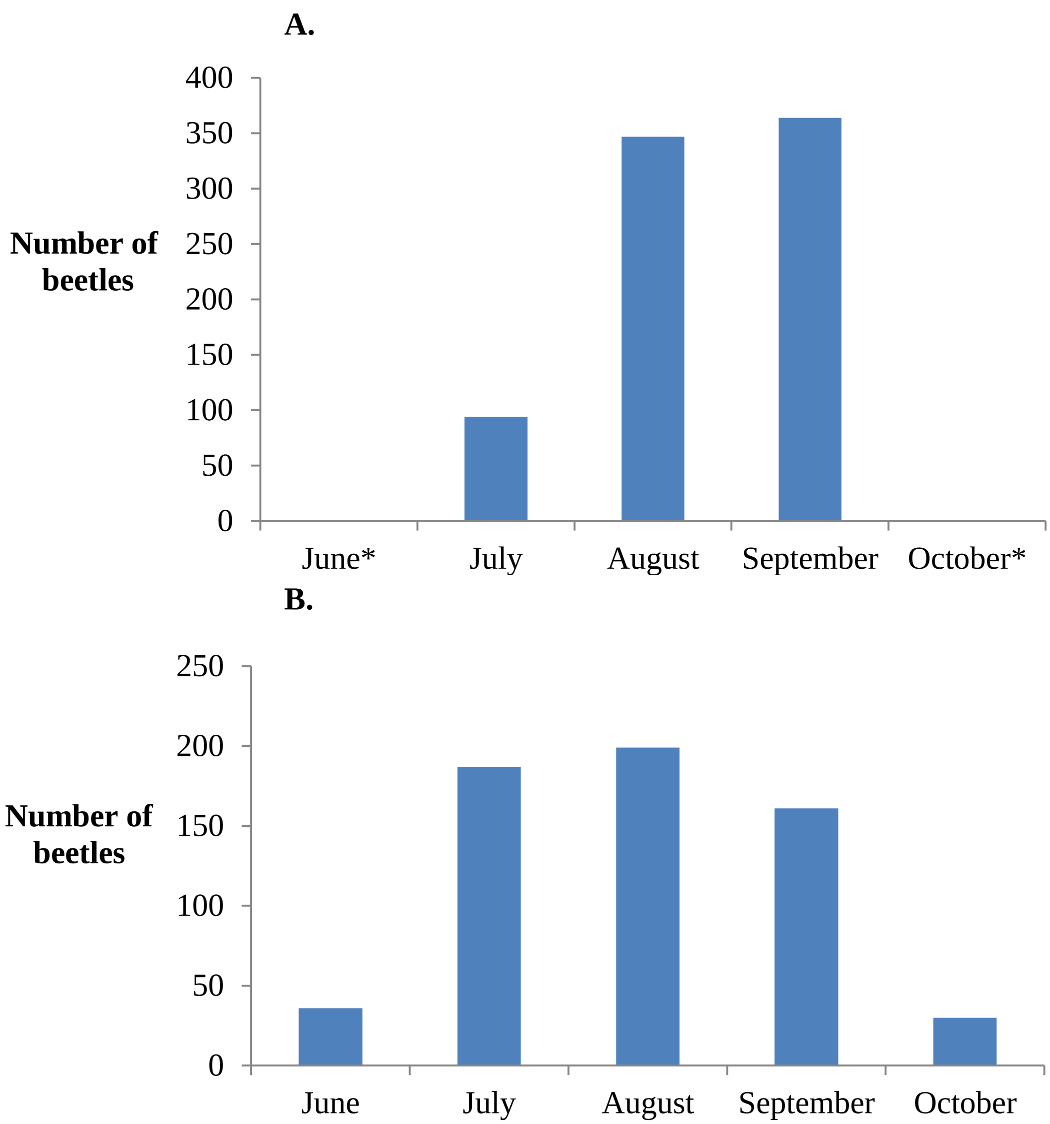
The estimate for 2016 population size at its peak moving through the primitive site every two weeks is ~ 2100 (527- 8389 ±95% CI) adult *C.woodii* (Table 6). For the 2016 dataset, of 32 candidate models, only one model had a ΔAICc weight of ≤ 2.00 (Table 3) with the second model's ΔAICc value equal to 2.32. The top model for the 2016 dataset was Φ(t*sex)ρ(t)pent(t)N(sex), where apparent survival differed by both time and sex, the capture probability varied by time and not sex, the entry into the population varied by time.

