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Determining the influence of environmental factors on amphibian road presence near the Fort Ord National Monument in Monterey County, California

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DETERMINING THE INFLUENCE OF ENVIRONMENTAL FACTORS ON AMPHIBIAN ROAD PRESENCE NEAR THE FORT ORD NATIONAL MONUMENT IN MONTEREY COUNTY, CALIFORNIA

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Master of Science

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by

Joshua Beasley

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CALIFORNIA STATE UNIVERSITY MONTEREY BAY

The Undersigned Faculty Committee Approves the

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ABSTRACT

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by
Joshua Beasley
Master of Science in Environmental Science
California State University Monterey Bay, 2024

Amphibian populations are declining globally and habitat fragmentation is a major cause. Roads fragment the landscape around the Fort Ord National Monument, representing a threat to amphibian populations through direct mortality from strikes, noise and light pollution, and runoff of chemicals. We surveyed roads surrounding the Fort Ord National Monument in Monterey County, California to assess the effect of habitat cover, traffic intensity, and wetland proximity on the location and magnitude of amphibian road kill. Our surveys turned up at least seven of nine local amphibian species alive on roads, six of which were also found dead on roads. These species represent two different life history groups: pond-dependent and non pond-dependent. Most amphibian activity occurred within 2 km of wetland, and we found evidence that higher traffic intensities are depressing pond-dependent populations while non pond-dependent populations remain relatively unaffected. There are several geographic hotspots of on-road amphibian activity that we identified for future mitigation efforts.

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INTRODUCTION

Rates of decline and extinction in amphibians are accelerating around the world. More amphibian species are at risk of extinction than any other studied group (Stuart et al. 2004), suggesting they are one of the several taxa suffering from the 6th mass extinction in our planet's history (Wake & Vredenburg 2008). According to data published by the International Union for the Conservation of Nature (IUCN), 32.5% of all amphibian species are threatened, 43.2% are experiencing population decrease, and 29.1% are too poorly understood to know if they are threatened or decreasing (Stuart et al. 2004). Many individual factors such as habitat loss, disease, climate change, biological invasions, and pollution have been proposed as drivers of local amphibian population declines. The combination of all of these factors has led to the global phenomenon of decline (Hayes et al. 2010).

Habitat loss and fragmentation are primary causes of declines in abundance and diversity of amphibian populations (Eigenbrod et al. 2008). Habitat fragmentation by roads is particularly damaging to amphibian populations (Beebee 2013) and directly causes mortality through vehicle strikes (Hels & Buchwald 2001; Langen et al. 2009), disrupts their behavior with noise (Tennessen et al. 2014), and degrades surrounding habitat quality with pollutant runoff (Trombulak and Frissell 2000). These problems have led to genetic isolation, inbreeding depression, and population declines in amphibians (Hamer et al. 2021; Lesbarrerès et al. 2003; Fahrig et al. 1995).

Amphibian populations are especially susceptible to fragmentation by roads, in part, because they demonstrate strong seasonality in activity. They become active in the fall as the landscape becomes wetter and cooler, and go dormant in late spring as temperatures rise and habitats dry. Photoperiod has also been shown to influence amphibian seasonal activity (Canavero & Arim 2009). Since amphibian activity is limited to the period when breeding and foraging habitat will remain wet and cool enough for use, any additional negative pressure from roads during this sensitive time may be disproportionately damaging.

Local amphibian species in Monterey County exhibit two life history strategies, aquatic-breeding and direct-developing. Aquatic-breeding amphibians typically gather at vernal pools, ponds, or streams to breed and lay eggs. They hatch into an aquatic larval stage that metamorphoses later in spring into the adult form. These amphibians often exhibit much more extreme seasonal migrations from upland habitat to breeding sites and back. California tiger salamanders can travel distances of up to 2.2 km when moving from summer retreats to breeding sites (Orloff 2011), although only an estimated 5% of adults move more than 620 m from a breeding site and 50% stay within 150 m (Trenham & Shaffer 2005). Kramer (1973) found that most chorus frogs stay within 100 m of their breeding pool but can travel over 200 m away, with a maximum daily movement of 42 m.

Direct-developing species do not have an aquatic larval stage, instead laying eggs directly in moist substrate. These eggs hatch into small versions of terrestrial adults. Because they do not require aquatic habitat for breeding and feeding, direct developing species do not exhibit large, overland, seasonal migrations. For example, Ensatina salamanders, a direct-developing genus in the family Plethodontidae, have been documented moving 5-10 meters on average over a study period (Olson & Kluber 2014) and up to 120 meters from a starting location (Staub et al. 1995). Other plethodontid salamanders move >10 meters regularly (Miloski 2010). While these movements are not substantial in comparison with species that migrate, they can still put populations near roads at risk of mortality.

Several strategies have been implemented to reduce the likelihood of direct mortality from vehicle strikes. Tunnels under roads with guiding fences have seen widespread use and varied success (Jackson & Tyning 1989; Allaback and Laabs 2003; Helldin & Petrovan 2019). Volunteers are sometimes recruited as "crossing guards" for amphibian populations, such as in Hopewell, New Jersey (Sourland Conservancy 2021) and Salisbury, Vermont (Otter Creek Audubon Society 2023). The Bonnyvale Environmental Education Center in Vermont even provides guidance for how to develop a crossing guard system in your local area (Bonnyvale Environmental Education Center 2023). Road closures are another method to reduce the barrier effect of roads. In Berkeley, California, South Park Drive in Tilden Regional Park is closed regularly during newt migrations (East Bay Regional Parks District 2023). However, this method is likely unfeasible for most roads outside of parks. For example, Alma Bridge Road alongside the Lexington Reservoir in Santa Clara County experiences similar newt migrations, but road closures would prevent residents from reaching their homes. Attempts to fund tunnel infrastructure underneath the road have failed. H. T. Harvey and Associates (2021) estimated 40% of the 14,000 newts attempting to cross Alma Bridge Road each year are killed by vehicle traffic, indicating the need for an immediate solution. They recommended a crossing guard system until more permanent infrastructure can be approved (H. T. Harvey and Associates 2021).

The described strategies are potentially time and labor intensive, and not every road is a barrier to amphibian movement or experiences the same degree of mortality. Increasing traffic intensity has been shown to increase mortality (Fahrig et al. 1995; Hels & Buchwald 2001; Mazerolle 2004). Habitat type influences the abundance and locations of road mortalities for various species (Langen et al. 2009; Gu et al. 2011, Matos et al. 2012). Wetland presence also influences abundance and locations of road crossings and mortalities (Langen et al. 2009; Gu et al. 2011). Finding areas where amphibian road crossing and mortality are most likely allows for the most efficient use of resources to implement management strategies.

In Monterey County, California, there are amphibian communities potentially threatened by the effects of roads. Within the Fort Ord National Monument (FONM) and surrounding natural open spaces, there are at least 8 native species of amphibians, three of which are direct-developing (Gabilan Mountains slender salamander [*Batrachoceps gavilanensis*], Monterey ensatina [*Ensatina eschscholtzii eschscholtzii*], Arboreal salamander [*Aneides lugubris*]) and five of which are aquatic-breeding (Sierran tree frog [*Pseudacris sierra*], Western toad [*Anaxyrus boreas*], California newt [*Taricha torosa*], California tiger salamander [*Ambystoma californiense*], California red legged frog [*Rana draytonii*]). California tiger salamanders and California red-legged frogs are both listed and protected by the U.S. Fish and Wildlife Service. Most of these organisms live at or near an interface between natural and urban habitats. Given that the county's human population has risen 34% since 1980 (Federal Reserve Bank of St. Louis 2023), roads are becoming an encroaching border around the natural spaces that these amphibians occupy.

