Prepared in cooperation with the California Department of Water Resources

Behavioral Response of Giant Gartersnakes (*Thamnophis gigas*) to the Relative Availability of Aquatic Habitat on the Landscape

Open-File Report 2017–1141

U.S. Department of the Interior
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Cover: Photograph showing a giant gartersnake (*Thamnophis gigas*) swimming, Sacramento Valley, California, representing giant gartersnake use of aquatic habitats in rice growing regions of California. Photograph by Jim Morris, California Rice Commission. Used with permission.

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RYAN K. ZINKE, Secretary

U.S. Geological Survey
William H. Werkheiser, Acting Director

U.S. Geological Survey, Reston, Virginia: 2017

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Suggested citation:
Reyes, G.A., Halstead, B.J., Rose, J.P., Ersan, J.S.M., Jordan, A.C., Essert, A.M., Fouts, K.J., Fulton, A.M., Gustafson, K.B., Wack, R.F., Wylie, G.D., and Casazza, M.L., 2017, Behavioral response of giant gartersnakes (*Thamnophis gigas*) to the relative availability of aquatic habitat on the landscape: U.S. Geological Survey Open-File Report 2017-1141, 134 p., https://doi.org/10.3133/ofr20171141.

ISSN 2331-1258 (online)

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Conversion Factors

International System of Units to Inch/Pound

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
Area		
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square hectometer (hm^2)	2.471	acre
square meter (m^2)	10.76	square foot (ft^2)
square hectometer (hm^2)	0.003861	section (640 acres or 1 square mile)
hectare (ha)	0.003861	square mile (mi^2)
Volume		
microliter (µL)	0.0000338	ounce, fluid (fl. oz)
deciliter (dL)	0.11	quart (qt)
liter (L)	1.057	quart (qt)
Mass		
gram (g)	0.03527	ounce, avoirdupois (oz)

Datum

Horizontal coordinate information is referenced to the Universal Transverse Mercator, North American Datum of 1927 (NAD 27).

Abbreviations

a –LoCoH	adaptive Local Convex Hull
AST	Aspartate aminotransferase
CDL	Crop Data Layer
CI	confidence interval
DWR	California Department of Water Resources
EVI	Enhanced Vegetation Index
LoCoH	Local Convex Hull
MCP	minimum convex polygon
MCMC	Markov-chain Monte Carlo
NDMI	Normalized Difference Moisture Index
SVL	snout-vent length
USGS	U.S. Geological Survey

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Abstract

Most extant giant gartersnake (*Thamnophis gigas*) populations persist in an agro-ecosystem dominated by rice, which serves as a surrogate to the expansive marshes lost to flood control projects and development of the Great Central Valley of California. Knowledge of how giant gartersnakes use the rice agricultural landscape, including how they respond to fallowing, idling, or crop rotations, would greatly benefit conservation of giant gartersnakes by informing more snake-friendly land and water management practices. We studied adult giant gartersnakes at 11 sites in the rice-growing regions of the Sacramento Valley during an extended drought in California to evaluate their response to differences in water availability at the site and individual levels. Although our study indicated that giant gartersnakes make little use of rice fields themselves, and avoid cultivated rice relative to its availability on the landscape, rice is a crucial component of the modern landscape for giant gartersnakes. Giant gartersnakes are strongly associated with the canals that supply water to and drain water from rice fields; these canals provide much more stable habitat than rice fields because they maintain water longer and support marsh-like conditions for most of the giant gartersnake active season. Nonetheless, our results suggest that maintaining canals without neighboring rice fields would be detrimental to giant gartersnake populations, with decreases in giant gartersnake survival rates associated with less rice production in the surrounding landscape. Increased productivity of prey populations, dispersion of potential predators across a larger landscape, and a more secure water supply are just some of the mechanisms by which rice fields might benefit giant gartersnakes in adjacent canals. Results indicate that identifying how rice benefits giant gartersnakes in canals and the extent to which the rice agro-ecosystem could provide these benefits when rice is fallowed would inform the use of water for other purposes without harm to giant gartersnakes. Our study also suggests that without such understanding, maintaining rice and associated canals in the Sacramento Valley is critical for the sustainability of giant gartersnake populations.

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Introduction

Background

The California Department of Water Resources (DWR), in collaboration with other parties, is tasked with monitoring and managing California water resources. As part of this role, DWR supports efforts that improve water supply reliability for many competing uses and consumers. Although agriculture and irrigation are the largest consumers of water in California, economic considerations can lead to fluctuations in water supply across different crop types, uses, and regions, with geographic transfers of water and fallowing of crop fields being two common practices to manage limited water supplies. Many species of wildlife and plants depend on agricultural water supplies, and water transfers and fallowing rice could affect species dependent on the aquatic habitat that rice and its supporting infrastructure of canals provide.

Giant gartersnakes (*Thamnophis gigas*) are native to, and occur only in, wetlands and marshes in the Central Valley of California. The amount of historical wetland habitat in this region has decreased by more than 90 percent (Dahl, 1990), and conversion of historical wetland habitat to agriculture generally has resulted in the loss of wetlands. Unlike other crops, rice agriculture provides marsh-like wetland habitat on which many wildlife species now rely (Elphick, 2000). Giant gartersnakes currently persist primarily in rice agriculture and remnant or constructed wetlands, and because of the loss of natural habitat and extirpation from much of their former range, they were listed as threatened under the California and U.S. Endangered Species Acts (California Department of Fish and Game Commission, 1971; U.S. Fish and Wildlife Service, 1993). Because of their dependence on rice in the Sacramento Valley, water transfers and fallowing of rice fields could affect survival and movement of giant gartersnakes and their prey.

Although giant gartersnakes are now associated with and persist in rice agriculture, they spend much of their late March–early October active season associated with water conveyance infrastructure rather than rice fields (Halstead and others, 2016), which have cover-forming emergent vegetation only during June, July, and August. Aquatic habitat may remain in canals even if adjacent fields are fallowed, although water quantity and quality may fluctuate greatly. During periods of drought, economic drivers to fallow rice fields, as well as less annual rainfall and snowmelt, further decrease water input to aquatic habitats.

How an animal responds to less habitat is affected by the ecology and physiology of the species, and whether they are driven to seek new habitat, concentrate their activities in a smaller area, or decrease their metabolic rate or alter their behavior in a way that allows them to wait for conditions to change (Roe and others, 2003). These responses are not mutually exclusive, and plasticity across and within species may account for large amounts of variation in response to habitat changes. Poikilothermic organisms have the ability to decrease metabolic activity during periods of diminished habitat quality, which may favor a strategy of waiting for conditions to improve. How an organism responds to changing habitat quality may directly and indirectly affect its health, survival, and fitness as well. If animals respond by searching for more favorable habitat, there may be increased risks of predation and inability to locate higher quality habitat, especially if the animal is already metabolically stressed. However, remaining stationary and decreasing activity may lessen fecundity or lead to mortality if conditions remain unfavorable for an extended period of time.

Willson and others (2006) studied how several semi-aquatic snakes in the Southeastern United States varied in their response to drought at an isolated wetland, and found that responses to drought varied widely among species. For example, black swamp snakes (*Seminatrix pygaea*) aestivated within the wetland, and effects of drought were relatively small. Effects of drought also were minimal on cottonmouths (*Agkistrodon piscivorus*), which migrated to the wetland as it filled and away from it as it dried each year. Watersnakes of the genus *Nerodia*, which are ecologically and taxonomically similar to giant gartersnakes, remained at the wetland and were either extirpated (Florida green watersnakes [*N. floridana*]) or had decreased fecundity and decreases in relative abundance (southern watersnakes [*N. fasciata*]; Willson and others, 2006). Whether giant gartersnakes will use one or a combination of these strategies or exhibit a novel response as water availability and habitat quality fluctuate in these managed agricultural areas is unknown.

The health of individual animals may provide insights into the status of a population that might not be apparent in ecological or behavioral measures. Detailed health examinations including blood work also may provide more information than individual size and measures of body condition based on the relations between mass and length. During a drought, decreased water availability could lead to dehydration and stress in giant gartersnakes, and impaired health could lead to lower survival, fecundity, and growth of individuals of this threatened species. Previous work on the health of free-ranging giant gartersnakes found some cause for concern. Wack and others (2012) collected 49 giant gartersnakes from four sites in the Central Valley: (1) the Natomas Basin and (2) Cosumnes River Preserve in Sacramento County, (3) Grasslands Ecological Area in Merced County, and (4) Mendota Wildlife Area in Fresno County, and measured various plasma biochemistry and hematological parameters to establish a baseline of the health of giant gartersnakes. Wack and others (2012) found that compared to non-threatened valley gartersnakes (*T. sirtalis fitchi*) at the same sites, giant gartersnakes had elevated white blood cell, heterophil, azurophil, and lymphocyte counts, and that these differences were clinically significant. The explanation for these discrepancies was not definitive. Differences between the two species could indicate the greater toll environmental stresses are having on giant gartersnakes compared to co-occurring valley gartersnakes. Wack and others (2012) suggested that the elevated white blood cell counts in giant gartersnakes could be a sign of chronic inflammation. However, the observed disparities could simply be differences in baseline levels of blood cell counts between the two species. Health assessments have the potential to complement studies of movement behavior and survival to more fully understand how the extent of rice cultivation affects individual giant gartersnakes. Specifically, studying hematological and blood chemistry parameters may reveal sub-lethal effects of a snake’s environment on its health.

Goals and Objectives

The primary goal of this study was to examine the relation between rice fallowing, water availability, and the ecology of giant gartersnakes. Specifically, we aimed to determine how the extent of rice agriculture in the Central Valley landscape affects the spatial ecology (home range area, movement frequency, and movement rate) of radio-tagged giant gartersnakes, as well as their selection of habitat components, health, and survival. Understanding how giant gartersnakes behaviorally respond to fluctuating water use in the rice agro-ecosystem is important for the development of water management plans that support the stability and persistence of giant gartersnake populations.

Giant Gartersnake Biology

Giant gartersnakes are precinctive to wetlands in the Central Valley of California. They were first described in the southern San Joaquin Valley by Fitch (1940) as a subspecies of aquatic gartersnakes (at that time, *Thamnophis ordinoides*). Further taxonomic revisions resulted in the consideration of giant gartersnakes as a subspecies of Sierra gartersnakes (*Thamnophis couchii*). Because giant gartersnakes are morphologically distinguishable from and do not occur at the same locations as their most closely related species, aquatic gartersnakes (*Thamnophis atratus*) and Sierra gartersnakes, they were recognized as a full species in 1987 (Rossman and Stewart, 1985).

Giant gartersnakes are highly aquatic and historically occurred in marshes, sloughs, and other habitats with slow-moving, relatively warm water and emergent vegetation, especially tules (*Schoenoplectus* [*Scirpus*] *acutus*). Although conversion of wetlands to agriculture has nearly extirpated giant gartersnakes from the San Joaquin Valley, this species persists in remnant marshes, sloughs, and rice agriculture in the Sacramento Valley (Halstead and others, 2010). Canals associated with rice agriculture can provide marsh-like habitat conditions throughout the active season of giant gartersnakes (late March–early October; Wylie and others, 2009), and rice fields are emergent wetlands for a part of the active season (Halstead and others, 2016).

Giant gartersnakes feed primarily on small fish, frogs, and tadpoles (Rossman and others, 1996; Ersan, 2015). Specific amphibian prey include tadpoles and small adults of American bullfrogs (*Lithobates catesbeianus*), and tadpoles and adults of Sierran treefrogs (*Pseudacris sierra*). Fish prey include but are not limited to mosquitofish (*Gambusia affinis),* and small cyprinid (Cyprinidae spp.) and centrarchid (Centrarchidae spp.) fishes. Giant gartersnakes innately prefer native Sierran treefrogs to introduced American bullfrogs and fishes (Ersan, 2015), and free-ranging giant gartersnakes selected Sierran treefrog metamorphs and American bullfrog adults more than introduced fishes (Ersan, 2015).

Giant gartersnakes are the longest species of gartersnake (Rossman and others, 1996). Like most natricine (Natricinae spp.) snakes, giant gartersnakes are sexually dimorphic in size, with females the larger sex (Wylie and others, 2010). Like most reptiles, small giant gartersnakes grow faster than large giant gartersnakes (Coates and others, 2009). Males and females exhibit differing seasonal growth patterns, with males forgoing foraging (and growth) for reproductive opportunities in the early spring (Coates and others, 2009). Similarly, male body condition is much lower than female body condition during the spring mating season, but males and females enter brumation in similar condition (Coates and others, 2009). Body condition might be related to the thermal ecology of giant gartersnakes. Female giant gartersnakes exhibit elevated body temperatures during June, July, and August (Wylie and others, 2009), which is the period when they are gravid. In contrast, males exhibit elevated body temperatures in the winter and early spring (Wylie and others, 2009), likely to prepare for the spring mating season. Elevated body temperature of males might be metabolically costly, causing decreased body condition for male snakes in spring.

Although some aspects of the demography of giant gartersnakes are difficult to determine, detailed study of populations in the Sacramento Valley has yielded some insight into their population ecology. Giant gartersnakes in the Sacramento Valley tend to produce smaller litters than those historically observed in the San Joaquin Valley. In the San Joaquin Valley, mean litter size was 23 (standard deviation=9.06; Hansen and Hansen, 1990). In the Sacramento Valley, mean litter size was 17 (95-percent confidence interval [CI]=13–21; Halstead and others, 2011). Mean parturition date was August 13, although parturition can occur from early July through early October (Halstead and others, 2011). Neonates in the Sacramento Valley are born with a snout-vent length (SVL) of about 209 mm, and a mass of about 4.9 g (Halstead and others, 2011). Litter size varies interannually and is potentially linked to resource availability, and large females produce more, rather than larger, offspring (Halstead and others, 2011).

Survival of adult female giant gartersnakes in the Sacramento Valley varies among sites and years. At an average site in an average year, annual survival probability of adult females implanted with radio transmitters (greater than 180 g) was 0.61 (95-percent CI=0.41–0.79; Halstead and others, 2012). Individuals are at 2.6 times (1.1–11.1) greater daily risk of mortality in aquatic habitats than in terrestrial habitats (Halstead and others, 2012), likely because most terrestrial locations occur when snakes are in refuges, such as under vegetation or in burrows. The effect of linear habitats (that is, canals or streams) on daily risk of mortality varied with context; in rice-growing agricultural systems, daily risk of mortality was less in canals than away from canals, but in systems with natural or restored marshes, risk of mortality was less in these two-dimensional habitats than in simple linear canals (Halstead and others, 2012). Overall survival was greatest in a site with a relatively large network of restored marshes (Halstead and others, 2012).

Other factors can affect the survival of giant gartersnakes. Based on capture-mark-recapture studies in the American Basin, female giant gartersnakes had higher apparent survival probability than males (Hansen and others, 2015). In contrast, apparent survival did not vary between the sexes in the Natomas Basin, but was positively related to size (Hansen and others, 2015). Weather patterns can affect giant gartersnake survival as well; in the American Basin, spring precipitation was negatively related to giant gartersnake apparent survival (Hansen and others, 2015).

Abundance, density, and body condition of giant gartersnakes vary by site, presumably relating to habitat differences among sites. Abundances and densities were greatest in a natural perennial wetland, less in a natural wetland modified to serve as a source and drain for agricultural irrigation, less still in rice agriculture, and least in seasonal marshes managed for waterfowl (moist soil management in summer, flooded in winter; Wylie and others, 2010). Body condition of females followed a similar pattern to abundance (Wylie and others, 2010).

Prior to modern settlement, the range of giant gartersnakes extended from Butte County in the north to Kern County in the south (Fitch, 1940; Hansen and Brode, 1980). The draining of wetlands and subsequent urban and agricultural development contributed to the loss of more than 90 percent of wetlands in the Central Valley (Frayer and others, 1989). The few remaining natural wetlands are fragmented and the natural cycle of seasonal valley flooding by High Sierra snowmelt has been limited as water presently is diverted by a network of dams and levees. As a result, giant gartersnake populations have become fragmented, with only small isolated populations remaining in the San Joaquin Valley. These factors precipitated the listing of giant gartersnakes by the State of California (California Department of Fish and Game Commission, 1971), and later by the U.S. Fish and Wildlife Service, as a threatened species with a recovery priority designation of 2C: full species, high degree of threat, and high recovery potential (U.S. Fish and Wildlife Service, 1993, 1999).

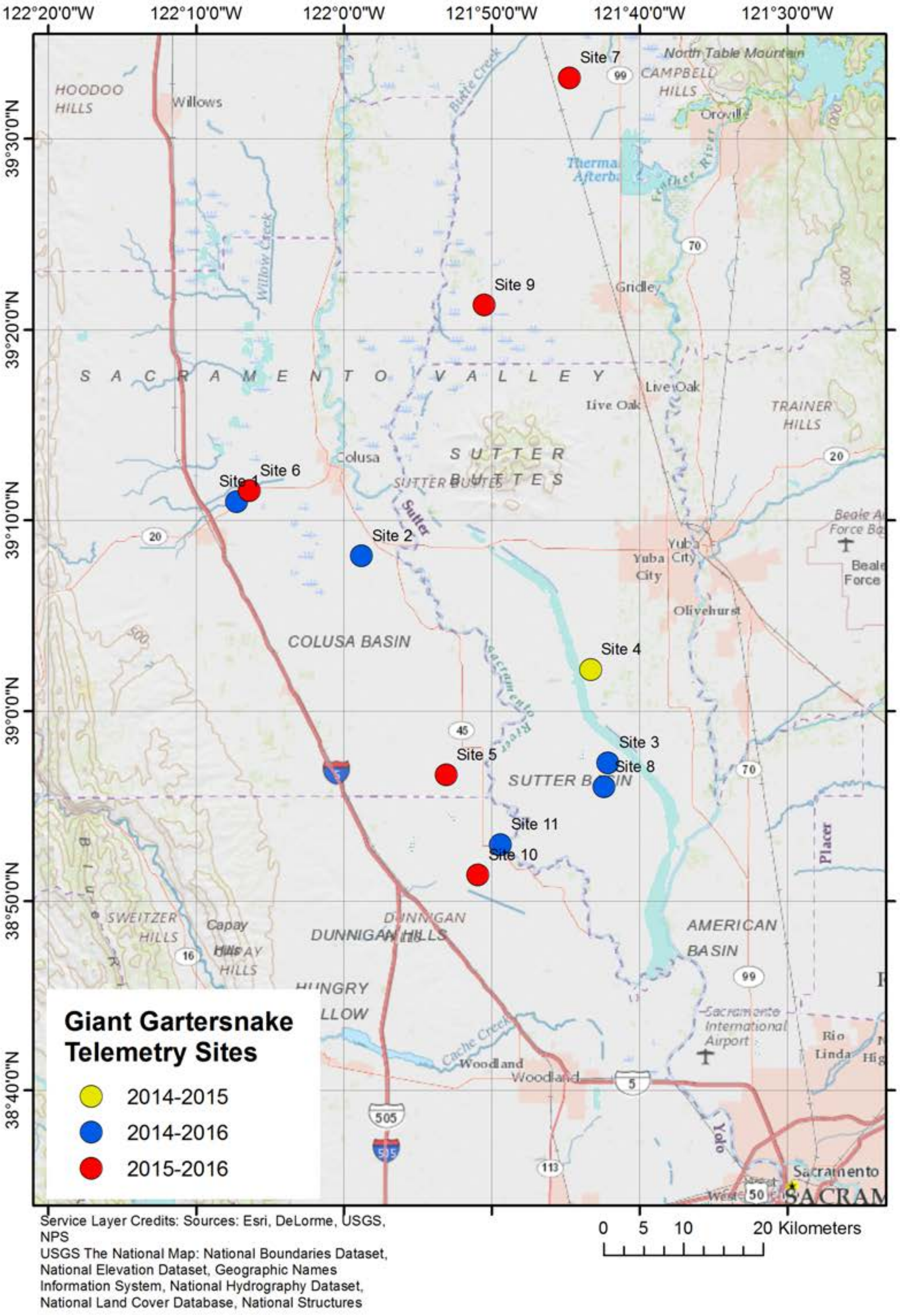
Description of Study Area

We conducted our study at 11 sites on private rice farms in the Sacramento Valley (fig. 1). Sites were located in the Colusa Basin (Colusa County, four sites; Yolo County, two sites), Butte Basin (Butte County, two sites) and Sutter Basin (Sutter County, three sites; table 1), and were selected to meet the following criteria:

1. Sites were selected to provide good spatial representation of the Sacramento Valley.
2. Sites were selected to be paired, such that sites near one another were selected to have different rice availability to the maximum extent allowable under conditions (3) and (4).
3. Only sites with known populations of giant gartersnakes were selected.
4. Only sites where we could obtain permission to trap and radio track snakes were selected.

Of these criteria, (3) and (4) were particularly restrictive and limited the differences in water availability between spatially paired sites as indicated by criterion (2). Therefore, water availability between site pairs was not always greater than differences in water availability among regions (table 2). Thus, the range of conditions under which we were able to study giant gartersnakes at these sites does not necessarily indicate the endpoints of the continuum of water availability. In particular, the effects of lower water availability than observed at our sites might have effects on giant gartersnakes that we were unable to measure in this study.

The Sacramento Valley has a Mediterranean climate, with hot, dry summers and mild, wet winters. Historically, winter rains and snowmelt from the Sierra Nevada to the east resulted in the overflow of river channels and vast expanses of emergent wetland habitat throughout much of the Central Valley (Singer and others, 2008). The damming of rivers, draining of wetlands, and subsequent urban and agricultural development have contributed to the loss of more than 90 percent of the wetlands in the Central Valley (Frayer and others, 1989). Our study primarily occurred in and around the canals used as a water supply and drain for surrounding agriculture. Agriculture around the canals was dominated by rice, although some of the sites were surrounded by fallowed rice fields (table 2). Rarely, other crops including tomato, alfalfa, and sunflowers were grown in adjacent fields.



Service Layer Credits: Sources: Esri, DeLorme, USGS, NPS
USGS The National Map: National Boundaries Dataset, National Elevation Dataset, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures

Figure 1. Location of giant gartersnake (*Thamnophis gigas*) radio telemetry sites in the Sacramento Valley, California, 2014–16.

Table 1. Sampling effort and number of giant gartersnakes (*Thamnophis gigas*) captured for assessment of the effects of water availability on giant gartersnake behavior, Sacramento Valley, California, 2014–16.

[Numbers in parenthesis indicate how many snakes had a mass of more than 200 g. An asterisk (*) indicates that the snake had a mass slightly less than 200g, but was used as a telemetry snake]

Site No.	Year	Traps	Trap-days	Sampled dates	Number of giant gartersnake:				
					Individuals	Captures	Males	Females	Telemetry
1	2014	100	1,898	May 15–June 5	41	75	18 (0)	23 (5)	5
	2015	100	3,821	Apr 22–July 10	22	39	17 (1)	7 (4)	7
2	2014	400	10,995	May 8–Aug 31	29	40	15 (2*)	13 (2)	4
	2015	100	100	Apr 23	4	4	2 (1)	2 (2)	5
3	2014	150	5,598	May 14–July 12	29	38	17 (0)	12 (6*)	6
	2015	100	4,020	Apr 29–May 6, June 4–Sept 1	22	33	8 (1)	14 (3)	6
4	2014	100	6,149	May 8–July 11	28	38	16 (0)	12 (4*)	4
5	2015	100	2,100	Aug 13–Sept 4	2	2	0 (0)	2 (2*)	2
6	2014	100	2,386	June 10–July 3	16	26	7 (0)	9 (0)	0
	2015	100	3,999	Apr 20–June 16	7	13	4 (0)	3 (1)	1
7	2015	100	2,800	May 5–June 21	22	37	8 (0)	14 (5)	5
8	2014	100	3,800	June 14–July 3	10	13	3 (0)	7 (5)	5
	2015	150	9,438	Apr 27–28 Aug 28	11	16	5 (0)	7 (5)	3
9	2015	100	6,900	May 30–Aug 31	32	77	17 (0)	15 (4)	4
10	2015	200	9,474	Apr 25–Aug 24	16	27	10 (0)	6 (5)	4
11	2014	100	1,995	May 20–June 10	31	40	15 (0)	16 (5*)	5
	2015	100	400	Apr 24–Apr 27	5	5	1 (0)	4 (3)	5

Table 2. Property sizes and crop types of giant gartersnake (*Thamnophis gigas*) capture locations, in the Sacramento Valley, California, 2014–16.

		2014			2015			2016		
Site	Total area (hectares)	Rice (hectares (%))	Other crops (hectares (%))	Fallow (hectares (%))	Rice (hectares (%))	Other crops (hectares (%))	Fallow (hectares (%))	Rice (hectares (%))	Other crops (hectares (%))	Fallow (hectares (%))
1	1183.8	946.2 (79.9)	8.9 (0.8)	196.5 (16.6)	1023.4 (86.4)	8.6 (0.7)	126.8 (10.7)	1139.9 (96.3)	1.5 (0.1)	13.4 (1.1)
2	2177.7	1405.5 (64.5)	504.1 (23.1)	134.5 (6.2)	1067.5 (49)	401.4 (18.4)	572.4 (26.3)	1478.4 (67.9)	446 (20.5)	123.7 (5.7)
3	1251.3	786.6 (62.9)	22.7 (1.8)	402.2 (32.1)	806 (64.4)	13.3 (1.1)	388.7 (31.1)	1167.1 (93.3)	3.1 (0.2)	34 (2.7)
4	178.4	108.8 (61)	0.5 (0.3)	66.8 (37.4)	120.4 (67.5)	2.2 (1.2)	52.7 (29.6)	172.7 (96.8)	0 (0)	3.8 (2.1)
5	346.2	149.6 (43.2)	0.5 (0.1)	196.3 (56.7)	87.9 (25.4)	60 (17.3)	200.1 (57.8)	248.9 (71.9)	68.1 (19.7)	29.3 (8.5)
6	96.0	0 (0)	0.1 (0.1)	94.1 (97.9)	0 (0)	0.1 (0.1)	94.1 (97.9)	92.4 (96.3)	0.1 (0.1)	1.3 (1.3)
7	452.2	266.9 (59)	5.2 (1.2)	180.3 (39.9)	385.3 (85.2)	7 (1.6)	60.4 (13.4)	357.8 (79.1)	0.5 (0.1)	94.4 (20.9)
8	191.4	185.8 (97.1)	0.9 (0.5)	3 (1.6)	184.1 (96.2)	3.2 (1.7)	4.5 (2.4)	115.8 (60.5)	55.2 (28.8)	17.6 (9.2)
9	364.5	342.2 (93.9)	3.7 (1)	11.2 (3.1)	224 (61.5)	4.8 (1.3)	127.5 (35)	343.2 (94.2)	0.2 (0)	12.8 (3.5)
10	3217.7	3077 (95.6)	21.9 (0.7)	91.7 (2.9)	2817.7 (87.6)	134.9 (4.2)	245.4 (7.6)	2782.2 (86.5)	170.4 (5.3)	234.8 (7.3)
11	1677.2	211 (12.6)	844 (50.3)	578.8 (34.5)	825.1 (49.2)	610 (36.4)	198.5 (11.8)	672.1 (40.1)	828.2 (49.4)	130.5 (7.8)

Methods

Capture Methods

We captured giant gartersnakes for radio telemetry by trapping with modified floating aquatic funnel traps (Casazza and others, 2000; Halstead and others, 2013) and opportunistically by hand. In 2014, we selected seven sites for trapping, and trapped each site between May 9 and August 31 (table 1). In 2015, we selected four additional sites and continued trapping at all sites selected in 2014 (except Site 4) between April 20 and September 9 (table 1). All traplines were adjacent to either actively growing or fallowed rice fields.

