HABITAT USE AND MOVEMENT PATTERNS OF TWO REDWOOD FOREST SALAMANDERS, *ANEIDES VAGRANS* AND *ENSATINA ESCHSCHOLTZII*, WITH AN EXAMINATION OF THE EFFICACY OF PIT TAGS FOR MARKING SMALL PLETHODONTIDS

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A Thesis Presented to

The Faculty of Humboldt State University

In Partial Fulfillment of the Requirements for the Degree

Master of Science in Biology

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May 2017

ABSTRACT

HABITAT USE AND MOVEMENT PATTERNS OF TWO REDWOOD FOREST SALAMANDERS, *ANEIDES VAGRANS* AND *ENSATINA ESCHSCHOLTZII*, WITH AN EXAMINATION OF THE EFFICACY OF PIT TAGS FOR MARKING SMALL PLETHODONTIDS

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The habitat use and movements of small, secretive salamanders are generally poorly understood, in part due to the difficulty associated with marking and recapturing such animals. This study was designed to test the efficacy, both in the laboratory and in the field, of using passive integrated transponder (PIT) tags to mark and track two small-bodied plethodontid salamander species native to coastal northwestern California, *Aneides vagrans*, the Wandering Salamander, and *Ensatina eschscholtzii,* the Ensatina Salamander.

Aneides vagrans inhabits tree crowns. Using cover objects and visual encounter surveys, I searched for *A. vagrans* in the angiosperm understory canopy at least twice monthly from February 2015 through June 2016. All fieldwork was conducted at the Redwood Experimental Forest, a US Forest Service property in Klamath, California. I found no evidence that *A. vagrans* is present in this habitat, and thus I could not PIT tag or track the movements of this species.

In the laboratory, I compared the survival, change of mass, and general behavior of PIT tagged *E. eschscholtzii* to a control group. There was no significant difference

between groups in initial mass or snout-vent length. Incision points for all tagged salamanders had healed to the point of scarring after four days and no signs of infection were seen. Upon conclusion of the 90 day experiment, I observed 100% survival and tag retention. Implantation of a PIT tag had no significant effect on percent change in mass or general behavior.

To test the efficacy of remote detection of fossorial salamanders and track their movements, I used visual encounter surveys and artificial cover objects to capture and tag over 50 free-ranging *E. eschscholtzii* from October 2015 to March 2016. Using a PIT tag reader connected to a portable antenna, I detected tagged *E. eschscholtzii* from July 2016 to January 2017. I mapped location data from the remote detection surveys and used it to calculate movement distances for each animal. I found no significant difference in the average distance moved between males and females. Furthermore, I found a significant increase in average recapture rate using remote detection compared to visual encounter surveys using artificial cover objects. This shows the promising advantages of using PIT tags to mark small plethodontids, including the ability to remotely detect small, secretive individuals and a corresponding increase in recapture rates.

ACKNOWLEDGMENTS

I thank Dr. John Reiss, for providing his expertise, advice, and support for the duration of this project. I thank Dr. Sharyn Marks, Dr. Michael Mesler, and Dr. Stephen Sillett for their insight through various stages of planning, conducting, and presenting this research. I thank Dr. Robert Van Pelt for helping me map the movement of *Ensatina* and for providing maps of my research plot. I thank Dr. Sharyn Marks and the Department of Biological Sciences for granting me access to incubators in which to house animals.

I thank my wonderful wife, Morgan Brown, for sacrificing so many weekends to assist me in the field. I thank my loyal dog, Blue, for being a fearless safety-buddy in a forest full of bear tracks. I also thank the many good friends who joined me in the field and/or helped me brainstorm along the way: David Biegle, Madeline Cooper, Adam Cummings, Roger Ezri, Lee Hecker, Shannon Hedge, Lauren Smith, and Ethan Snee.

I especially thank Jim Campbell-Spickler for teaching me to climb, lending me equipment, regularly assisting me in the field, teaching me to be a better biologist, and for being a great friend. I thank my parents, Daniel and Pamela Brown, for raising me to be the person I am today, and for always encouraging me to pursue my dreams.

I thank Save the Redwoods League, the Department of Biological Sciences Master's Grant and the Biological Graduate Student Association Travel Grant for financial assistance. Lastly, I thank the ancient trees who watch over our foggy coast for their inspiration and their protection these last few years.

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CHAPTER 1: HABITAT USE OF *ANEIDES VAGRANS*

Introduction

In the crowns of the world's tallest trees, researchers have found an unexpected resident: *Aneides vagrans*, the Wandering Salamander. *Aneides vagrans*, a member of the family Plethodontidae, is known to occupy the canopy of ancient coast redwood trees (*Sequoia sempervirens*) for extended periods of time, and it is estimated that a single large redwood can support upwards of 30 individual salamanders (Spickler et al. 2006). Many plethodontid salamanders, including those in the genus *Aneides,* do not require aquatic habitat for breeding because they have direct development (Petranka 2010; Stebbins 2003). Thus, it is possible for an individual to complete its life cycle without any water body so long as the environment provides constant, moist refugia.

The morphology of *A. vagrans* indicates that they are highly adapted for climbing vertical surfaces. It has a rounded, prehensile tail that assists in clinging and climbing. Furthermore, *A. vagrans* has long limbs and slender digits that include sub-terminal, square-shaped toe pads (Petranka 2010; Stebbins 2003). In addition to a number of common terrestrial habitats, such as large logs on the forest floor, talus, cracks and crevices in rocks and bark, stumps, woody debris, and brush piles (Corn and Bury 1991; Whitaker et al. 1986; Petranka 2010; Stebbins 2003), *A. vagrans* have long been hailed as the most arboreal salamanders in North America (Leonard et al. 1993; Van Denburgh

1916), with recent observations of individuals over 80 meters above the ground (Spickler et al. 2006).

The fern mats found in the tall redwood canopies may be the primary refugia for *A. vagrans* in its arboreal niche. In fact, the two most significant predictors of salamander abundance in a given tree are the average water storage of fern mats and the mass of fern mats in canopy crotches (Spickler et al. 2006). On several occasions, researchers noted *A. vagrans* occupying tunnels and cavities amidst epiphytic fern mats (usually the fern *Polypodium scouleri*) high above the forest floor (Sillett and Bailey 2003). But since the angiosperm understory within these old-growth forests also hosts epiphytic fern mats (usually *P. glycyrrhiza*), it is reasonable to suspect that *A. vagrans* could be utilizing arboreal niches in the angiosperm understory as well. It is this hypothesis that I set out to test.

In particular, the primary question I sought to answer was simply whether *A. vagrans* is present in the angiosperm understory. In addition, I sought to collect movement data on any *A. vagrans* found there. Although the presence of *A. vagrans* in the conifer canopy has been established, due to seasonal restrictions on study associated with the nesting of endangered Marbled Murrelets, it is unknown if seasonal patterns in movement and habitat use exist (Spickler et al. 2006). My secondary question was thus whether *A. vagrans* moves between the forest floor and these angiosperm crowns, and if so, whether that movement is driven by seasonal, abiotic conditions. To answer these

questions, I placed cover objects in four angiosperm tree crowns, as well as on the ground below these trees, and checked these cover objects routinely for over a year.

Methods

This study was carried out within a plot in the Redwood Experimental Forest managed by the U.S. Forest Service in Klamath, California. This 60mx30m research plot was chosen because *A. vagrans* has been documented in the crowns of tall conifers here, and neighboring plots host ongoing research on these animals. This plot is located in a research area, which minimized the threat of vandalism or damage to the equipment by the general public. Cover objects were placed in and under four angiosperm understory trees that fall within the boundaries of the plot (Figure 1) – two *Acer macrophyllum* (bigleaf maple; trees 2154 and 2136), and two *Alnus rubra* (red alder; trees 2135 and 2151).