Table 1. Summary of the marking occasions and dates during the study on the population of *Chrysina woodii* for the 2015 and 2016 survey periods in the Davis Mountain State Park.

2015		2016	
Marking occasion	Dates	Marking occasion	Dates
		1	June 4th to June 5th
		2	June 19th to June 20th
		3	July 2nd to July 3rd
		4	July 16th to July 17th
1	July 30th to July 31st	5	July 30th to July 31st
2	Aug 6th to Aug 8th	6	Aug 13th to Aug 14th
3	Aug 28th to Aug 30th	7	Aug 27th to Aug 28th
4	Sept 12th to Sept 13th	8	Sept 10th to Sept 11th
5	Sept 26th to Sept 27th	9	Sept 24th to Sept 25th
		10	Oct 8th to Oct 9th
		11	Oct 22nd to Oct 23rd



Figs. 2. Number of observations of copulation between one male and one female (A.) and evidence of digging in adult females (B.) in *Chrysina woodii* by month in the Davis Mountains State Park primitive site.



Figs. 3. Total number of *Chrysina woodii* marked during A.) 2015 and B.) 2016 in the Davis Mountain State Park primitive site. Months marked with * denote months that were not sampled or had data lost.

Table 2. Summary of the best supported Cormack-Jolly-Seber models for the survival rate estimation (Φ) and recapture probability (ρ) of *Chrysina woodii* within Program MARK.

Model	QAICc[a]	ΔQAICc	QAICc Weight	Model Likelihood	No. Par.	QDeviance
2015 (Ĉ = 2.583)						
Φ (sex)ρ(.)	84.66	0.00	0.45	1.00	3	17.94
Φ (.) ρ (.)	85.93	1.26	0.24	0.53	2	21.24
Φ (.) ρ (sex)	87.54	2.87	0.10	0.23	3	18.78
2016 (Ĉ = 2.422)						
Φ(sex)ρ(.)	208.00	0.00	0.38	1.00	3	33.04
Φ (.) ρ (sex)	208.50	0.40	0.30	0.78	3	33.53
Φ (.) ρ (.)	209.80	1.70	0.16	0.41	2	36.82
Φ (sex) ρ (sex)	210.00	1.90	0.14	0.36	4	33.00

[a]Models were selected using second order quasi-Akaike Information Criterion (QAICc) for small sample sizes and ΔQAICc of ≤ 2 were considered to have substantial support for the model. Model parameters include; Φ_i apparent survival,which could vary by time (t) or sex and ρ_i probability of recapture, which could vary by (t) or (sex).

Table 3 Summary of the survival estimates generated by the top models for 2015 and 2016 seasons of adult *C.woodii* in the primitive site of the Davis Mountains State Park

		95% Confidence Interval	
Sex	**Estimate (%)**	**Lower (%)**	**Upper (%)**
2015			
Male	97	81	99
Unknown	94	90	96
2016			
Male	95	91	97
Female	90	82	95

Table 4. Summary of the best supported POPAN models for 2015 and 2016 tested within Program MARK to estimate population sizes of Chrysina woodii in the Davis Mountains State Park.