We completed road surveys in areas near the FONM in Monterey County, California to locate amphibian road crossing and mortality hotspots and determine the influence of traffic intensity, habitat type adjacent to the road, and distance to wetland on road mortality frequency for local amphibian species. By improving our understanding of the effects of roads on both aquatic-breeding and direct-developing amphibians, we hope to provide management recommendations for protecting local species here as well as similar species elsewhere.

METHODS

STUDY AREA

This study focused on roads surrounding the Former Fort Ord (FFO) in Monterey County, CA. The core of the FFO is currently split between the Bureau of Land Management (BLM) and Department of Defense (DOD), and is bordered by CSU Monterey Bay campus, Inter-Garrison Road, and Reservation Road to the north, Highway 68 to the east and south, and General Jim Moore Boulevard to the west. There is a complex habitat matrix surrounding the FFO, made up of single-family home neighborhoods, commercial business parks, golf courses, and other open space areas such as Toro County Park, Jacks Peak County Park, and Frog Pond Wetland Preserve. Some urban areas are highly dense and have little to no natural habitat remaining, including the East Garrison neighborhood to the northeast and the city of Seaside to the west. Other areas are less urbanized and have some natural habitat interspersed between development, such as San Benancio and Corral de Tierra to the south and CSUMB's East Campus housing to the north (Fig. 1). The persisting natural habitat consists primarily of coast live oak woodland, coastal scrub, chaparral, and annual grassland. Roads within the study area are primarily two-lane asphalt with speed limits ranging from 25-50 mph.

SITE SELECTION

To explore the relationship between amphibian road mortality and the predictors chosen for this study, we developed a random site selection method. We first acquired the Census Bureau TIGER/Line road layer (United States Census Bureau 2021) for Monterey County. In ArcGIS Pro (Environmental Systems Research Institute [ESRI]. 2022. ArcGIS Pro Release 3.0.1. Redlands, CA), we excluded any roads that were unsafe or illegal to walk on, such as highways. We then divided all roads into 1-km segments and excluded any shorter segments from consideration. To describe vegetation characterizing each 1-km segment, we used vegetation cover types provided by CALVEG (Forest

Service 2018). We assigned a majority cover type within a 300-m buffer of each road segment, which would contain the vast majority of maximum amphibian movements. There were four majority cover types: urban, woodland, shrub, and herbaceous. We also used the U.S. Fish and Wildlife Service's National Wetland Inventory (NWI) (United States Fish and Wildlife Service 2022) to generate a distance to wetland value for each road segment. Distances were classified into three categories: ≤ 250 m (Langen et al. 2009; Green et al. 2021), 250-1,000 m (Gu et al. 2011), and 1,000-2,000 m (Orloff 2011; Hamer et al. 2021) from the nearest wetland. Most of the amphibians in this study do not move beyond 250 m from a wetland, while 2,000 m represents the furthest migration distance. Categories represent the average distance of the whole road segment to the nearest wetland. Using majority cover and distance resulted in 12 road segment classes. We aimed to select at least 5 road segments per road segment class to incorporate variable rates of traffic intensity. The combination of four majority vegetation cover types, three distance from wetland categories, and five sites per class to cover a range of traffic intensities would yield 60 survey sites. However, due to limited availability of road segments that were both safe to survey and matched the conditions of each class, we identified a total of 45 segments for this study (Table 1, Fig. 2A).

We also investigated cover as a continuous predictor *post hoc*. Continuous cover was defined on a scale from 0 to 1, with 0 being completely urban cover within a 300-m buffer of the road segment, and 1 being completely natural cover (Fig. 2B). We considered natural cover as anything non-urban or non-barren in the CALVEG database. While this predictor loses detail when it comes to separating the effect of different natural cover types, it gains detail when it comes to distinguishing the quality and usability of adjacent habitat, given the negative effect of urban cover on amphibians (Green et al. 2021).

Survey Method

We generated an ArcGIS Pro web map of the study area that can be accessed via ArcGIS Field Maps. We used this map in the field to locate each 1-km road segment, where we walked transects to collect GPS points of both live and dead amphibians. Upon arriving at the start of a transect, we recorded the time, weather, road condition, road ID number, and survey ID number. We started a timer and began walking at a steady pace in a direction opposite to traffic. While walking, we used a bright flashlight to monitor the closest lane of traffic. Once we reached the end of the transect, we crossed the road and walked back towards the beginning, monitoring that side on the way back. Walking surveys were chosen rather than driving surveys to increase amphibian detection likelihood (Slater 2002; Beebee 2013). To ensure the safety of all observers conducting surveys, as well as to avoid conflicts with oncoming traffic, we developed and followed a field safety protocol that kept all observers visible to drivers and outside the path of oncoming traffic (Appendix 1). We estimated traffic intensity by using tally counters to count vehicles that passed us while surveying. We later converted counts into vehicles per minute. One of the primary investigators was present for all surveys and participating volunteers were provided example photos of road killed amphibians to ensure similar detection rates across transects. Once encountered, live or dead amphibians were identified to species and the location was entered onto ArcGIS Field Maps using a mobile phone.

STATISTICAL ANALYSIS

To assess the effect of traffic intensity, nearby vegetation cover, and distance to wetland on amphibian presence and mortality, we developed a multilevel Bayesian model (Gelman & Hill 2007) for counts of amphibians, *y*, derived from observations, i, at sites, j, as follows:

$$y_i \sim NB\ (\ \mu_i\ , \phi\ )$$

$$\mu_i = \ exp(\beta_0 + \ \beta_T T_i + \gamma_D D_{j[i]} + \gamma_C C_{j[i]}{}^T + \gamma_{j[i]})$$

$$\gamma_j \sim N(0, \sigma)$$

where μ is the expected number of amphibians counted per survey, *T* is the traffic intensity during the survey (vehicles/minute), *D* is the average distance of the road segment from the nearest wetland (meters), *C* is the majority cover type within 300 m of the road, represented as a vector of indicator values for each cover type (or fractional natural cover, under the *post hoc* analysis), β_0 is an intercept parameter, β_T is a population-level parameter, γ_D and γ_C are site-level parameters, γ_j is a random site grouping effect, and ϕ and σ are variance parameters.

We used the statistical software R (v4.2.2; R Core Team 2022) to run our models with the package rstanarm using the tool stan_glmer (Goodrich et al. 2024). Our models used four chains of 10,000 iterations each, discarding 5,000 iterations as burn-in. Convergence was verified by r-hat < 1.01 and ESS > 400 (Vehtari et al. 2021). We used 91% and 76% credible intervals to define evidence as being 'strong' or 'substantial', respectively (this corresponds to 10:1 odds and √10:1 odds, *sensu* Kass & Raftery 1995). All continuous variables were standardized to allow them to be intercomparable. We assumed predictors did not have a credible effect if the 76% interval overlapped with zero. We also estimated the distance containing 95% of amphibian activity by integrating the model equation with respect to distance.