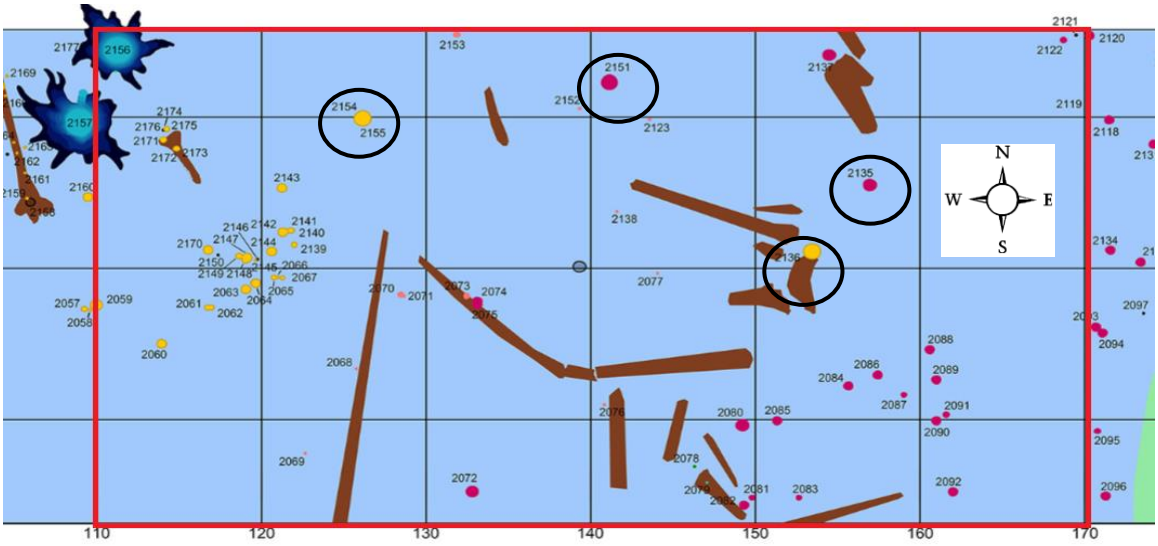

Figure 1. Map of the 60mx30m angiosperm understory plot utilized to search for *A. vagrans* from February 2015 – June 2016. Trees whose crowns were regularly inspected are circled in black and include 2135, 2136, 2151, and 2154. Yellow points represent bigleaf maples, pink points represent red alders, and the size of the points represents diameter of the tree. Brown polygons represent downed trees and other significant woody debris. The plot boundary is indicated with a red border. Two tall spruce trees (2156 and 2157) known to harbor *A. vagrans* appear in the northwest corner of the plot. Map courtesy of Dr. Robert Van Pelt.

These trees were selected because they are some of the largest understory trees inside the plot and they possess the most potential salamander habitat. The diameter at breast height (DBH) was recorded for all focal trees: 63.5 cm, 90.5 cm, 88.3 cm, and 87.4 cm for trees 2135, 2136, 2151, and 2154, respectively. The height was also recorded for all focal trees: 26.1 m, 23.9 m, 25.6 m, and 22.6 m for trees 2135, 2136, 2151, and 2154, respectively. The elevation at the base of these understory trees is approximately 11 meters above sea level. All four trees are within 20 meters of each other, yet there is no overlapping of crowns. These angiosperm trees are also within 20 meters of tall *Picea sitchensis* (Sitka spruce) and *Sequoia sempervirens* (redwood); *Aneides vagrans* is present in both *S. sempervirens* and *P. sitchensis* in the Redwood Experimental Forest (J. Spickler, personal communication).

Cover objects were constructed from 1'x6'x6' redwood fence boards. Pairs of boards were cut and assembled into 18"x18" cover objects with redwood spacers used to create a 1 cm gap between the top of the cover object and the bottom of the cover object (Figure 2).

Figure 2. Artificial cover objects (left) created for the forest floor and deployed under focal hardwood trees. Saddle-shaped cover objects (right) utilized a slightly different shape to help them cling to the canopy surfaces, but provided an equal amount of salamander crack-habitat inside.

Saddle-shaped cover objects (n=20), assembled using angled cuts and a staple gun, were secured horizontally on lateral branches and vertically on trunk surfaces in the canopy using thin nylon cord (Figures 3-4).

Figure 3. Researcher checking cover objects in the crown of an *Acer macrophyllum* tree on a routine plot survey. Red circle shows the researcher on rope in angiosperm crown.

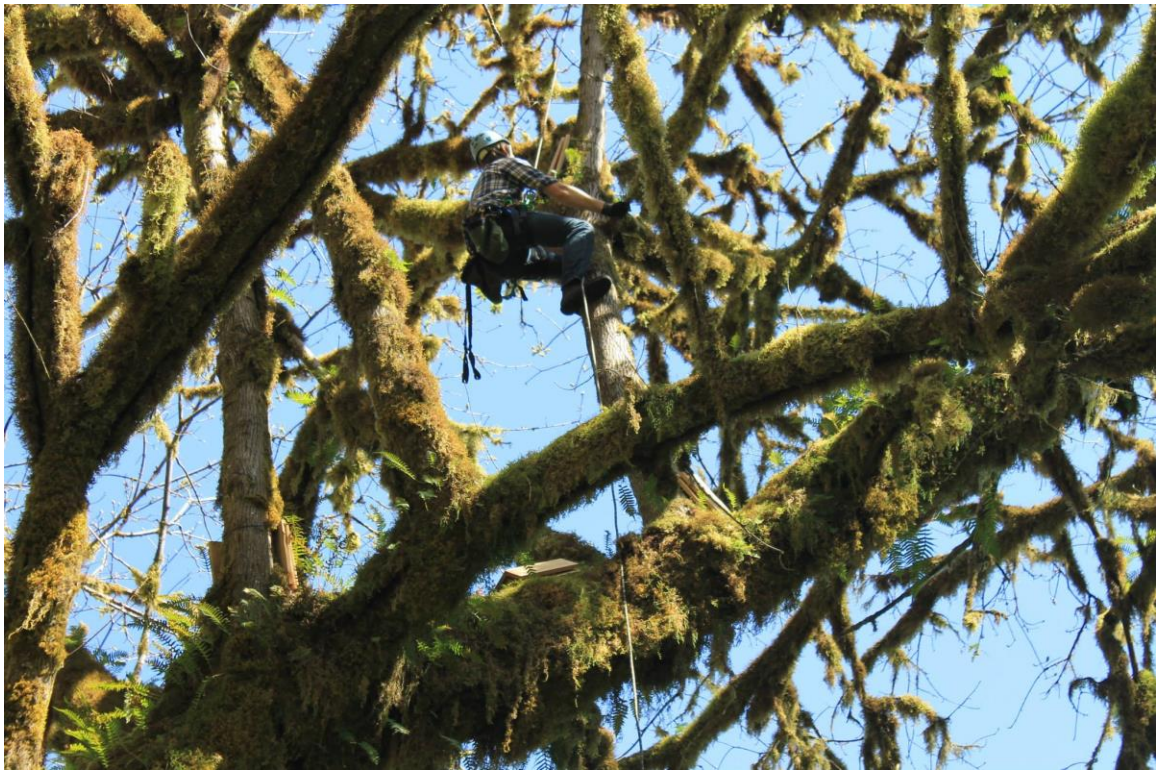

Figure 4. A close-up photo reveals several wooden cover objects placed in the crown of this angiosperm tree as a researcher climbs.

Additionally, flat cover objects (n=20) were placed on the forest floor at the base of the focal trees. This cover object design exploits the preference by *A. vagrans* for narrow cracks in wood, rock, and other substrates, and was consistently yielding *A. vagrans* captures in nearby conifer crowns (J. Spickler, personal communication). The plot was surveyed for salamanders 2-3 times per month, from February 2015 through June 2016, for a total of 41 visits. Each plot survey lasted roughly six hours, during which time I climbed all focal trees, checked arboreal cover objects, checked fern mats, scanned trunks, checked ground cover objects, and flipped woody debris hunting for *A. vagrans*.

Results

In spite of my extensive search, I found no evidence that *A. vagrans* are utilizing the crowns of angiosperms. In fact, despite placing 40 cover objects, tailored to the habitat requirements of *A. vagrans,* in and around four understory trees, I did not find a single *A. vagrans* in my plot during this study. Although many plethodontid salamanders were found in and under my cover objects during my ground surveys, the only species observed were Ensatina (*E. eschscholtzii*) and California Slender Salamander (*Batrachoseps attenuatus*). Meanwhile, other researchers continued to capture *A. vagrans* in nearby redwood and spruce crowns using the same cover object design (J. Spickler, personal communication). Since studying the movement of *A. vagrans* requires their presence, the secondary question regarding canopy movement patterns could not be examined.

Discussion

Despite the presence of apparently suitable habitat, I found no evidence that *A. vagrans* utilizes angiosperm understory tree crowns at the Redwood Experimental Forest. There are several possible explanations for the lack of evidence of *A. vagrans*. Absence of evidence is not necessarily evidence of absence: the fact that no *A. vagrans* were found in the angiosperm understory does not necessarily mean that they were not there. Since epiphytic fern mats are sensitive refugia that can take decades to establish, I was extremely careful not to disturb any of them while surveying the understory crowns; consequently, it is possible that the salamanders were there but simply hidden from view beneath the mats. However, while they are known to hide under fern mats in tall conifer crowns, they also frequently abandon fern mats to hunt from cover objects (Spickler, personal communication). In fact, during my surveys of the understory my colleagues were frequently alerting me over a 2-way radio transceiver of numerous salamander captures from cover objects in a redwood just outside of my plot. Taking my data at face value, then, why would *A. vagrans* occupy the tall conifers but not the understory angiosperms?

In the old-growth canopy the two most significant predictors of *A. vagrans* presence and abundance are fern mat size and water-holding capacity (Spickler et al. 2006). While a single large redwood crown can support a complex network of fern mats of different sizes, heights, and aspect, the much smaller understory angiosperm trees boast much less complexity and typically host only one or two relatively small fern mats.