Model	ΔAICc	AICc Weight	Model Likelihood	No. Par	Deviance
2015					
Φ(t*sex)p(t*sex)pent(t)N(sex)	0.00	0.71	1.00	22	-799.17
Φ (t*sex)p(t)pent(t*sex)N(sex)	3.02	0.16	0.22	19	-789.52
Φ (t*sex)p(t*sex)pent(t*sex)N(sex)	3.42	0.13	0.18	24	-800.24
2016					
Φ(t*sex)ρ(t)pent(t)N(sex)	0.00	0.66	1.00	30	-2375.11
Φ (t*sex)p(t*sex)pent(t)N(sex)	2.32	0.21	0.31	36	-2386.10
Φ (t*sex)p(t*sex)pent(t*sex)N(sex)	3.49	0.12	0.17	39	-2391.68
Φ phi(t)p(t*sex)pent(t)N(sex)	7.38	0.02	0.01	38	-2385.53

The top supported models were selected using a combination of quasi- Akaike Information Criterion and second order delta AIC for small sample size (ΔAICc). Φi- probability of an animal surviving between occasions, ρ_i- probability of capture, b_i- probability of entry into the population from the super-population (N). Parameters can be dependent on time or sex or be independent of time and sex.

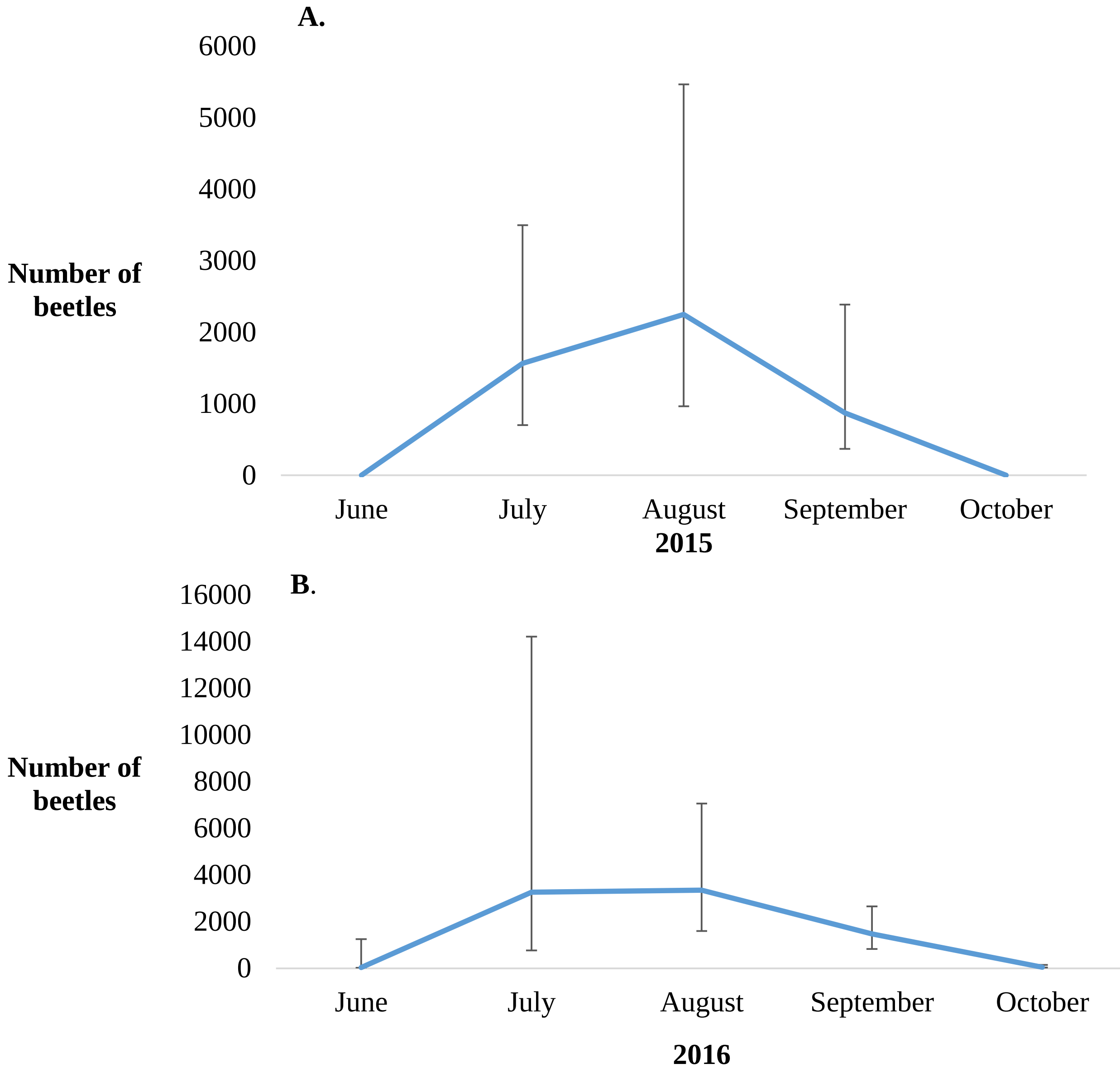


Fig. 4. Total Population estimates by month for adult *Chrysina woodii* in the Davis Mountains State Park primitive site with ±95% CI expressed by the error bars. Estimates were acquired using the Jolly Seber (POPAN parameterization) model in Program MARK for A.) 2015 and B.) 2016.

Table 5. Population estimates by occasion generated by the top model (Φ(t*sex)p(t*sex)pent(t)N(sex)) using the Jolly-Seber (POPAN parameterization) model in Program MARK for the 2015 season. Estimates were generated for each marking occasion for *Chrysina woodii* in the Davis Mountains State Park primitive site.