Results

Survey Summary

We surveyed 87 times across 45 1-km road segments between 18 September 2022 and 5 May 2023. At least one amphibian was found on 27 of the 45 segments, and we observed mortality on 24 of those 27 segments (Fig. 3). In total, we observed 40 amphibians alive on the road (AOR) and 64 amphibians dead on the road (DOR), representing 7 different native species: *Ambystoma californiense*, *Anaxyrus boreas*, *Aneides lugubris*, *Batrachoceps gabilanensis/luciae* (the study area covered the range maps for both species and individuals were not distinguished), *Ensatina eschscholtzii eschscholtzii*, *Pseudacris sierra*, and *Taricha torosa* (Table 2). A total of 66 observations were of pond-dependent species, which were mostly *P. sierra* (Fig. 4). Although one *A. californiense* was found, we did not display its location due to its federally threatened status. A total of 38 observations were of non pond-dependent species, which were relatively evenly spread across the study area (Fig. 5). No invasive amphibians were found.

We only surveyed on "rain days," when California Irrigation Management Information System (CIMIS) gauge 193 in Pacific Grove, CA registered at least 0.01 inches of rain between 8:00 and 20:00 the day of the survey (California Department of Water Resources. 2024. CIMIS Station Reports. Available from https://cimis.water.ca.gov/WSNReportCriteria.aspx [Accessed 18 October 2023]).

Between 1 September 2022, and 31 May 2023, the gauge indicated 54 rain days; we surveyed on 32 of those days. Missed rain days were not surveyed due to scheduling conflicts or illness.

We conducted 33 surveys that were within 250 m of a wetland, 33 surveys that were between 250 and 1,000 m from a wetland, and 21 surveys that were between 1,000 and 2,000 m from a wetland. We conducted 30 surveys at "urban" sites, 20 surveys at "herbaceous" sites, 16 surveys at "shrub" sites, and 21 surveys at "woodland" sites. We surveyed 6 sites with < 25% natural cover, 19 sites with 25-50% natural cover, 30 sites with 50-75% natural cover, and 32 sites with > 75% natural cover. The minimum traffic rate observed was 0 vehicles per minute (0.00/min), the maximum traffic rate was just under 5 vehicles per minute (4.71/min), and the average traffic rate was 1 vehicle every 2 minutes (0.47/min).

STATISTICAL ANALYSIS

We combined alive on road (AOR) and dead on road (DOR) observations for each life history model, since analyzing AOR and DOR observations separately did not yield meaningfully different results.

In the *a priori* analysis, there was strong evidence that pond-dependent amphibian abundance was reduced on roads that were further from wetlands (91% CI: -1.32 to -0.08, Fig. 6) and that 95% of pond-dependent amphibian activity occurs within 2 km of a wetland (Fig. 7). There was also substantial evidence that pond-dependent amphibians were less common on roads where traffic intensity was higher (91% CI: -1.80 to 0.07, Fig. 6). For non pond-dependent amphibians, there was substantial evidence that abundance was higher where traffic intensity was higher (91% CI: -0.06 to 0.84, Fig 6). Both life history groups showed similar responses to cover, but pond-dependent amphibians were most positively associated with shrub-defined habitat while non-pond dependent amphibians were most positively associated with urban-defined habitat (Fig. 6).

In the *post hoc* analysis, there was strong evidence that pond-dependent amphibian abundance was increased on roads surrounded by more natural cover (91% CI: 0.06 to 1.20, Fig. 8). Pond-dependent amphibians were also substantially less likely on roads with higher traffic intensities (91% CI: -1.41 to 0.16, Fig. 8). Distance of the road segment from wetland had no credible effect on amphibian abundance, but road segments closer to wetlands were more likely to have more natural cover (Pearson: -0.44). Non pond-dependent amphibians were strongly positively associated with higher traffic intensities (91% CI: 0.02 to 0.87, Fig. 8), but were not credibly affected by distance to wetland or percent natural cover.

DISCUSSION

Amphibians were found on the majority of road segments surveyed during the study period. On almost all of the segments where we found live amphibians, we also found amphibian mortality, even on segments with minimal traffic. We observed nearly all local species of amphibians, except California red-legged frogs (*Rana draytonii*) and American bullfrogs (*Lithobates catesbeianus*). This highlights the importance of roads as a source of mortality risk for local amphibians, regardless of life history strategy or species.

In the *a priori* analysis, the presence of pond-dependent amphibians was positively associated with proximity to wetland and negatively associated with traffic intensity. *Post hoc*, pond-dependent amphibians were positively associated with increasing natural cover and negatively associated with traffic intensity. Increasing natural cover is moderately correlated with decreasing distance to wetland, so the fact that wetland did not show up as a strong predictor in the *post hoc* model could be explained by the importance of wetland presence and natural habitat presence combined. Larger quantities of intact natural habitat surrounding a wetland typically support more robust amphibian populations at that wetland (Semlitsch 1998; Green et al. 2021). Wetlands without enough surrounding upland habitat may have smaller amphibian populations, yielding fewer observations on a nearby road.

Our results demonstrate the importance of both wetland presence and natural cover for pond-dependent amphibians. These species exhibit movement distances of anywhere from 100 m to 2 km between breeding habitat and upland habitat (Kramer 1973; Deguise and Richardson 2009; Orloff 2011), and our model predicted that 95% of observations would occur within that 2-km buffer. Combined with the high density of road surfaces within the study area, we expected higher amphibian abundance to be associated with increasing proximity of roads to wetlands. We did not expect that increasing traffic intensity would be associated with lower amphibian abundance. However, previous research found the same trend and assumed it could be due to the negative effect of roads reducing population sizes over time (Fahrig et al. 1995). In addition to mortality from vehicle strikes, traffic on roads can degrade surrounding habitats and disrupt amphibian behavior with noise (Trombulak and Frissell 2000; Tennessen et al. 2014). This explanation matches observed population declines at wetlands within 250 m of urbanization and within 1,000 m of roads (Green et al. 2021; Hamer et al. 2021).

Non pond-dependent amphibians were more likely on roads with increased traffic intensity. Neither cover nor proximity to wetland had credible effects on non pond-dependent amphibians in the *a priori* or *post hoc* analyses. The direction of effect of cover and wetland proximity matched what we observed in pond-dependent amphibians, but traffic intensity was the opposite. Mazerolle (2004) found that the probability of mortality was highly variable in response to changes in traffic intensity, while Hels and Buchwald (2001) predicted that mortality probability would increase with increasing traffic intensity. However, both of these studies were focused on pond-breeding amphibians, and non pond-breeding amphibians are far more sedentary (Staub et al. 1995; Miloski et al. 2010; Olson and Kluber 2014). Given that this life history lacks a predictable seasonal migration, it is possible that any road adjacent to functional habitat could cause road mortality, and the intensity of that mortality would be guided both by traffic intensity and the robustness of the population. In this study system, there may be evidence that non pond-dependent amphibian populations are still highly robust, given that higher traffic has led to more observations, not less.

The focus of most amphibian road mortality research has been on pond-dependent amphibians with a predictable migration (Beebe 2013), but all three local species of non pond-dependent amphibians were also found on roads. Future urbanization and development should take both life histories into account, and a need exists to better understand the movement patterns and risk factors for non pond-dependent species to guide their management effectively.

We encountered 1.2 amphibians per km surveyed, compared with 0.72 (Matos et al. 2012), 2.1 (Gu et al. 2011), 2.4 (Hels and Buchwald 2001), 4.8 (Fahrig et al. 1995), 14 (Hobbs 2013), 27 (Langen et al. 2009) and 66 (Mazerolle 2004). Our encounter rate is representative of surveys across a large variety of sites experiencing different environmental conditions, as recommended by Farig et al. (1995), opposed to a focused effort at one site over a long period, which was the method followed by several other researchers. Because of the differences in conditions surveyed, numbers of transects surveyed, prior information about the location of hotspots, traffic intensities, cover types, and species, it can be challenging to functionally compare encounter rates with other studies to determine the severity of amphibian road mortality in this area.