Smaller, apparently drier fern mats could be responsible for the lack of *A. vagrans* in the angiosperm crowns.

It is also possible that the angiosperms lack certain habitat requirements for *A. vagrans* that the conifers provide, most notably reproductive niches. Salamanders in the genus *Aneides* lay their eggs in interstitial spaces in wood, rock, or other substrates (Davis 2002; Petranka 2010; Stebbins 2003; Welsh and Wilson 1995). Anecdotally, interstitial spaces in the trunks and branches of the angiosperms were shallow or completely absent, whereas tall conifers have numerous cracks and crevices. Furthermore, *Aneides* courtship requires a circular walk and tail rub (Davis 2002; Sapp 2002; Sapp and Kiemnec-Tyburczy 2011), so it is possible that tall conifer crowns simply offers larger, horizontal surfaces needed for courtship and mating.

Epiphytic coverage and habitat heterogeneity may influence salamander presence and should be compared between tall conifers and angiosperms. Although the angiosperms have plenty of epiphytes, especially bryophytes, they cover the trees thoroughly, unlike the conifers, which have large bare areas on their trunks and parts of their branches. The presence of exposed bark between fern mats in conifer crowns also contributes to habitat heterogeneity, which may support a wider variety, higher abundance, or more stable supply of prey items.

When no old-growth canopy is available, as is the case throughout much of their range, *A. vagrans* can be found in moist terrestrial habitats. Specifically, they are found under exfoliating bark, in cracks and cavities of decomposing logs, stumps, snags, and in

talus (Davis 2002; Leonard et al. 1993, Stebbins 2003; Welsh and Wilson 1995). Cracks and crevices, essential microhabitat characteristics in these terrestrial habitats, are not common features in the angiosperm crowns, and the bark of angiosperms does not tend to peel or exfoliate readily enough to provide large amounts of suitable habitat. It seems that no matter where *A. vagrans* is found, be it in tall conifers, fallen logs, or even on talus slopes, they are seeking out narrow cracks and crevices that the angiosperm understory simply does not provide.

Further investigation is needed to test some of these potential explanations for the absence of *A. vagrans* in the angiosperm understory. Future studies could attempt to quantify the size and water holding capacity of the angiosperm fern mats for comparison against tree-level quantities of ferns, soils, and water in tall redwoods (Sillett & Bailey 2003; Sillett & Van Pelt 2007; Spickler et al. 2006). Additionally, available crack-space could be quantified and compared in tall conifer crowns and angiosperm crowns. If detected, such differences in microhabitat features might help explain why *A. vagrans* utilizes conifer canopy habitat but not the angiosperm understory.

CHAPTER 2: EFFICACY OF PIT TAGS TO EXAMINE HABITAT USE AND MOVEMENT OF *ENSATINA ESCHSCHOLTZII*

Introduction

Plethodontid salamanders, due to their small size and secretive lifestyles, are especially difficult to mark and individually identify. Mark-recapture studies involving terrestrial plethodontid salamanders have historically utilized toe clipping and visual elastomer implants (Ferner 1979; Corn and Bury 1991; Donnelly et al. 1994; Davis and Ovaska 2001; Spickler et al. 2006). More recently, passive integrated transponder (PIT) tags have been used successfully in plethodontids from the eastern United States (Connette and Semlitsch 2012). PIT tags were previously used in fish, frogs, and other larger bodied species, but only recently have they been engineered small enough to be used in plethodontids. In an initial study examining their efficacy, the use of PIT tags did not impact the growth or survival of two species within the genus *Plethodon* and the tags enabled remote detection of fossorial individuals (Connette and Semlitsch 2012).

Marking plethodontid salamanders with PIT tags offers a number of obvious advantages when compared to toe clipping and visual implants. First, PIT tags offer a permanent identification number for individual salamanders. Toe clipping is not permanent because the toes of amphibians often regenerate, making it difficult to read an individual's mark over time. Coloring agents used in fluorescent visual implant elastomers (VIE) have been known to fade and migrate over time, likewise leading to mark recognition complications (Davis and Ovaska 2001). Secondly, PIT tags are superior to visual marking techniques because PIT tag numbers are unambiguous and easily interpreted. Perhaps most

importantly, PIT tags are superior to visual markings for amphibians because they offer the opportunity for remote detection. This opportunity is especially important for plethodontid salamanders because they are secretive and can be difficult to relocate after tagging. Salamanders are known for their use of underground burrow systems (Davic and Welsh 2004; Stebbins 2003; Petranka 2010), which can further complicate mark-recapture studies, especially when surface conditions are dry.

Because the PIT tag technology has only been used a few times for terrestrial plethodontid salamanders (Connette and Semlitsch 2012, 2015; O'Donnell et al. 2016; Ousterhout and Semlitsch 2014), and only in the eastern U.S., I sought to test its safety and efficacy for investigating habitat use and movement of *Ensatina eschscholtzii*, a common plethodontid salamander of California.

Like many plethodontid salamanders, *E. eschscholtzii* is associated with moist, terrestrial habitats. Microhabitat features known to harbor *Ensatina* include decaying logs, leaf litter, debris piles, talus, and even the fossorial burrows of small mammals (Petranka 2010; Stebbins 2003; Welsh and Wilson 1995). In these environments, *E. eschscholtzii* can be particularly difficult to detect via visual encounter surveys.

My research sought to demonstrate that the PIT tag technique is safe for *E. eschscholtzii*, that PIT tagged *E. eschscholtzii* can be effectively located in the wild using a PIT tag reader connected to a wand antenna, and that those recorded locations can be used to investigate habitat use and movement patterns. While my study was focused on *E. eschscholtzii*, the methods from this study should be applicable to other species of similar

body size, such as *Aneides vagrans*, which inhabits the redwood forest canopy (Chapter 1). Year-round monitoring of *A. vagrans* in the redwood forest canopy has been impossible in the past due to research restrictions that protect the nesting of the endangered Marbled Murrelet (Spickler et al. 2006). This alternative, remote method of data acquisition would allow for year-round data collection without disturbing the canopy during nesting season, and thus have potentially important applications in forest restoration and management, as well as improving our basic understanding of redwood forest ecology.

Long-term mark-recapture studies of vertebrate populations are increasingly important in the field of ecology, because they provide the ability to treat temporal variation during data analysis. As such, it is imperative that researchers compiling long-term datasets select the tagging method most conducive to the species they wish to study. Survival and growth of amphibians have not been shown to be negatively impacted by PIT tag implantation, and remote detection of PIT tagged salamanders in enclosures is possible once the tags have been implanted (Connette and Semlitsch 2012, 2015; Ousterhout and Semlitsch 2014). The effectiveness of remote detection of free-ranging, PIT tagged plethodontids has been demonstrated over many months in Missouri (O'Donnell et al. 2016), but previous research is lacking for plethodontids in the western United States.

In the present study, I examined the impacts of PIT tags on the health and survival of *E. eschscholtzii*, both in a controlled lab experiment and in the field. Since it has been

shown that PIT tagged plethodontids can be detected remotely through soil (Connette and Semlitsch 2012), I also tested the ability of PIT tags to help map the movements of my tagged, free-living *Ensatina* in space and time, and used these data to examine salamander movement patterns.

Methods: Laboratory Experiment

Thirty individual *Ensatina*, each greater than two grams in weight, were captured from the Arcata Community Forest, Humboldt County, California between April and May of 2016. All animals were maintained in a growth chamber under controlled environmental conditions (13-14° C, 12:12 hour light/dark cycle) at Humboldt State University. Animals were housed in individual plastic boxes (23x18x15cm) with fitted tops. Boxes were lined with a layer of medium consisting of a few centimeters of moist EcoEarth (Zoo Med Inc., San Louis Obispo, CA). The medium was changed at least once a month, more frequently if needed. Small, terracotta planting pots were broken in half and placed in each terrarium as cover objects; cover objects provided refuge for the animals in order to minimize stress. All animals were given at least two weeks to adjust to captive conditions before starting the experiment. All animals were fed two small to medium-sized crickets, obtained from a local pet store, twice weekly. During scheduled feeding events, crickets were dropped into each container, and animals were left to feed on their own. Mass in grams was recorded once weekly in order to investigate the impact of PIT tags on feeding and growth.

All captured animals were weighed using a digital scale, measured from snout to vent (SVL) with a ruler, and then randomly assigned to one of two groups: control (n=15) or experimental (n=15). The control animals were maintained under identical conditions and food levels as the experimental animals. On the day of tagging, all 30 individuals were anesthetized (see details below), but only individuals in the experimental group were given

a tag. All animals were observed daily for 90 days, with additional observations occurring every hour for the first 12 hours after a tagging event.