We trapped new sites until we obtained five individuals large enough for radio telemetry, and trapped existing sites until we had captured a target of five individuals large enough for telemetry, to account for snake mortality or signal loss. We measured, individually marked (by passive integrated transponder [PIT] tag, unique brand [Winne and others, 2006], or both), and determined the sex of each captured individual. We released all individuals less than (<) 200 g mass at their location of capture immediately after processing, and we retained individuals greater than or equal to (≥) 200 g in cloth sacks in climate-controlled chambers and transported them to the U.S. Geological Survey (USGS) Dixon Field Station for radio transmitter implantation.

Telemetry Methods

We attempted to locate all individuals surgically implanted with radio transmitters daily following their release, although difficulty obtaining radio fixes on snakes sometimes resulted in skipped days. We used R-1000 telemetry receivers (Communication Specialists, Inc., Orange, California; http://www.com-spec.com/) and handheld three-element yagi antennas (Wildlife Materials, Inc., Carbondale, Illinois; http://wildlifematerials.com/) to detect transmitter signals and locate snakes. Upon locating a snake or identifying a small (usually <2 m^2) area from which the signal was strongest, we collected information on the individual's location and behavior, as well as environmental variables. In particular, we recorded the individual's location to <5 m accuracy in Universal Transverse Mercator North American Datum of 1927 (UTM NAD27) coordinates with a handheld global positioning system (GPS; Model eTrex 10, Garmin Ltd., http://www.garmin.com/).

In addition to location, we recorded the individual's position relative to the surface of the ground or water, whether it had moved more than 1 m since the last time it had been located, distance to water, body position, temperature, and behavior. We recorded environmental conditions (air, soil, and water temperatures; percentage of cloud cover; wind speed), percentage of cover of habitats (open water, floating vegetation, submerged vegetation, emergent vegetation, terrestrial vegetation, litter, rock, and bare ground), percentage of cover of plant species or higher taxonomic category, and vegetation heights of each vegetation type, within a circle of 1 m diameter centered on the individual snake.

For analysis of resource selection, we also recorded the same environmental and habitat data at a location at a random uniform (minimum = 1, maximum = 360) azimuth and random uniform (minimum = 2, maximum = 50) meter distance from the individual snake's location. During brumation (October–March), we decreased the frequency of monitoring to once or twice per week. In addition to data from individual snake locations and random points, we assessed the status of nearby fields to determine whether they were cultivated rice fields, fallow fields, or other agricultural crops. These data were used to ground-truth data on rice field status based on remote sensing data.

Analysis

Spatial Distribution and Extent of Rice and Wetlands

To quantify cultivated rice on the landscape, we modified a methodology to detect early rice field flooding and late rice season drawdown from Landsat 8 imagery at a 30-m resolution (Zhong and others, 2016). We used the relation between the Normalized Difference Moisture Index (NDMI) and Enhanced Vegetation Index (EVI) to detect rapid increases in moisture content in agricultural fields in the Sacramento Valley. NDMI and EVI rasters are spectral indices derived from Landsat 8 Surface Reflectance obtained on a 16-day return period. NDMI and EVI images were ordered for Landsat Path 44, Row 33 (USGS Earth Observation and Science Center), which encompasses the entire study area. The analysis was limited to non-tree crop agricultural land use areas, because tree crops are not rapidly converted to other crop types, as identified by the 2015 Crop Data Layer (CDL; U.S. Department of Agriculture National Agricultural Statistical Service). We developed a set of logical statements to determine changes in NDMI from scene to scene during the rice planting season, where increases in NDMI greater than (>)0.02/d (i.e., >0.32 between scenes) indicate rapid increase in moisture. Because the derived NDMI raster is on a scale of -10,000 to 10,000 rather than -1 to 1, the absolute change in NDMI between sequential scenes to indicate flooding was an increase of 3,200. Additionally, raster cells also had to meet the requirement that NDMI>EVI to indicate a lack of emergent vegetation during flooding (Zhong and others, 2016).

Once a pixel was classified as flooded rice during the planting season, it remained rice until drawdown of water in fields began. To calibrate decreases in NDMI that indicate water drawdown, we used data provided by several farmers about the drawdown and harvest dates of their fields. Average NDMI field values for our ground-truthed fields indicate peak values between 5,000 and 6,000. A significant decrease in NDMI values occurs in the following two images around the time that water delivery to the rice fields ends and de-watering begins. Using this as a guide, we identified drawdown as any cells where NDMI values decreased to less than 5,000 in two consecutive scenes, allowing for the possibility of a field to be in the process of de-watering but not yet completely drained (a process that takes at least 10 days and can occur between Landsat scene dates). All calculations were conducted in ModelBuilder, in ArcGIS 10.2.2 (Environmental Systems Research Institute. Redlands, CA).

Accuracy was determined by comparing rice classification in the 2015 CDL layer to the maximum extent of rice classified by our methodology. We generated 10,000 random points and extracted classification from our tool (rice compared to not rice) to the 2015 CDL classification, and generated a confusion matrix from the R package “Caret” (Kuhn, 2016), to determine sensitivity (the ability of this method to correctly identify sample pixels as rice fields), specificity (the ability of this method to correctly not identify non-rice sample pixels), and accuracy (the sensitivity and specificity of the method, divided by the true numbers of rice and non-rice pixels in our test sample) of our classification method. Our rice classification tool classified rice with 96.3-percent (95-percent CI=95.9–96.7-percent) accuracy, with a sensitivity of 85.7 percent and specificity of 97.5 percent.

Home Range and Movement

Analyses of home range, rice availability, and movement were limited to the giant gartersnake active season from April 1 through October 31. Extent of rice and other aquatic features was extracted from 100-m and 500-m buffers around each snake telemetry point and random point. Area of other aquatic features were defined by the National Hydrography Dataset (NHD; U.S. Geological Survey, 2016) at 3-m resolution as large ditches, canals, ponds, lakes, marshes, and wetlands. Extent of flooded rice also was determined within the minimum convex polygon (MCP) and a 500-m buffer around the MCP for each snake.

Giant gartersnake home ranges were calculated using two methods. MCPs comprising the smallest polygon that encloses all the outer telemetry locations were calculated using the MCP function in the “adehabitatHR” package (Calenge, 2006). We also used Adaptive local convex hulls (*a*-LoCoH) home ranges to determine 50-percent core use and 95-percent home range sizes for all snakes for which we had adequate sample sizes. *a*-LoCoH home ranges more accurately depict an animal’s space use than MCPs and can indicate geographic barriers better than parametric methods of home range estimation, such as the commonly used kernel density estimator. The *a*-LoCoH method creates a variable radius around points that adjusts to the spread of telemetry locations, which better identifies more frequently used areas while adapting to greater spread of relocations in the 95-percent home range (Getz and others, 2007; Lyons and others, 2013). A custom function was used to calculate area-observation curves to determine the area of asymptote (the number of telemetry locations needed for an individual where additional points no longer increase the size of the home range) for 15 snakes in 2015, indicating that 40 locations were needed for MCP area to asymptote (Haines and others, 2009). We therefore limited the construction of *a*-LoCoH home ranges to snakes that had at least 40 active season locations for a given year. Individual *a*-LoCoH home ranges were calculated for each snake by first selecting a range of k values (k = 5–20), where each hull is constructed by selecting the k-1 nearest neighbors for each point. Hulls and isopleths were constructed for these values, and plots of k to area, and k to edge-area ratio were examined. A k value was selected to avoid spurious jumps in the area of 95-percent isopleths, and minimize patchiness (edge-area ratio) in the 50-percent core area. Once a suitable k value was selected, a maximum a value was selected, and hulls, isopleths and a to area, and a to edge-area plots were constructed for a sequence of 20 a values and examined to select an optimal a value for the individual. To evaluate how extent of rice habitat on the landscape affects home range size, we tested the relationship between available rice within 500 m of each snake’s MCP and the 50 and 95-percent *a*-LoCoH home range sizes of each snake using a mixed effects generalized linear model with individual as a random effect. Home range areas were log-transformed prior to analysis. Core and home range areas were displayed with extent of cultivated rice as defined by the 2014–2016 CDL (appendix A, figs A1–A51).

One way animals may respond to less habitat is to cluster activities in more concentrated areas, which would lead to higher home range overlap between individuals. To examine the proportion of overlap of giant gartersnake home ranges in relation to flooded rice habitat, we used mixed effects hurdle models. For the response variable, we calculated proportion of overlap of the 50 and 95-percent isopleths for all pairs of snakes within each site per year for which we had sufficient points to calculate an *a*-LoCoH home range, using the R package “rgeos” (Bivand and others, 2017). We calculated the weighted mean (weighted by the size of each snake homerange) of the proportion of rice within the 500-m buffer of the MCP of each pair of snakes as the independent variable, with site and year as random effects. Hurdle models consist of two components: (1) a binomial model to calculate the probability of determining whether or not a certain condition is met (in this case, whether two giant gartersnake home ranges or core areas overlap), and (2) a second model to determine the degree of overlap, given the first hurdle is crossed. We used a binomial generalized additive model to calculate the probability of two snakes overlapping, and a generalized additive model with beta distribution to calculate the amount of overlap. Analyses were conducted in the R package “gamlss” (Rigby and others, 2005).

To calculate the core and home range fidelity of giant gartersnakes from year to year, we used mixed effects hurdle models. We again calculated percent overlap of the 50 and 95-percent *a*-LoCoH isopleths for all snakes for which we calculated home ranges for multiple years. We used hurdle models, consisting of a binomial generalized additive model to calculate the probability of a snake overlapping its home range or core area in subsequent years, and a generalized additive model with beta distribution to calculate the amount of overlap (Rigby and others, 2005).

To examine how snake movements may be related to habitat conditions, we evaluated the relation between flooded rice availability and the frequency and rate of giant gartersnake daily movements over the active season using mixed effects logistic regression. We calculated movement distances between locations using the R package “adehabitat” (Calenge, 2006), and then determined which intervals included movements >3 m and movements >100 m. We chose 3 m as a movement threshold for probability of movement because smaller movements could be caused by GPS error or minor changes in position of unobserved individuals, rather than true changes in location. For larger movements, we chose 100 m from an individual’s previous location. We included year, individual, and site, as nested random effects allowing for varying intercepts, and proportion of flooded rice within the 100-m buffer of a snake’s position and a third order polynomial of Julian date (numbered day of the year, beginning on January 1) as continuous covariates, and constructed separate models for male and female snakes. Movement rate was calculated as the distance between subsequent locations, divided by the amount of time between telemetry locations. The effect of rice and date on log-transformed movement rates was examined using a mixed effects generalized linear model, with proportion of rice within 100 m of a snake’s position and a third order polynomial of Julian date as fixed effects, and year, individual, and site, as nested random effects allowing for varying intercepts. Separate analyses were conducted for male and female giant gartersnakes. We report estimates of regression coefficients and 95-percent confidence intervals (1.96 × Standard Error), with significance denoted for parameters for which confidence intervals do not overlap 0. For plots of fitted estimates of parameters, we held other variables constant at the mean value.

Habitat Selection

Information about how giant gartersnakes select or avoid habitats, vegetation types, or structural attributes of habitat is essential to manage water and habitats to benefit giant gartersnakes. For example, positively selected habitat and vegetation types can be targeted for preservation on the landscape, and those that are avoided could be improved through restoration. Perhaps more important in a working agricultural landscape, actions with the potential to harm snakes, such as dewatering, disking, mowing, and others, can be limited in areas that have attributes consistent with selection by giant gartersnakes to avoid or minimize the potential negative effects of these actions on giant gartersnake populations.

To assess the habitat relations of adult giant gartersnakes in rice agriculture, we used a Bayesian analysis of hierarchical case-control logistic regression models, with giant gartersnake locations (“used”) as the cases and random points (“available”) as controls (Halstead and others, 2016). Our model was hierarchical in that it included site and individual-level random effects for model coefficients that place the individual as the sample unit, from which observations are considered subsamples, and allowed for the selection of habitat attributes to vary among individuals (Gillies and others, 2006). Because use and availability were matched in space and time, we did not explicitly account for year in our analysis. Instead, we assumed that year and season effects were captured in the availability of habitats. The structure of the model, therefore, was:

$$logit(p_i) = \sum_{k=1}^{k=K}\left(\beta_{l,k} \times x_{i,l}\right) \tag{1}$$

$$y_i \sim Bernoulli(p_i)$$

where y_i is a vector of ones for each observation pair i,
p_i is the probability of use relative to availability,
$\beta_{l,k}$ is a matrix of variable l and individual k specific coefficients, and
$x_{i,l}$ is a matrix of the differences between used and available habitats or vegetation types for each observation pair i and each variable l.

The coefficient for snake k within site j was distributed as $\beta_{l,k} \sim \text{normal}(\mu_{l,j}, \sigma_{l,j})$, with the site mean coefficients in turn distributed as $\mu_{l,j} \sim \text{Normal}(\mu_l, \sigma_l)$. This parameterization of the hierarchical case-control logistic regression model, which uses differences between measurements of used and available points for each variable as predictor variables, does not contain an intercept, which is fixed by the study design to be zero (matched pairs of cases and controls means that the probability of a case is 0.5, which is zero on the logit-scale). The coefficients in this model represent the log-odds of use with a unit (in the present case, 10 percent) increase in the difference between the habitat variable at the snake location and the habitat variable at the paired random location.

We fit three separate case-control models to the data—one to estimate the selection of microhabitats, another to estimate the selection of specific vegetation types, and a third to estimate the selection of vegetation height categories, all within the 1 m diameter circular quadrat centered on the snake or random point. We chose to model these different aspects of habitat separately to limit the number of predictor variables in a given model. We chose to model microhabitats and vegetation types that were most common, had the greatest variation, or addressed important management questions. These variables were presumed to be most predictive of relative probability of use and to inform habitat management for conserving giant gartersnakes. For the microhabitat model, we included percentage of cover of open water, emergent aquatic vegetation, terrestrial vegetation, litter (debris or dead vegetation that is no longer standing), and bare ground. For the vegetation model, we included percentage of cover of tule, cattail, water-primrose, smartweed, rice, watergrass, single-stemmed grasses, and forbs. We evaluated selection of vegetation of different heights (categories were 0, 1–15 cm, 15–50 cm, 50–100 cm, and >1 m), regardless of species composition. Data input into the model were scaled to units of 10-percent difference so that parameter estimates were on a scale that could be related to observable differences in the field. Coefficients in each of the models were transformed to selection (odds) ratios as $e^{coefficient}$. Combined with the data transformation to units of 10 percent, selection ratios represent the change in odds of a location being selected with a 10 percent increase in the percent cover of that habitat or vegetation type or vegetation height category. Variables whose 95-percent credible interval for the selection ratio did not overlap one were considered avoided (selection ratio < 1) or selected (selection ratio > 1). We selected priors to be uninformative, with normal(0, 1.648) priors on model coefficients and half-Cauchy(1) priors on standard deviations (Gelman, 2006).

Bayesian analysis of models used Markov chain Monte Carlo (MCMC) sampling carried out in JAGS (Plummer, 2003). Model burn-in, sampling iterations, and thinning rates were selected to ensure that convergence was achieved, and effective sample sizes were >5,000 for all monitored parameters. Posterior inference was based on five chains of 100,000 iterations each, after a burn-in period of 10,000 iterations. We thinned the MCMC output by a factor of five; thus, posterior inference was based on 100,000 samples from the stationary posterior distribution. We fit each model with JAGS version 4.2.0 (Plummer, 2003) called from R version 3.2.1 (R Core Team, 2016) using the package “jagsUI” (Kellner, 2016). We diagnosed convergence with visual examination of history plots and with the Gelman-Rubin statistic (Gelman and Rubin, 1992); no evidence for lack of convergence was observed ($\hat{R}<1.01$ for all monitored parameters).

Veterinary Methods

After 1–5 days in captivity, we transported individuals to the Sacramento Zoo for surgery by an experienced veterinarian (Dr. Ray Wack, DVM), who surgically implanted Holohil SI-2T radio transmitters (9 g; Holohil Systems Ltd., Carp, Ontario, Canada; http://www.holohil.com/) into the body cavity of the snakes using standard methods (Reinert and Cundall, 1982). At the time of surgery, the veterinarian drew 1.0 mL of blood (< 0.5 of snake body mass) from the ventral tail vein for hematocrit and plasma biochemistry. Blood was not collected in the field because it is difficult to safely draw blood from conscious giant gartersnakes (Dr. Ray Wack, DVM, personal observation).Veterinary staff at the Sacramento Zoo observed individuals and conducted a complete health assessment for each individual until full recovery from anesthesia.

After recovery from anesthesia, post-surgical snakes were returned to the Dixon Field Station to recover for 1–2 weeks, during which time they were administered analgesics and antibiotics as prescribed by a veterinarian. We released individuals at their location of capture after they completed their course of prescribed analgesics and antibiotics and ate normally. We did not locate released individuals for 1 week post-release to allow them to heal and acclimate to their natural environment.

We measured a suite of blood parameters to characterize the health of radio-tracked snakes. These parameters can be divided into two categories: (1) hematology, and (2) plasma biochemistry. Hematological parameters include red blood cell count, pack cell volume (percentage of total blood volume made up of red blood cells), hemoglobin (grams per deciliter), plasma protein (grams per deciliter), and white blood cell count. We further separated white blood cell count by seven different types of cells—heterophils, band cells, lymphocytes, monocytes, eosinophils, basophils, and azurophils. We determined pack cell volume by centrifuging microhematocrit tubes for 10 minutes and measuring the proportion of the sample comprising red blood cells. We measured plasma protein using a handheld refractometer (JorVet model J351, Jorgensen Laboratories Inc., Loveland, Colorado). We measured hemoglobin content using a modified azidemethemoglobulin reaction following Wack and others (2012). We manually counted red blood cells and white blood cells within 3 hours of blood collection using the unipette method and a hemocytometer (Campbell and Ellis, 2007). To measure the proportion of white blood cell types, we stained a blood smear and counted at least 100 white blood cells under 1,000× magnification.

Plasma biochemistry parameters include aspartate aminotransferase (AST) (International Units per liter [IU/L]), bile acids (micromoles per liter), creatinine kinase (IU/L), uric acid (milligrams per deciliter [mg/dL]), glucose (mg/dL), calcium (mg/dL), phosphorus (mg/dL), total protein (grams per deciliter [g/dL), albumin (g/dL), globulin (g/dL), potassium (millimoles per deciliter [mmol/dL]), and sodium (mmol/dL). We compared hematological and plasma biochemistry parameters to baseline values from 46 “apparently healthy” giant gartersnakes examined in 2008 by Wack and others (2012).

We measured plasma biochemistry parameters by first centrifuging a heparinized blood microtainer tube for 10 minutes. We then measured these parameters using a VetScan analyzer (Abaxis North America, Union City, California) with an avian/reptile specific rotor (Avian/Reptilian Profile Plus). We analyzed plasma biochemistry within 30 minutes of blood sample collection.

Health Assessment

To test how season, individual characteristics, time spent in captivity, and the surrounding environment influenced snake health, we constructed hierarchical regression models for each hematological and plasma biochemistry parameter (table 3). We included a random effect of individual, because some individuals received two or three health assessments in different years. We also included a random effect of site to account for the non-independence of individuals collected from the same site. To evaluate how a snake's size and sex might affect blood parameters, we tested for the effects of snake sex, size (snout-vent length, SVL), and an interaction between sex and size on all response variables. We also tested for an effect of season on blood parameters by including linear and quadratic effects of Julian date on each blood parameter. We tested for an effect of the time spent in captivity on all blood parameters by including the number of days a snake was held in captivity before its health examination as a covariate. Finally, to measure the relation between extent of rice cultivation and snake health, we included the proportion of rice within a 500-m buffer of an individual's home range (minimum convex polygon, MCP). We analyzed models in JAGS version 4.2.0 (Plummer, 2003) and R version 3.3.1 (R Core Team, 2016) using the "jagsUI" package (Kellner, 2016). We ran models on three independent chains for 110,000 iterations each, with the first 10,000 iterations discarded as burn-in. We assessed convergence visually with history plots and with the $\hat{R}$ statistic (Gelman and others, 2004); we saw no evidence of lack of convergence (maximum $\hat{R}$ <1.01). We evaluated the strength of the relation between potential explanatory variables and blood parameters by measuring if the 95-percent credible interval of the variable coefficient overlapped zero. If the credible interval overlapped zero, then that variable was not considered to be related to a blood parameter, whereas if the credible interval did not overlap zero, we concluded that there was a significant relation between the variable and the blood parameter. Unless otherwise noted, we report posterior medians and symmetrical 95-percent credible intervals.

Table 3. Description of hematology and plasma biochemistry model parameters and their priors.

Symbol	Description	Prior distribution
Y	Response variable	Deterministic node
α_0	Average value	normal(0,100)
σ_{ind}	Individual standard deviation	half-Cauchy(1)
σ_{site}	Site standard deviation	half-Cauchy(1)
β_{sex}	Effect of being male on response	normal(0,100)
β_{size}	Effect of snout-vent length on response	normal(0,100)
$\beta_{sex\ x\ size}$	Effect of sex (male) by size interaction on response	normal(0,100)
β_{date}	Linear effect of Julian date on response	normal(0,100)
$\beta_{date}{}^2$	Quadratic effect of Julian date on response	normal(0,100)
β_{rice}	Effect of proportion rice within a 500-meter buffer of minimum convex polygon home range on response	normal(0,100)
β_{cap}	Effect of the number of days spent in captivity before examination on response	normal(0,100)

Survival

We modeled survival based on snake mortality times using survival analysis (Williams and others, 2001; Ibrahim and others, 2005). Survival, or time-to-event, analysis is widely used in engineering, human health studies (e.g., clinical trials of treatment efficacy), and wildlife telemetry studies. In these models, survival is treated as a continuous process observed at discrete intervals, and coefficients (β) represent log hazard ratios, or the log of the multiplicative change in weekly risk of mortality with a unit increase in the predictor variable. These models also accommodate staggered entry (entry of individuals during the course of the study), interval censoring (individuals being unobserved for a time within the study, later to be observed either alive or dead), and right truncation or censoring (individuals intentionally [e.g., transmitter removal] or accidentally [e.g., lost signal]) removed from the study before they die. Because we wanted to account for seasonal differences in the baseline risk of mortality, but also wanted to evaluate predictor variables that varied seasonally (e.g., proportion rice within 100 m of snake locations in a one week period), we used two different formulations of survival models. For both models, we used weekly time steps and set the beginning of the study to June 25, 2014, when the first individuals were released with radio transmitters. We also formulated both models as shared frailty models that allowed snakes from the same sites to have similar risks of mortality based on their shared characteristics (e.g., exposure to unmeasured variables such as contaminants, closer relatedness within sites than between sites, etc.; Halstead and others, 2012). Priors for all parameters of both models were selected to be uninformative (table 4).

Table 4. Description of survival model parameters and their priors.

Model	Symbol	Description	Prior distribution
Piecewise constant hazard	S_{ijkl}	Survival function	Deterministic node
	CH_{ijkl}	Cumulative hazard (risk of mortality)	Deterministic node
	UH_{ijkl}	Weekly hazard (risk of mortality)	Deterministic node
	γ_l	Piecewise baseline (constant) log hazard, for $l = 1$ (rice growing season), $l = 2$ (brumation), and $l = 3$ (active season prior to flood-up)	uniform(-8,-5)
	η_k	Random site effect	normal(0,σ_{site})
	σ_{site}	Site standard deviation	half-Cauchy(1)
	β_{sex}	Ln(hazard ratio) for males (relative to females)	t(0,1,1)
	β_{size}	Ln(hazard ratio) for snout-vent length	t(0,1,1)
	β_{r500}	Ln(hazard ratio) for proportion rice within a 500 m buffer of minimum convex polygon home range	t(0,1,1)
Constant hazard	S_{ijk}	Survival function	Deterministic node
	CH_{ijk}	Cumulative hazard (risk of mortality)	Deterministic node
	UH_{ijk}	Daily hazard (risk of mortality)	Deterministic node
	γ_0	Baseline (constant) log hazard	uniform(-8,-5)
	η_k	Random site effect	normal(0,σ_{site})
	σ_{site}	Site standard deviation	half-Cauchy(1)
	β_{rice}	Ln(hazard ratio) for mean proportion rice within 100 m of individual’s locations in a week	t(0,1,1)
	β_{c_rice}	Ln(hazard ratio) for cumulative mean weekly proportion rice within 100 m of individual’s locations	t(0,1,1)
	β_{w_dist}	Ln(hazard ratio) for mean weekly distance from water	t(0,1,1)

The first model we analyzed was a piecewise constant hazard model that allowed different weekly risks of mortality in each of three seasons—(1) emergence from brumation (the reptile equivalent of hibernation) until flood up of canals and rice fields (April–May); the remainder of the rice growing season and giant gartersnake active season, when rice fields are flooded and have a cover-providing canopy of rice plants (June–September); and brumation, when snakes are inactive underground (October–March). Within each of these seasons, giant gartersnakes were assumed to have a constant weekly risk of mortality. To this piecewise constant baseline hazard, we added individual giant gartersnake covariates that might affect survival, including sex, SVL at the beginning of the tracking period, and the annual proportion of rice within 500 m of each individual's minimum convex polygon home range. Because only large adult snakes can be monitored with radio telemetry, we expected little growth during the tracking period for each snake, and assumed that SVL at the beginning of the tracking period was a reasonable estimate of size for individual snakes. Because many snakes were tracked over multiple rice growing seasons, we calculated the annual proportion of rice within 500 m of each snake's MCP. The annual cycle for this covariate began with the beginning of the active season in one year, and ended at the end of the emergence and pre-flood-up period the following year. This allowed the effects of the amount of rice in the snake's home range to carryover through brumation and emergence until rice was once again available as habitat. Continuous covariates (SVL and proportion rice) were centered and standardized to mean = 0, SD = 1 prior to analysis. The survival function for this model was $S_{ijkl} = e^{-CH_{ijkl}}$, where $CH_{ijkl} = \sum_{j=1}^{T} UH_{1:j,ikl}$, and $UH_{ijkl} = \exp\begin{pmatrix} \gamma_l + \beta_{sex} \times sex_i + \beta_{size} \times SVL_i + \\ \beta_{r500} \times rice\_500_{im} + \eta_k \end{pmatrix}$, where $\eta_k \sim$ normal(0, σ_{site}) represents shared frailty as a random site effect on the baseline hazard. Subscripts *i*, *j*, *k*, *l*, and *m* reference individual snake, week, site, season, and year, respectively, and *T* is the maximum number of weeks a population was monitored.