Despite the differences in methodology, by conducting road surveys, these previous studies all determined that either wetland proximity or nearby habitat were important predictors of amphibian presence on roads. The analysis in this paper aligns with that conclusion. We recommend special care be taken when developing infrastructure to preserve wetlands and any surrounding natural open space to limit damaging amphibian populations. In particular, South Boundary Road, Ryan Ranch, Abrams Road, and Watkins Gate Road are all hotspots for finding amphibians. We recommend mitigation efforts such as undercrossings to help lessen the impact of roads on those amphibian populations, especially if development is to continue in those areas.

California passed AB 2087 in 2016, providing funding for Regional Conservation Investment Strategy (RCIS) plans, with the goal of promoting voluntary regional involvement in conservation planning. Monterey County adopted its own RCIS that has been approved by the California Department of Fish and Wildlife with goals to 1) increase land acquisition and protection; 2) enhance, restore, and establish habitats; 3) restore creeks and rivers; and 4) enhance corridors and linkages between habitats (AECOM 2021). California also passed AB 1474 in 2023 with the goal of developing 2.5 million new homes in the next 8 years to alleviate the current housing crisis (California Department of Housing and Community Development. 2023. Statewide Housing Plan. Available from https://statewide-housing-plan-cahcd.hub.arcgis.com/ [Accessed 11 April 2024]). The push to develop “unused” land for the purpose of increasing housing may threaten local resources, which makes plans like the RCIS critical for ensuring conservation goals are also met. However, very little information is available on the effects of local roads on amphibian populations. Our results contribute to the goals and effectiveness of the Monterey RCIS as well as other regional conservation plans dealing with similar road-wildlife conflict.

CONCLUSION

Our findings provide a novel assessment of amphibian presence on roads in Monterey County, California. Pond-dependent amphibians were associated with roads that have a high percentage of surrounding natural cover and were close to wetlands. Roads with higher traffic levels may have depressed adjacent pond-dependent amphibian populations, which creates a conservation priority for roads that are surrounded by natural cover, are within 2 km of a wetland, and have relatively low levels of traffic. Further urban development in areas that meet those criteria would be likely to contribute to the decline of local pond-dependent amphibian populations. Non pond-dependent amphibians have been virtually unstudied as road kill but represented over a third of our observations. They were positively associated with roads that had higher traffic intensities, indicating evidence of robust populations regardless of traffic intensity. This unique life history group deserves further research, especially given their high diversity and ubiquitous presence in California. A population size assessment for both life history groups would be highly informative for understanding what fraction of those populations are encountering and getting killed on roads.

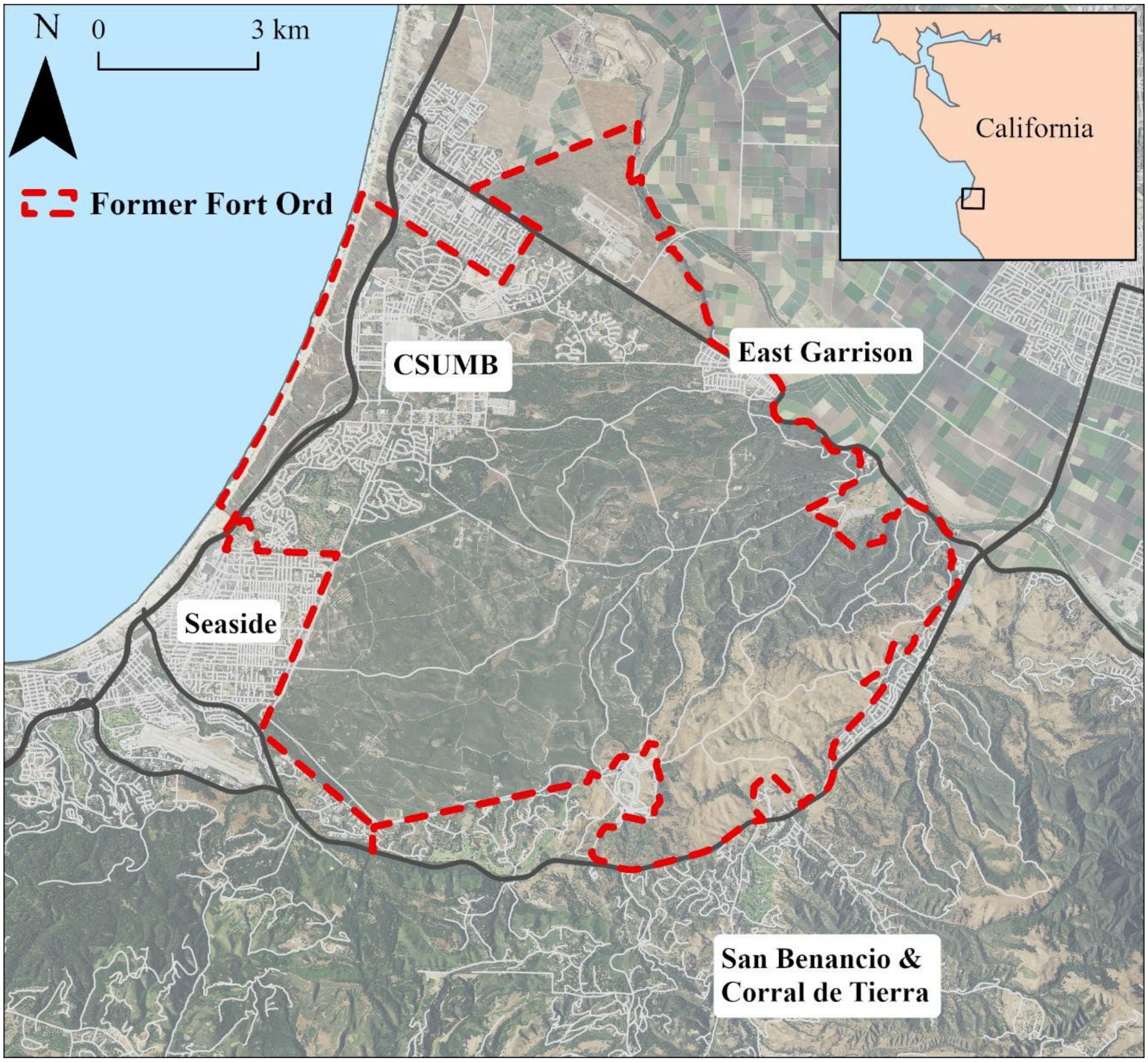

Figure 1. The Former Fort Ord in Monterey, CA contains and is surrounded by a mosaic of urban and natural environments, creating a high probability of road-wildlife conflict. CSUMB = California State University, Monterey Bay.