			95% confidence interval	
Marking occasion	N-hat	Standard error	Lower	Upper
Male				
1	-	-	-	-
2	6	12.69	0	77
3	460	300.83	143	1481
4	460	300.83	143	1481
5	29	5.51	21	43
Female				
1	43	20.20	18	104
2	43	20.21	18	104
3	46	21.27	20	109
4	34	28.60	8	142
5	5	2.11	2	111
Unknown				
1	1523	649.42	684	3393
2	1525	648.99	685	3392
3	171	50.42	98	302
4	171	50.42	98	302
5	174	51.65	99	308

Estimates indicated by a (-) were unable to be calculated due to small sample size.

Table 6. Population estimates by occasion generated by the top model (Φ(t*sex)p(t)pent(t)N(sex)) using the Jolly-Seber (POPAN parameterization) model in Program MARK for the 2016 season. Estimates were generated for each marking occasion for *Chrysina woodii* in the Davis Mountains State Park primitive site.

			95% confidence interval	
Marking occasion	N-hat	Standard error	Lower	Upper
Male				
1	8	120.16	0	775
2	16	3.31	11	24
3	20	3.80	14	29
4	726	704.03	147	3581
5	1411	1107.00	363	5483
6	1287	514.20	605	2736
7	1186	411.25	613	2295
8	930	253.32	550	1571
9	364	119.68	194	682
10	39	6.19	29	53
11	3	11.90	0	81
Female				
1	5	68.42	0	441
2	9	2.02	6	14
3	11	2.27	7	16
4	402	425.35	74	2197
5	690	582.54	164	2906
6	607	273.81	261	1411
7	266	119.25	115	616
8	143	54.08	70	293
9	41	20.61	16	104
10	1	1.00	0	5
11	0	1.00	0	11