Once in the lab, members of the experimental group were anesthetized by immersion in a 0.02% Benzocaine solution. An individual was considered anesthetized when it lost the ability to right itself, and was no longer responsive to human contact. Once anesthetized, the animals were injected with a 0.05 g, 8mm long PIT tag (Biomark, Boise, ID). PIT tags were implanted near the 7^{th} costal groove using a MK25 implanter (Biomark, Boise, ID). Nitrile gloves were worn while tagging and changed between tagging events. A single drop of Bactine (Bayer, Leverkusen, Germany) was rubbed on the incision to prevent infection, and the animal was given time to recover from the anesthetics on a wet paper towel. Control group animals were simply anesthetized, then allowed to recover. An animal was considered to have recovered when it regained the ability to right itself and normal locomotion was restored. After recovery, each animal was returned to its assigned terrarium.

After the initial 12-hour period, all animals (including controls) were checked once daily for signs of infection, mortality, or abnormal behavior, such as lethargy, thrashing, impaired locomotion, or impaired feeding. Furthermore, the status of the wound was noted each day in order to assess average healing time. Healing was defined as the closing of the wound completely (i.e., when the skin was no longer torn). These daily check-ups were complemented by weekly weighing events to check for significant weight loss, which could be a sign of distress. I used t-tests to compare initial mass of the two groups, initial

SVL of the two groups, and change and percent change in mass between the groups. Upon conclusion of the lab experiment, animals were euthanized according to IACUC protocol and donated to the Humboldt State University teaching collection.

Methods: Field Experiment

In the field, I established a 60m x 30m plot in the angiosperm understory of the Redwood Experimental Forest and deployed the flat, wooden cover objects described in Chapter 1 to capture *E. eschscholtzii* for a mark-recapture study. Once captured, animals were scanned with a Global Pocket Reader Plus handheld PIT tag reader (Biomark, Boise, ID); if an individual was already marked, it was measured, weighed, and released immediately at the point of capture. Newly captured individuals were anesthetized (as described above), measured for total length and SVL, weighed, and sexed. After measuring, the animals were injected with a 8mm PIT tag, and visual implant elastomer (VIE; Northwest Marine Technology, Shaw Island, WA) was injected into the base of the tail using a 0.3cc insulin syringe with a 9 gauge needle to be used for identification in the event of PIT tag loss. PIT tags were inserted into the body cavity of the salamanders whereas the VIE was placed subcutaneously on the lateral side of the base of the tail. Each animal was given time to recover from the anesthetic on wet paper towel and considered recovered when it regained the ability to right itself and normal locomotion was restored. After recovery, each animal was released at the point of capture.

From July 2015 through June 2016, I captured, marked, and recaptured *E. eschscholtzii* using cover objects. I then ran transects with a Biomark (Boise, ID) HPR Plus PIT tag reader connected to a Biomark (Boise, ID) BP Plus portable antenna (Figure 5) from July 2016 through January 2017 in order to test the efficacy of remote detection of fossorial *E. eschscholtzii*, and track their movements across the landscape over time. All

movement mapping was done using data collected during these remote detection surveys from July 2016 – January 2017. Transects searches took approximately 0.5 hours to complete and, due to battery limitations associated with the RFID reader, each plot survey consisted of four transects walked over a 2 hour period (see below).

Figure 5. Scanning the plot established in the angiosperm understory of the Redwood Experimental Forest in Klamath, CA. Equipment featured include an HP Plus PIT tag reader connected to a BP Plus portable antenna; together they can be used to scan large areas for fossorial, PIT tagged animals.

Once an individual *E. eschscholtzii* was remotely detected for the first time, I attached flagging with capture information (PIT tag number, date and time, etc.) above the site of detection. In order to map movement, I recorded distance and azimuth to the nearest tree for all detections. I began each plot survey by rescanning the flagged detection points from

the previous survey. If an individual was not detected in the same spot, I scanned within a 3 m radius of the flagging to check for small movement events. To do this, I stood under the flagged location and scanned the forest floor in radiating lines that went out 3 meters, always making sure to bring the antenna back to the flag using the same radiating line before starting the next. If the same tag was detected within the 3 m search radius, the new capture information was added to the flag and moved to the new site of detection. The shortest distance between detection sites was measured and recorded. If a tag was not re-detected within the 3 m search radius, the flagging was left in place only to be moved if future detections of that same individual occurred. Once surveys for all previously detected salamanders had been done, I ran random transects in 30m x 4m belts from North to South across the plot to look for new remote detections (Figure 6). Points along the north boundary of the plot from which transect belts began were selected using a random number generator and a map of the plot. Tags that were detected in the same location for the duration of the experiment were excavated upon conclusion of the field experiment to check for animal survival and possible tag rejection.

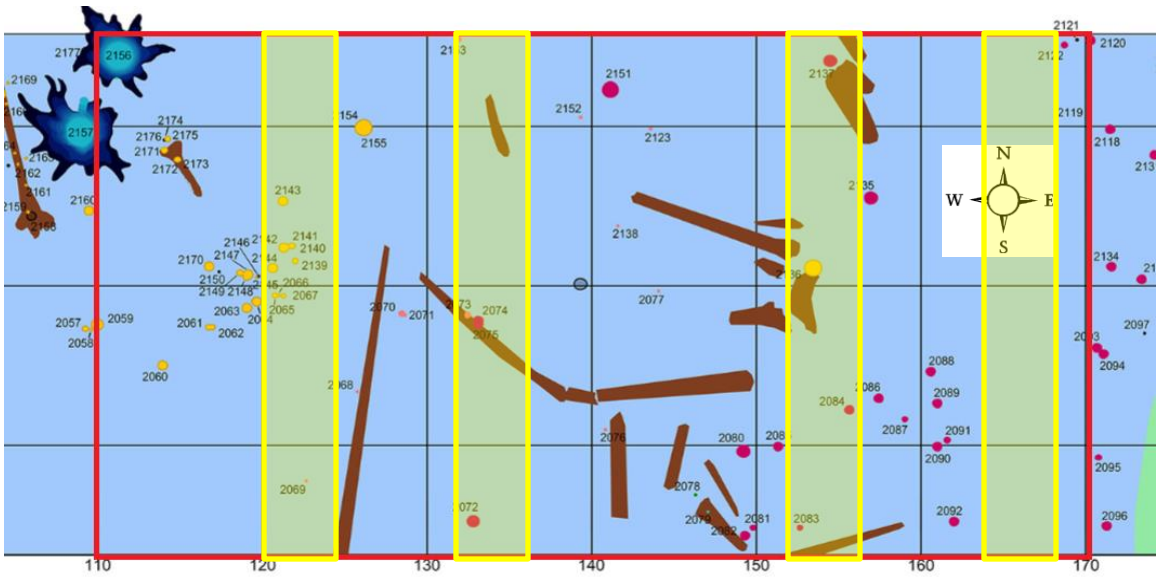

Figure 6. Diagram of 30x 4m belt transects surveyed to search for remotely detected *E. eschscholtzii*. Each vertical rectangle (yellow) represents one belt transect. Four belt transects appear on this diagram to illustrate that four belt transects were surveyed per plot visit due to battery limitations associated with the PIT tag readers. All transects were conducted within the boundaries of the plot, outlined with the larger, horizontal rectangle (red). Bigleaf Maples, red alders, and Sitka spruce are represented by the circular polygons (yellow, pink, and blue, respectively) and the oblong polygons (brown) represent downed logs.

Results: Laboratory Experiment

Prior to tag implantation, mean salamander mass and SVL were 3.001 ± 0.140 g and 51.467 ± 0.790 mm, respectively, for the tagged group and 3.138 ± 0.142 g and 49.933 ± 1.021 mm, respectively, for the control group. There was no significant difference between groups in initial mass (t = 0.687, df = 27.996 p = 0.498) or SVL (t = -1.19, df = 26.28, p = 0.245). Incision points for all salamanders had healed to the point of scarring after two days and no signs of infection were seen. No lethargy, thrashing, impaired locomotion, or impaired feeding were observed.

Upon conclusion of the 90-day experiment, I observed 100% survival and tag retention. The standardized feeding of salamanders twice weekly resulted in slight increases in mass for both groups (Figure 7). Implantation of a PIT tag had no significant effect on percent change in mass (Figure 8; t = 0.332, df = 25.535, p = 0.742). The SVL of both groups was almost unchanged after 90 days, with averages for both groups increasing by less than 1 mm (Table 1).