The second model we evaluated was a constant hazard model, for which the probability of mortality was the same for every week of the study, but for which we allowed temporal variation in the hazard using individual covariates that changed weekly. The covariates we examined for this model were the weekly mean proportion of rice within 100 m of the individual snake's locations, the cumulative (running) mean weekly proportion of rice within 100 m of the individual snake's locations, and the mean weekly distance from water. The weekly mean proportion of rice was used to estimate acute effects of the amount of rice near the snake on the weekly risk of mortality, and the cumulative weekly mean proportion of rice was used to estimate cumulative effects of the amount of rice near the snake on the risk of mortality. For the cumulative mean proportion of rice, we repeated the last calculated value during the rice growing season through brumation until flood up the following year, rather than using values of zero rice and allowing the cumulative mean proportion of rice to decrease while snakes were inactive. Because mean proportion rice and cumulative proportion rice were correlated ($\rho = 0.56$, $P < 0.001$), we selected the most informative covariate on risk of mortality by several methods. First, we fit a full model that used an indicator variable "switch" to turn off one of the rice covariates when the other was on. We then further examined models using both rice covariates and each rice covariate to examine the effects on inference from the model. The survival function under the full model with both rice covariates included was estimated as $S_{ijk} = e^{-CH_{ijk}}$, where $CH_{ijk} = \sum_{j=1}^{T} UH_{1:j,ik}$ and $UH_{ijk} = \exp\begin{pmatrix} \gamma_0 + \beta_{rice} \times rice_{ij} + \beta_{c\_rice} \times c\_rice_{ij} + \\ \beta_{w\_dist} \times w\_dist_{ij} + \eta_k \end{pmatrix}$, where, as before, $\eta_k \sim \text{normal}(0, \sigma_{site})$ represents shared frailty as a random site effect on the baseline hazard. Subscripts are the same as for the first model, and definitions of parameters and their prior specifications are listed in table 4.

For both survival models, we visually examined goodness-of-fit by comparing survival curves generated by the continuous time proportional hazards models described above with a non-parametric Kaplan-Meier survival curve. Briefly, Kaplan-Meier curves are generated as the proportion of events (deaths) observed within an interval relative to the number of possible events that could have occurred in that interval (number of radio-tracked snakes at the beginning of the interval). The step-wise nature of these curves offers a useful tool to evaluate the fit of parametric survival models.

Both survival models were run on 5 chains of 20,000 iterations each, after a burn-in period of 10,000 iterations by calling JAGS 4.2.0 (Plummer, 2003) from R 3.3.1 (R Development Core Team, 2016), using the package jagsUI (Kellner, 2016). We assessed convergence visually with history plots and with the $\hat{R}$ statistic (Gelman and others, 2004); no evidence of lack of convergence existed (maximum $\hat{R}$<1.01). Unless otherwise indicated, we report the posterior median and 95-percent symmetrical credible interval.

Results

From 2014 through 2016, we implanted 59 snakes from 11 sites with radio transmitters (table 5). We obtained a total of 8,228 telemetry relocations, and 7,039 active season (April 1–October 31) telemetry relocations. The amount of cultivated rice, other crops, and fallowed fields, available within the habitats occupied by giant gartersnakes varied by site and by year (table 6).

Table 5. Summary of observation dates, sample sizes, fate and cause of death (if known), and movement statistics for radio-tracked giant gartersnakes (*Thamnophis gigas*), Sacramento Valley, California, 2014–16.

[Home ranges were not calculated for individuals with fewer than 40 active season (April 1–October 31) locations. Small variation in annual and overall home range areas for individuals tracked in only 1 year was caused by random jittering of observations that occurred at the same location. For cause of snake deaths, carcasses with evidence of predation or scavenging were grouped as unknown. **Abbreviations:** *a*-LoCoH, adaptive Local Convex Hull; NA, Not applicable]

Site No.	ID	Year	Dates monitored	Number of locations	Fate (cause)	Median movement distance (meters)	Median movement rate (meters per day)	Area within isopleth of the a-LoCoH home range (hectares)	
								50-percent isopleth	95-percent isopleth
1	3099	2014	June 25–Dec 29	87	Alive	13.15	7.97	0.30	1.35
1	3099	2015	Jan 5–Dec 29	190	Alive	5.10	5.00	0.14	0.53
1	3099	2016	Jan 8–July 3	20	Released	175.18	40.00	NA	NA
1	3120	2015	July 16–Dec 29	96	Alive	18.44	17.26	1.38	1.75
1	3120	2016	Jan 8–Apr 24	71	Mortality (Unknown)	24.59	19.11	0.11	0.27
1	3143	2014	June 25–July 2	2	Mortality (Unknown)	NA	NA	NA	NA
1	3158	2014	June 25–Dec 29	87	Alive	7.92	6.04	0.14	0.66
1	3158	2015	Jan 5–Jan 27	4	Mortality (Unknown)	NA	NA	NA	NA
1	3162	2014	July 9–Dec 29	74	Alive	13.04	7.28	0.43	0.87
1	3162	2015	Jan 5–Dec 29	194	Alive	4.36	4.12	0.61	3.46
1	3162	2016	Jan 8–Apr 24	20	Released	7.81	7.81	NA	NA
1	3167	2014	June 25–Dec 1	82	Alive	14.42	13.04	2.80	13.27
1	3167	2015	Feb 10–June 10	44	Mortality (Unknown)	2.83	2.83	NA	NA
1	3301	2015	June 10–Dec 29	132	Alive	17.69	17.49	0.44	1.92
1	3301	2016	Jan 8–May 27	42	Released	25.18	15.50	NA	NA
1	3367	2015	July 23–Dec 29	91	Alive	17.03	15.93	0.24	2.34
1	3367	2016	Jan 8–June 17	59	Released	9.52	8.80	0.32	0.46
2	3220	2014	July 23–Mar 19	67	Alive	42.95	26.02	0.19	1.79
2	3220	2015	Jan 5–Aug 21	113	Lost Signal	26.51	25.59	0.66	5.73
2	3221	2014	July 23–Mar 16	66	Alive	24.61	18.37	0.96	5.20
2	3221	2015	Jan 5–Dec 29	178	Alive	44.65	35.06	3.42	28.91
2	3221	2016	Jan 8–June 23	62	Released	18.03	9.01	0.29	1.81

Site No.	ID	Year	Dates monitored	Number of locations	Fate (cause)	Median movement distance (meters)	Median movement rate (meters per day)	Area within isopleth of the a-LoCoH home range (hectares)	
								50-percent isopleth	95-percent isopleth
2	3250	2014	Sept 11–Oct 22	14	Mortality (Unknown)	2.83	2.24	NA	NA
2	3254	2015	May 13–Dec 29	154	Alive	7.04	7.04	1.38	7.78
2	3254	2016	Jan 8–Apr 19	17	Released	19.10	7.11	NA	NA
2	3255	2015	May 13–Dec 29	153	Alive	20.11	19.53	0.28	1.09
2	3255	2016	Jan 8–Apr 14	15	Released	207.21	43.49	NA	NA
2	4216	2014	Sept 2–Mar 19	39	Alive	5.00	2.55	NA	NA
2	4216	2015	Jan 5–Dec 29	181	Alive	20.46	18.61	1.92	6.91
2	4216	2016	Jan 8–Mar 25	11	Mortality (Unknown)	NA	NA	NA	NA
3	3079	2014	July 9–Dec 29	80	Alive	27.54	17.99	0.06	0.24
3	3079	2015	Jan 5–Dec 30	186	Alive	11.05	9.22	1.71	5.15
3	3079	2016	Jan 8–May 2	22	Released	159.11	107.02	NA	NA
3	3082	2014	July 7–Dec 29	79	Alive	7.62	7.62	0.32	0.53
3	3082	2015	Jan 5–July 9	71	Mortality (Irrigation pump)	10.22	5.44	0.12	0.43
3	3103	2014	July 14–Dec 29	76	Alive	18.84	15.22	0.30	0.55
3	3103	2015	Jan 5–Apr 13	20	Mortality (Unknown)	16.60	6.42	NA	NA
3	3134	2014	July 23–Dec 9	42	Mortality (Irrigation pump)	23.54	23.54	NA	NA
3	3137	2014	July 9–Dec 29	80	Alive	13.30	12.68	0.12	0.85
3	3137	2015	Jan 5–Apr 26	25	Mortality (Unknown)	5.83	1.94	NA	NA
3	3237	2014	Aug 7–Dec 29	56	Alive	79.61	47.01	0.89	1.60
3	3237	2015	Jan 5–July 7	156	Mortality (Unknown)	6.40	6.32	0.30	0.65
3	3289	2015	May 21–Dec 30	151	Alive	5.05	5.00	0.34	0.46
3	3289	2016	Jan 8–Apr 15	15	Released	88.81	34.10	NA	NA
4	3160	2014	June 30–Mar 19	92	Alive	27.00	20.51	1.10	2.02
4	3160	2015	Jan 5–May 11	36	Released	53.94	51.04	NA	NA
4	3224	2014	July 23–Dec 29	65	Alive	23.09	20.10	0.22	1.24
4	3224	2015	Jan 5–Jan 27	4	Mortality (Unknown)	NA	NA	NA	NA
4	3225	2014	July 23–Mar 19	73	Alive	99.02	68.61	1.69	8.71
4	3225	2015	Jan 5–May 8	34	Mortality (Unknown)	6.27	5.25	NA	NA

Site No.	ID	Year	Dates monitored	Number of locations	Fate (cause)	Median movement distance (meters)	Median movement rate (meters per day)	Area within isopleth of the a-LoCoH home range (hectares)	
								50-percent isopleth	95-percent isopleth
4	3238	2014	Aug 7–Oct 28	42	Mortality (Unknown)	60.51	31.99	1.00	4.64
5	3373	2015	Sept 2–Dec 29	51	Alive	11.70	5.83	0.09	0.23
5	3373	2016	Jan 8–July 29	73	Mortality (Unknown)	4.00	3.61	0.48	39.40
5	3376	2015	Sept 2–Dec 29	51	Alive	5.54	4.74	NA	NA
5	3376	2016	Jan 8–Aug 2	78	Released	69.01	44.02	0.14	1.01
6	3263	2015	May 21–Dec 29	152	Alive	15.07	14.02	0.41	3.54
6	3263	2016	Jan 8–Jan 26	3	Mortality (Unknown)	NA	NA	NA	NA
7	2177	2015	May 27–Dec 29	138	Alive	22.67	16.64	0.34	4.03
7	2177	2016	Jan 8–May 16	26	Mortality (Trap mortality)	46.34	19.10	NA	NA
7	3300	2015	June 10–Dec 29	128	Alive	12.86	11.71	1.07	1.89
7	3300	2016	Jan 8–May 10	22	Released	50.23	13.22	NA	NA
7	3326	2015	June 17–Dec 29	120	Alive	6.40	5.00	0.09	0.49
7	3326	2016	Jan 8–May 23	28	Released	16.35	4.01	NA	NA
7	3350	2015	July 10–Dec 29	101	Alive	38.01	34.06	0.35	2.14
7	3350	2016	Jan 8–Apr 16	14	Mortality (Unknown)	4.12	1.37	NA	NA
7	11321	2015	June 17–Dec 29	121	Alive	17.19	10.85	1.34	5.88
7	11321	2016	Jan 8–May 11	23	Mortality (Roadkill)	93.01	46.50	NA	NA
8	3202	2014	July 14–Dec 9	72	Alive	98.63	86.87	0.40	0.61
8	3202	2015	Jan 5–Dec 30	119	Alive	49.25	38.83	1.57	6.13
8	3202	2016	Jan 8–Jul 20	71	Released	25.00	15.53	0.36	2.54
8	3215	2014	July 14–Dec 9	70	Alive	16.03	12.37	0.14	0.35
8	3215	2015	Jan 5	1	Lost Signal	NA	NA	NA	NA
8	3235	2014	July 24–Dec 1	63	Mortality (Unknown)	9.00	8.98	0.10	0.26
8	3239	2014	Aug 7–Dec 29	53	Alive	22.85	15.52	0.41	1.06
8	3239	2015	Jan 5–Feb 17	7	Lost Signal	NA	NA	NA	NA
8	3243	2014	Aug 15–Dec 9	44	Alive	17.03	16.03	NA	NA
8	3243	2015	Jan 5	1	Lost Signal	NA	NA	NA	NA
8	3295	2015	June 3–July 1	23	Mortality (Unknown)	4.00	4.00	NA	NA

Site No.	ID	Year	Dates monitored	Number of locations	Fate (cause)	Median movement distance (meters)	Median movement rate (meters per day)	Area within isopleth of the a-LoCoH home range (hectares)	
								50-percent isopleth	95-percent isopleth
8	3336	2015	June 24–Dec 30	117	Alive	37.24	31.89	0.33	3.01
8	3336	2016	Jan 8–June 16	53	Released	51.52	31.58	0.40	0.92
8	3374	2015	Sept 2–Dec 30	51	Alive	19.88	13.72	0.95	1.65
8	3374	2016	Jan 8–Sept 4	116	Released	68.73	48.30	0.51	3.02
8	3379	2015	Sept 8–Dec 30	46	Alive	11.70	10.00	NA	NA
8	3379	2016	Jan 8–Sept 6	113	Released	59.51	45.18	1.02	7.88
9	3311	2015	June 10–Dec 29	129	Alive	9.74	8.57	0.77	3.98
9	3311	2016	Jan 8–June 15	27	Mortality (Unknown)	4.30	1.54	NA	NA
9	3322	2015	July 23–Dec 29	87	Alive	14.12	12.39	0.87	1.99
9	3322	2016	Jan 8–May 8	24	Released	40.20	20.10	NA	NA
9	3343	2015	July 1–Dec 29	109	Alive	16.95	13.60	0.21	0.45
9	3343	2016	Jan 8–June 15	27	Mortality (Unknown)	48.63	22.45	NA	NA
9	3354	2015	July 16–Dec 29	95	Alive	4.00	4.00	0.14	0.87
9	3354	2016	Jan 8–Apr 27	18	Mortality (Unknown)	3.12	2.12	NA	NA
10	3303	2015	June 10–Dec 30	132	Alive	5.10	5.10	0.33	4.36
10	3303	2016	Jan 8–May 26	39	Released	8.04	7.81	NA	NA
10	3320	2015	June 17–Dec 30	127	Alive	44.01	38.90	0.66	5.73
10	3320	2016	Jan 8–June 23	60	Released	29.02	24.08	0.19	1.79
10	3328	2015	June 24–Dec 30	120	Alive	6.89	6.25	0.74	2.23
10	3328	2016	Jan 8–Apr 14	15	Released	544.71	111.27	NA	NA
10	3363	2015	July 16–Dec 30	98	Alive	15.55	14.40	2.19	4.64
10	3363	2016	Jan 8–Apr 19	17	Mortality (Unknown)	5.05	2.95	NA	NA
10	3378	2015	Sept 8–Dec 30	46	Alive	3.00	2.83	NA	NA
10	3378	2016	Jan 8–Aug 25	110	Released	23.09	15.51	0.39	1.48
11	3131	2014	June 25–Dec 29	86	Alive	10.20	7.07	0.26	1.13
11	3131	2015	Jan 5–Dec 30	181	Alive	9.85	8.54	0.38	0.89
11	3131	2016	Jan 8–Apr 14	14	Released	138.88	17.36	NA	NA
11	3146	2014	July 9–Dec 29	75	Alive	83.55	42.70	0.68	4.76

Site No.	ID	Year	Dates monitored	Number of locations	Fate (cause)	Median movement distance (meters)	Median movement rate (meters per day)	Area within isopleth of the a-LoCoH home range (hectares)	
								50-percent isopleth	95-percent isopleth
11	3146	2015	Jan 5–July 19	88	Mortality (Unknown)	24.19	21.03	0.87	2.89
11	3153	2014	June 25–Oct 23	72	Mortality (Unknown)	42.01	34.56	1.14	4.92
11	3179	2014	June 25–July 10	8	Mortality (Unknown)	186.81	104.26	NA	NA
11	3188	2014	July 9–Sept 19	38	Lost Signal	12.33	9.88	NA	NA
11	3258	2015	May 13–Dec 30	157	Alive	36.40	34.13	1.68	7.26
11	3258	2016	Jan 8–Apr 6	13	Released	NA	NA	NA	NA
11	3259	2015	May 21–Aug 20	84	Mortality (Unknown)	18.63	17.86	0.22	0.97
11	3264	2015	May 21–Dec 30	152	Alive	18.57	14.93	0.45	13.51
11	3264	2016	Jan 8–Apr 15	15	Released	36.89	7.24	NA	NA

Table 6. Summary of crop land cover types within the minimum convex polygon (MCP) for all giant gartersnakes (*Thamnophis gigas*) at each telemetry site in the Sacramento Valley, California, 2014–16.

[Crop types were determined from 30-m resolution Crop Data Layers for 2014–16 (CDL; U.S. Department of Agriculture National Agricultural Statistical Service)]

			Land cover area (hectares)			Percentage of land cover type		
Site	Year	MCP area	Rice	Fallowed	Other crops	Rice	Fallowed	Other crops
1	2014	403.4	200.6	194.0	1.4	49.7	48.1	0.4
	2015	329.3	250.9	66.3	2.5	76.2	20.1	0.8
	2016	99.8	94.4	0.8	0.1	94.6	0.8	0.1
2	2014	671.2	586.7	58.4	13.2	87.4	8.7	2.0
	2015	936.9	696.9	188.5	31.2	74.4	20.1	3.3
	2016	682.6	637.2	36.2	0.5	93.3	5.3	0.1
3	2014	315.8	159.4	135.4	3.4	50.5	42.9	1.1
	2015	218.5	187.5	11.3	1.9	85.8	5.2	0.9
	2016	61.7	58.2	1.4	0.1	94.4	2.2	0.1
4	2014	156.1	85.1	63.8	0.8	54.5	40.9	0.5
	2015	84.6	53.2	22.4	2.3	62.9	26.5	2.7
5	2015	38.4	0.0	38.3	0.0	0.0	99.6	0.0
	2016	217.6	214.3	3.5	0.4	98.5	1.6	0.2
6	2015	59.8	46.3	6.6	0.3	77.4	11.0	0.5
7	2015	155.5	115.7	35.6	2.9	74.4	22.9	1.9
	2016	26.6	22.8	2.9	0.0	85.6	10.8	0.0
8	2014	313.4	144.3	124.9	23.2	46.0	39.9	7.4
	2015	111.9	98.4	3.2	8.6	87.9	2.8	7.6
	2016	277.3	226.2	22.8	20.5	81.6	8.2	7.4
9	2015	37.7	3.1	32.0	0.4	8.1	84.6	1.0
	2016	36.5	34.0	1.0	0.0	93.2	2.7	0.0
10	2015	157.7	153.4	1.6	0.7	97.3	1.0	0.5
	2016	198.1	195.2	0.4	0.0	98.6	0.2	0.0
11	2014	156.3	7.9	135.2	7.0	5.1	86.5	4.5
	2015	414.7	304.7	67.1	20.3	73.5	16.2	4.9
	2016	27.7	16.8	9.4	0.8	60.8	33.8	2.9

Home Range and Movement

The probability of moving >3m for males was not related to the area of rice within 100 m of their locations, but was related to the second-order polynomial of Julian date, with male gartersnakes moving more frequently in July (probability=0.91, 95-percent CI=0.85–96), as compared to earlier and later in the active season (table 7; fig. 2a and 2b). The frequency of movements for females was related to the amount of rice within 100 m of their locations, with females more likely to make movements as proportion of rice within 100 m increased from 0 percent rice (probability=0.79, 95-percent CI=0.75–0.83) to 100 percent (probability=0.89, 95-percent CI=0.85–0.91). Frequency of female movements also was affected by a third-order polynomial effect of Julian date, with females more likely to move early in the season after emergence from brumation (probability=0.91, 95-percent CI=0.87–0.95), and during August and September after parturition (probability=0.83, 95-percent CI=0.79–0.86; table 7 and fig. 2c, 2d).

Table 7. Regression coefficient estimates of giant gartersnakes (*Thamnophis gigas*) moving more than 3 meters, based on proportion of rice within 100 meters of the snake's location, and a third order polynomial of Julian date.

[Bold parameters denote statistically significant variables]

Sex	Parameter	Estimate	Standard Error
Male	Intercept	2.088	0.451
	Rice	-0.418	0.631
	Julian Date	**-0.891**	**0.241**
	Julian Date^2	**-0.402**	**0.137**
	Julian Date^3	0.075	0.088
Female	Intercept	1.338	0.133
	Rice	**0.756**	**0.192**
	Julian Date	**0.254**	**0.084**
	Julian Date^2	**-0.207**	**0.039**
	Julian Date^3	**0.198**	**0.031**

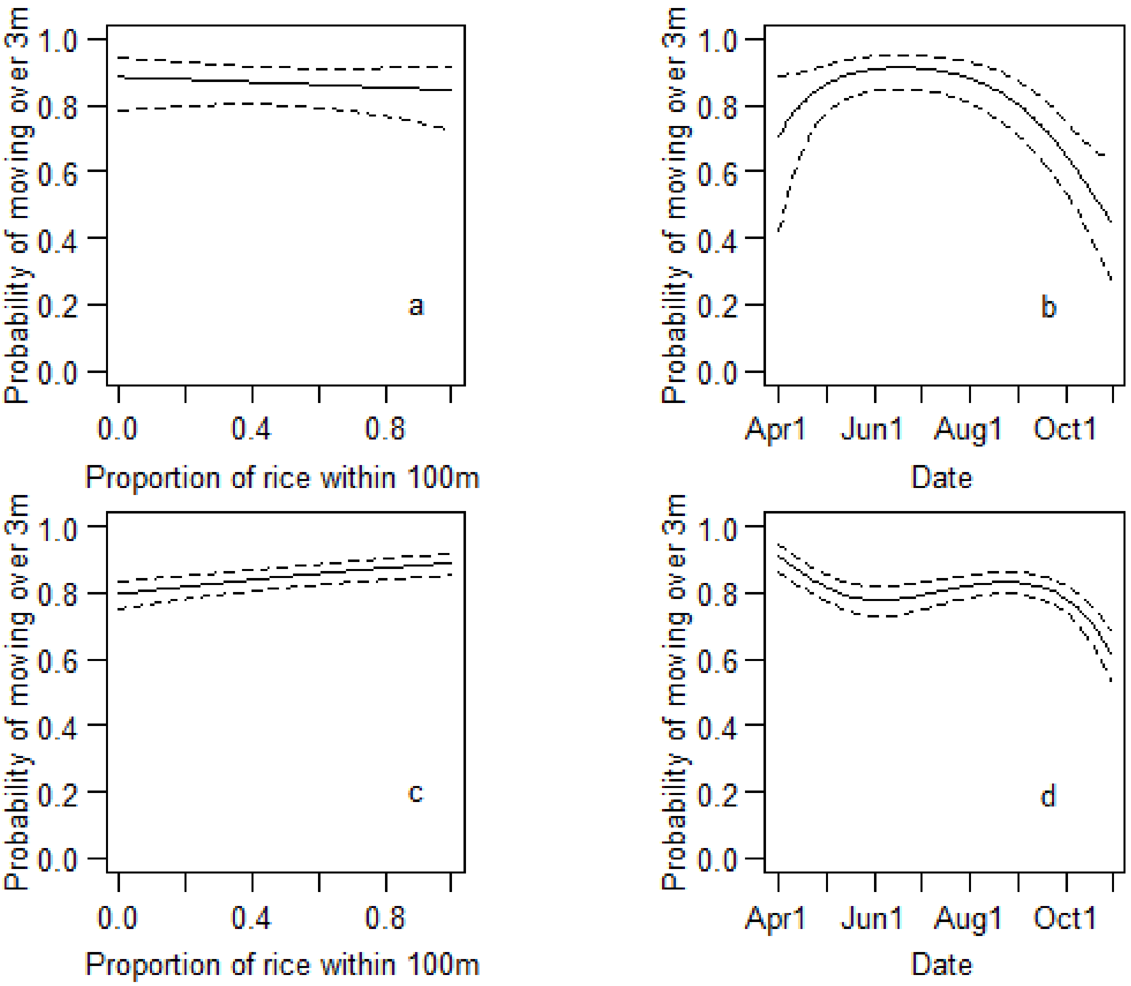


Figure 2. Probabilities of giant gartersnakes (*Thamnophis gigas*) moving more than 3 meters from their location based on proportion of rice within 100 meters and Julian date. Males (n=4): a, b. Females (n=54): c, d. Solid line represents mean model prediction, and dashed lines represent 95-percent confidence intervals.

The probability of movements of more than 100 m for male giant gartersnakes was not affected by the amount of rice within 100 m of their location or Julian date, with male gartersnakes having a 0.19 probability of moving over 100 m (95-percent CI=0.12–0.29; table 8 and fig. 3a, 3b). The frequency of movements over 100 m for females was affected by the amount of rice within 100 m of their location, with females more likely to make large movements as the proportion of rice within 100 m increased from 0 percent rice (probability=0.19, CI=0.16–0.22) to 100 percent rice (probability=0.37, 95-percent CI=0.31–0.44). Frequency of female movements also was affected by a third-order polynomial effect of Julian date, with females most likely to move over 100 m early in the active season after emergence from brumation (probability= 0.42, 95-percent CI=0.32–0.52), and after parturition (probability= 0.23, CI=0.20–0.26) in mid-August (table 8, fig. 3c, 3d).

Table 8. Probability of giant gartersnakes (*Thamnophis gigas*) moving more than 100 meters, based on proportion of rice within 100 meters of the snake's location, and a third order polynomial of Julian date.