DISCUSSION

Life History. Adult *C. woodii* begin to emerge in late May and early June, with the population in the Davis Mountains reaching their peak in July and August, following which beetles slowly begin to decline and disappear by mid to late October following cooler weather. Copulation was observed beginning in July for 2016 and observed throughout August and September and evidence of egg laying becoming more apparent later in the season around August and September (Fig. 2). Sex ratios observed in 2016 (M=455, F=155) were similar as observed in the endangered stag beetle *Lucanus cervus,* as seen in Chiari et al. (2014) that exhibit male biased sex ratios (Stoks 2001) in that males were caught in greater abundance compared to females which could potentially reduce the accuracy of the female estimates. The observations of copulation align with the increased number of adults emerging, and the incidences of potential egg laying behavior in females corresponds to increased precipitation in the area and the seasonal flow of Limpia Creek within the primitive site (Data, U. C. 2017). Eggs are believed to be deposited in areas with soft soil and higher abundance of rotting wood due to the most species in the genus *Chrysina* depositing egg in rotten logs, which are more abundant in tropical areas of their range (Hawks 2002) but can be scarce in the mountains of west Texas. Larvae are believed to be feeding on a combination of plant material and wood material that is deposited by the flooding of Limpia and Keesey Creeks. In captivity, development from egg to adult took roughly eight months, but it was noted that specimens who pupated around this time were severely stunted in size, indicating that a more varied diet and time are required for these beetles to reach an average adult size (T. G. Maddox, personal observation). In the Davis Mountains State Park adults of *C. woodii* were only observed feeding on *Juglans microcarpa,* however it is worth noting that *C.*

woodii in areas such as the Guadalupe Mountains have been reported to feed on oak trees (Fullington 1979). In the primitive sites, oak trees were moderately abundant but only a few instances of beetles being found on the trees occurred, with little evidence of beetles actually feeding, instead just exhibiting resting.

Beetles were observed throughout the day with peak flying activity occurring in the early afternoon confirming that they are primarily a diurnal species. Beetles could be collected easily in the cooler early morning because they would often exhibit decreased movement and escape response. Once disturbed, beetles had a tendency to simply drop to the ground and remain motionless for a few seconds before attempting to flee into tall brush or soil. *Chrysina woodii* can be considered cryptic, often displaying similar shape and coloration as the walnuts produced by *J. microcarpa*. Beetles could often be found hanging on the underside of branches, typically on the outside portion of the foliage, allowing for greater freedom in escape behaviors. This cryptic coloration is further exaggerated with the iridescence displayed by the beetle, providing excellent camouflage when exposed to direct sunlight. Beetles could be detected easier in low light conditions, such as early morning or under moderate cloud cover. Beetles were observed taking flight in early afternoon and in Site 3 exhibited crepuscular activity, with multiple adults flying close to sunset. Beetles could occasionally be collected in large numbers when engaging in swarming behaviors around females; as many as eleven males have been observed competing for a single female in a group. Females could be observed exhibiting evidence of digging behaviors being covered in moist soil, often being found with black scratch marks on the elytra and pronotum from scraping against rough terrain.

Predation was not observed during the 8 month period that surveys were conducted. Members of *Chrysina* within the United States appear to subsists on a diet of plants that have known noxious and allelopathic chemicals including the pines (terpenes), oaks (tannins) and walnuts (juglone) which may impart a bitter taste (Levin 1976) to the beetles after consumption of their leaves. The assimilation of these chemicals may serve to deter predators from actively pursuing them. It has been noted by Fullington (1976) that the elytra of *C. gloriosa* have been found in the dung of raccoons in the Guadalupe Mountains. Within the Davis Mountain State Park, one example of dung contain *C. woodii* was noted in Site 3 in Keesey Creek along Highway 188 where an overpass connects the primitive and primary sites of the park. This was most likely not an observation of predation, but an instance of scavenging by a fox or raccoon as the ground became increasingly littered with deceased beetles that had fallen from trees near the end of their life span in October.