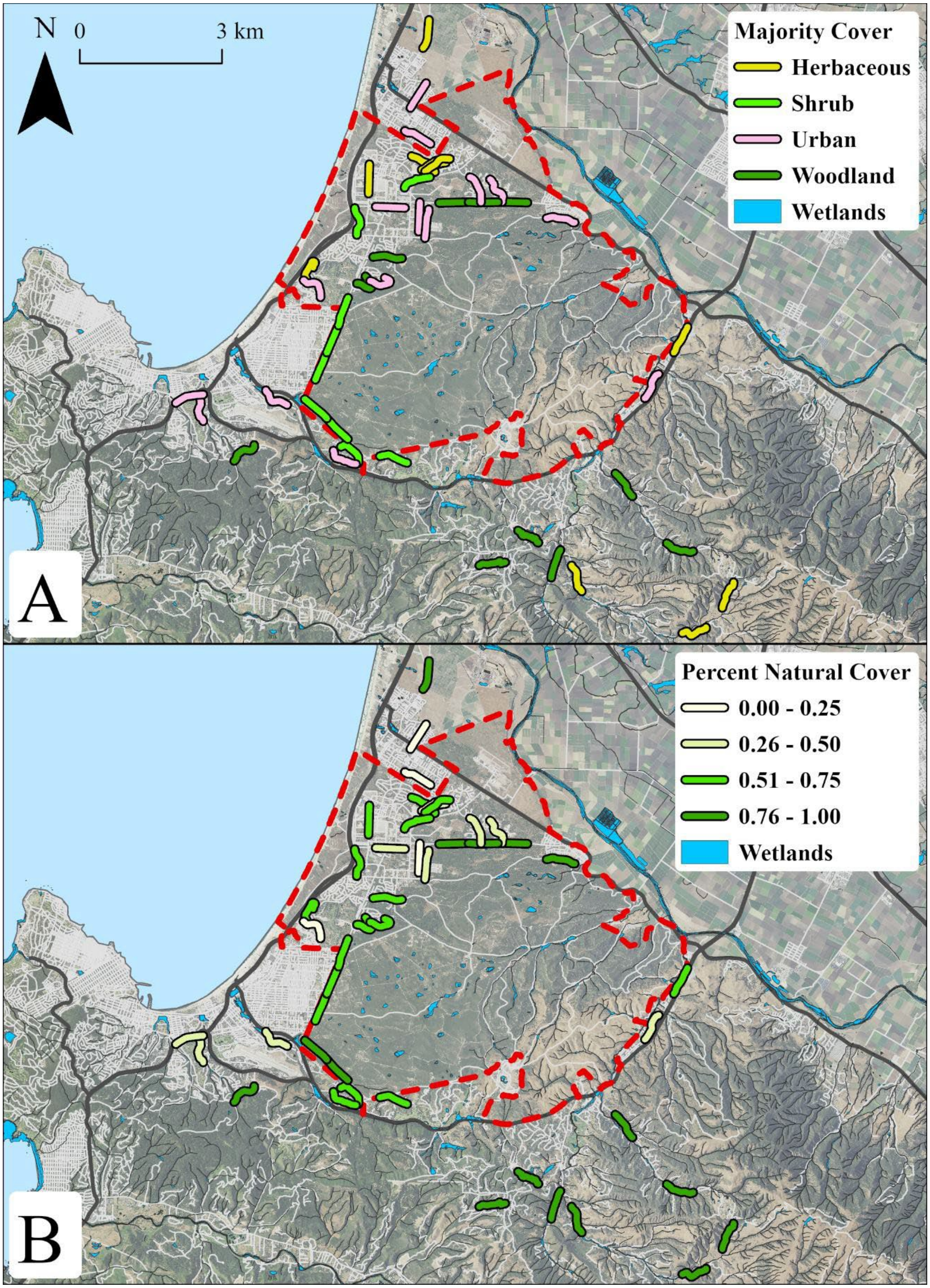

Figure 2. Survey segments in the vicinity of the Former Fort Ord. Sites were chosen to capture a range of vegetation cover, distance from wetland, and traffic intensity.

Table 1. Full list of survey segments separated by class. Classes were determined by a combination of cover type and distance to wetland. Traffic intensity and percent natural cover were calculated after surveys had been completed.

Road Name	Class	Cover Type	Vehicles/min	Distance to Wetland (m)	Percent Natural Cover
Sylvan Rd	1	Urban	0.00	79	0.39
Mark Thomas Dr	1	Urban	0.73	213	0.26
Rosita Rd	1	Urban	0.19	108	0.45
Lower Ragsdale Dr	1	Urban	0.11	125	0.57
Portola Dr	1	Urban	0.27	195	0.30
de Forest Rd	2	Urban	0.81	755	0.05
Schoonover Rd	2	Urban	0.23	265	0.33
Peninsula Point Dr	2	Urban	0.08	533	0.25
Watkins Gate Rd	2	Urban	0.52	252	0.95
Abrams Dr	2	Urban	1.43	469	0.49
1st St	3	Urban	0.03	1633	0.43
8th St	3	Urban	0.43	1422	0.41
Reindollar Ave	3	Urban	0.68	1659	0.04
7th Ave	3	Urban	0.43	1462	0.13
Ardennes Cir	3	Urban	0.03	1043	0.63
8th St	3	Urban	0.43	1422	0.41
8th St	3	Urban	0.43	1422	0.41
Upper Ragsdale Dr	4	Shrub	0.32	243	0.66
S Boundary Rd	4	Shrub	0.26	43	0.91
S Boundary Rd	4	Shrub	0.30	50	0.94
York Rd	5	Shrub	0.04	384	0.75
Gen Jim Moore Blvd	5	Shrub	0.57	526	0.60
Gen Jim Moore Blvd	5	Shrub	0.75	407	0.58
Gen Jim Moore Blvd	5	Shrub	1.28	338	0.65
1st Ave	6	Shrub	0.11	1062	0.72
Imjin Rd	6	Shrub	4.71	1324	0.68
Hidden Hills Rd	7	Woodland	0.19	95	0.80
Robley Rd	7	Woodland	0.09	44	0.88
San Benancio Rd	7	Woodland	0.21	10	0.88
Calera Canyon Rd	7	Woodland	0.07	15	0.83
San Benancio Rd	7	Woodland	0.71	70	0.75
Inter-Garrison Rd	8	Woodland	0.68	776	0.86
Olmsted Rd	8	Woodland	0.12	323	0.78
Metz Rd	8	Woodland	0.10	580	0.57
Inter-Garrison Rd	8	Woodland	1.57	447	0.92
Inter-Garrison Rd	8	Woodland	0.57	308	0.82
Normandy Rd	9	Woodland	0.04	1512	0.64
Corral de Tierra Rd	10	Herbaceous	0.03	8	0.98
Portola Dr	10	Herbaceous	0.17	123	0.71
Corral de Tierra Rd	10	Herbaceous	0.41	48	0.86
Corral de Tierra Rd	10	Herbaceous	0.00	123	0.85
Corral de Tierra Rd	10	Herbaceous	0.03	8	0.98
Buna Rd	11	Herbaceous	0.04	325	0.55
2nd Ave	11	Herbaceous	0.75	813	0.51
del Monte Blvd	11	Herbaceous	1.32	468	0.98
Marina Heights Dr	12	Herbaceous	0.42	1392	0.64
Bluffs Dr	12	Herbaceous	0.04	1157	0.48
Abrams Dr	12	Herbaceous	0.58	1139	0.53