[Bold parameters indicate statistically significant effects]

Sex	Parameter	Estimate	Standard Error
Male	Intercept	-1.396	0.350
	Rice	-0.124	0.498
	Julian Date	-0.048	0.191
	Julian Date^2	-0.027	0.147
	Julian Date^3	-0.098	0.083
Female	Intercept	-1.475	0.111
	Rice	**0.954**	**0.182**
	Julian Date	**0.161**	**0.084**
	Julian Date^2	**-0.129**	**0.047**
	Julian Date^3	**-0.153**	**0.032**

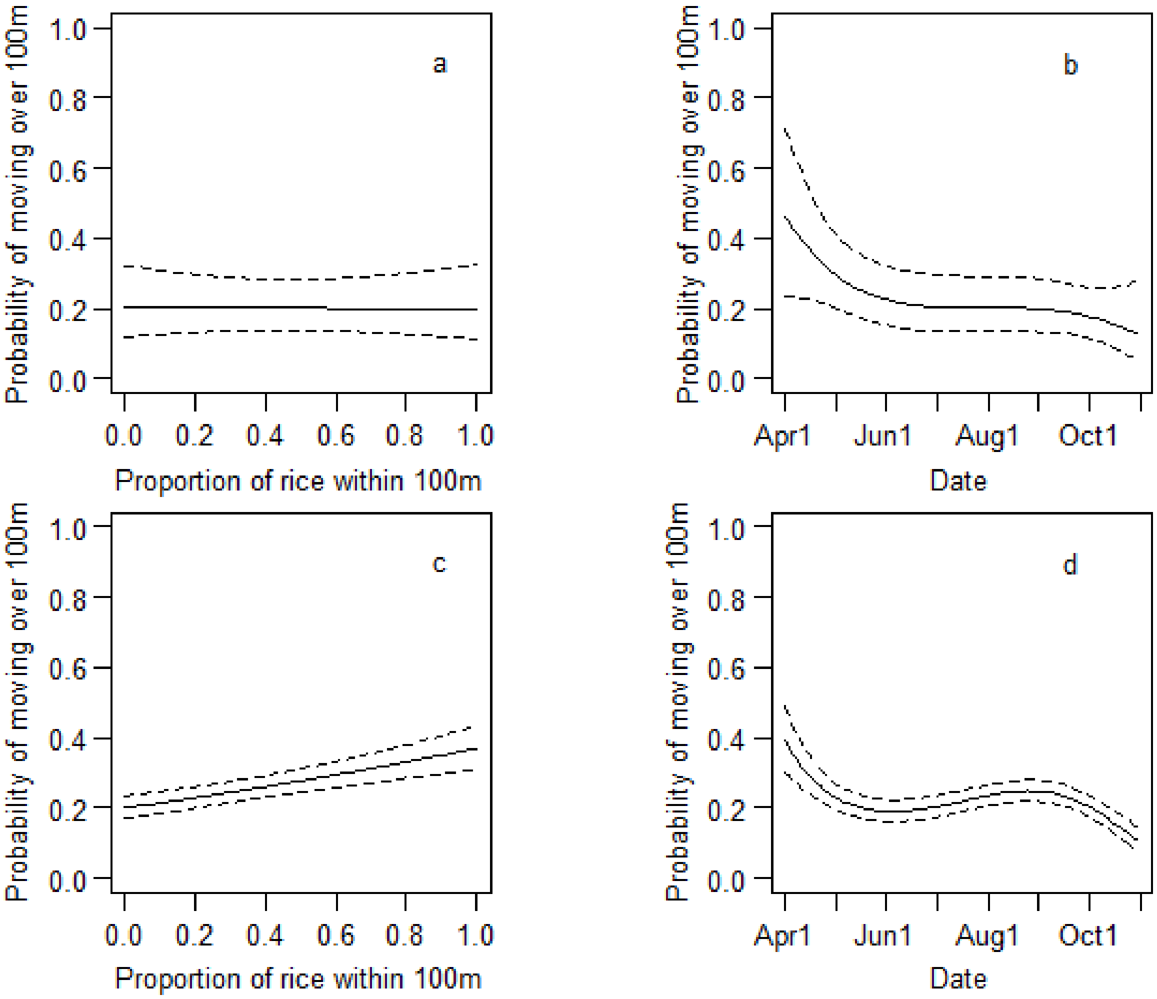


Figure 3. Probabilities of giant gartersnakes (*Thamnophis gigas*) moving more than 100 meters from their location based on proportion of rice within 100 meters and Julian date. Males (n=4): a, b. Females (n=54): c, d. Solid line represents mean model prediction, and dashed lines represent 95-percent confidence intervals.

The average movement rate of males was not related to area of rice within 100 m of their location, with an average rate of movement of 24.32 m/d (95-percent CI=16.87–34.89 m/d; table 9 and fig. 4a). Average movement rates of males did vary by a second-order polynomial effect of Julian date, with male movement rates increasing and peaking in June (movement rate=33.74 m/d, 95-percent CI=22.89–49.49 m/d), and gradually decreasing towards the end of October (movement rate=3.59 m/d, 95-percent CI=1.51–7.39 m/d; fig. 4b). Average movement rates of females were related to area of rice within 100 m of their location, with an average rate of movement of 27.09 m/d (95-percent CI=23.34–31.41 m/d). Predicted average movement rates decreased to 19.09 m/d (95-percent CI=16.06–22.66 m/d) when there was no flooded rice within 100 m, and increased to 38.81 m/d (95-percent CI=31.36–47.97 m/d) when there was 100 percent rice within 100 m (table 9; fig. 4c, 4d). Movement rates varied with a third-order polynomial effect of Julian date, with female movements being high in early April (movement rate=21.28 m/d, 95-percent CI=15.55–28.98 m/d), decreasing, and then peaking again in August (movement rate=23.13 m/d, 95-percent CI=19.94–26.79; table 9 and fig. 4c, 4d), before decreasing to the end of October.

Table 9. Regression coefficient estimates for average movement rates (log meters per day) of giant gartersnakes (*Thamnophis gigas*), based on proportion of rice within 100 meters of the snake's location, and a third order polynomial of Julian date.

[Bold parameters denote statistically significant variables]

Sex	Parameter	Estimate	Standard Error
Male	Intercept	3.383	0.242
	Rice	-0.308	0.343
	Julian Date	**-0.589**	**0.128**
	Julian Date^2	**-0.323**	**0.090**
	Julian Date^3	0.015	0.053
Female	Intercept	3.000	0.083
	Rice	**0.684**	**0.121**
	Julian Date	**0.147**	**0.055**
	Julian Date^2	**-0.387**	**0.027**
	Julian Date^3	**-0.185**	**0.020**

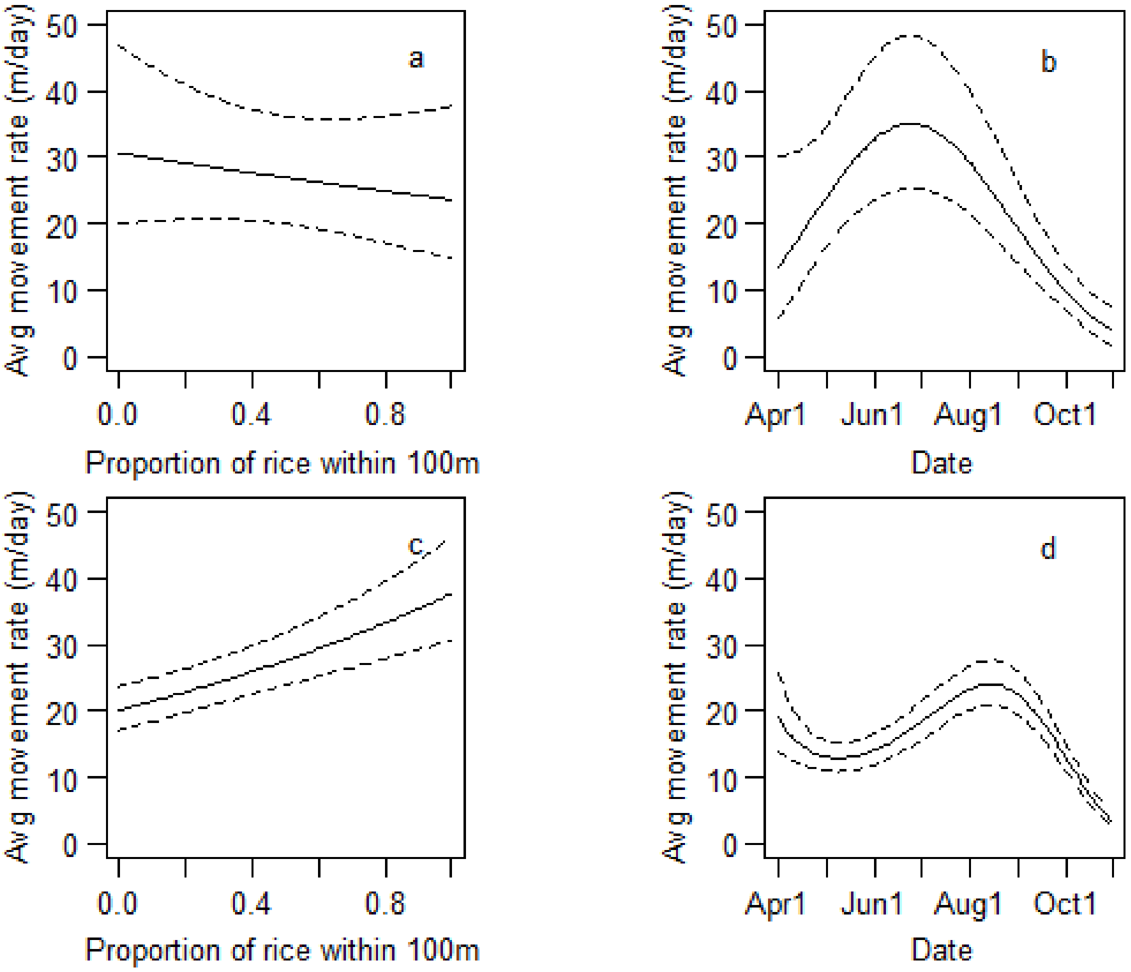


Figure 4. Average movement rates (meters per day [m/d]) of giant gartersnakes (*Thamnophis gigas*) based on proportion of rice within 100 meters and Julian date. Males (n=4): a, b. Females (n=54): c, d. Solid line represents mean model prediction, and dashed lines represent 95-percent confidence intervals

We constructed 70 *a*-LoCoH active season home ranges for the 50 giant gartersnakes that had >40 telemetry points during a given active season (table 5). Active season core use areas varied more among sites than individuals, and core use areas were largely confined to aquatic habitat features adjacent to fields, regardless of whether rice was grown or not (appendix A, figs. A1–A51). Mean 50-percent isopleth core sizes were 0.65 ha (range=0.06–3.42 ha, table 5). Mean 95-percent home range sizes were 3.70 ha (range=0.23–39.40 ha, table 5). The area of 50-percent isopleth core area was not related to the proportion of rice within 500 m of a giant gartersnake's MCP home range (table 10). Similarly, the area of 95-percent isopleth home range area also was not related to the proportion of rice within 500 m of a giant gartersnake's home ranges (table 10).

We compared core and home range overlap among 101 pairs of giant gartersnakes. Core areas had low probability of overlapping, with 17.8 percent of snake-pairs within each site overlapping in the 50-percent isopleth, with a mean overlap of 1.9 percent (range=0–33 percent). Home range overlap was more common, with 43.6 percent of snake-pairs within each site overlapping in the 95-percent isopleth, and a mean proportion of overlap at 2.9 percent (range=0–21 percent). Weighted mean proportion of rice within the 500-m buffer of snake home ranges was unrelated to extent of overlap in either the 50 percent or 95-percent isopleths (table 11).

Table 10. Parameter estimates for core and home range areas of giant gartersnakes (*Thamnophis gigas*) in relation to rice habitat within 500-meter buffer, Sacramento Valley, California, 2014–16.

[For all models, the response variable (core area or home range area) was transformed by taking the natural logarithm prior to analysis]

Model	Parameter	Estimate	Standard Error
Core (log 50% Isopleth)	Intercept	-0.69	0.364
	Rice	-0.239	0.5438
Home Range (log 95% Isopleth)	Intercept	0.708	0.462
	Rice	-0.055	0.678

Table 11. Parameter estimates for 50-percent core and 95-percent home range overlap in response to weighted mean extent of rice within 500-meter buffer between pairs of giant gartersnakes (*Thamnophis gigas*), Sacramento Valley, California, 2014–16.

[Models were constructed with two-stage hurdle models, where probability refers to whether overlap occurred, and proportion refers to amount of overlap]

Model	Parameter	Estimate	Standard Error
Core (50% Isopleth) Overlap Probability	Intercept	-2.252	1.102
	Rice	0.023	1.642
Core (50% Isopleth) Overlap Proportion	Intercept	-2.603	0.483
	Rice	0.638	0.68
Home range (95% Isopleth) Overlap Probability	Intercept	-0.587	0.754
	Rice	0.517	1.144
Home range (95% Isopleth) Overlap Proportion	Intercept	-3.362	0.49
	Rice	1.03	0.697

We compared core and home range fidelity among 16 giant gartersnakes for which we calculated home ranges over multiple years (14 giant gartersnakes across 2 years, 2 across 3 years). Core areas overlapped in subsequent years for 61 percent of the giant gartersnakes, with a mean proportion of overlap of 7.0 percent (range=0–28 percent). Home range areas overlapped in subsequent years for 94.4 percent of the giant gartersnakes, with a mean proportion of overlap of 9.4 percent (range=0–21 percent). Weighted mean proportion of rice within the 500-meter buffer of snake home ranges was unrelated to extent of overlap in either the 50-percent or 95-percent isopleths (table 12).

Table 12. Parameter estimates for 50-percent core and 95-percent home range overlap of individual giant gartersnakes (*Thamnophis gigas*) tracked in subsequent years, in response to weighted mean extent of rice within 500-meter buffer of home ranges, Sacramento Valley, California, 2014–16.

[Models were constructed with two-stage hurdle models, where probability refers to whether overlap occurred, and proportion refers to amount of overlap]

Model	Parameter	Estimate	Standard Error
Core (50% Isopleth) Overlap Probability	Intercept	1.75	2.351
	Rice	-1.827	3.208
Core (50% Isopleth) Overlap Proportion	Intercept	-2.339	0.509
	Rice	0.328	0.705
Home range (95% Isopleth) Overlap Probability	Intercept	0.381	6.07
	Rice	5.448	9.792
Home range (95% Isopleth) Overlap Proportion	Intercept	-2.732	0.608
	Rice	0.642	0.818

Habitat Selection

Habitats used by and available to giant gartersnakes varied among sites, particularly with regard to open water, emergent and terrestrial vegetation, litter, and bare ground (table 13). Giant gartersnakes selected microhabitats associated with cover (table 13; fig. 5). Terrestrial vegetation was the only microhabitat positively selected throughout the Sacramento Valley, and bare ground was the only habitat avoided at the same scale (fig. 5), although litter was positively selected and open water was avoided at some sites (table 12). Across the Sacramento Valley, snakes were 1.17 (95-percent credible interval=1.09–1.27) times more likely to select areas with a 10 percent increase in terrestrial vegetation, and 0.76 (0.69–0.83) times as likely to select areas with a 10 percent increase in bare ground (table 14). Selection varied most among sites with regard to selection of litter, and least with regard to the neutral response to open water (table 15).

Giant gartersnakes selected most vegetation types, but avoided cultivated rice (table 16; fig. 6). Tules were the most strongly selected vegetation type (Sacramento Valley odds ratio=1.71 [95-percent credible interval=1.22–2.55]), but differences among positively selected vegetation types were not statistically significant (fig. 6). Snakes were 0.70 (95-percent credible interval=0.53–0.84) times as likely to use a location with a 10 percent increase in the percentage of cover of cultivated rice (table 16; fig 6). Variation among sites was highest in selection of cultivated rice, and least in selection of forbs (table 17).

Giant gartersnakes generally selected taller vegetation (table 18; fig. 7). At the scale of the Sacramento Valley, giant gartersnakes were 0.78 (95-percent credible interval=0.74 – 0.82) times as likely to use a location with vegetation cover <1 cm in height, but 1.09 (95-percent credible interval=1.02–1.16) times more likely to use locations with vegetation height >100 cm (table 18; fig. 7). Selection varied most among sites with regard to avoidance of vegetation 1–15 cm in height, and least with regard to avoidance of vegetation <1 cm in height (table 19).

Table 13. Percentage of cover of microhabitats, vegetation types, and vegetation heights used by giant gartersnakes (*Thamnophis gigas*) and at random points within 50 meters of giant gartersnake locations, overall and by study site, Sacramento Valley, California, 2014–16.

[Values in the table are mean values (with standard deviation in parentheses). Note that the Sacramento Valley (overall) means and standard deviations were calculated across sites.<, less than; >, greater than]

Group	Variable	Site	Used	Random
Microhabitat	Open water	Sacramento Valley (overall)	7.16 (2.61)	12.71 (6.61)
		Site 1	6.57 (18.68)	11.13 (28.39)
		Site 2	7.96 (22.15)	20.44 (38.41)
		Site 3	9.55 (22.15)	11.11 (29.18)
		Site 4	2.13 (8.89)	6.60 (22.92)
		Site 5	7.09 (18.72)	12.89 (31.34)
		Site 6	4.19 (15.94)	4.22 (17.96)
		Site 7	6.62 (19.01)	8.76 (25.25)
		Site 8	8.51 (20.66)	12.96 (31.19)
		Site 9	5.45 (16.73)	9.85 (27.48)
		Site 10	9.39 (24.53)	13.79 (31.26)
		Site 11	11.35 (26.75)	28.11 (43.9)
	Floating vegetation	Sacramento Valley (overall)	1.54 (2.10)	0.91 (0.98)
		Site 1	0.13 (2.97)	0.12 (2.69)
		Site 2	0.60 (6.03)	1.13 (8.68)
		Site 3	2.14 (10.85)	1.31 (10.09)
		Site 4	3.18 (12.9)	2.52 (12.68)
		Site 5	2.14 (11.04)	0.08 (1.29)
		Site 6	0.00 (0.00)	0.03 (0.40)
		Site 7	0.06 (1.02)	0.22 (2.62)
		Site 8	7.04 (20.08)	2.87 (15.16)
		Site 9	0.25 (2.59)	0.31 (4.68)
		Site 10	0.60 (3.66)	0.83 (6.4)
		Site 11	0.78 (5.46)	0.60 (5.91)
	Submerged vegetation	Sacramento Valley (overall)	0.31 (0.39)	0.16 (0.21)
		Site 1	0.13 (3.31)	0.16 (3.59)
		Site 2	0.07 (1.54)	0.04 (0.97)
		Site 3	0.72 (6.45)	0.48 (5.52)
		Site 4	0.48 (5.83)	0.61 (7.59)
		Site 5	0.04 (0.65)	0.00 (0.00)
		Site 6	0.00 (0.00)	0.00 (0.00)
		Site 7	0.03 (0.75)	0.13 (3.36)
		Site 8	1.21 (8.87)	0.25 (4.27)
		Site 9	0.57 (5.46)	0.06 (0.99)
		Site 10	0.11 (3.10)	0.00 (0.00)
		Site 11	0.06 (1.97)	0.00 (0.00)

Group	Variable	Site	Used	Random
	Emergent vegetation	Sacramento Valley (overall)	32.70 (15.57)	27.36 (8.31)
		Site 1	22.84 (35.79)	29.01 (43.03)
		Site 2	46.74 (41.13)	28.76 (42.84)
		Site 3	24.89 (36.41)	19.39 (36.77)
		Site 4	32.32 (39.4)	28.21 (41.69)
		Site 5	13.95 (27.31)	18.05 (36.15)
		Site 6	66.07 (40.03)	35.23 (45.84)
		Site 7	49.12 (39.93)	39.55 (45.21)
		Site 8	30.53 (35.7)	31.22 (43.22)
		Site 9	31.99 (38.69)	18.40 (31.83)
		Site 10	24.88 (37.14)	37.29 (45.87)
		Site 11	16.36 (33.35)	15.90 (35.43)
	Terrestrial vegetation	Sacramento Valley (overall)	35.10 (9.54)	18.11 (6.42)
		Site 1	40.35 (34.70)	18.87 (32.41)
		Site 2	26.83 (35.98)	10.88 (25.37)
		Site 3	44.52 (40.29)	25.95 (37.65)
		Site 4	44.65 (39.52)	30.72 (40.3)
		Site 5	50.13 (37.87)	18.14 (32.41)
		Site 6	21.14 (31.83)	23.60 (38.91)
		Site 7	22.80 (30.01)	13.55 (27.03)
		Site 8	30.70 (32.69)	16.51 (29.24)
		Site 9	31.28 (36.48)	17.16 (31.75)
		Site 10	40.14 (37.75)	13.87 (28.27)
		Site 11	33.56 (32.98)	9.97 (24.56)
	Litter	Sacramento Valley (overall)	13.50 (4.51)	11.21 (6.34)
		Site 1	15.41 (22.37)	8.38 (20.54)
		Site 2	10.43 (18.58)	4.86 (14.52)
		Site 3	8.75 (17.74)	8.13 (19.65)
		Site 4	13.88 (24.34)	9.42 (20.98)
		Site 5	11.65 (17.74)	7.70 (19.83)
		Site 6	5.97 (13.85)	9.06 (22.88)
		Site 7	17.07 (25.83)	13.59 (25.39)
		Site 8	9.55 (19.01)	9.91 (23.78)
		Site 9	18.88 (26.17)	27.34 (33.57)
		Site 10	19.23 (27.61)	17.65 (31.29)
		Site 11	17.71 (24.89)	7.30 (19.57)
	Rock	Sacramento Valley (overall)	1.06 (1.03)	1.88 (1.92)
		Site 1	2.68 (12.25)	1.27 (6.72)
		Site 2	1.54 (9.73)	3.03 (13.64)
		Site 3	2.42 (11.7)	5.13 (21.40)
		Site 4	0.14 (1.61)	0.13 (1.58)

Group	Variable	Site	Used	Random
		Site 5	0.17 (2.59)	0.00 (0.00)
		Site 6	0.13 (1.61)	3.12 (14.28)
		Site 7	0.13 (2.15)	0.44 (5.37)
		Site 8	0.62 (6.51)	0.31 (4.36)
		Site 9	2.32 (12.2)	1.89 (12.79)
		Site 10	0.25 (4.27)	0.36 (4.90)
		Site 11	1.29 (7.81)	5.01 (20.10)
	Bare ground	Sacramento Valley (overall)	8.63 (5.22)	27.40 (6.89)
		Site 1	11.89 (20.99)	30.80 (40.28)
		Site 2	5.82 (14.11)	30.86 (40.80)
		Site 3	7.01 (14.75)	28.31 (38.41)
		Site 4	3.21 (8.06)	21.21 (34.58)
		Site 5	14.83 (26.79)	42.32 (44.77)
		Site 6	2.50 (8.67)	24.74 (38.72)
		Site 7	4.26 (13.08)	23.73 (35.09)
		Site 8	11.83 (21.55)	25.69 (36.48)
		Site 9	9.26 (21.86)	24.79 (32.18)
		Site 10	5.39 (12.69)	16.04 (29.86)
		Site 11	18.89 (27.28)	32.89 (42.32)
Vegetation type	Tule (*Schoenoplectus acutus*)	Sacramento Valley (overall)	1.41 (1.64)	0.42 (0.44)
		Site 1	4.59 (17.26)	1.24 (8.84)
		Site 2	2.04 (12.03)	0.33 (4.72)
		Site 3	3.16 (13.83)	0.45 (4.90)
		Site 4	0.87 (8.20)	0.03 (0.48)
		Site 5	0.04 (0.47)	0.00 (0.00)
		Site 6	0.00 (0.00)	0.81 (8.21)
		Site 7	0.00 (0.00)	0.00 (0.00)
		Site 8	3.32 (13.63)	1.01 (8.91)
		Site 9	1.30 (8.59)	0.51 (4.45)
		Site 10	0.00 (0.04)	0.01 (0.22)
		Site 11	0.20 (3.14)	0.19 (4.20)
	Cattail (T*yph*a spp.)	Sacramento Valley (overall)	5.47 (5.04)	1.52 (1.17)
		Site 1	2.59 (12.68)	1.97 (12.22)
		Site 2	15.38 (28.73)	2.07 (12.07)
		Site 3	2.90 (13.11)	0.97 (7.41)
		Site 4	2.03 (10.21)	0.16 (2.44)
		Site 5	0.84 (5.36)	0.87 (8.93)
		Site 6	12.96 (25.25)	2.24 (11.44)
		Site 7	2.79 (9.30)	0.44 (3.96)
		Site 8	9.06 (21.99)	3.74 (16.35)
		Site 9	7.14 (18.99)	2.96 (12.85)
		Site 10	4.33 (17.63)	1.18 (9.33)

Group	Variable	Site	Used	Random
		Site 11	0.20 (3.77)	0.16 (3.30)
	Water-primrose (*Ludwigia* spp.)	Sacramento Valley (overall)	6.64 (10.94)	1.94 (2.43)
		Site 1	1.31 (10.08)	0.60 (6.57)
		Site 2	7.06 (23.77)	3.67 (17.49)
		Site 3	4.09 (17.59)	0.85 (7.79)
		Site 4	5.69 (17.27)	2.51 (12.49)
		Site 5	0.31 (4.66)	0.00 (0.00)
		Site 6	38.52 (43.51)	8.23 (25.93)
		Site 7	0.04 (0.71)	0.01 (0.37)
		Site 8	2.43 (13.54)	1.60 (11.15)
		Site 9	6.06 (22.16)	2.89 (15.17)
		Site 10	0.19 (3.80)	0.02 (0.55)
		Site 11	7.33 (24.03)	0.97 (8.90)
	Smartweed (*Polygonum* spp.)	Sacramento Valley (overall)	2.88 (4.00)	1.00 (1.31)
		Site 1	2.94 (12.96)	0.60 (5.46)
		Site 2	0.62 (5.29)	0.22 (3.05)
		Site 3	2.29 (11.47)	0.57 (6.21)
		Site 4	4.40 (15.67)	2.03 (11.52)
		Site 5	0.00 (0.00)	0.18 (1.85)
		Site 6	0.56 (4.12)	0.00 (0.00)
		Site 7	14.2 (30.38)	3.86 (17.18)
		Site 8	1.95 (11.74)	0.30 (4.11)
		Site 9	2.97 (14.09)	2.85 (11.15)
		Site 10	1.60 (7.94)	0.37 (4.11)
		Site 11	0.12 (1.50)	0.01 (0.16)
	Cultivated rice (*Oryza sativa*)	Sacramento Valley (overall)	5.88 (3.07)	18.77 (7.36)
		Site 1	6.48 (23.84)	21.86 (39.76)
		Site 2	10.48 (29.00)	19.38 (38.42)
		Site 3	4.36 (19.58)	13.93 (33.30)
		Site 4	8.94 (27.19)	18.40 (37.39)
		Site 5	7.18 (24.81)	16.02 (35.04)
		Site 6	6.14 (23.67)	20.33 (39.27)
		Site 7	5.14 (19.74)	26.58 (41.36)
		Site 8	1.41 (10.78)	19.29 (36.79)
		Site 9	0.58 (7.54)	4.50 (20.22)
		Site 10	9.01 (28.01)	33.01 (44.87)
		Site 11	5.00 (20.47)	13.21 (32.47)
	Watergrass (*Echinochloa* spp.)	Sacramento Valley (overall)	5.06 (4.34)	1.91 (1.47)
		Site 1	1.05 (7.34)	1.55 (8.43)
		Site 2	6.85 (18.17)	1.86 (11.15)
		Site 3	4.47 (17.26)	1.28 (9.46)