Marking. Initially, a method utilizing acrylic paint similar to Chiari (2014) was used to mark *C. woodii*. Problems occurred almost immediately with the acrylic paint not adhering to the smooth elytra or underside of the abdomen. Efforts were made to polish the elytra with an abrasive etching tool; however this did not increase the effectiveness of the paint. Marks eventually wore off after a period of two to three weeks indicated by small flecks of colored paint remaining on the underside of the beetles. This method most likely did not work in this area due to the abundance of moisture present in the mountains, as well as the digging and copulatory actions and smooth exoskeleton of the beetles and is not recommended for this particular species. Utilizing the handheld soldering iron as noted by Currie (1996) to mark the elytra proved to be an effective method of marking *C. woodii* as the mark was able to be found on individuals that had been deceased for over a year as well as not causing harm to the wings or soft dorsal portion of the abdomen. Marks could additionally be adjusted and made relatively light as not to standout and reduce the survivability of the beetles by altering their camouflage, which would violate one of the assumptions of Jolly Seber models.

Survival Rate Estimation. For both the 2015 and 2016 season, survival rates for both sexes overlapped in the 95% confidence intervals and were not assessed using any other variables like body size or mass (Table 3). The similar survival rates for both sexes and unsexed beetles could be a result of their cryptic nature and the fact that predation was not observed for either sex during both of the marking seasons meaning both sexes have roughly the same survival rate for each of their intervals. Due to the fact that emigration occurs in this species and was taken into account, it is possible that the survival rates are underestimated because the model cannot differentiate between an individual that has perished or left the area. Additionally, both sexes are only active for a maximum of five months of the year and the survival rates here only take into account the adult forms of *C.woodii*; future research should take into consideration of the survival rate of larvae. The survival rates in 2015 and 2016 between males varied slightly in the 95% CI this was most likely due to sample size and number of captures in 2015, but still overlap enough to be considered similar for both years suggesting fairly constant survival rates. Due to the delayed ability to accurately sex beetles during the first year (2015), estimates for the female beetles were not able to be calculated due to low sampling size and recapture occasions. Initial analyses using two seasons of data suggest that survival does not vary drastically by sex alone for adults of *C. woodii* due to overlapping 95% CI intervals. These results are similar to the study by López-Pantoja et al. (2008) on the cerambycid species *Cerambyx welensii* who found that survival, while varying between years, was not significantly different between the sexes. The survival rates generated for both seasons should be tested further using more collecting seasons as well as comparing body size or climatic conditions in future studies to estimate more accurate survival rates.

Population Estimation. Population size of *Chrysina woodii* was estimated for both the 2015 and 2016 marking season. The estimated population size by occasion is interpreted as the total number of adult *C.woodii* moving through the primitive site during the intervals between occasions and does not represent the total number present at any particular point in time. Estimates for the 2015 season excludes female sex data due to the inability to accurately sex the individuals early in the study and small sample size and instead the estimates of the unknown should be considered more accurate to the true pop size. To estimate the total population, all three sites were combined to generate an estimate for the entire length of Limpia Creek within the primitive site of the Davis Mountains. A low recapture rate appears to be a common issue in mark release studies (Hanks et al. 1998), and can result in overestimates of population size if recapture rates are low. Similar recapture rates were to Tikkamäki et al. (2010) were encountered in this study in that they were relatively low, which could account for the large 95% CI intervals seen in Figure 4. For this study, the maximum dispersal distances observed was around 1.10 kilometers over the course of a 24 hour period, suggesting this is a highly mobile species capable of covering large distances similar to the dispersal of *Lucanus cervus* in the study by Chiari et al. (2014). Because individuals were recaptured in sites other than their original marking site, and these estimates should be treated as the number of adult *C. woodii* that travel through the primitive site of the Davis Mountains State Park primitive site rather than a definitive number of beetles that can be found on a given occasion.