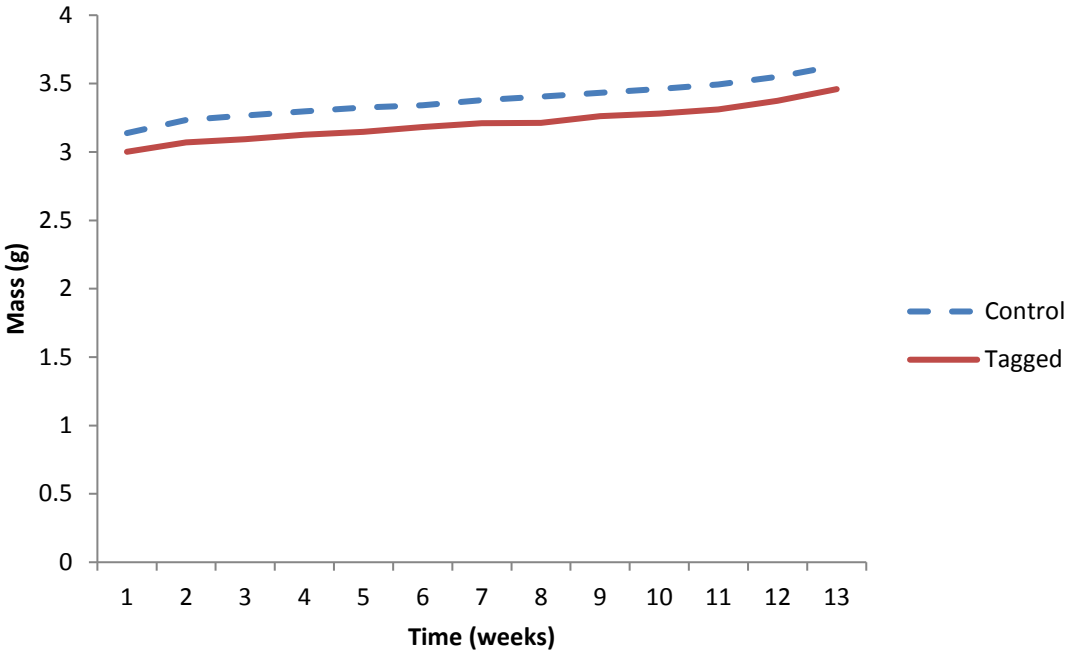

Figure 7. Mass of *E. eschscholtzii* as measured once weekly in the laboratory at Humboldt State University. The solid line represents weekly averages for individuals marked with passive integrated transponder tags (Tagged, n=15) and the dashed line represents weekly averages for the unmarked group (Control, n=15).

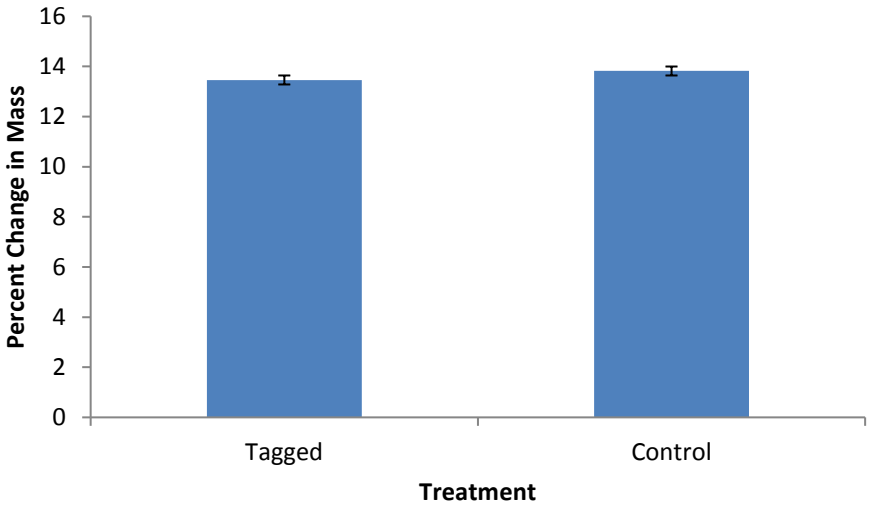

Figure 8. Average percent change in mass of *E. eschscholtzii* that were either marked with passive integrated transponder tags (Tagged, n=15) or left unmarked (Control, n=15) for 90 days in a laboratory at Humboldt State University. Error bars represent standard error.

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Table 1. Average snout-vent length (SVL) ± SE of *E. eschscholtzii* that were either marked with passive integrated transponder tags (Tagged, n=15) or left unmarked (Control, n=15) in the laboratory at Humboldt State University. All SVLs are in millimeters.

Treatment	SVL on Day 1	SVL on Day 90
Control	49.93 ± 1.02	50.07 ± 0.98
Tagged	51.47 ± 0.79	51.60 ± 0.77

Results: Field Experiment

Over the course of 17 months I captured, PIT tagged, and released 51 *E. eschscholtzii* in the plot (Appendix A). On average, I remotely detected 22% of the marked salamanders per plot survey, a statistically significant increase from 14% when using cover objects and visual encounters alone (t = -2.684, df = 18, p = 0.015; Table 2; Appendix B). At the conclusion of the field experiment, I had remotely detected 78% of the 51 tagged individuals, and 95% of those salamanders had moved at least once, thus confirming survival and tag retention. Some animals were tagged as early as February 2015, thus their movements suggest survival and tag retention over 18-22 months. Other animals were tagged as late as June 2016, thus their movements suggest survival and tag retention over 2-6 months.

Locations and subsequent movements were mapped to check for trends in movement pattern (Figure 9). Free-ranging salamanders in my plot moved an average of 2.9 m per movement event with the longest movement recorded at 13.4 m. Average distance moved did not differ based on sex (t = 1.639, df = 80, p = 0.105). Two salamanders did not move for 90 days or more, and both were found dead in those locations. No corpses remained for autopsies, but the PIT tags of the two deceased individuals were found next to the visual implant elastomers injected into their tails to confirm they had been PIT tagged.

Table 2. Recapture rates of *E. eschscholtzii* for the ten most recent visual encounter surveys (VES) and the ten total remote detection surveys (REM) conducted in the angiosperm understory of the Redwood Experimental Forest in Klamath, California. Recapture rates differed significantly between the survey types (t = -2.684, df = 18, p = 0.015).

Date	# Recap	# Marked	% Population Recaptured	Survey Type
2/6/2016	6	40	15.0	VES
2/17/2016	8	44	18.2	VES
2/27/2016	6	45	13.3	VES
3/13/2016	8	45	17.8	VES
3/27/2016	9	46	19.6	VES
4/10/2016	7	48	14.6	VES
4/20/2016	7	48	14.6	VES
6/8/2016	5	50	10.0	VES
6/15/2016	6	50	12.0	VES
6/26/2016	4	51	7.8	VES
7/14/2016	3	51	5.9	REM
8/1/2016	7	51	13.7	REM
8/30/2016	11	51	21.6	REM
10/1/2016	8	51	15.7	REM
10/18/2016	11	51	21.6	REM
10/25/2016	12	51	23.5	REM
11/1/2016	14	51	27.5	REM
11/21/2016	14	51	27.5	REM
12/13/2016	17	51	33.3	REM
1/8/2017	15	51	29.4	REM