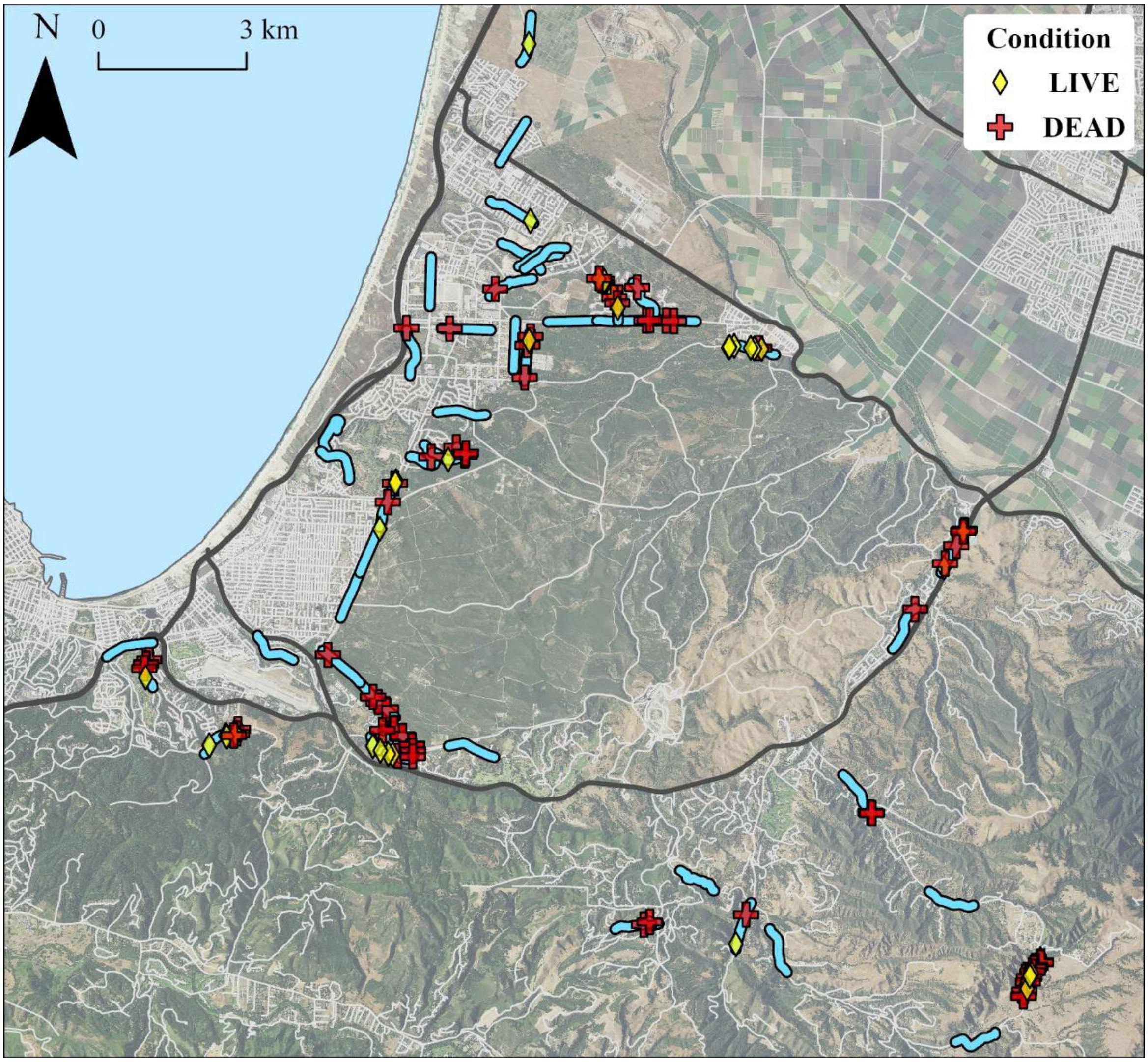

Figure 3. Live and dead amphibian observations during surveys in Monterey County, CA.

Table 2. Counts of all amphibian observations. No non-native species were found.

Group	Live Count	Dead Count	Total
Pond-Dependent	23	43	66
Non Pond-Dependent	17	21	38
AMCA (CA Tiger salamander)	1	0	1
ANBO (Western toad)	4	6	10
PSRE (Sierran tree frog)	14	30	44
TATO (CA newt)	4	7	11
ANLU (Arboreal salamander)	6	6	12
BAGA (Slender salamander)	7	3	10
ENES (Ensatina salamander)	4	12	16

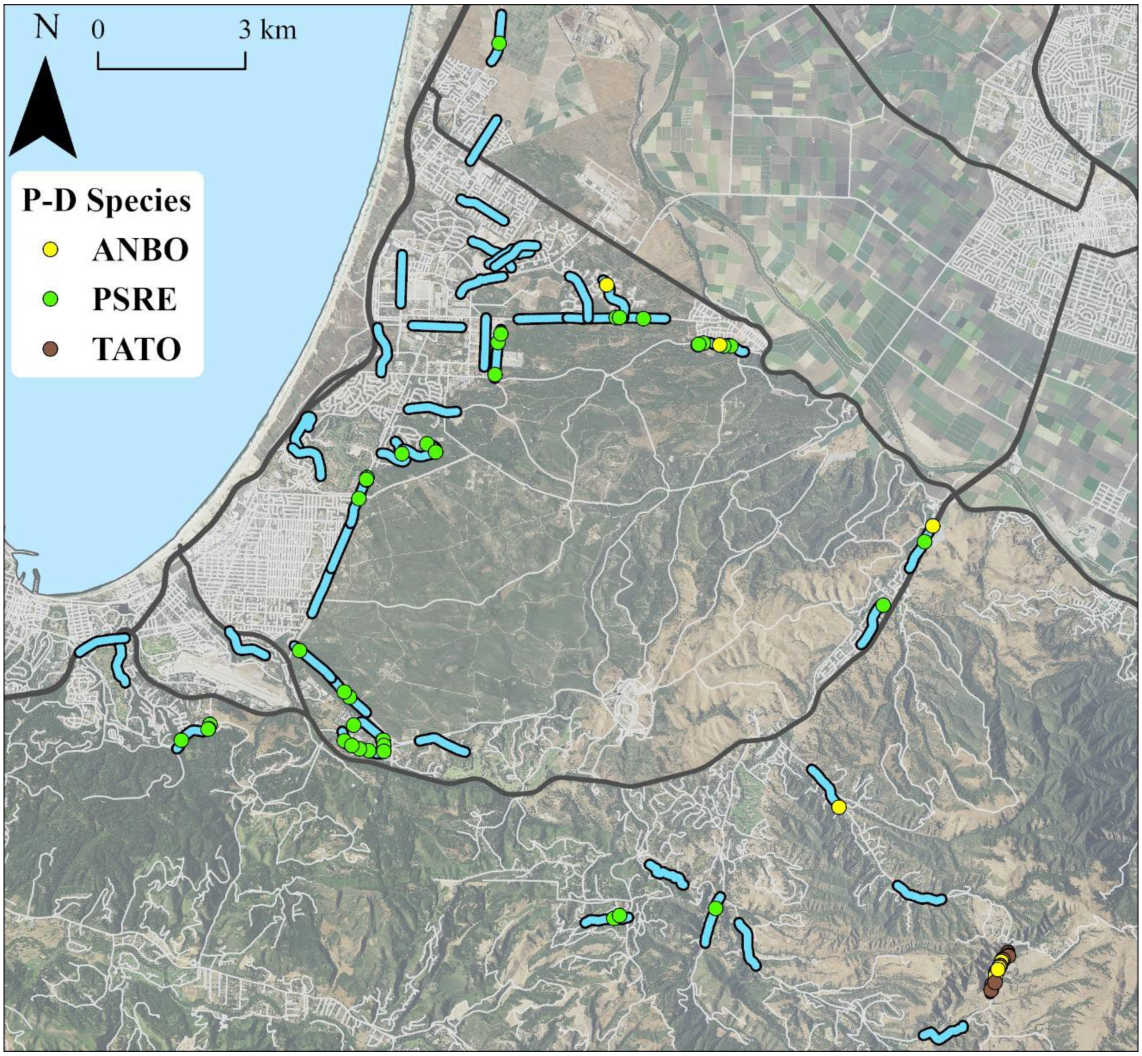

Figure 4. Pond-dependent amphibian observations during surveys in Monterey County, CA. The single California tiger salamander observation was not mapped. ANBO = *Anaxyrus boreas* (Western toad), PSRE = *Pseudacris sierra* (Sierran tree frog), TATO = *Taricha torosa* (California newt)