For the 2015 season only one model had a ΔAICc of ≤ 2 and had an AICc weight of 0.71 (Table 4). The best fit model for 2015 assumes that apparent survival varied by time and sex (Φ (t*sex)) probability of recapture varied by time and sex (p(t*sex)) and that the entry into the population varied by time (pent(t)). Due to the unequal sampling and delayed ability to sex individuals, the 2015 data (Table 5) should be interpreted with caution as this was the preliminary study and only consisted of half of the sampling periods compared to 2016. Figure 4A suggests a sharp increase in the number of beetles beginning in July, and peaking in August, while beginning to decline in September. This data set only included the end of July and August through September, so the sharp increase in the number of beetles is due to small sampling size and occasions and most likely represents a skewed rate of emergence.

For the 2016 season (Table 4), the best fit model differed from the 2015 model in that the probability of capture and entry into the population varied by time but not sex (p(t)pent(t)). The occasion 5 estimate for the 2016 has a particularly large 95% confidence interval for population size which can be attributed to only have three recaptures during that period. The 2016 model selection and data, should be considered the more accurate representation of the population due to the consistent sampling and larger sampling size compared to the 2015 dataset. Similar to the 2015 dataset (Figure 4B), emergence begins in June and increases until August where it begins to decline and adults die by mid to late October.

Chiari et al. (2014) suggests the sampling for beetles in areas of abundance could be indicative of a "hot spot" phenomena (Pratt 2000), which could skew the abundance estimates. The sampling of only the areas in the Davis Mountains State Park primitive site with the highest abundance of host plant could be an example of this "hot spot" phenomena and result in very high estimates for a relatively small area. Overall, the estimates suggest that the beetles passing through and utilizing the primitive site are relatively abundant, and that the area could be major corridor for the mobile adults of *C. woodii* ,but further comparisons of other sites and entire park would be needed to determine this. The Davis Mountains State Park primitive site appears to be very favorable habitat for these beetles and care should be exercised when clearing creek beds and other areas that have a high density of the host tree present. Due to the fact that *C. woodii* is restricted to the higher elevations in west Texas, this species' populations have the potential to become negatively impacted as climate change alters the landscape further, driving these species higher up their respective sky islands. In addition to the changing climate, *C. woodii* and other members of the genus face the risk of over collection due to their attractive coloration, and could become locally extirpated in areas where the abundance of host plant or suitable elevation are limited. This study serves as only a base estimation and further research and monitoring the populations of *C. woodii* over time in the Davis Mountains State Park.

LITERATURE CITED

Burnham, K. P., and Anderson, D. R. 2003. Model selection and multimodel inference: a practical information-theoretic approach. Springer Science and Business Media.

Chiari, S., Zauli, A., Audisio, P., Campanaro, A., Donzelli, P. F., Romiti, and Carpaneto, G. M. 2014. Monitoring presence, abundance and survival probability of the stag beetle, Lucanus cervus, using visual and odour-based capture methods: i mplications for conservation. Journal of insect conservation, 18: 99-109.

Currie, C. R., Spence, J. R., and Niemelä, J. 1996. Competition, cannibalism and intraguild predation among ground beetles (Coleoptera: Carabidae): a laboratory study. The Coleopterists' Bulletin, 50: 135-148.

Data, U. C. 2010. Climate Fort Davis – Texas Available from: http://www.usclimatedata.com/climate-on-your-site.php?id=ustx0470 (accessed 10, July 2017). Texas, United States

D. C. Hawks, 2002. "Jewel Scarabs," Programs Information: Nebraska State Museum, Paper 15.

Del Rio, L. F., Arwin, H., and Järrendahl, K. 2016. Polarizing properties and structure of the cuticle of scarab beetles from the *Chrysina* genus. Physical Review E, 94: 012409.

Fullington, R. W., and Harrington, D. 1979. *Plusiotis woodi* and *Plusiotis gloriosa* (Scarabaeidae); First Report of the Guadalupe Mountains National Park, Texas. In Biological investigations in the Guadalupe Mountains National Park, Texas: proceedings of a symposium held at Texas Tech University, Lubbock, Texas, April 4-5, 1975 4:113.