Group	Variable	Site	Used	Random
		Site 4	2.85 (11.29)	1.70 (9.30)
		Site 5	1.14 (6.19)	0.19 (2.08)
		Site 6	2.51 (8.31)	2.29 (13.42)
		Site 7	15.51 (26.09)	5.57 (16.54)
		Site 8	4.88 (17.85)	3.07 (13.11)
		Site 9	8.90 (23.52)	2.18 (11.06)
		Site 10	6.41 (20.26)	0.89 (7.88)
		Site 11	1.05 (6.99)	0.48 (4.92)
	Turf grasses (Poaceae)	Sacramento Valley (overall)	2.41 (3.81)	2.05 (1.00)
		Site 1	3.22 (12.37)	3.21 (13.95)
		Site 2	1.47 (7.79)	1.45 (8.79)
		Site 3	1.35 (8.89)	1.55 (9.40)
		Site 4	0.20 (3.10)	0.93 (8.21)
		Site 5	3.24 (11.83)	2.05 (12.05)
		Site 6	2.25 (10.40)	4.06 (15.60)
		Site 7	2.47 (11.44)	2.82 (12.76)
		Site 8	4.11 (15.52)	1.48 (8.85)
		Site 9	3.13 (14.04)	1.56 (10.10)
		Site 10	4.05 (15.63)	2.49 (12.93)
		Site 11	0.97 (7.16)	0.89 (7.91)
	Annual grasses (Poaceae	Sacramento Valley (overall)	11.92 (8.76)	4.75 (2.41)
		Site 1	8.71 (20.53)	4.59 (16.65)
		Site 2	6.48 (20.66)	3.94 (17.31)
		Site 3	13.54 (26.32)	7.14 (21.56)
		Site 4	10.06 (23.97)	5.11 (17.57)
		Site 5	33.21 (38.74)	10.44 (26.68)
		Site 6	3.59 (12.40)	4.94 (19.39)
		Site 7	5.44 (15.46)	2.22 (11.15)
		Site 8	5.69 (16.70)	2.99 (13.14)
		Site 9	10.89 (21.76)	3.47 (14.45)
		Site 10	22.71 (33.28)	5.44 (18.46)
		Site 11	10.81 (23.31)	1.98 (11.20)
	Forbs	Sacramento Valley (overall)	16.54 (6.68)	9.27 (3.86)
		Site 1	25.45 (28.63)	10.06 (22.60)
		Site 2	15.09 (28.91)	5.02 (15.92)
		Site 3	26.57 (33.76)	15.96 (29.26)
		Site 4	25.64 (36.01)	14.61 (30.38)
		Site 5	10.05 (18.19)	5.02 (15.77)
		Site 6	10.32 (21.47)	12.16 (28.36)
		Site 7	10.04 (20.47)	7.04 (18.67)
		Site 8	15.28 (24.06)	10.29 (22.60)
		Site 9	12.57 (24.29)	10.15 (24.36)

Group	Variable	Site	Used	Random
		Site 10	11.08 (20.34)	5.44 (15.97)
		Site 11	19.88 (28.52)	6.19 (19.01)
Vegetation height	<1 centimeter	Sacramento Valley (overall)	15.79 (7.05)	40.11 (3.32)
		Site 1	18.46 (25.74)	41.93 (42.46)
		Site 2	13.78 (24.84)	51.29 (43.63)
		Site 3	16.55 (25.02)	39.43 (41.53)
		Site 4	5.35 (11.84)	27.81 (37.98)
		Site 5	21.92 (30.14)	55.21 (43.57)
		Site 6	6.69 (18.50)	28.96 (40.27)
		Site 7	10.88 (22.08)	32.49 (39.02)
		Site 8	20.34 (27.16)	38.65 (41.03)
		Site 9	14.71 (25.78)	34.65 (36.07)
		Site 10	14.77 (26.13)	29.83 (38.09)
		Site 11	30.24 (33.44)	61.00 (43.51)
	1–15 centimeters	Sacramento Valley (overall)	3.78 (1.48)	5.94 (1.07)
		Site 1	5.76 (17.14)	6.59 (19.16)
		Site 2	2.52 (12.02)	5.29 (16.33)
		Site 3	3.85 (15.18)	5.35 (16.93)
		Site 4	3.68 (15.64)	6.86 (21.37)
		Site 5	3.38 (10.30)	5.76 (18.10)
		Site 6	1.06 (8.47)	5.31 (17.38)
		Site 7	5.36 (15.89)	8.42 (21.38)
		Site 8	2.42 (10.99)	6.14 (17.56)
		Site 9	3.11 (13.97)	4.75 (17.98)
		Site 10	5.27 (15.71)	6.04 (17.89)
		Site 11	5.15 (16.76)	4.80 (17.55)
	16–50 centimeters	Sacramento Valley (overall)	18.39 (4.61)	13.51 (3.52)
		Site 1	17.07 (29.65)	14.34 (31.62)
		Site 2	19.96 (34.64)	11.83 (30.03)
		Site 3	16.97 (30.25)	12.56 (29.37)
		Site 4	21.74 (35.46)	16.36 (33.59)
		Site 5	16.66 (29.86)	15.30 (32.75)
		Site 6	30.07 (40.27)	21.50 (38.68)
		Site 7	13.28 (26.40)	14.16 (31.34)
		Site 8	14.33 (26.58)	9.69 (26.10)
		Site 9	14.98 (29.01)	10.09 (26.30)
		Site 10	19.39 (31.62)	13.48 (30.32)
		Site 11	17.87 (31.05)	9.34 (27.00)
	51–100 centimeters	Sacramento Valley (overall)	17.28 (4.05)	14.94 (5.53)
		Site 1	15.87 (30.25)	16.55 (34.74)
		Site 2	17.28 (32.39)	15.32 (34.48)

Group	Variable	Site	Used	Random
		Site 3	21.03 (34.13)	15.59 (33.11)
		Site 4	21.28 (35.03)	20.78 (37.01)
		Site 5	15.24 (30.46)	7.89 (25.08)
		Site 6	23.81 (37.79)	15.00 (34.79)
		Site 7	17.05 (31.00)	17.48 (35.32)
		Site 8	11.65 (25.25)	16.03 (33.66)
		Site 9	14.24 (27.86)	7.73 (22.67)
		Site 10	20.93 (34.84)	24.82 (42.22)
		Site 11	11.71 (26.77)	7.10 (23.75)
	>100 centimeters	Sacramento Valley (overall)	20.30 (4.48)	8.21 (3.22)
		Site 1	17.77 (29.05)	8.24 (23.08)
		Site 2	25.91 (35.90)	5.15 (19.61)
		Site 3	21.37 (34.35)	9.52 (26.43)
		Site 4	19.93 (31.74)	10.29 (26.22)
		Site 5	20.95 (36.28)	5.59 (21.22)
		Site 6	22.56 (32.12)	13.12 (31.10)
		Site 7	26.09 (35.46)	9.52 (25.60)
		Site 8	20.35 (30.94)	11.98 (28.39)
		Site 9	22.81 (33.62)	9.32 (23.19)
		Site 10	13.80 (29.33)	4.53 (18.37)
		Site 11	11.72 (25.32)	3.03 (15.08)

Table 14. Overall and site-specific selection ratios for giant gartersnake (*Thamnophis gigas*) selection of microhabitats in rice-growing regions of the Sacramento Valley, California, 2014–16.

[Rows in bold represent positive selection of the microhabitat overall or at that site; rows in italics represent avoidance of the microhabitat overall or at that site. Values in the table are posterior medians (95-percent credible intervals)]

Microhabitat	Site	Selection ratio
Open water	Sacramento Valley (overall)	0.94 (0.88 – 1.01)
	Site 1	*0.92 (0.84 – 1.00)*
	Site 2	0.92 (0.83 – 1.02)
	Site 3	0.95 (0.88 – 1.04)
	Site 4	0.93 (0.82 – 1.04)
	Site 5	0.93 (0.82 – 1.06)
	Site 6	0.94 (0.82 – 1.13)
	Site 7	0.97 (0.88 – 1.13)
	Site 8	*0.92 (0.85 – 0.99)*
	Site 9	0.92 (0.80 – 1.02)
	Site 10	0.97 (0.89 – 1.11)
	Site 11	0.93 (0.86 – 1.01)
Emergent vegetation	Sacramento Valley (overall)	1.02 (0.94 – 1.11)
	Site 1	0.95 (0.86 – 1.06)
	Site 2	1.08 (0.96 – 1.21)
	Site 3	1.05 (0.94 – 1.20)
	Site 4	1.05 (0.94 – 1.18)
	Site 5	0.99 (0.81 – 1.19)
	Site 6	1.04 (0.85 – 1.31)

Microhabitat	Site	Selection ratio
	Site 7	1.05 (0.95 – 1.18)
	Site 8	0.94 (0.82 – 1.08)
	Site 9	1.06 (0.92 – 1.21)
	Site 10	0.96 (0.85 – 1.09)
	Site 11	1.06 (0.95 – 1.20)
Terrestrial vegetation	**Sacramento Valley (overall)**	**1.17 (1.09 – 1.27)**
	Site 1	**1.15 (1.05 – 1.27)**
	Site 2	**1.21 (1.06 – 1.43)**
	Site 3	**1.12 (1.01 – 1.23)**
	Site 4	1.13 (0.99 – 1.29)
	Site 5	**1.20 (1.03 – 1.45)**
	Site 6	1.17 (0.98 – 1.42)
	Site 7	**1.16 (1.04 – 1.30)**
	Site 8	**1.12 (1.01 – 1.24)**
	Site 9	**1.14 (1.01 – 1.28)**
	Site 10	**1.26 (1.11 – 1.44)**
	Site 11	**1.26 (1.11 – 1.42)**
Litter	Sacramento Valley (overall)	1.07 (0.97 – 1.19)
	Site 1	1.12 (0.98 – 1.30)
	Site 2	**1.20 (1.01 – 1.41)**
	Site 3	1.02 (0.92 – 1.13)
	Site 4	1.14 (0.95 – 1.38)
	Site 5	1.05 (0.85 – 1.29)
	Site 6	1.07 (0.85 – 1.38)
	Site 7	1.09 (0.96 – 1.25)
	Site 8	0.96 (0.85 – 1.11)
	Site 9	0.97 (0.85 – 1.15)
	Site 10	1.03 (0.91 – 1.18)
	Site 11	**1.18 (1.03 – 1.31)**
Bare ground	*Sacramento Valley (overall)*	*0.76 (0.69 – 0.83)*
	Site 1	*0.79 (0.70 – 0.90)*
	Site 2	*0.73 (0.64 – 0.81)*
	Site 3	*0.75 (0.67 – 0.83)*
	Site 4	*0.75 (0.63 – 0.87)*
	Site 5	*0.74 (0.61 – 0.88)*
	Site 6	*0.76 (0.62 – 0.93)*
	Site 7	*0.73 (0.61 – 0.84)*
	Site 8	*0.76 (0.70 – 0.81)*
	Site 9	*0.78 (0.68 – 0.91)*
	Site 10	*0.75 (0.63 – 0.87)*
	Site 11	*0.85 (0.73 – 0.96)*

Table 15. Logit-scale standard deviations describing among-site variation in microhabitat selection ratios for giant gartersnakes (*Thamnophis gigas*) in rice-growing regions of the Sacramento Valley, California, 2014–16.

[Values in the table are posterior medians (95-percent credible intervals). <, less than]

Microhabitat	Standard deviation
Open water	0.05 (<0.01 – 0.15)
Emergent vegetation	0.08 (0.02 – 0.19)
Terrestrial vegetation	0.08 (0.01 – 0.18)
Litter	0.11 (0.04 – 0.23)
Bare ground	0.08 (0.01 – 0.20)

Table 16. Overall and site-specific selection ratios for giant gartersnake (*Thamnophis gigas*) selection of vegetation types in rice-growing regions of the Sacramento Valley, California, 2014–16.

[Rows in bold represent positive selection of the vegetation type overall or at that site; rows in italics represent avoidance of the vegetation type overall or at that site. Values in the table are posterior medians (95-percent credible intervals)]

Vegetation type	Site	Selection ratio
Tule (*Schoenoplectus acutus*)	**Sacramento Valley (overall)**	**1.71 (1.22 – 2.55)**
	Site 1	**1.71 (1.17 – 2.68)**
	Site 2	**1.75 (1.20 – 3.20)**
	Site 3	**1.86 (1.30 – 3.71)**
	Site 4	**1.77 (1.12 – 4.11)**
	Site 5	1.71 (0.87 – 3.73)
	Site 6	1.64 (0.70 – 3.01)
	Site 7	1.71 (0.84 – 3.74)
	Site 8	1.59 (0.97 – 2.39)
	Site 9	**1.65 (1.05 – 2.71)**
	Site 10	1.71 (0.84 – 3.74)
	Site 11	**1.68 (1.01 – 2.93)**
Cattail (*Typha* spp.)	**Sacramento Valley (overall)**	**1.41 (1.20 – 1.71)**
	Site 1	**1.27 (1.09 – 1.58)**
	Site 2	**1.58 (1.26 – 1.94)**
	Site 3	**1.43 (1.10 – 2.00)**
	Site 4	**1.44 (1.03 – 2.35)**
	Site 5	1.35 (0.88 – 1.94)
	Site 6	**1.46 (1.04 – 2.28)**
	Site 7	**1.54 (1.19 – 2.23)**
	Site 8	**1.36 (1.12 – 1.74)**
	Site 9	**1.30 (1.08 – 1.64)**
	Site 10	**1.38 (1.07 – 1.81)**
	Site 11	1.38 (0.99 – 2.03)
Water-primrose (*Ludwigia* spp.)	**Sacramento Valley (overall)**	**1.41 (1.19 – 1.72)**
	Site 1	**1.42 (1.13 – 1.98)**
	Site 2	**1.39 (1.09 – 1.82)**
	Site 3	**1.46 (1.21 – 1.92)**
	Site 4	**1.39 (1.15 – 1.74)**
	Site 5	**1.42 (1.01 – 2.24)**
	Site 6	**1.42 (1.05 – 1.95)**
	Site 7	**1.42 (1.00 – 2.24)**
	Site 8	**1.33 (1.02 – 1.71)**
	Site 9	1.31 (0.91 – 1.68)
	Site 10	**1.42 (1.00 – 2.17)**
	Site 11	**1.50 (1.20 – 2.21)**
Smartweed (*Polygonum* spp.)	**Sacramento Valley (overall)**	**1.46 (1.25 – 1.86)**
	Site 1	**1.48 (1.27 – 1.80)**
	Site 2	**1.50 (1.16 – 2.32)**
	Site 3	**1.48 (1.21 – 1.99)**
	Site 4	**1.46 (1.13 – 2.27)**
	Site 5	1.44 (0.93 – 2.22)
	Site 6	**1.46 (1.03 – 2.46)**
	Site 7	**1.35 (1.15 – 1.64)**
	Site 8	**1.52 (1.19 – 2.39)**
	Site 9	1.35 (0.95 – 1.79)
	Site 10	**1.47 (1.17 – 2.15)**
	Site 11	**1.49 (1.11 – 2.74)**
Cultivated rice (*Oryza sativa*)	*Sacramento Valley (overall)*	*0.70 (0.53 – 0.84)*
	Site 1	*0.65 (0.34 – 0.88)*
	Site 2	0.81 (0.58 – 1.04)

Vegetation type	Site	Selection ratio
	Site 3	*0.72 (0.47 – 0.93)*
	Site 4	*0.78 (0.56 – 0.99)*
	Site 5	0.70 (0.40 – 1.06)
	Site 6	0.75 (0.46 – 1.11)
	Site 7	*0.71 (0.53 – 0.86)*
	Site 8	*0.60 (0.36 – 0.80)*
	Site 9	*0.66 (0.32 – 0.95)*
	Site 10	*0.73 (0.54 – 0.90)*
	Site 11	*0.70 (0.43 – 0.89)*
Watergrass (*Echinochloa* spp.)	**Sacramento Valley (overall)**	**1.35 (1.19 – 1.56)**
	Site 1	**1.24 (1.01 – 1.50)**
	Site 2	**1.43 (1.19 – 1.75)**
	Site 3	**1.34 (1.09 – 1.71)**
	Site 4	**1.37 (1.12 – 1.73)**
	Site 5	**1.37 (1.04 – 1.93)**
	Site 6	1.33 (0.94 – 1.74)
	Site 7	**1.37 (1.18 – 1.61)**
	Site 8	**1.31 (1.11 – 1.57)**
	Site 9	**1.37 (1.16 – 1.70)**
	Site 10	**1.39 (1.17 – 1.84)**
	Site 11	**1.37 (1.06 – 1.88)**
Annual grasses (Poaceae)	**Sacramento Valley (overall)**	**1.34 (1.21 – 1.50)**
	Site 1	**1.28 (1.14 – 1.47)**
	Site 2	**1.34 (1.07 – 1.73)**
	Site 3	**1.26 (1.12 – 1.44)**
	Site 4	**1.27 (1.01 – 1.55)**
	Site 5	**1.39 (1.16 – 1.68)**
	Site 6	**1.31 (1.05 – 1.67)**
	Site 7	**1.35 (1.10 – 1.78)**
	Site 8	**1.26 (1.10 – 1.46)**
	Site 9	**1.42 (1.22 – 1.69)**
	Site 10	**1.36 (1.21 – 1.55)**
	Site 11	**1.45 (1.23 – 1.77)**
Forbs	**Sacramento Valley (overall)**	**1.29 (1.18 – 1.40)**
	Site 1	**1.36 (1.22 – 1.52)**
	Site 2	**1.37 (1.18 – 1.59)**
	Site 3	**1.23 (1.14 – 1.36)**
	Site 4	**1.26 (1.11 – 1.46)**
	Site 5	**1.32 (1.10 – 1.70)**
	Site 6	**1.26 (1.03 – 1.54)**
	Site 7	**1.25 (1.10 – 1.41)**
	Site 8	**1.24 (1.09 – 1.42)**
	Site 9	**1.21 (1.02 – 1.42)**
	Site 10	**1.28 (1.15 – 1.45)**
	Site 11	**1.35 (1.24 – 1.49)**

Table 17. Logit-scale standard deviations describing among-site variation in vegetation type selection ratios for giant gartersnakes (*Thamnophis gigas*) in rice-growing regions of the Sacramento Valley, California, 2014–16.

[Values in the table are posterior medians (95-percent credible intervals)]

Vegetation type	Standard deviation
Tule (*Schoenoplectus acutus*)	0.17 (0.01 – 0.78)
Cattail (*Typha* spp.)	0.14 (0.01 – 0.40)
Water-primrose (*Ludwigia* spp.)	0.11 (0.01 – 0.41)
Smartweed (*Polygonum* spp.)	0.12 (0.01 – 0.45)
Cultivated rice (*Oryza sativa*)	0.18 (0.02 – 0.53)
Watergrass (*Echinochloa* spp.)	0.09 (0.01 – 0.30)
Annual grasses (Poaceae)	0.09 (0.01 – 0.24)
Forbs	0.08 (0.01 – 0.20)

Table 18. Overall and site-specific selection ratios for giant gartersnake (*Thamnophis gigas*) selection of vegetation heights in rice-growing regions of the Sacramento Valley, California, 2014–16.

[Rows in bold represent positive selection of the height category overall or at that site; rows in italics represent avoidance of the height category overall or at that site. Values in the table are posterior medians (95-percent credible intervals). <, less than; >, greater than]

Vegetation height category	Site	Selection ratio
< 1 centimeter	*Sacramento Valley (overall)*	*0.78 (0.74 – 0.82)*
	Site 1	*0.78 (0.71 – 0.82)*
	Site 2	*0.77 (0.69 – 0.82)*
	Site 3	*0.79 (0.75 – 0.84)*
	Site 4	*0.78 (0.70 – 0.84)*
	Site 5	*0.78 (0.69 – 0.84)*
	Site 6	*0.79 (0.71 – 0.86)*
	Site 7	*0.78 (0.73 – 0.82)*
	Site 8	*0.79 (0.75 – 0.84)*
	Site 9	*0.79 (0.74 – 0.87)*
	Site 10	*0.79 (0.74 – 0.85)*
	Site 11	*0.79 (0.74 – 0.84)*
1–15 centimeters	*Sacramento Valley (overall)*	*0.84 (0.76 – 0.92)*
	Site 1	*0.81 (0.70 – 0.92)*
	Site 2	*0.83 (0.69 – 0.95)*
	Site 3	*0.84 (0.73 – 0.95)*
	Site 4	0.86 (0.73 – 1.02)
	Site 5	0.84 (0.69 – 1.01)
	Site 6	0.84 (0.68 – 1.03)
	Site 7	*0.83 (0.70 – 0.94)*
	Site 8	*0.78 (0.65 – 0.91)*
	Site 9	0.88 (0.73 – 1.06)
	Site 10	*0.85 (0.76 – 0.94)*
	Site 11	0.92 (0.81 – 1.02)
16–50 centimeters	Sacramento Valley (overall)	*0.95 (0.89 – 1.00)*
	Site 1	*0.91 (0.83 – 1.00)*
	Site 2	0.95 (0.89 – 1.02)
	Site 3	0.96 (0.91 – 1.02)
	Site 4	0.93 (0.83 – 1.01)
	Site 5	0.94 (0.80 – 1.06)
	Site 6	0.96 (0.83 – 1.10)
	Site 7	*0.91 (0.82 – 1.00)*
	Site 8	0.95 (0.87 – 1.03)

Vegetation height category	Site	Selection ratio
	Site 9	0.97 (0.87 – 1.10)
	Site 10	0.96 (0.89 – 1.04)
	Site 11	1.01 (0.93 – 1.10)
51–100 centimeters	*Sacramento Valley (overall)*	*0.91 (0.86 – 0.97)*
	Site 1	*0.85 (0.79 – 0.93)*
	Site 2	*0.91 (0.85 – 0.98)*
	Site 3	0.95 (0.88 – 1.02)
	Site 4	*0.90 (0.80 – 1.00)*
	Site 5	0.92 (0.82 – 1.05)
	Site 6	0.92 (0.80 – 1.09)
	Site 7	*0.91 (0.85 – 0.96)*
	Site 8	*0.88 (0.79 – 0.96)*
	Site 9	0.94 (0.83 – 1.05)
	Site 10	*0.89 (0.83 – 0.96)*
	Site 11	*0.94 (0.87 – 1.04)*
>100 centimeters	**Sacramento Valley (overall)**	**1.09 (1.02 – 1.16)**
	Site 1	1.07 (0.95 – 1.17)
	Site 2	**1.12 (1.03 – 1.24)**
	Site 3	1.09 (0.97 – 1.20)
	Site 4	1.08 (0.96 – 1.19)
	Site 5	1.10 (0.98 – 1.25)
	Site 6	1.09 (0.96 – 1.24)
	Site 7	**1.09 (1.02 – 1.19)**
	Site 8	1.05 (0.93 – 1.16)
	Site 9	**1.13 (1.02 – 1.26)**
	Site 10	1.10 (1.00 – 1.24)
	Site 11	1.09 (1.00 – 1.19)

Table 19. Logit-scale standard deviations describing among-site variation in vegetation height selection ratios for giant gartersnakes (*Thamnophis gigas*) in rice-growing regions of the Sacramento Valley, California, 2014–16.

[Values in the table are posterior medians (95-percent credible intervals).<, less than; >, greater than]

Vegetation height category	Standard deviation
<1 centimeter	0.03 (<0.01 – 0.10)
1–15 centimeter	0.08 (0.01 – 0.21)
16–50 centimeter	0.05 (0.01 – 0.14)
50–100 centimeter	0.06 (0.01 – 0.15)
>100 centimeter	0.05 (<0.01 – 0.14)

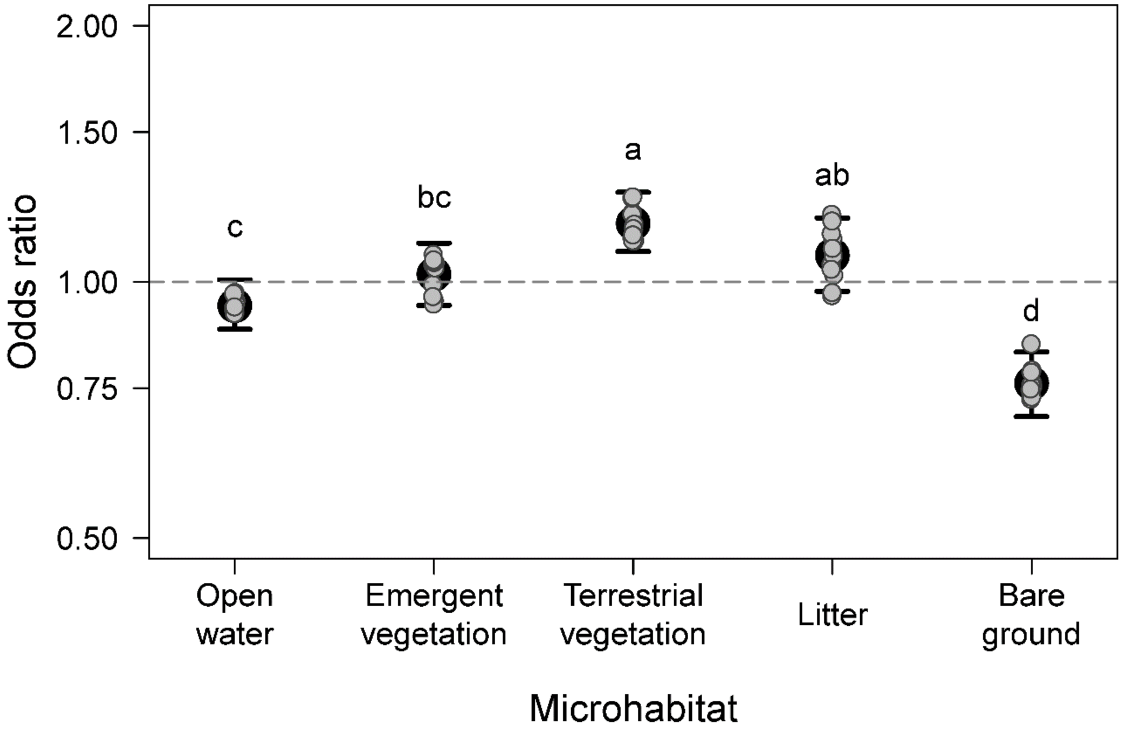


Figure 5. Odds ratios for selection of microhabitats by giant gartersnakes (*Thamnophis gigas*) in rice-growing regions of the Sacramento Valley, California, 2014–16. Odds ratios represent the change in odds of giant gartersnakes using a 0.79-square-meter circular quadrat with a 10 percent increase in the percentage of cover of the microhabitat. Large circles represent posterior medians for the Sacramento Valley, error bars represent 95 percent credible intervals for the Sacramento Valley, and gray circles represent posterior medians at individual study sites. Giant gartersnakes did not statistically differ in the strength of selection for microhabitats with the same letter above the error bars.