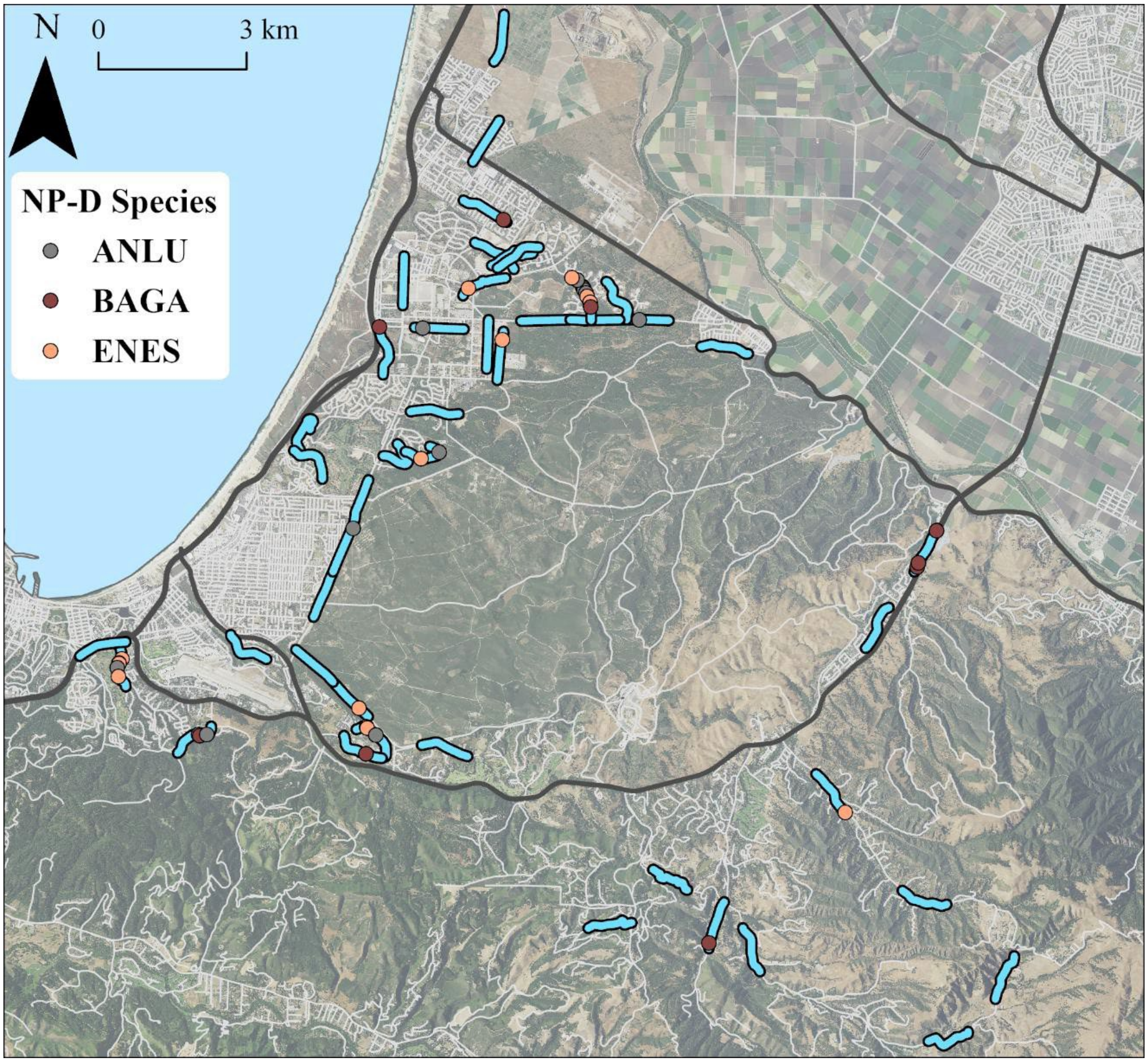

Figure 5. Non pond-dependent amphibian observations during surveys in Monterey County, CA. ANLU = *Aniedes lugubris* (Arboreal salamander), BAGA = *Batrachoseps gavilanensis / luciae* (Slender salamander), ENES = *Ensatina eschscholtzii eschscholtzii* (Monterey ensatina salamander)

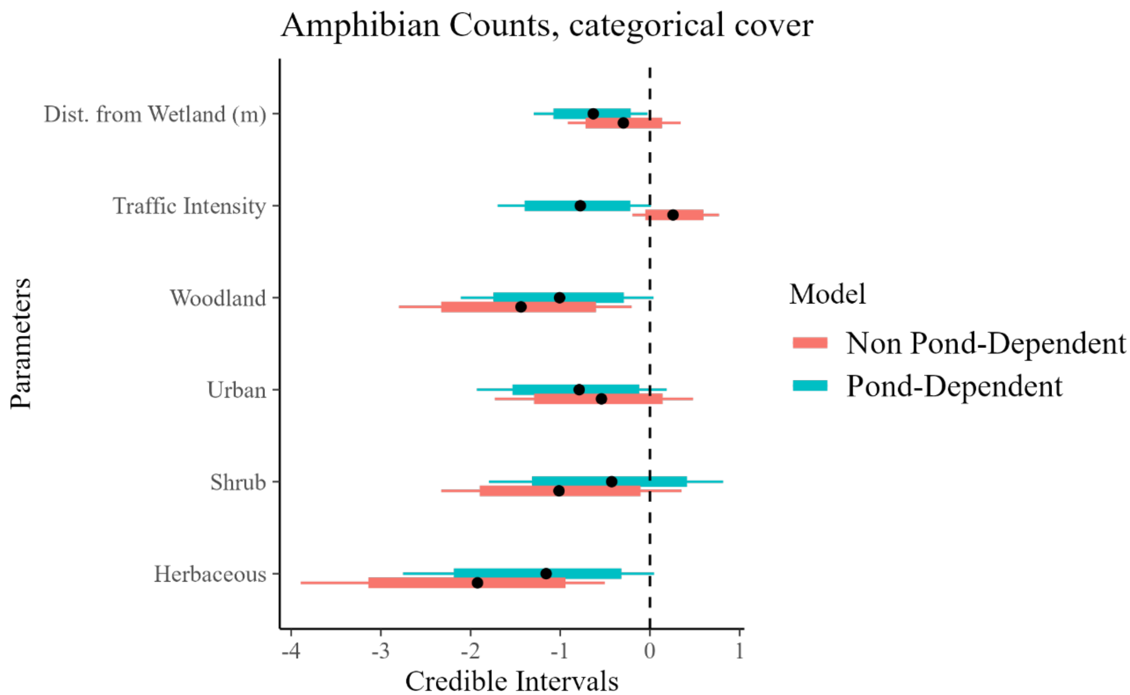

Figure 6. Credible intervals produced by the *a priori* model for both amphibian life histories. Cover is represented by majority type within a 300-m buffer of the survey segment.