Hanks LM, Millar JG, Paine TD 1998. Dispersal of the eucalyptus longhorned borer (Coleoptera: Cerambycidae) in urban landscapes. Environ Entomol 27: 1418–1424

Horn, G.H. 1885. Descriptions of new North American Scarabaeidae. Transactions of the American Entomological Society, 12: 117-128.

Levin, D. A. 1976. The chemical defenses of plants to pathogens and herbivores. Annual review of Ecology and Systematics, 7: 121-159.

López-Pantoja, G., Nevado, L. D., and Sánchez-Osorio, I. 2008. Mark-recapture estimates of the survival and recapture rates of *Cerambyx welensii* Küster (Coleoptera cerambycidae) in a cork oak dehesa in Huelva (Spain). Central European Journal of Biology, 3: 431-441.

McMonigle, O. 2006. The complete guide to rearing flower and jewel scarabs. Elytra & Antenna.

Moore, M. R., Jameson, M. L., Garner, B. H., Audibert, C., Smith, A. B., and Seidel, M. 2017. Synopsis of the pelidnotine scarabs (Coleoptera, Scarabaeidae, Rutelinae, Rutelini) and annotated catalog of the species and subspecies. ZooKeys, 666, 1.

Pratt, C. R. 2000. An investigation into the status history of the stag beetle Lucanus cervus (Linnaeus)(Lucanidae) in Sussex. *Coleopterist*, 9: 75-90.

Schwarz C. J., Arnason AN 1996. A general methodology for the analysis of capture-recapture experiments in open populations. Biometrics 52:860–873

Skinner, H. 1905. Descriptions of new Coleoptera from Arizona with notes on some other species. Entomological News 16: 289-292.

Stoks, R. 2001. Male-biased sex ratios in mature damselfly populations: real or artefact? Ecological Entomology, 26: 181-187.

Tikkamäki, T., and Komonen, A. 2011. Estimating population characteristics of two saproxylic beetles: a mark-recapture approach. Journal of Insect Conservation, 15: 401-408.

Tirmenstein, D. A. 1990. Juglans microcarpa. In: Fire Effects Information System, U.S. Department of Agriculture, Forest Service, Available: http://www.fs.fed.us/database/feis/ [2017, July 13].

Young, F. N. 1957. Notes on the habits of *Plusiotis gloriosa* Le Conte (Scarabaeidae). The Coleopterists' Bulletin, 11: 67-70.

White, G. C., and Burnham, K. P. 1999. Program MARK: survival estimation from populations of marked animals. 46: S120-S139.

BIOGRAPHY

Biographical: Timothy Glenn Maddox
3919 Willowbend Drive
The Colony, Texas 75056 (Permanent mailing address)
(214)-532-8231
Tmaddox91@yahoo.com

Education: Angelo State University
San Angelo, Texas
Master of Science in Biology (Jan 2015 to August 2017)

Professional Positions:

Teaching Assistant-Department of Biology, Angelo State University, Aug 2016- 2017
Duties included teaching weekly laboratory sections for non-major biology students for BIO 1408 (Human Biology), BIO 1409 (Man and the Environment), BIO 4442 (Arachnology) and holding office hours and grading homework and laboratory assignments, and inputting grades into Blackboard.

Graduate Assistant- Department of Biology, Angelo State University, Aug 2015-2016
Duties included preparing and maintaining labs for Entomology, Biological Oceanography, and Invertebrate Zoology as well as preparing study material and review sessions.

Biology Department Student Employee-Angelo State University, Aug 2013-2015
Duties included maintaining the dermestid beetle colony for the processing and cleaning of museum material for the Angelo State Natural History Collection as well as integrated pest management for the mammalogy and ornithology collections at Angelo State. Duties also included specimen upkeep for the herpetological collection at Angelo State University, and specify data entry and general museum maintenance and upkeep.

Professional Affiliations:

Entomological Society of America
Southwestern Association of Naturalists
The Coleopterists' Society
Texas Society of Mammologist