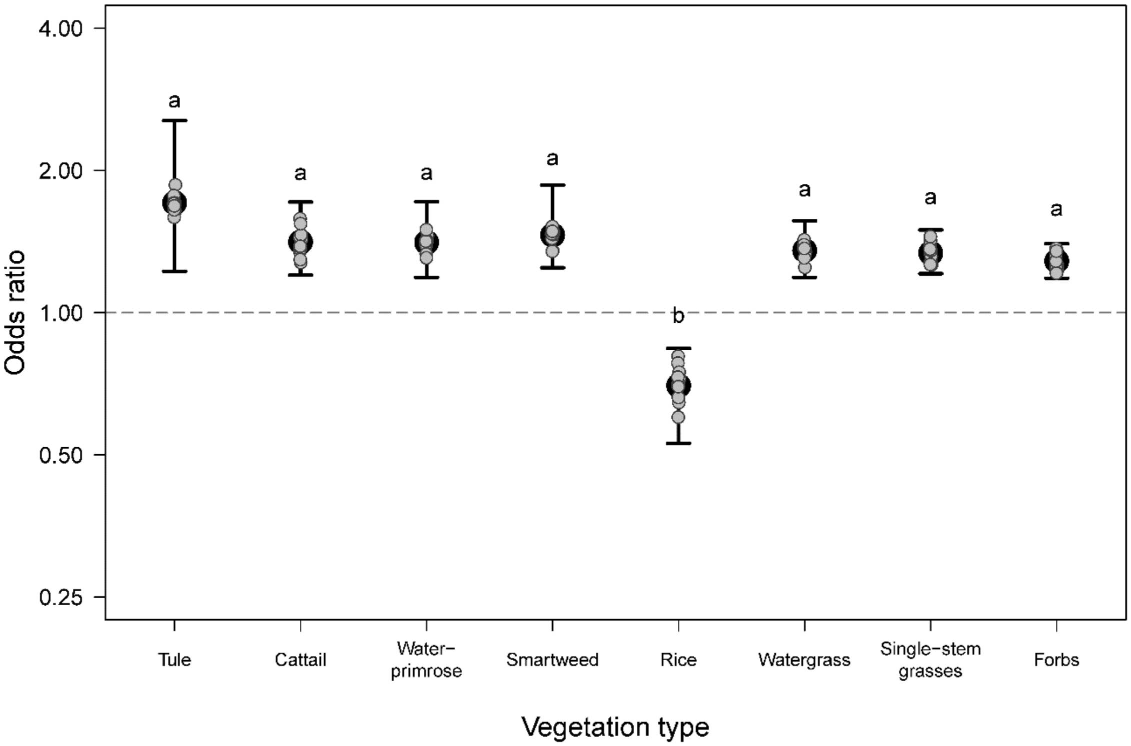


Figure 6. Odds ratios for selection of vegetation types by giant gartersnakes (*Thamnophis gigas*) in rice-growing regions of the Sacramento Valley, California, 2014–16. Odds ratios represent the change in odds of giant gartersnakes using a 0.79-square-meter circular quadrat with a 10 percent increase in the percentage of cover of the vegetation type. Large circles represent posterior medians for the Sacramento Valley, error bars represent 95-percent credible intervals for the Sacramento Valley, and gray circles represent posterior medians at individual study sites. Giant gartersnakes did not statistically differ in the strength of selection for vegetation types with the same letter above the error bars.

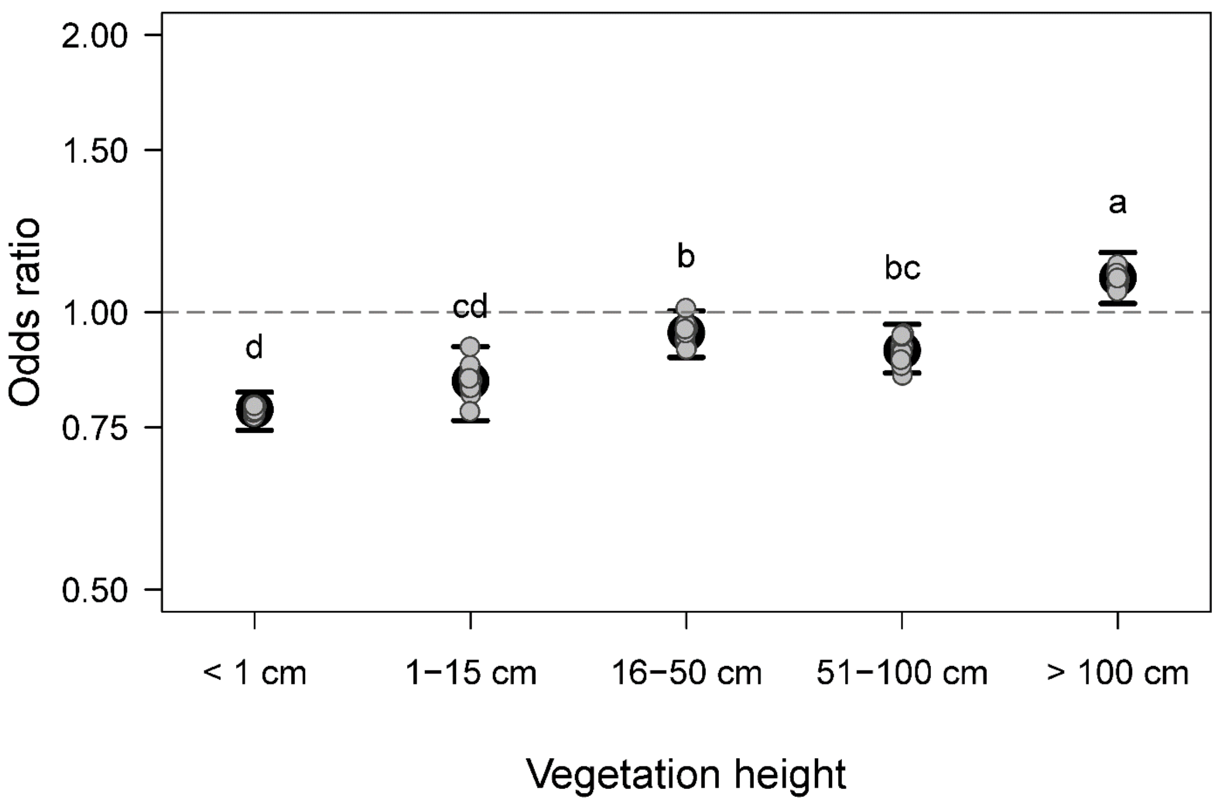


Figure 7. Odds ratios for selection of vegetation height categories by giant gartersnakes (*Thamnophis gigas*) in rice-growing regions of the Sacramento Valley, California, 2014–16. Odds ratios represent the change in odds of giant gartersnakes using a 0.79-square-meter circular quadrat with a 10 percent increase in the percentage of cover of vegetation in the specified height category. Large circles represent posterior medians for the Sacramento Valley, error bars represent 95-percent credible intervals for the Sacramento Valley, and gray circles represent posterior medians at individual study sites. Giant gartersnakes did not statistically differ in the strength of selection for vegetation height categories with the same letter above the error bars.

Health Assessment

Comparison to Reference Values

Overall, we performed 86 health assessments of 58 giant gartersnakes, including 54 females and 4 males, during 2014–16. Snakes were held in captivity for an average of 10 days (range 1–45 days) before they received a health assessment. Thirty-three snakes had blood drawn once, 22 snakes had blood drawn twice, and three snakes had three blood samples taken. Due to sample size and processing, not all analytes were obtained for all samples. There were a few notable differences between the health parameters of snakes sampled in this study and the values from snakes collected in 2008 and reported by Wack and others (2012). The median white blood cell count of snakes collected in this study was almost half of the median count from "apparently healthy" snakes reported in Wack and others (2012; tables 20 and 21). Specifically, median lymphocyte, heterophil, and azurophil counts are much lower in this study than for snakes captured in 2008 and analyzed by Wack and others (2012) (fig. 8).

Red blood cell count, hemoglobin concentration, and pack cell volume measurements from snakes in this study were all very similar to the reference values reported by Wack and others (2012) (tables 20 and 21). Similarly, most of the plasma biochemistry values measured for snakes in this study are within the baseline ranges reported by Wack and others (2012; fig. 9, tables 20 and 21). Notable exceptions include phosphorus, which had a 39 percent higher median concentration in this study (5.3 mg/dL) compared to the reference value (3.8 mg/dL), and creatinine kinase, which had both a lower median concentration (387 compared to 439 IU/L) and higher maximum concentration (3,028 compared to 1,666 IU/L) in this study compared to the results of Wack and others (2012). Finally, although the median AST value from this study (16.5 IU/L) was lower than the reference value (22 IU/L), the observed range of values was similar (tables 20 and 21).

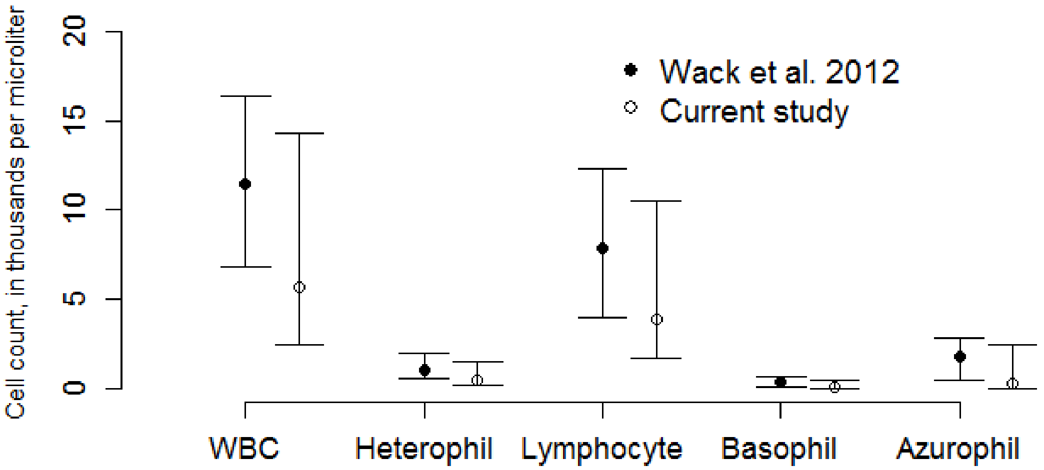


Figure 8. Comparison of white blood cell (WBC) counts in giant gartersnakes (*Thamnophis gigas*) from the current study (open circles) to published reference values from Wack and others (2012). Circles represent median values, bars represent 10th and 90th percentiles of measured counts.

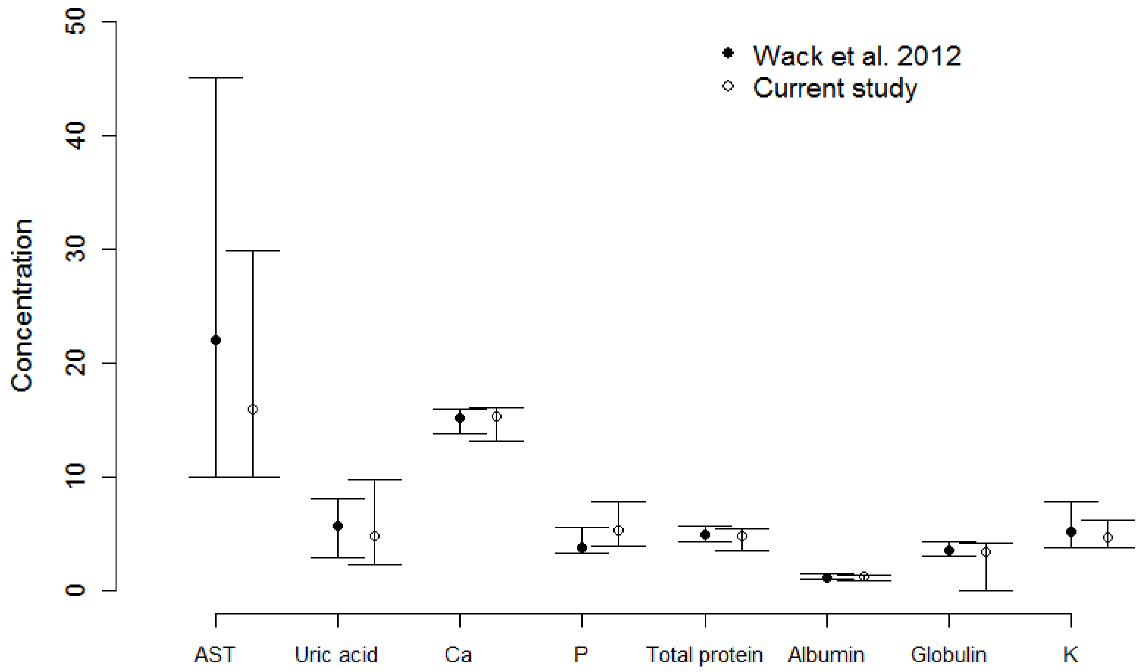


Figure 9. Comparison of selected plasma biochemistry values in giant gartersnakes (*Thamnophis gigas*) from the current study to published reference values from Wack and others (2012).Circles represent median values, bars represent 10th and 90th percentiles of measured values. Units for the concentration values are as follows: AST (aspartate aminotransferase; International Units per liter), uric acid (milligram per deciliter [mg/dL]), calcium (Ca; mg/dL), phosphorus, (P; mg/dL), total protein (gram per deciliter [g/dL]), albumin (g/dL), globulin (g/dL), and potassium, (K; millimoles per deciliter).

Table 20. Hematological and plasma biochemistry values from giant gartersnakes (*Thamnophis gigas*) collected Sacramento Valley, California, 2014–16.

[g/dL, gram per deciliter; IU/L, International Units per liter; µL, microliter; µmol/L, micromoles per liter; mg/dL, milligram per deciliter; mmol/dL, millimoles per deciliter; <, less than]

Parameter	Number	Median	10th percentile	90th percentile	Minimum	Maximum
White blood cell count (× 10^3/ µL)	86	5.7	2.5	14.3	0.2	24.2
Red blood cell count (× 10^6/ µL)	84	0.8	0.5	1.1	0.2	3.8
Hemoglobin (g/dL)	86	9.0	5.8	11.4	2.4	13.8
Pack cell volume (%)	86	27.0	18.5	35.0	8.0	41.0
Heterophils (× 10^3/µL)	86	0.5	0.2	1.5	0.0	3.6
Lymphocytes (× 10^3/µL)	86	3.9	1.7	10.5	0.0	19.4
Basophils (× 10^3/µL)	85	0.1	0.0	0.5	0.0	0.8
Azurophils (× 10^3/µL)	86	0.3	0.0	2.5	0.0	4.4
Eosinophils (× 10^3/µL)	86	0.0	0.0	0.0	0.0	0.1
Band cells (× 10^3/µL)	86	0.0	0.0	0.0	0.0	1.1
Monocytes (× 10^3/µL)	86	0.0	0.0	0.3	0.0	1.2

Parameter	Number	Median	10th percentile	90th percentile	Minimum	Maximum
Plasma protein (g/dL)	85	5.4	4.2	6.9	1.4	9.6
Aspartate aminotransferase (IU/L)	86	16.5	10.0	30.0	7.0	80.0
Bile acids (µmol/L)	86	387	152	1,431	76	3,028
Creatinine kinase (IU/L)	86	4.8	2.3	9.9	0.5	17.8
Uric acid (mg/dL)	86	76	53	104	30	144
Glucose (mg/dL)	86	15.4	13.2	16.1	0.0	16.1
Calcium (mg/dL)	86	5.3	4.0	7.9	2.6	13.3
Phosphorus (mg/dL)	86	4.8	3.6	5.5	2.0	6.4
Total protein (g/dL)	86	1.3	1.0	1.5	0.9	2.0
Albumin (g/dL)	85	3.5	0.8	4.2	0.0	4.9
Globulin (g/dL)	86	4.7	3.8	6.3	3.1	7.9
Potassium (mmol/dL)	86	159	152	165	146	170
Sodium (mmol/dL)	86	5.7	2.5	14.3	0.2	24.2

Table 21. Hematological and plasma biochemistry values from giant gartersnakes (*Thamnophis gigas*) collected in Fresno, Merced, and Sacramento Counties, California, 2008 (as reported by Wack and others, 2012). Note that Wack and others (2012) did not report cell counts for eosinophils, band cells, or monocytes.

[g/dL, gram per deciliter; IU/L, International Units per liter; µL, microliter; µmol/L, micromoles per liter; mg/dL, milligram per deciliter; mmol/dL, millimoles per deciliter]

Parameter	Number	Median	10th percentile	90th percentile	Minimum	Maximum
White blood cell count (× 10^3/ µL)	46	11.5	6.8	16.4	2.5	18.6
Red blood cell count (× 10^6/ µL)	46	0.8	0.5	1.1	0.2	1.4
Hemoglobin (g/dL)	46	10	7.7	11.8	6.9	13.6
Pack cell volume (percent)	46	31	22	38	17	45
Heterophils (× 10^3/ µL)	45	0.99	0.51	1.97	0.35	2.18
Lymphocytes (× 10^3/µL)	46	7.9	3.98	12.28	1.27	14.97
Basophils (× 10^3/µL)	45	0.33	0.13	0.64	0.09	0.83
Azurophils (× 10^3/µL)	44	1.75	0.5	2.79	0.37	4.4
Plasma protein (g/dL)	45	5	4.5	5.8	4.2	6.7
Aspartate aminotransferase (IU/L)	44	22	10	45	8	74
Bile acids (µmol/L)	45	35	35	35	0	35
Creatinine kinase (IU/L)	42	439	74	1,070	20	1,666
Uric acid (mg/dL)	44	5.7	2.9	8.2	1.2	13.1
Glucose (mg/dL)	43	81	58	115	44	154
Calcium (mg/dL)	45	15.2	13.8	16	12.9	20
Phosphorus (mg/dL)	43	3.8	3.3	5.6	1.9	6.3
Total protein (g/dL)	44	5	4.4	5.7	3.9	6.1
Albumin (g/dL)	45	1.2	1.1	1.6	1	1.7
Globulin (g/dL)	43	3.6	3.1	4.3	2.7	4.7
Potassium (mmol/dL)	44	5.2	3.9	7.9	2.7	8.8
Sodium (mmol/dL)	44	159	150	166	147	170

Model Results

The proportion of rice within a snake's buffered home range was not related to any hematological or plasma biochemistry parameter. Most hematological and plasma biochemistry parameters did not exhibit a strong relationship with any proposed explanatory variable (appendix B). White blood cell count, red blood cell count, pack cell volume, heterophil count, lymphocyte count, basophil count, azurophil count, monocyte count, plasma protein, AST, creatinine kinase, glucose, calcium, total protein, globulin, and sodium levels were all unrelated to snake size, sex, season, days spent in captivity prior to examination, or the proportion of rice within a snake's buffered home range. For all of the blood parameters we examined, the amount of unexplained variation was greater than the amount of variation that was attributable to differences among sites or differences among individual snakes.

A few measured blood parameters did show significant relationships with proposed explanatory variables. Hemoglobin concentrations were higher in male giant gartersnakes than females (βsex = 3.02 [0.10 – 5.91]; fig. 10). There is great uncertainty in the average hemoglobin concentration for males, due to the small number of male snakes examined. Phosphorus concentration was related to season; there was a negative linear relationship between Julian date and the concentration of phosphorus in snake plasma (βdate = -0.62 [-1.1 – -0.14]; fig. 11). In other words, phosphorus concentration declined as the season moved from spring to summer. Uric acid concentration in the plasma also showed a seasonal pattern in the form of a quadratic relationship (βdate = -1.04 [-1.9 – -0.16]; βdate^2 = 0.77 [0.16 – 1.40]). The best fit model described a seasonal pattern where uric acid concentration decreased from a peak in early spring to a minimum in late spring to mid-summer, before increasing slightly in late summer (fig. 12). Albumin concentration was positively related to snake size; longer snakes tended to have higher albumin levels in their plasma (βsize = 0.06 [0.01 – 0.12]) (fig. 13).

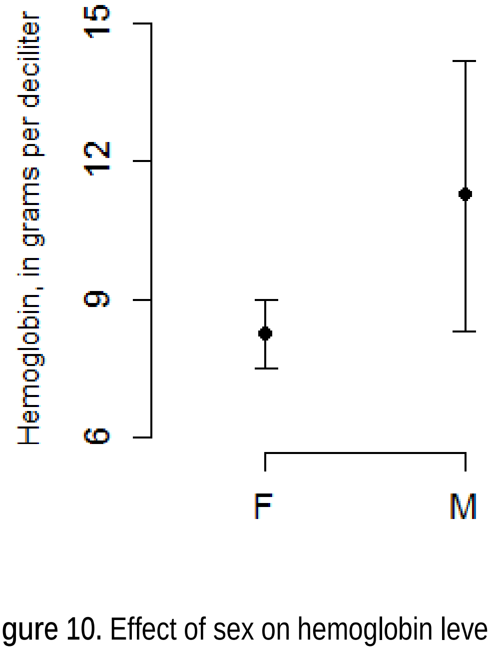


Figure 10. Effect of sex on hemoglobin levels in giant gartersnakes (*Thamnophis gigas*) sampled in the Sacramento Valley, California, 2014–16. Filled circles represent posterior medians from a hierarchical model with a fixed effect of sex and random effects of site and individual, and error bars represent 95-percent credible interval of values for each sex.

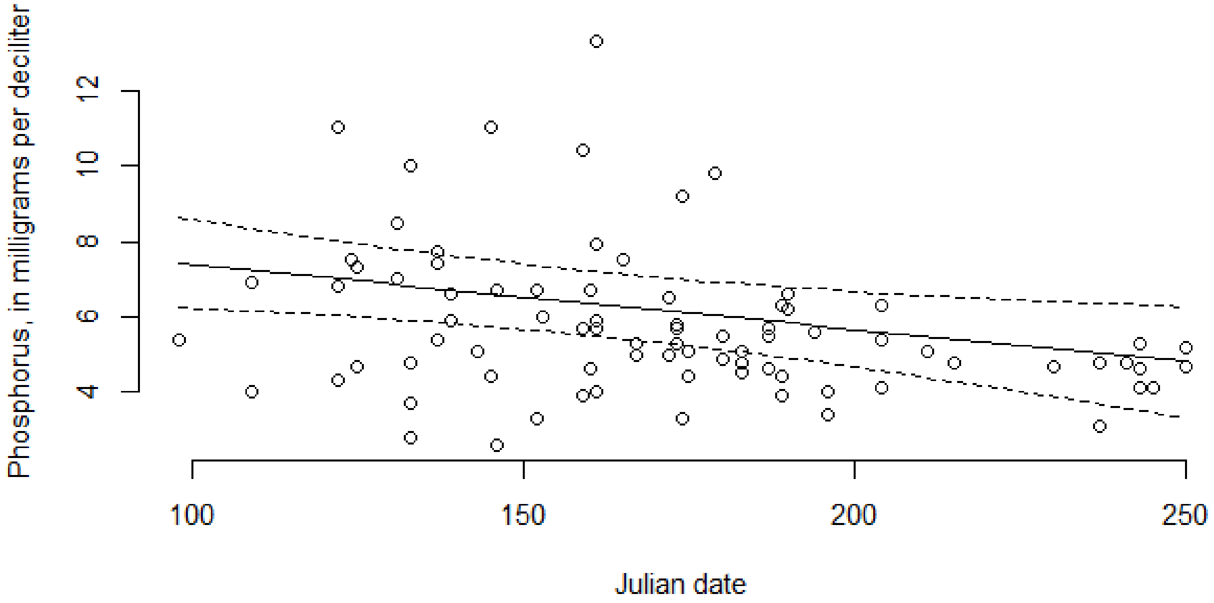


Figure 11. Plasma phosphorus concentration compared to Julian date in giant gartersnakes (*Thamnophis gigas*) sampled in the Sacramento Valley, California, 2014–16. Solid line represents mean model fit, and the dashed lines represent 95-percent credible intervals.

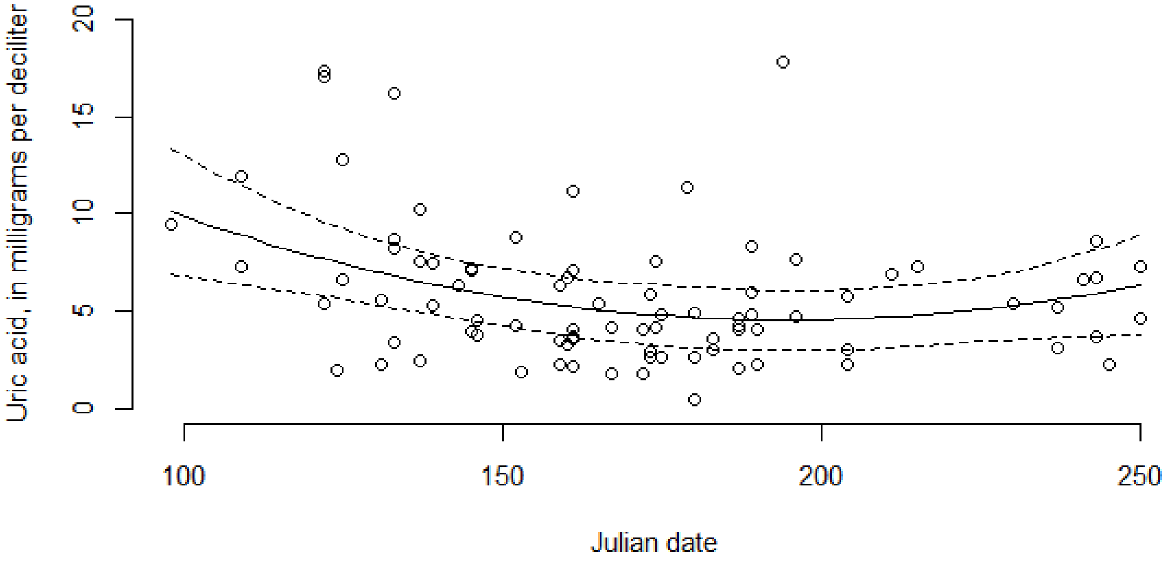


Figure 12. Uric acid concentration compared to Julian date in giant gartersnakes (*Thamnophis gigas*) sampled in the Sacramento Valley, California, 2014–16. Solid line represents mean model prediction, and dashed lines represent 95-percent credible intervals.