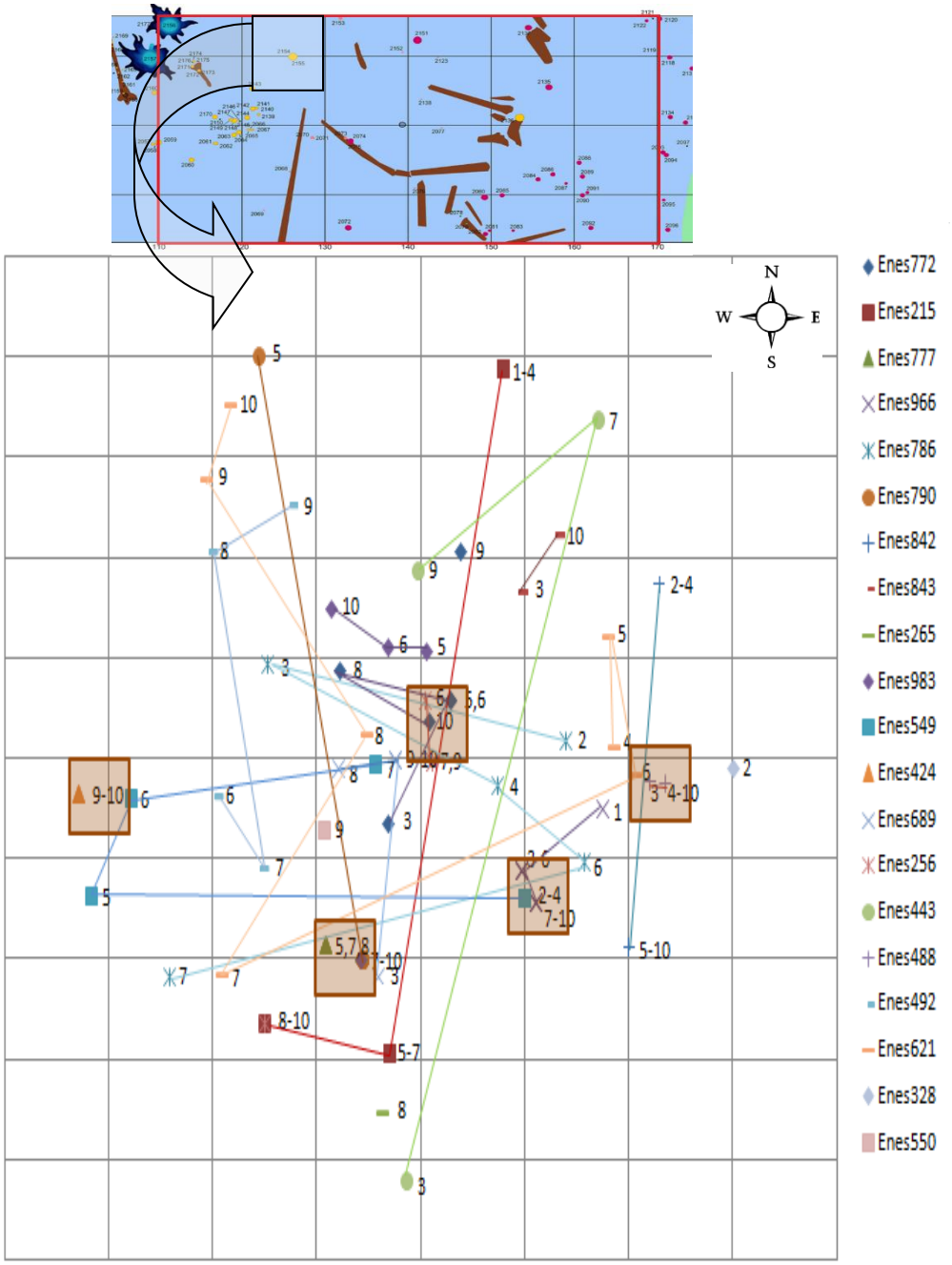

Figure 9. Representative map of *E. eschscholtzii* locations over 10 remote detection surveys. The plot map and arrow (top) show an 8x10 m area used by a subset of the marked population. Twenty actively recaptured animals in this area were mapped to visualize habitat use and movement patterns. Each unique symbol represents a different salamander, each occurrence of a symbol represents a salamander location, and the numbers beside each symbol represent the survey number. Brown, transparent squares represent wooden cover objects used by researchers to initially capture and PIT tag *E. eschscholtzii*. Gridlines are set at 1m scale.

Discussion

Accurately estimating population size, home range, vital rates, immigration and emigration, and other ecological characteristics can be especially difficult when studying cryptic, burrowing species (Moore et al. 2010; Ryan et al. 2015). Most studies examining plethodontid salamander ecology are based primarily on the surface-activity of these animals, which constitutes a small fraction of their habitat use. Previous studies have examined the effect of PIT tags on amphibians (Connette and Semlitsch 2012; Connette and Semlitsch 2015; Ryan et al. 2015; Whiteman et al. 2016), compared detection ranges of PIT tag antennas (Cucherousset et al. 2005), and described the successful use of PIT telemetry in juvenile salamanders (Ousterhout and Semlitsch 2014). Here, I demonstrated the successful use of PIT tags for marking and remotely detecting the small-bodied plethodontid salamander *E. eschscholtzii* in the angiosperm understory of an old-growth redwood forest.

The 100% tag retention and survival of specimens in my laboratory experiment is comparable to other experiments that used the same sized tags (Connette and Semlitsch 2012; Ousterhout and Semlitsch 2014). There was no significant difference in percent mass change between the control and the tagged groups at the conclusion of the experiment, which is also consistent with trends observed in previous experiments (Ousterhout and Semlitsch 2014). Healing of the incision site took an average of one day and a maximum of two days, which is also in line with that of other studies (Connette and Semlitsch 2012). All animals retained the ability to capture their own prey in the lab

setting and their ballistic feeding mechanism did not appear to be impacted by the PIT tags, indicating that there may not be any long-term effects of PIT tag implantation on growth and survival in *E. eschscholtzii*.

The risk of mortality cannot be overlooked when inserting a PIT tag into the body cavity of a small plethodontid. In order to minimize the risk of mortality in the field, I only deployed 8mm PIT tags despite the increased detection range of larger tags (Ousterhout and Semlitsch 2014). The high percentage of animals remotely detected in my free-ranging population for nearly 18 months suggests that the PIT tag technique is effective for long-term mark-recapture studies of plethodontid salamanders in an open system. Although a significant difference in recapture rates between VES and remote detection surveys was observed, temporal variation could account for this difference. Terrestrial salamanders can be difficult to relocate for long-term, population-level analyses when compared to more predictable aquatic species. Remote detection through PIT tag implantation could make plethodontid salamanders, which have been shown to be indicator species in redwood forests (Welsh and Droege 2000), more attractive focal species in forest and population ecology in years to come. The ability to confirm death of tagged individuals is also a benefit of PIT tagging, as it allows for more accurate estimates of population demographics.

Some basic metrics of *E. eschscholtzii* movement were estimated based on periodic plot surveys in which I scanned the forest floor with RFID readers; however, I hesitate to make definitive statements about seasonal movement patterns or home ranges

without following marked animals over multiple years. My findings are consistent with previous investigations, which suggest that *Ensatina* and similar plethodontid species only move occasionally and in short bouts (Rosenberg et al. 1998; Spickler et al. 2006; Staub et al. 1995; Wells and Wells 1976). Given the Mediterranean climate of California, I would expect the movements of *Ensatina* and other desiccation sensitive salamanders to vary by season, but further research still needs to be done.

The movement of vertebrates across a landscape can have broad implications for the entire ecological community. For instance, pond and stream-breeding amphibians are renowned for connecting terrestrial and aquatic ecosystems; is it possible that directly developing plethodontids could be just as important for connecting different types of terrestrial habitats? In-situ investigations examining *A. vagrans* possibly connecting the forest floor to tall conifer crowns using PIT telemetry are already underway (S. Sillett and J. Spickler, personal communication).

The recent drought in California undoubtedly impacted desiccation-sensitive populations, but studying those effects can be difficult when free-living individuals respond by retreating to inaccessible locations. Since most surveys of semi-fossorial species rely on surface activity, there exists the danger of misinterpreting shifts in habitat use as population declines or changes in demographics. Systematic sampling biases associated with terrestrial salamander surveys can result in misleading trends over time (Connette et al. 2015). As such, it is imperative to find a way to remotely detect plethodontid salamanders and all semi-fossorial species used in ecological research to

maintain investigative vigilance in the face of a changing climate. Regardless of what the future holds, PIT telemetry through remote detection, as demonstrated here, offers advances in the study of movement ecology, habitat use, and population dynamics of small-bodied animals, while reducing the level of disturbance associated with drift fences, pitfall traps, stump ripping, log flipping, and other popular mark-recapture survey techniques. Remote detection surveys lead to more probable detection of marked animals than unmarked, a drawback that should be considered when trying to estimate population sizes.

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APPENDIX A

Appendix A. Table of data collected while initially marking *Ensatina* in the Redwood Experimental Forest from February 2015 – June 2016. Locations refer to which cover object an animal was found using (G indicating a terrestrial cover object, A indicating an arboreal cover object) with an indication of whether the animal was atop, inside, or under the cover object.

Date (m/d/y)	Tag #	Recap?	SVL (mm)	Total (mm)	Weight (g)	Sex	Location
10/10/2015	985153000334551	No	38	61	0.98	Immature	Inside G9
10/10/2015	985153000358621	No	49	91	3.23	Female	Inside G10
10/18/2015	985153000358621	Yes	50	91	3.42	Female	Inside G10
10/18/2015	985153000357983	No	49	88	3.2	Female	Inside G2
10/18/2015	985153000358520	No	51	107	2.65	Male	Under G11
10/18/2015	985153000358549	No	46	102	2.61	Immature	Inside G7
10/18/2015	985153000358927	No	46	92	4.78	Female	On Trail
10/18/2015	985153000376492	No	51	94	3.91	Female	Under G19
10/18/2015	985153000377256	No	56	101	4.02	Female	Inside G5
10/18/2015	985153000379328	No	56	101	3.95	Female	Behind A3
10/25/2015	985153000261820	No	53	109	3.09	Male	Inside G2
10/25/2015	985153000376550	No	50	91	2.8	Female	Atop G13
10/25/2015	985153000377488	No	57	112	3.18	Male	Under G16
11/11/2015	985153000358621	Yes	50	91	3.42	Female	Inside G10
11/11/2015	985153000376492	Yes	50	92	3.97	Female	Inside G19
11/11/2015	985153000359610	No	39	67	1.34	Immature	Inside G18
11/11/2015	985153000357904	No	49	108	2.75	Male	Under G19
11/11/2015	985153000357966	No	52	114	3.5	Male	Inside G3
11/11/2015	985153000359375	No	61	108	4.83	Female	Under G6
11/11/2015	985153000405215	No	49	94	3.35	Female	Inside G5
11/20/2015	985153000357904	Yes	49	108	2.77	Male	Under G19
11/20/2015	985153000359375	Yes	61	108	4.5	Female	Under G6
11/20/2015	985153000446711	No	43	85	1.39	Male?	Inside G17
11/20/2015	985153000358805	No	56	97	4.23	Female	Under G20
11/20/2015	985153000376689	No	49	92	3.57	Female	Under G4
11/28/2015	985153000405215	Yes	50	95	3.35	Female	Inside G5
11/28/2015	985153000445720	No	42	85	2.16	Male?	Inside G7
11/28/2015	985153000356932	No	53	93	3.58	Female	Inside G16
11/28/2015	985153000357265	No	55	107	3	Male	Inside G14
11/28/2015	985153000357831	No	51	106	3.01	Male	Under G8
11/28/2015	985153000359424	No	56	119	3.83	Male	Inside G6