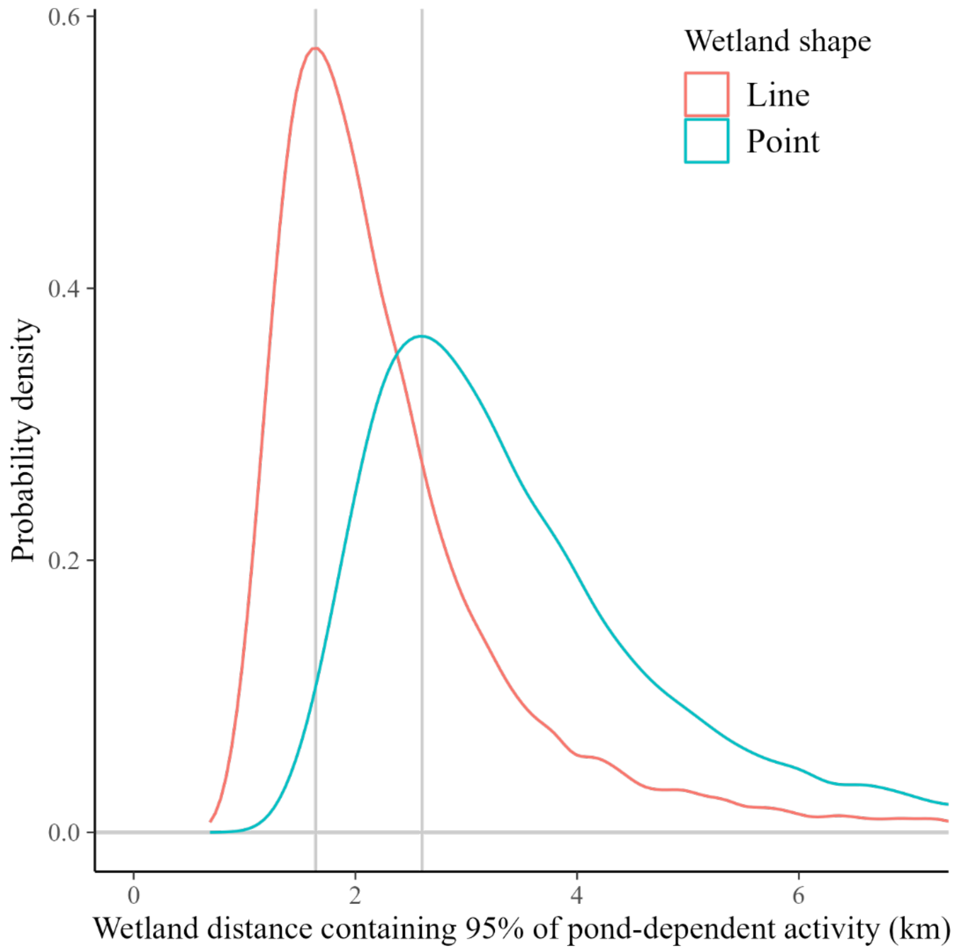

Figure 7. Model-predicted probability densities of encountering pond-dependent amphibians as a function of distance from wetland.

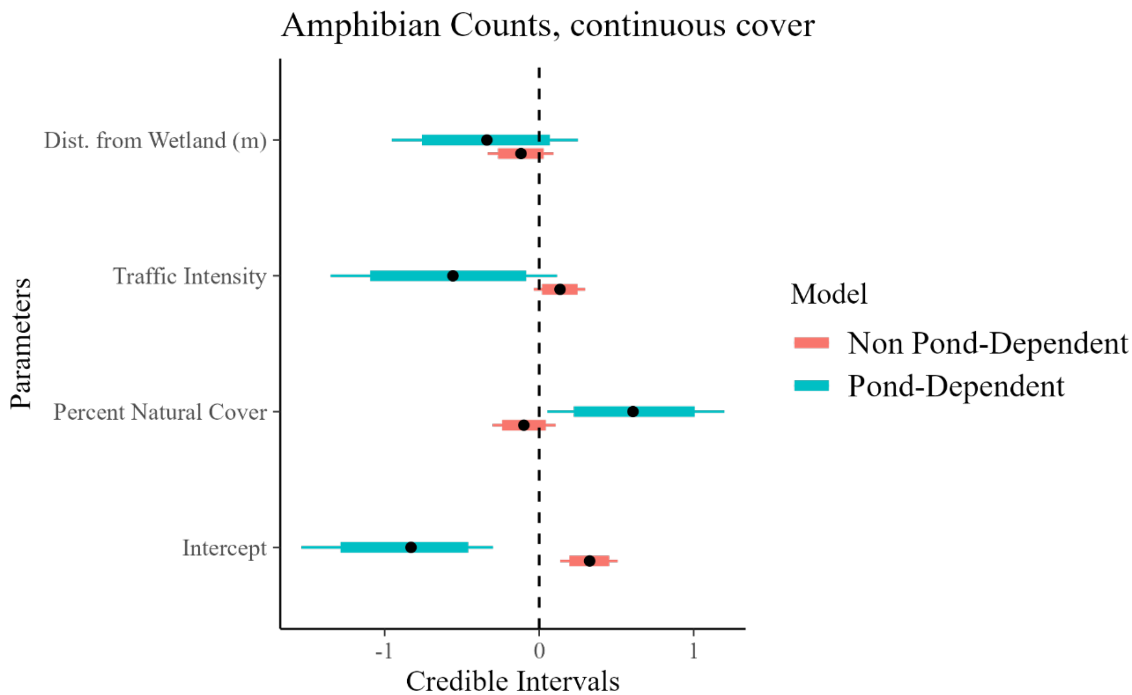

Figure 8. Credible intervals produced by the *post hoc* model for both amphibian life histories. Cover is represented by natural percentage within a 300-m buffer of the survey segment.

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APPENDIX A

FIELD SAFETY

Field Safety Protocol / Agreement for Amphibian Mortality Surveys
(updated 13-Nov-2022)

During this project, field surveys will take place on roads within Monterey County to search for amphibians that are actively crossing or have been killed by vehicles. These surveys will occur at night (typically starting between 8 and 8:30 PM PST) and usually during rain. Walking surveys were chosen because they improve detection likelihood over driving surveys (Beebee, 2013). Previous research investigating relationships between road mortality and environmental predictors such as adjacent habitat type, traffic intensity, and wetland presence also selected walking surveys over driving surveys (Hels & Buchwald, 2001; Langen et al., 2009; Gu et al., 2011; Hobbs, 2013).

All roads chosen within this project have sidewalks, bike lanes, or shoulders at least one meter in width that allow a person on foot to avoid traffic. However, some risk is still present by nature of a walking survey. In order to ensure reasonable safety of participants, the following procedures will be followed during surveys:

- Survey leader will check in and out upon commencing and completion of a survey to ensure someone knows their whereabouts at all times
- Upon arrival at a site, participants will park vehicles safely off the road in areas designed for vehicle parking
- All participants will be equipped with high-visibility vests and a headlamp or flashlight
- All participants will be asked to wear light-colored clothing and appropriate footwear/rain gear to avoid slipping on wet surfaces
- Surveys will be conducted in the direction opposite of vehicle traffic
- One participant will always be assigned to monitoring oncoming vehicle traffic and will call surveyors away from the road when vehicles are approaching
- All participants will step a safe distance (> 1 meter) away from the road edge at least 30 seconds prior to a vehicle passing
- There will be no attempts to handle live or dead animals on the road surface
- In the event of extreme rain or wind that may inhibit the ability of drivers to see surveyors or properly maintain control of their vehicles, participants will return to their vehicles, pause the survey, and wait for conditions to improve

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