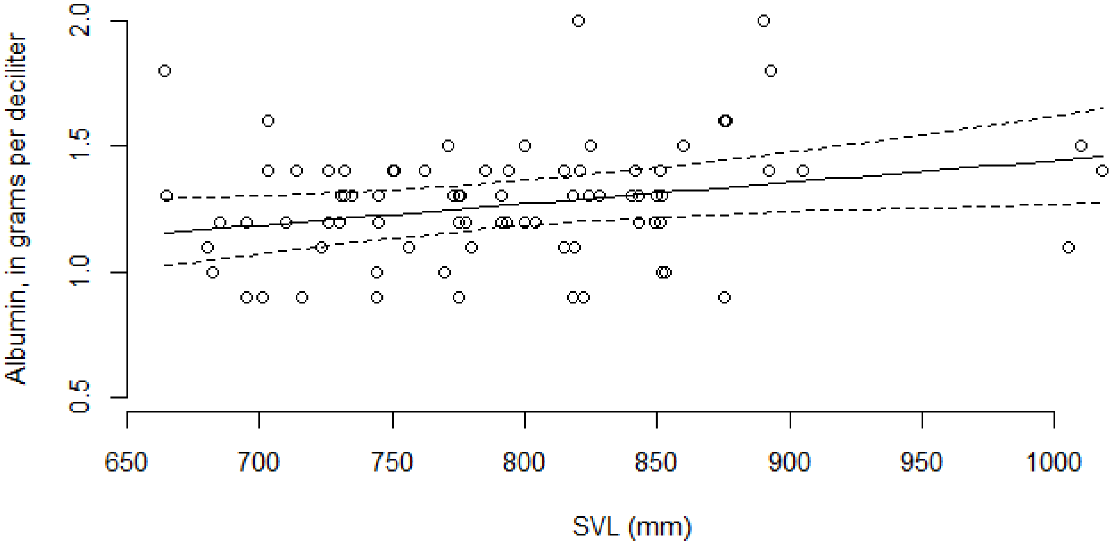


Figure 13. Plasma albumin concentration compared to snake snout-vent length (SVL, in millimeters [mm]) in giant gartersnakes (*Thamnophis gigas*) sampled in the Sacramento Valley, California, 2014–16. Solid line represents mean model prediction, and dashed lines represent 95-percent credible intervals.

Survival

The piecewise constant hazard model appeared to fit well, although it produced higher survival estimates and narrower credible intervals than the Kaplan-Meier survival curve (fig. 14). Based on this model, weekly mortality risk for giant gartersnakes was 8.6×10^{-3} (95-percent credible interval = $3.8 \times 10^{-3} – 1.7 \times 10^{-2}$) during the growing season, 5.1×10^{-3} ($2.2 \times 10^{-3} – 1.0 \times 10^{-2}$) during brumation, and 3.1×10^{-2} ($1.4 \times 10^{-2} – 6.1 \times 10^{-2}$) during the early part of the giant gartersnake active season, before flood up and emergence of rice. Weekly mortality risk varied relatively little among sites (σ_{site} = 0.21 [0.01 – 0.75]; fig. 15). Mean annual survival of an adult female giant gartersnake with an average covariate profile was 0.58 (0.41 – 0.73; fig. 15). Size of adult giant gartersnakes had little effect on risk of mortality (β_{size} = -0.03 [-0.51 – 0.40]; fig. 16). In contrast, the posterior distributions of the hazard ratios for sex and the annual proportion of rice within 500 m of an individual's minimum convex polygon home range were mostly < 1 (β_{sex} = -0.72 [-3.03 – 0.53], probability negative = 0.86; β_{rice} = -0.33 [-0.71 – 0.06], probability negative = 0.95; fig. 16), indicating a reduced risk of mortality with being male and with increasing proportion rice in and near the home range (fig. 17). Thus, females and snakes with less rice in and near their home ranges had lower survival rates than males and snakes with more rice in and near their home ranges (fig. 18). Decreasing the proportion of rice within 500 m of a giant gartersnake's home range from a mean of 0.64 by one standard deviation to 0.41 increased the daily risk of mortality by 1.24 (0.93 – 1.88) times (fig. 17).

The second model with a constant hazard and time-varying covariates appeared to fit less well than the seasonal model based on visual comparison with the Kaplan-Meier survival curve (fig. 19). In a preliminary model with competing effects of weekly mean proportion rice and cumulative weekly mean proportion rice, the cumulative mean was preferred by a ratio of 3.9:1. We therefore based inference on a model with cumulative mean weekly proportion rice. Under this model, mean weekly mortality risk for giant gartersnakes was 8.7×10^{-3} ($4.9 \times 10^{-3} – 1.4 \times 10^{-2}$), and weekly mortality risk varied relatively little among sites (σ_{site} = 0.26 [0.01 – 0.92], fig. 20). Posterior mean annual survival probability of adult giant gartersnakes at constant mean values of the cumulative mean proportion rice and distance to water was 0.64 (0.48 – 0.78; fig. 20). Annual survival probability based on the mean (across individuals) weekly covariate profiles was slightly lower at 0.60 (0.45 – 0.74; fig. 19). The cumulative mean proportion of rice and distance to water both decreased the hazard for giant gartersnakes (β_{c_rice} = -0.43 [-0.89 – -0.01], probability negative = 0.98; β_{w_dist} = -0.73 [-1.78 – 0.01], probability negative = 0.97, fig. 21), indicating a reduced risk of mortality with increasing distance from water and cumulative mean proportion rice within 100 m of the snake's location (fig. 22). Thus, snakes had lower survival in and very near water and when they had less cumulative exposure to rice near their locations than when they were farther from water or had more cumulative exposure to rice near their locations (fig. 23).

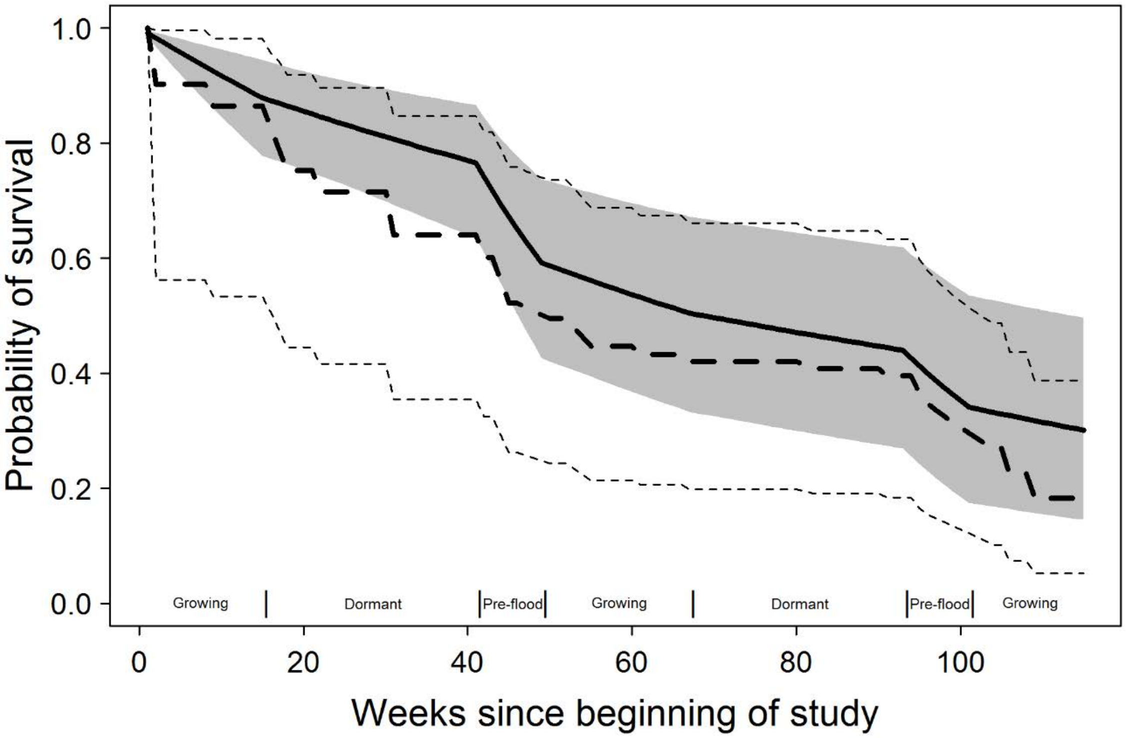


Figure 14. Survival curves for female giant gartersnakes (*Thamnophis gigas*) in the Sacramento Valley, California, 2014–16, with average covariate profiles estimated using a step-wise constant hazard model (solid line and gray area) and a Kaplan-Meier non-parametric survival curve (dashed lines). Bold lines represent the posterior median; the gray shaded area and light lines represent 95-percent credible intervals. Text along the abscissa indicates the rice growing cycle used to define seasons between which the step-wise constant hazard model allowed different baseline risks of mortality.

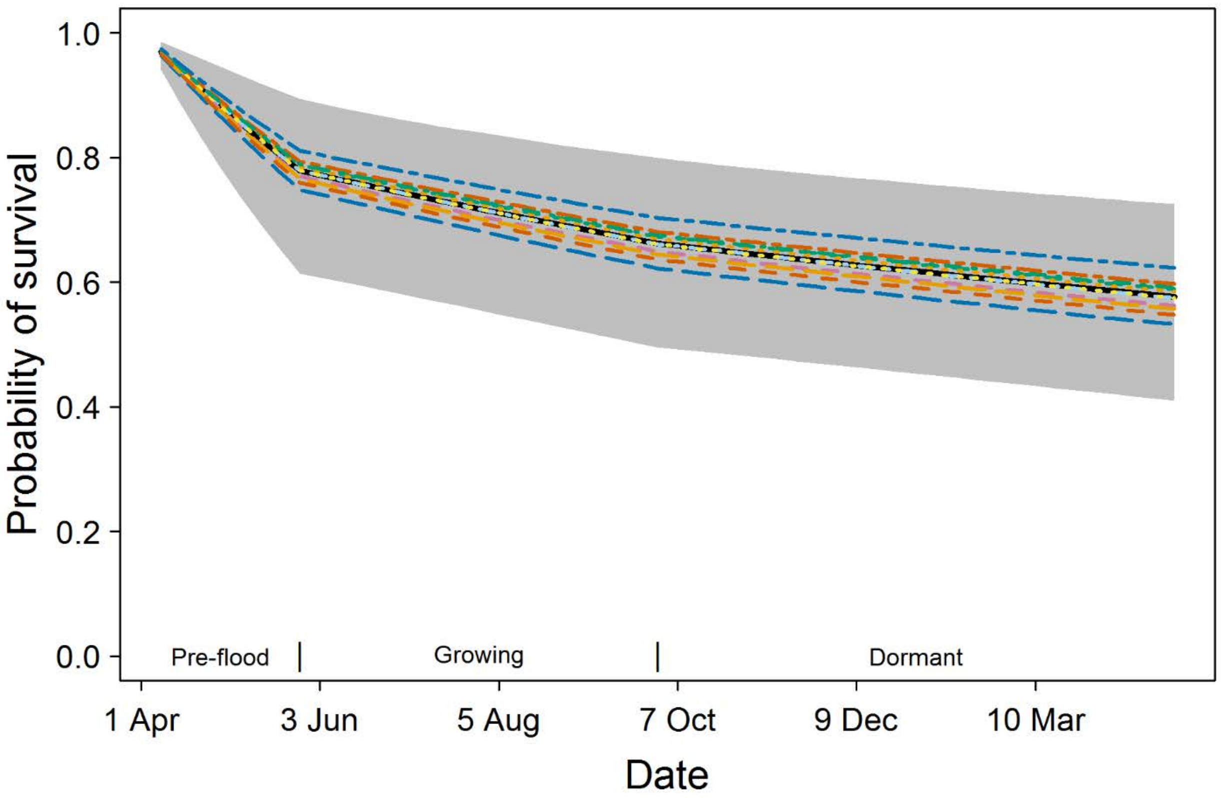


Figure 15. Annual survival curve for female giant gartersnakes (*Thamnophis gigas*) in the Sacramento Valley, California, 2014–16, with average covariate profiles estimated using a step-wise constant hazard model (solid line and gray area). Median survival curves for individual sites are indicated by different line and color patterns. The black solid line represents the average median survival curve for rice-growing regions in the Sacramento Valley; the gray shaded area represent the 95-percent credible interval for this region. Credible intervals for individual sites are omitted for clarity. Text along the abscissa indicates the rice growing cycle used to define seasons between which the step-wise constant hazard model allowed different baseline risks of mortality.

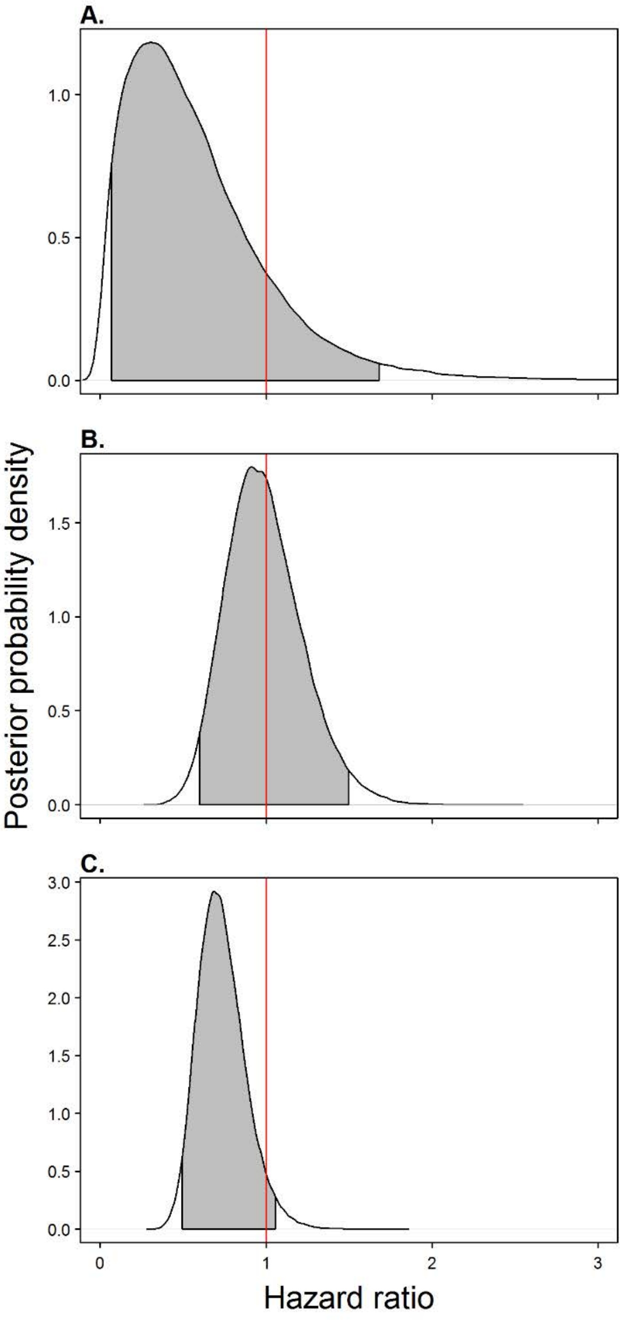


Figure 16. Posterior distributions for hazard ratios for the effects of male sex (A), snout-vent length (B), and annual proportion rice within 500 m of the individual's minimum convex polygon home range (C) on the weekly risk of mortality for adult giant gartersnakes (*Thamnophis gigas*) in the Sacramento Valley, California, 2014–16. The shaded area represents the 95-percent credible interval; the vertical red line indicates a hazard ratio of one, which represents no effect on mortality risk.

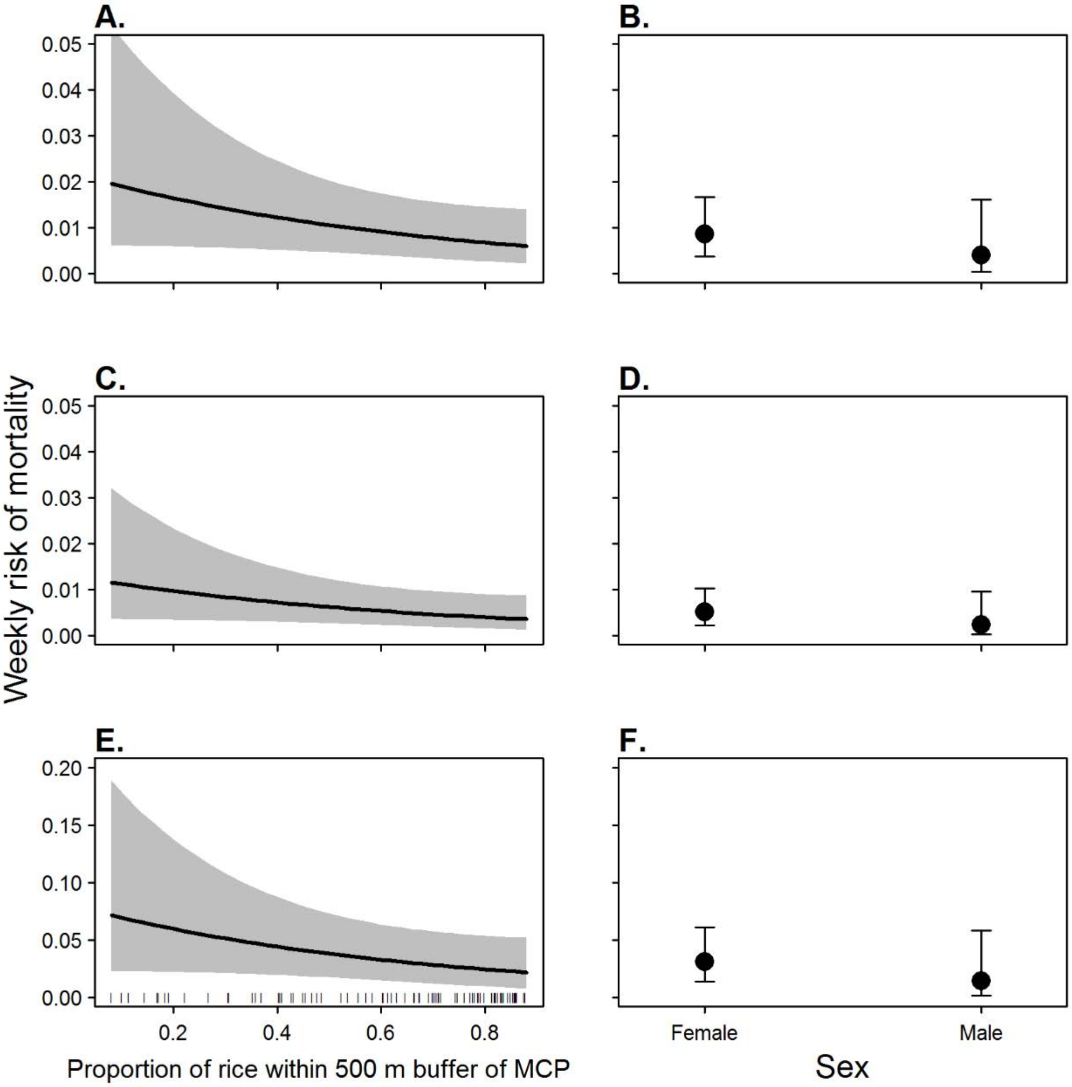


Figure 17. Effect of the proportion of rice within 500 m of giant gartersnake (*Thamnophis gigas*) minimum convex polygon (MCP) home ranges (A, C, E) and sex (B, D, F) on weekly risk of mortality in rice-growing regions of the Sacramento Valley, California, 2014–16, during the rice growing season (A, B), brumation (C, D), and emergence/pre-flood up (E, F). Solid lines and dots represent posterior medians; gray shaded areas and error bars represent 95-percent credible intervals. Tick marks inside the abscissa in graph E represent the annual proportion of rice within a 500-m buffer of individual snake MCPs.

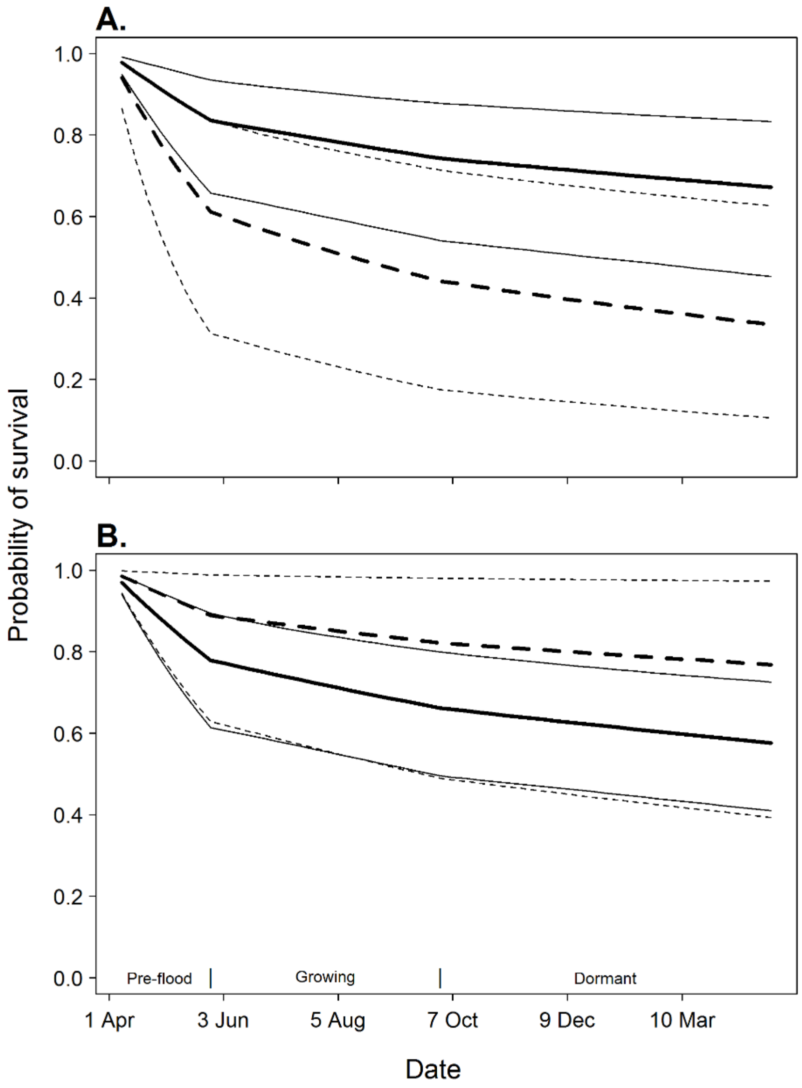


Figure 18. Survival curves for giant gartersnakes (*Thamnophis gigas*) inhabiting an area with 86 percent rice within 500 m of their minimum convex polygon (MCP) home range (solid lines), and for giant gartersnakes with 18 percent rice within 500 m of their MCP home range (dashed lines) (A), and female (solid lines) and male (dashed lines) giant gartersnakes in rice-growing regions (B) of the Sacramento Valley, California, 2014–16. Bold lines represent posterior medians; light lines represent 95-percent credible intervals. Text along the abscissa indicates the rice growing cycle used to define seasons between which the step-wise constant hazard model allowed different baseline risks of mortality. Values for percent rice were based on the 95th and 5th percentiles of observed annual percent rice within 500 m of MCP home ranges.

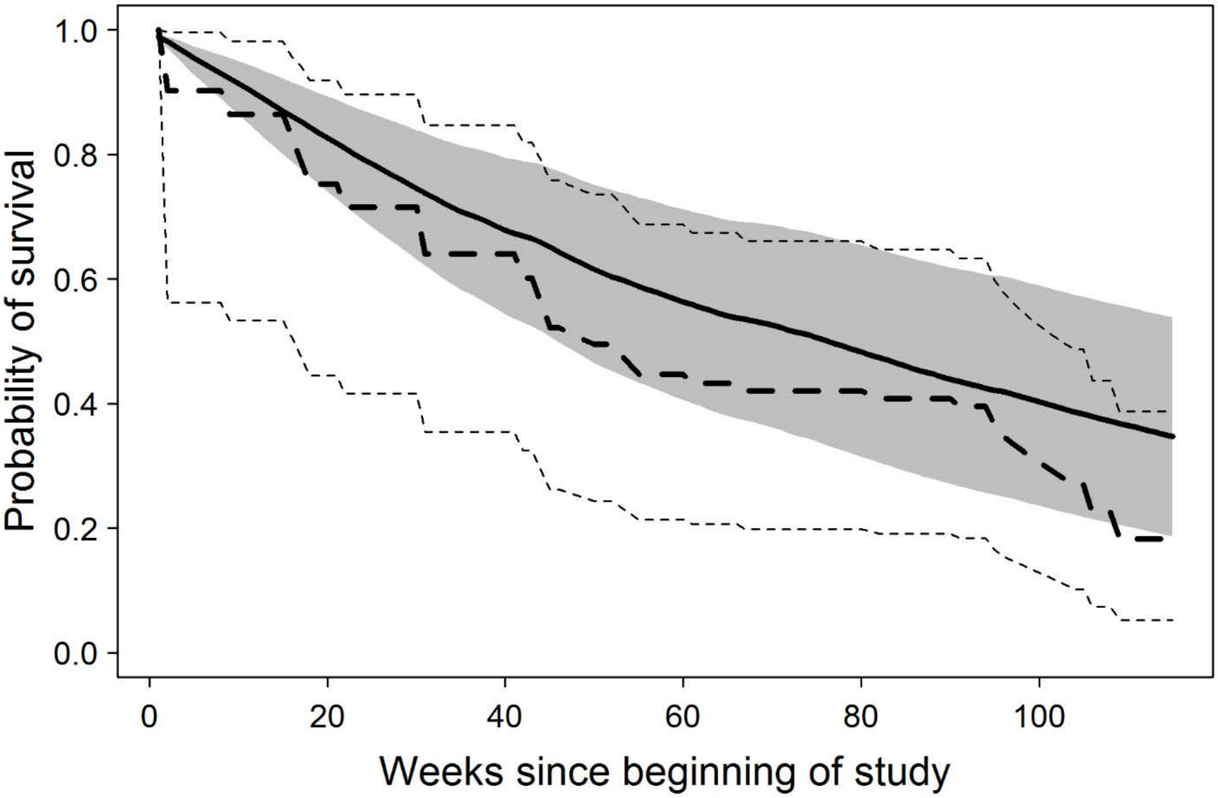


Figure 19. Survival curves for giant gartersnakes (*Thamnophis gigas*) in the Sacramento Valley, California, 2014–16, with average (across individual) weekly covariate profiles estimated using a constant hazard model with time-varying covariates (solid line and gray area) and a Kaplan-Meier non-parametric survival curve (dashed lines). Bold lines represent the posterior median; the gray shaded area and light lines represent 95-percent credible intervals.