Date (m/d/y)	Tag #	Recap?	SVL (mm)	Total (mm)	Weight (g)	Sex	Location
11/28/2015	985153000375852	No	56	97	4.33	Female	Inside G17
12/4/2015	985153000358621	Yes	50	92	3.51	Female	Under G12
12/4/2015	985153000376492	Yes	51	94	4.06	Female	Inside G17
12/4/2015	985153000798990	No	54	104	4.02	Male	Under G17
12/4/2015	985153000261873	No	55	93	3.97	Female	Inside G7
12/12/2015	985153000359610	Yes	40	67	1.39	Immature	Under G20
12/12/2015	985153000357288	No	54	92	3.48	Female	Under G7
12/12/2015	985153000358454	No	52	107	3.03	Male	Inside G8
12/12/2015	985153000440219	No	52	101	3.21	Male	Under G8
12/30/2015	985153000377256	Yes	55	101	4.79	Female	Under G5
12/30/2015	985153000357966	Yes	52	113	3.27	Male	Inside G4
12/30/2015	985153000376689	Yes	50	93	3.85	Female	Under G4
12/30/2015	985153000357265	Yes	55	106	2.82	Male	Inside G14
12/30/2015	985153000357831	Yes	51	107	2.67	Male	Under G6
12/30/2015	985153000359424	Yes	56	120	3.78	Male	Inside G6
12/30/2015	982000405545786	No	52	112	2.93	Male	Under G6
12/30/2015	982000405545210	No	55	97	4.32	Female	Inside G6
12/30/2015	982000405545842	No	46	87	2.43	Female	Inside G6
1/8/2016	985153000358520	Yes	51	107	2.67	Male	Inside G2
1/8/2016	985153000358549	Yes	47	102	2.68	Male	Under G8
1/8/2016	985153000357966	Yes	52	113	3.29	Male	Under G5
1/8/2016	985153000359375	Yes	61	108	4.56	Female	Inside G6
1/8/2016	985153000357831	Yes	51	107	2.7	Male	Under G3
1/8/2016	985153000359424	Yes	56	120	3.81	Male	Under G8
1/8/2016	982000405545974	No	53	90	3.31	Male	Under G16
1/8/2016	982000405545774	No	57	105	4.92	Female	Inside A10
1/8/2016	982000405545777	No	53	113	3.57	Female	Inside G19
1/8/2016	982000405545827	No	53	95	4.52	Female	Inside A14
1/18/2016	985153000377256	Yes	55	101	3.68	Female	Under G5
1/18/2016	985153000356932	Yes	53	93	3.63	Female	Inside G17
1/18/2016	985153000357265	Yes	55	107	3.05	Male	Inside G5
1/18/2016	985153000357831	Yes	51	107	2.69	Male	Under G5
1/18/2016	982000405545332	No	51	85	3.03	Male	Inside G16
1/18/2016	982000405545794	No	53	109	3.23	Male	Inside G19
2/6/2016	985153000358520	Yes	51	107	2.78	Male	Inside G8
2/6/2016	985153000357265	Yes	55	107	2.96	Male	Inside G14

Date (m/d/y)	Tag #	Recap?	SVL (mm)	Total (mm)	Weight (g)	Sex	Location
2/6/2016	985153000357831	Yes	51	106	2.88	Male	Inside G14
2/6/2016	985153000359424	Yes	56	119	3.9	Male	Inside G6
2/6/2016	985153000358621	Yes	50	91	3.42	Female	Inside G10
2/6/2016	985153000357983	No	49	88	3.2	Female	Inside G2
2/17/2016	985153000376492	Yes	51	94	4.52	Female	Inside G20
2/17/2016	985153000405215	Yes	50	95	3.8	Female	Inside G5
2/17/2016	982000405545777	Yes	53	113	3.47	Female	Inside G20
2/17/2016	982000405545772	No	48	116	2.91	Male	Inside G8
2/17/2016	982000405545790	No	51	95	3.78	Female	Inside G3
2/17/2016	982000405545843	No	53	108	2.94	Male	Inside G1
2/17/2016	985153000378443	No	48	82	2.56	Female	Inside G11
2/17/2016	985153000359424	Yes	56	120	3.81	Male	Under G8
2/27/2016	985153000356943	No	50	101	3.02	Male	Inside G6
2/27/2016	985153000359424	Yes	56	120	3.86	Male	Inside G8
2/27/2016	985153000356932	No	53	93	3.68	Female	Inside G16
2/27/2016	985153000357265	No	55	107	3.1	Male	Inside G14
2/27/2016	985153000357831	No	51	106	2.98	Male	Under G8
3/13/2016	985153000358520	Yes	51	107	3.01	Male	Inside G9
3/13/2016	982000405545794	Yes	53	109	3.21	Male	Under G20
3/13/2016	985153000357265	Yes	55	106	2.72	Male	Inside G14
3/13/2016	985153000357831	Yes	51	107	2.69	Male	Under G7
3/13/2016	985153000359424	Yes	56	120	3.58	Male	Inside G7
3/13/2016	982000405545786	No	52	112	2.99	Male	Inside G6
3/13/2016	982000405545210	No	55	97	4.13	Female	Under G6
3/13/2016	982000405545777	No	53	113	3.44	Female	Inside G18
3/27/2016	982000405545862	No	54	108	3.4	Male	Inside G20
3/27/2016	982000405545843	Yes	53	108	3.08	Male	Inside G1
3/27/2016	982000405545777	Yes	53	113	3.35	Female	Inside G20
3/27/2016	982000405545772	No	48	116	2.98	Male	Inside G8
3/27/2016	982000405545790	No	51	95	3.79	Female	Inside G3
3/27/2016	985153000378443	No	48	82	2.63	Female	Inside G11
3/27/2016	985153000357288	No	54	92	3.39	Female	Under G7
3/27/2016	985153000358454	No	52	107	3.09	Male	Inside G9
3/27/2016	985153000440219	No	52	101	3.18	Male	Under G8
4/10/2016	985153000358549	Yes	47	102	2.8	Male	Under G6
4/10/2016	985153000376492	Yes	51	93	3.92	Female	Inside G16

Date (m/d/y)	Tag #	Recap?	SVL (mm)	Total (mm)	Weight (g)	Sex	Location
4/10/2016	985153000357831	Yes	51	107	2.82	Male	Inside G2
4/10/2016	982000405545114	No	55	94	4.21	Female	Inside G3
4/10/2016	982000405545463	No	57	112	3.98	Male	Inside G5
4/10/2016	985153000359424	Yes	56	120	3.6	Male	Inside G7
4/10/2016	982000405545786	No	52	112	3.05	Male	Inside G6
4/20/2016	982000405545843	Yes	53	108	3.15	Male	Under G2
4/20/2016	985153000357966	Yes	52	113	3.27	Male	Inside G4
4/20/2016	985153000376689	Yes	50	93	3.89	Female	Under G5
4/20/2016	985153000357265	Yes	55	106	2.85	Male	Inside G14
4/20/2016	985153000357831	Yes	51	107	2.56	Male	Inside G6
4/20/2016	985153000359424	Yes	56	120	3.66	Male	Under G6
4/20/2016	985153000379328	No	56	101	3.99	Female	Inside G2
6/8/2016	982000405545134	No	52	94	3.54	Female	Inside G4
6/8/2016	982000405545269	No	54	95	4.08	Female	Under G4
6/8/2016	985153000405215	Yes	51	96	3.88	Female	Inside G5
6/8/2016	982000405545843	Yes	53	108	3.19	Male	Under G2
6/8/2016	985153000445720	Yes	43	86	2.35	Male	Inside G8
6/15/2016	985153000405215	Yes	51	96	3.64	Female	Inside G5
6/15/2016	985153000376689	Yes	50	93	3.73	Female	Inside G2
6/15/2016	982000405545772	Yes	48	116	3.08	Male	Inside G6
6/15/2016	985153000405215	Yes	51	96	3.81	Female	Inside G5
6/15/2016	985153000358549	Yes	47	102	2.78	Male	Under G6
6/15/2016	982000405545463	Yes	57	112	3.92	Male	Inside G3
6/26/2016	982000405545444	No	54	96	3.98	Female	Under G6
6/26/2016	985153000358549	Yes	47	103	3.22	Male	Inside G8
6/26/2016	985153000405215	Yes	51	96	3.64	Female	Inside G5
6/26/2016	985153000357831	Yes	51	107	2.82	Male	Inside G3

APPENDIX B

Appendix B. Table of all remote detections of PIT tagged *Ensatina* made in the Redwood Experimental Forest from July 2016 – January 2017. Distance moved is the shortest distance between a given location and the previous location of an individual animal.

Date (m/d/y)	Survey #	ID	Sex	Distance to tree (m)	Tree #	Azimuth	Distance Moved (m)
7/14/2016	1	985153000405215	Female	4	2154	229	NA
7/14/2016	1	985153000357966	Male	3.5	2154	98	NA
7/14/2016	1	985153000446907	Male	2.1	2154	300	NA
8/1/2016	2	985153000358549	Male	2.4	2154	125	NA
8/1/2016	2	985153000379328	Female	6	2156	91	NA
8/1/2016	2	982000405545786	Male	2.8	2153	266	NA
8/1/2016	2	985153000405215	Female	4.2	2154	22	NA
8/1/2016	2	982000405545463	Male	2.1	2136	306	NA
8/1/2016	2	982000405545842	Female	4.9	2154	69	NA
8/1/2016	2	985153000357966	Male	3.5	2154	98	0
8/30/2016	3	985153000358549	Male	2.4	2154	125	0
8/30/2016	3	982000405545786	Male	3.1	2153	288	1.2
8/30/2016	3	985153000405215	Female	4.2	2154	22	0
8/30/2016	3	982000405545842	Female	4.9	2154	69	0
8/30/2016	3	985153000357966	Male	2.2	2154	122	0.9
8/30/2016	3	982000405545772	Male	0.9	2151	225	NA
8/30/2016	3	985153000356932	Female	2.8	2136	355	NA
8/30/2016	3	985153000376689	Female	2.3	2154	201	NA
8/30/2016	3	985153000378443	Female	4.2	2154	184	NA
8/30/2016	3	982000405545843	Male	2.5	2143	48	NA
8/30/2016	3	985153000377488	Male	4.7	2136	93	NA
10/1/2016	4	985153000358549	Male	2.4	2154	125	0
10/1/2016	4	985153000357966	Male	2.2	2154	120	0
10/1/2016	4	985153000445720	Male	4.5	2136	292	NA
10/1/2016	4	985153000358621	Female	3.7	2140	88	NA
10/1/2016	4	985153000405215	Female	4.2	2154	22	0
10/1/2016	4	982000405545786	Male	1.5	2153	100	1.5
10/1/2016	4	985153000377488	Male	4.4	2136	93	0

Date (m/d/y)	Survey #	ID	Sex	Distance to tree (m)	Tree #	Azimuth	Distance Moved (m)
10/1/2016	4	982000405545842	Female	4.9	2154	69	0
10/18/2016	5	985153000405215	Female	3	2154	192	1.3
10/18/2016	5	982000405545790	Female	5.1	2154	322	NA
10/18/2016	5	985153000357966	Male	2.2	2154	120	0
10/18/2016	5	985153000357831	Male	3.6	2136	298	NA
10/18/2016	5	985153000358621	Female	3.8	2140	71	1.4
10/18/2016	5	982000405545842	Female	4.4	2154	115	0.5
10/18/2016	5	985153000358549	Male	6.5	2154	258	4.1
10/18/2016	5	982000405545772	Male	0.8	2151	43	1.7
10/18/2016	5	985153000377488	Male	4.4	2136	93	0
10/18/2016	5	982000405545777	Female	2.6	2136	225	NA
10/18/2016	5	985153000357983	Female	1.1	2154	5	NA
10/25/2016	6	985153000405215	Female	3	2154	192	0
10/25/2016	6	985153000357966	Male	2.2	2154	120	0
10/25/2016	6	985153000358621	Female	4.1	2140	92	1.6
10/25/2016	6	985153000357983	Female	1.3	2154	330	1.3
10/25/2016	6	982000405545842	Female	4.4	2154	115	0
10/25/2016	6	982000405545786	Male	3.3	2153	108	1
10/25/2016	6	985153000377256	Female	0.6	2153	7	NA
10/25/2016	6	985153000358549	Male	5.6	2154	266	2.3
10/25/2016	6	982000405545772	Male	0.8	2151	43	0
10/25/2016	6	985153000377488	Male	4.4	2136	93	0
10/25/2016	6	985153000376492	Female	4	2136	265	NA
10/25/2016	6	982000405545463	Male	6	2136	109	NA
11/1/2016	7	982000405545842	Female	4.4	2154	115	0
11/1/2016	7	982000405545790	Female	2.3	2154	210	4.2
11/1/2016	7	985153000358549	Male	0.9	2154	267	1.7
11/1/2016	7	985153000358621	Female	4.4	2140	241	2.1
11/1/2016	7	985153000405215	Female	3	2154	192	0
11/1/2016	7	985153000357966	Male	2.6	2154	123	0.4
11/1/2016	7	985153000357831	Male	6	2154	309	NA
11/1/2016	7	985153000377256	Female	0.2	2153	99	0.5
11/1/2016	7	982000405545786	Male	5.3	2154	246	5.3

Date (m/d/y)	Survey #	ID	Sex	Distance to tree (m)	Tree #	Azimuth	Distance Moved (m)
11/1/2016	7	985153000377488	Male	4.4	2136	93	0
11/1/2016	7	982000405545777	Female	2.6	2136	225	0
11/1/2016	7	985153000376492	Female	3.3	2136	251	2.1
11/1/2016	7	985153000378443	Female	4.8	2151	45	13.4
11/1/2016	7	985153000358805	Female	5.1	2136	201	NA
11/21/2016	8	985153000405215	Female	4	2154	229	0.5
11/21/2016	8	985153000357265	Male	3.6	2154	192	NA
11/21/2016	8	982000405545790	Female	2.3	2154	210	0
11/21/2016	8	985153000376689	Female	1.6	2154	267	0.6
11/21/2016	8	982000405545842	Female	4.4	2154	115	0
11/21/2016	8	985153000358621	Female	1.1	2143	283	2.2
11/21/2016	8	982000405545772	Male	1.8	2151	299	2
11/21/2016	8	982000405545827	Female	0.6	2136	280	NA
11/21/2016	8	982000405545777	Female	2.6	2136	225	0
11/21/2016	8	985153000376492	Female	4.6	2123	297	10.3
11/21/2016	8	985153000357966	Male	2.6	2154	123	0
11/21/2016	8	985153000377488	Male	4.4	2136	93	0
11/21/2016	8	985153000358805	Female	5.1	2136	201	0
11/21/2016	8	985153000358454	Male	3.3	2151	212	NA
12/13/2016	9	982000405545790	Female	2.3	2154	210	0
12/13/2016	9	985153000357983	Female	2.3	2154	210	1.3
12/13/2016	9	985153000376689	Female	0.5	2154	271	1.3
12/13/2016	9	985153000357966	Male	2.6	2154	123	0
12/13/2016	9	985153000358621	Female	5	2143	304	4.1
12/13/2016	9	985153000376550	Female	2	2140	249	NA
12/13/2016	9	985153000405215	Female	4	2154	229	0
12/13/2016	9	982000405545842	Female	4.4	2154	115	0
12/13/2016	9	985153000440219	Male	1.3	2154	282	NA
12/13/2016	9	985153000359424	Male	6.6	2154	267	NA
12/13/2016	9	985153000377256	Female	0.2	2153	99	0
12/13/2016	9	985153000378443	Female	1.9	2151	358	2.7
12/13/2016	9	982000405545772	Male	2.2	2151	20	2.7
12/13/2016	9	985153000376492	Female	3.6	2123	315	1.1

Date (m/d/y)	Survey #	ID	Sex	Distance to tree (m)	Tree #	Azimuth	Distance Moved (m)
12/13/2016	9	985153000377488	Male	4.4	2136	93	0
12/13/2016	9	982000405545827	Female	4.4	2136		NA
12/13/2016	9	982000405545774	Female	2.8	2136		NA
1/8/2017	10	985153000357265	Male	2.3	2154	210	1.1
1/8/2017	10	982000405545790	Female	2.3	2154	210	0
1/8/2017	10	985153000377256	Female	4	2154	229	13.1
1/8/2017	10	985153000405215	Female	4	2154	229	0
1/8/2017	10	985153000376689	Female	0.5	2154	271	0
1/8/2017	10	985153000357983	Female	2.3	2154	311	0.3
1/8/2017	10	982000405545772	Male	0.4	2151	23	2
1/8/2017	10	985153000359424	Male	6.6	2151	115	0
1/8/2017	10	985153000359375	Female	4.1	2154	255	NA
1/8/2017	10	982000405545842	Female	4.4	2154	115	0
1/8/2017	10	982000405545843	Male	3.4	2154	49	NA
1/8/2017	10	985153000358621	Female	5.1	2154	314	2.7
1/8/2017	10	982000405545827	Female	14.7	2136	NA	10.2
1/8/2017	10	982000405545862	Male	2.2	2151	82	NA
1/8/2017	10	985153000356943	Male	5.4	2151	290	NA