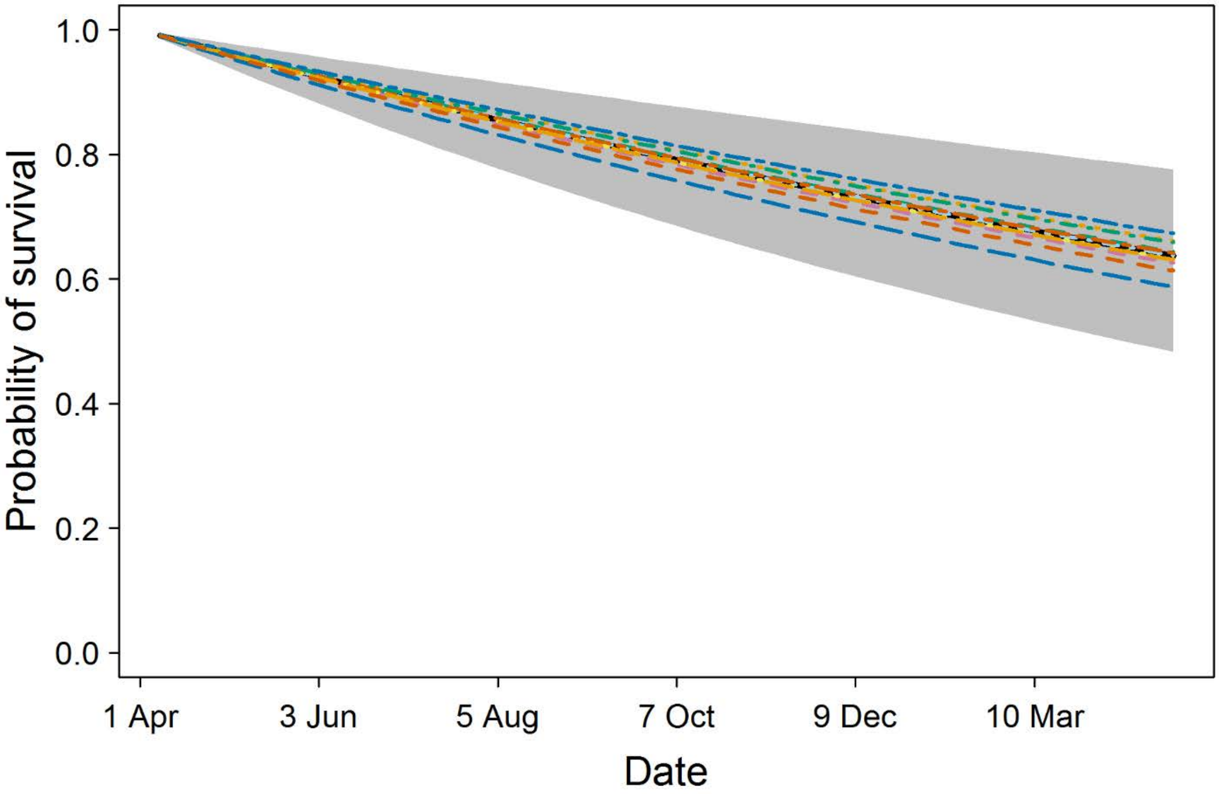


Figure 20. Annual survival curve for giant gartersnakes (*Thamnophis gigas*) in the Sacramento Valley, California, 2014–16, with average constant covariate profiles estimated using a constant hazard model with time-varying covariates (solid line and gray area). Median survival curves for individual sites are indicated by different line and color patterns. The black solid line represents the average median survival curve for rice-growing regions in the Sacramento Valley; the gray shaded area represents the 95-percent credible interval for this region. Credible intervals for individual sites are omitted for clarity.

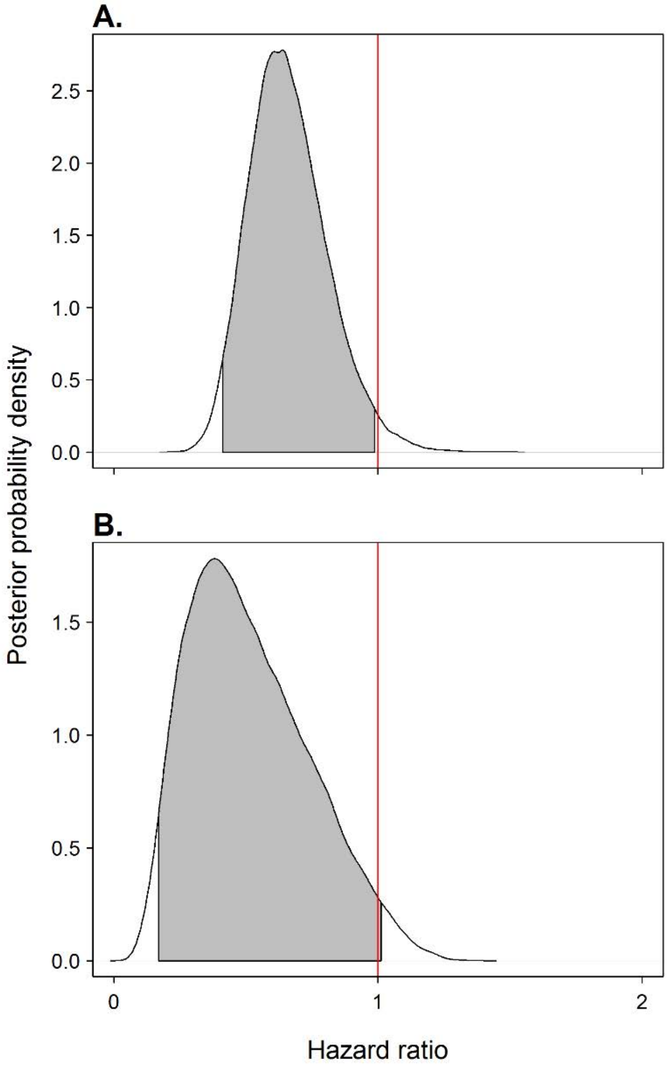


Figure 21. Posterior distributions for hazard ratios for the effects of cumulative mean weekly proportion rice within 100 m of giant gartersnake locations (A), and mean weekly distance from water on the weekly risk of mortality for adult giant gartersnakes (*Thamnophis gigas*) (B) in the Sacramento Valley, California, 2014–16. The shaded area represents the 95-percent credible interval; the vertical red line indicates a hazard ratio of one, which represents no effect on mortality risk.

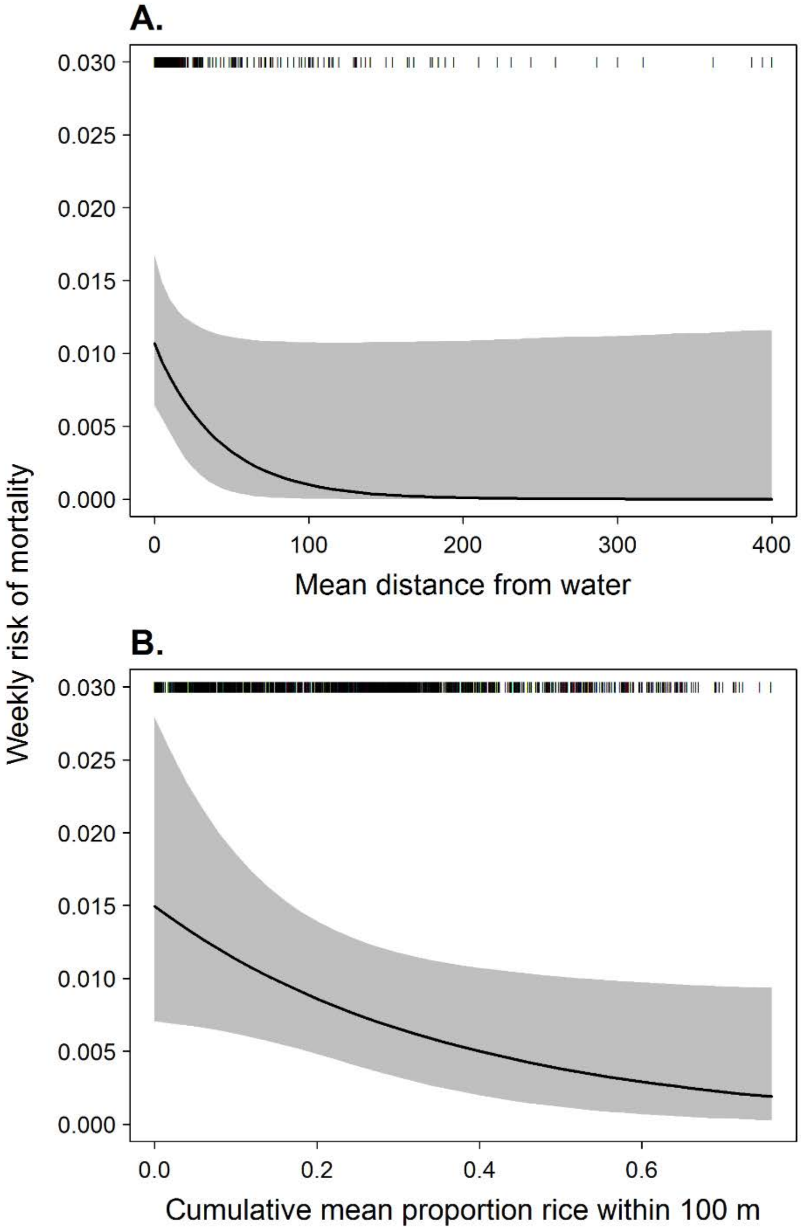


Figure 22. Effect of the mean distance from water (A) and the cumulative mean weekly proportion of rice within 100 m of giant gartersnake (*Thamnophis gigas*) locations on weekly risk of mortality in rice-growing regions (B) of the Sacramento Valley, California, 2014–16. Lines represent the posterior medians; gray shaded areas represent 95-percent credible intervals. Tick marks along the top of the plotting region in graph A represent observed values for distances from water, and those in graph B represent observed values of cumulative mean proportion rice within 100 m.

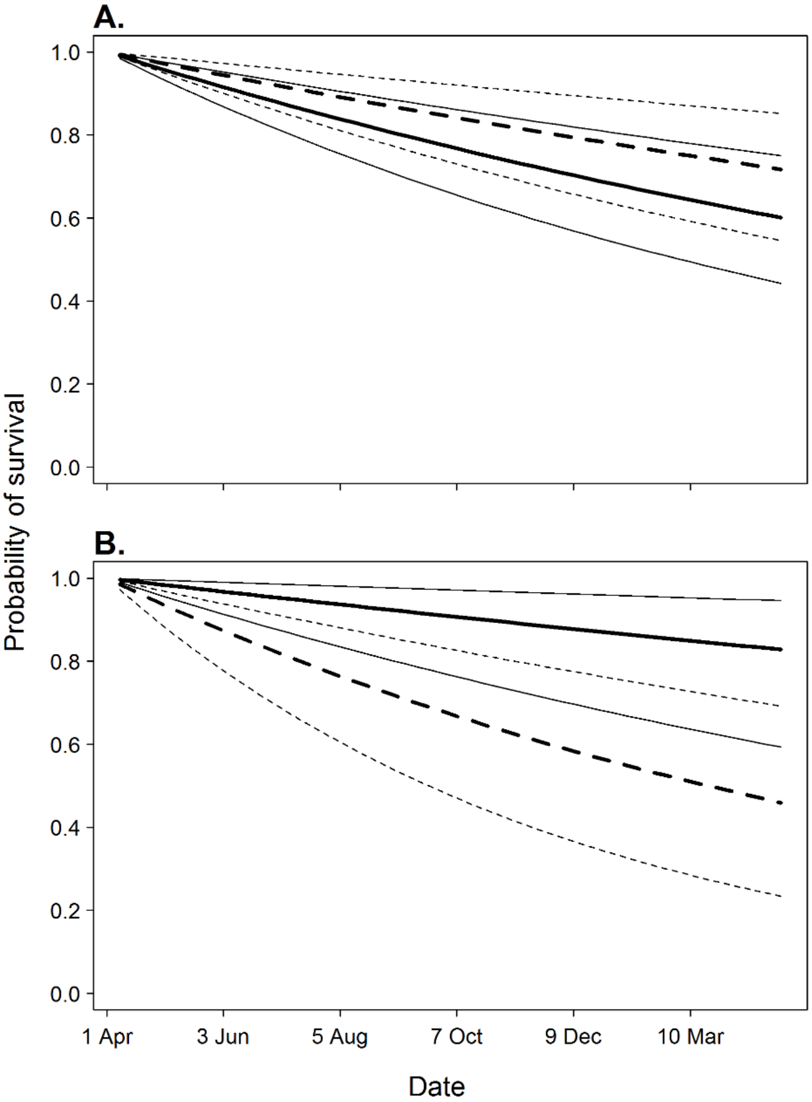


Figure 23. Survival curves for giant gartersnakes (*Thamnophis gigas*) 0 m from water (solid lines) and 30 m from water (dashed lines) (A), and giant gartersnakes with 0 percent cumulative mean rice within 100 m of their locations (dashed lines) and 52 percent cumulative mean rice within 100 m of their locations (solid lines) in rice-growing regions (B) of the Sacramento Valley, California, 2014–16. Bold lines represent posterior medians; light lines represent 95-percent credible intervals. Values for distances and percentages were based on the 5th and 95th percentiles of observed values.

Discussion

Regardless of how it was measured or modeled, giant gartersnakes that were associated with less rice near their locations or home ranges had lower survival rates than snakes with more rice available to them. Although we did not have the authority or ability to manipulate water and cropping patterns in the private ricelands used in this study, and therefore cannot infer causation, the observational data from this study strongly suggest a negative relationship between the amount of rice on the landscape and the survival rates of adult (mostly female) giant gartersnakes. The mechanism underlying this decrease in survival is unclear; however, it does not appear to be related to chronic deterioration of the health parameters we evaluated, increased movements, or changes in home range area because these variables were unaffected by the amount of rice on the landscape. Instead, other sources of mortality, such as starvation, malnutrition, impaired physiological or immunological function, or increased exposure to pathogens or predators are likely explanations. Predation, in particular, might be facilitated when giant gartersnakes and their predators, such as otters, wading birds, and raptors, are foraging in the same constrained linear waterways. Indeed, Halstead and others (2011) suggested this as the mechanism underlying the greater risk of mortality of giant gartersnakes in canals than restored wetlands, and Santos and Llorente (2009) suggested similar mechanisms for the decline of viperine snakes (*Natrix maura*) in the Ebro Delta, a rice-growing region in Spain. Not all giant gartersnake carcasses found in this study exhibited signs of predation, and additional hypotheses for increased risk of mortality in areas with reduced rice cultivation are worthy of study. Furthermore, multiple stressors could act together to increase risk of mortality, such as when hungry snakes increase foraging activity and therefore their exposure to predators.

Other variables also affected giant gartersnake survival. Distance from water had a positive effect on giant gartersnake survival. This seemingly counterintuitive result is consistent with seasonal movement patterns and previous research. Giant gartersnakes are found farthest from water during brumation, when they spend much of their time underground (Halstead and others, 2015); even during the active season, most giant gartersnakes located in terrestrial environments are found underground (Halstead and others, 2015). While snakes are taking refuge underground, they are at little risk of predation or many other sources of mortality. In contrast, snakes actively foraging in aquatic environments are exposed to predators and other sources of mortality. This mechanism also explains the higher risk of mortality of giant gartersnakes while they are in linear habitats than while they are in more complex areal habitats (Halstead and others, 2012).

Using the piecewise hazard indicated that the weekly risk of mortality of giant gartersnakes was greater during the emergence and pre-flood up period than during the active season and brumation, which were similar. Several mechanisms could cause higher mortality during this period. Snakes might be stressed after a long brumation period, leaving them vulnerable to starvation or exposed to predators. Suboptimal conditions for thermoregulation, including cool temperatures, could cause increased basking behavior. Basking combined with relatively little vegetation for cover could increase exposure to predators during the emergence period. Snakes also cannot forage during brumation, which leaves them vulnerable to starvation toward the end of brumation or early in the active season, before foraging occurs. This vulnerability could be exacerbated if water deliveries, which provide habitat for giant gartersnakes' aquatic prey, are delayed. Such delays are typical of drought years, and years with wet spring weather (above average rainfall in March and April) which delays field preparation. Providing water and prey to giant gartersnake populations as they emerge from brumation to forage in April and May and ensuring that snakes have thermoregulatory opportunities that also offer cover from predators might ameliorate the greater risk of mortality faced by giant gartersnakes in this season.

In addition to rice availability and distance to water, male giant gartersnakes in our study possibly had higher survival rates than females. Our small sample of males (n = 4) warrants caution in the interpretation of this finding, however. Indeed, the 95-percent credible interval for the male survival curve completely contained that for female snakes. Furthermore, our findings contradict survival estimates for giant gartersnakes in the American Basin (Hansen and others, 2015), where females had higher survival rates than males. Because giant gartersnakes are sexually dimorphic for size, the males in our sample were the very largest males, and capture-mark-recapture studies with much larger samples of smaller snakes are likely more reliable for estimating survival rates of male and juvenile snakes.

Surgical implantation of radio transmitters always carries the risk of biasing survival probabilities low. Without independent estimates of survival from the same location and time, it is difficult to evaluate whether transmitters have lethal effects on snakes. We suggest that potential negative effects of radio transmitters on survival in our study were small, because our annual survival estimates were similar to the highest capture-mark-recapture estimates for females in the American Basin and most adult snakes in the Natomas Basin (Hansen and others, 2015). Continuing capture-mark-recapture studies at the telemetry sites used in this study will help to evaluate the effects of surgically-implanted radio transmitters on giant gartersnake survival.

Decreased area of rice habitat also was related to less frequent and shorter movements by adult female giant gartersnakes. The reasons for decreased movements are not entirely clear, but one possibility is that a drier landscape is perceived as hostile to movement by female giant gartersnakes. Thus, the strategy used by adult female giant gartersnakes seems somewhat similar to that used by *Nerodia* experiencing drought in South Carolina—wait things out until the water comes back (Willson and others, 2006). This strategy resulted in extirpation or lower fecundity and population decreases for Florida green and southern watersnakes, respectively (Willson and others, 2006). Perhaps a similar sit–and–wait response also was related to the decreased survival of giant gartersnakes observed in this study. Although movements were decreased, there was no indication that adult female giant gartersnakes aestivated like the much smaller black swamp snakes in South Carolina (Willson and others, 2006).

The lack of any observed relation between the amount of rice and movement frequency or rate by males might be an artifact of the small sample of males monitored, or male movements might be less affected by the amount of aquatic habitat on the landscape. Such a scenario could occur if, for example, males were more tolerant of risky movements than females. Investigating the spatial ecology of male giant gartersnakes with a larger sample of individuals might be warranted if male movement and survival are found to be important to giant gartersnake population growth or demographic or genetic connectivity. Females made more frequent movements as extent of cultivated rice increased, which could indicate that increased habitat was viewed as more conducive to making movements. As our telemetry locations were taken for daily intervals during the active season, our measurements provide minimal estimates of distances. Future radio telemetry studies involving continuous or high frequency (e.g., hourly) observations of giant gartersnakes could reveal more detailed movement patterns. Nonetheless, our estimates likely provide reasonable estimates of overall activity and movement patterns.

Seasonal changes in the frequency and rate of movement of giant gartersnakes followed expected patterns related to their reproductive ecology. Male giant gartersnake movement peaked shortly after the spring mating season. A marked decrease in growth and body condition of male giant gartersnakes in the spring (Coates and others, 2009) suggests that males are anorexic during the spring mating season, and peak movements are likely associated with foraging activity. Males likely locate females in close proximity to their brumation sites, and spend substantial time courting females. Closely related and communally brumating red-sided gartersnakes (*Thamnophis sirtalis parietalis*) mate immediately upon spring emergence and prior to dispersing to their summer ranges (Gregory, 1974). Despite the lack of mass communal brumacula, giant gartersnake males seem to enlist a similar mating strategy.

In contrast to male giant gartersnakes, adult female giant gartersnakes had peaks of movement in April and again in August and September. Although the timing differed from that of male giant gartersnakes, the reason for more frequent and longer distance movements was likely the same—foraging. Reproduction is energetically costly for females (Shine, 2003), so females likely forage as much as possible upon emergence from brumation. As gestation proceeds, females are limited in their ability to move and in the space available to ingest prey by the bulk of the developing embryos they carry. Thus, females become relatively sedentary in late June and July. After giving birth, however, females again forage voraciously to store enough energy to make it through brumation and to reproduce the following year.

Movement patterns of both sexes, therefore, were consistent with the active foraging mode shown by most gartersnakes. Interestingly, movements to and from brumation sites did not seem important in the studied populations. Most individuals brumated in locations similar to those in which they sheltered during the active season—rodent burrows, crayfish burrows, and soil cracks immediately adjacent to canals. Deep flooding of our study sites is likely a rare event with the modern flood management system, so brumation near or within active season home ranges is likely the norm, rather than the exception, in most of the rice-growing regions of the Sacramento Valley.

Core areas and home ranges of giant gartersnakes were small and unaffected by the proportion of rice in the neighboring landscape. On average, one-half of a giant gartersnake's active season (i.e., core) locations were confined to an area less than 6,500 m^2. Assuming that most of these locations are within a 20-m-wide band centered on a canal, on average, giant gartersnakes would spend one-half their annual active season in a stretch of canal about 325 m long (6,500 m^2/20 m), although we note that core areas are not necessarily contiguous. Annual home range areas were relatively small as well, with mean home range area less than 4 ha (40,000 m^2; 1 ha equals about two football fields, including the end zones). The lack of a relation between rice availability and core and home range areas, combined with the positive (females) or nonexistent or non-detectable (males) relation between rice availability and movement frequency or rate, suggests that giant gartersnakes do not respond to decreases in extent of aquatic habitat by dispersing to areas with more habitat beyond their typical home ranges or movement patterns. Understanding how giant gartersnakes perceive the landscape and whether tactics can promote dispersal to stable habitat, could help inform effective conservation strategies.

As for core area and home range size, overlap of home ranges and core areas between individuals was unaffected by the amount of rice in the surrounding landscape. This was in contrast to expectations, because we hypothesized that a decrease in rice cultivation would lead to aggregation of snakes and greater home range overlap. In general, large adult giant gartersnake home range and core areas were unlikely to overlap, and when they did, the percentage of overlap was relatively small. It is likely that the true degree of core area and home range overlap was underestimated because (1) we only radio tracked a relatively small proportion of snakes in each population, (2) we only radio tracked adult snakes, and (3) most or all radio tracked individuals were female at each site. Estimates of overlap would increase as the proportion and representation of the population increased.

In contrast with little overlap among snakes, adult giant gartersnakes showed core area and home range fidelity among years. Annual core areas overlapped for over half our comparisons, and annual home ranges overlapped nearly 95 percent of the time, indicating that adult giant gartersnake space use is stable over time. Combined with relatively small core areas and home ranges, site fidelity indicates that changes to the local landscape, such as habitat conversion or reduced rice production, are likely to have negative consequences for giant gartersnakes.

Giant gartersnake selection of microhabitats and vegetation types was similar to expectations and observations from previous studies (Halstead and others, 2016), with some notable exceptions. It was unsurprising that, in general, microhabitats providing cover were selected, and those not providing cover were avoided; the lack of selection for emergent vegetation, however, was initially unexpected. During nearly one-half of the giant gartersnake active season, however, emergent vegetation in the form of rice fields dominates much of the landscape, but giant gartersnakes make relatively little use of this feature (figs. A1–A51). The results of the selection of vegetation types supports this hypothesis, with cultivated rice being avoided, but emergent aquatic vegetation associated with canals (such as tules, cattails, water-primrose, and smartweed) being selected. The most accurate depiction of giant gartersnake selection of emergent vegetation is that emergent vegetation in canals is positively selected, whereas emergent vegetation in rice fields is avoided, perhaps because canals provide more permanent water and taller emergent vegetation (e.g., tules and cattails) than rice fields.

Cover is not only important in aquatic habitats, but also in adjacent terrestrial locations. Giant gartersnakes spend more than one-half of their time during the active season in terrestrial environments near water, often underground (Halstead and others, 2015). Despite giant gartersnakes being subterranean much of the time they are in a terrestrial environment, vegetated cover in the terrestrial landscape is important for this species, and terrestrial vegetation and litter were the most strongly selected microhabitats. Annual grasses and forbs also were positively selected vegetation types typical of canal bank vegetation. In contrast to terrestrial vegetation and litter, bare ground was avoided by giant gartersnakes, likely because it does not provide cover from predators or a suitable thermal mosaic within which giant gartersnakes can regulate their body temperature.

Giant gartersnake selection of vegetation height categories further supports the importance of cover for thermoregulation, avoiding predation, and possibly foraging (Mullin and Mushinsky, 1995; Mullin and Gutzke, 1999). Herbaceous vegetation more than 1 m tall was selected by giant gartersnakes, and all shorter vegetation was avoided. Interestingly, the shorter the vegetation, the more strongly it was avoided. Maintaining tall emergent and terrestrial herbaceous vegetation in canals and along canal banks likely improves conditions for giant gartersnakes, provided that the water or soil surface is not completely shaded, thus limiting thermoregulatory opportunity.

Giant gartersnake health, as measured by the hematological and plasma biochemistry parameters examined, was not affected by habitat conditions. Nonetheless, some interesting patterns emerged. Giant gartersnakes collected from our study sites from 2014 to 2016 had much lower white blood cell counts (including heterophils, lymphocytes, basophils, and azurophils) than giant gartersnakes captured from Sacramento, Merced, and Fresno Counties in 2008 and analyzed by Wack and others (2012). The white blood cell counts for giant gartersnakes in this study are more similar to the values Wack and others (2012) report from valley gartersnakes, *Thamnophis sirtalis fitchi*, a common, non-threatened species that is found in many of the same habitats as giant gartersnakes. Wack and others (2012) hypothesized that the higher white blood cell count in giant gartersnakes relative to valley gartersnakes in their study was not simply a difference in the baseline health between two species, but rather could be a sign of chronic inflammation in giant gartersnakes. If that is the case, the lower white blood cell counts in this study are a sign that the giant gartersnakes we examined are in better health, or at least not suffering as much stress and inflammation as the giant gartersnakes examined by Wack and others (2012) previously. However, we cannot rule out an alternative explanation, which is that the white blood cell counts reported by Wack and others (2012) represent a normal, healthy “baseline” value for giant gartersnakes, and the lower white blood cell counts we report represent snakes with a compromised or weakened immune system.

High levels of the AST enzyme in plasma may indicate that body tissue or organs are diseased or damaged. The lower median AST value of giant gartersnakes in this study (16.5 IU/L) compared to Wack and others (2012), (22 IU/L) is not different enough to be considered clinically significant. The AST values measured in giant gartersnakes in this study are very similar to those found in valley gartersnakes by Wack and others (2012), which further suggests that the AST values in this study represent a normal baseline level.

Elevated creatinine kinase levels in blood plasma can be a sign of damage to muscle tissue, including skeletal muscle and heart tissue. The slightly lower median creatinine kinase concentration in this study (387 IU/L) compared to that reported by Wack and others (2012) (439 IU/L), is not a great enough difference to be clinically significant. However, nine giant gartersnakes in this study had creatinine kinase levels higher than the maximum value found in a giant gartersnake by Wack and others (2012). This indicates that, although most giant gartersnakes in this study had normal levels of creatinine kinase in their plasma, these nine snakes may have been experiencing stress to muscle tissue that caused elevated concentrations of this protein in their plasma. Interestingly, two of the snakes with the highest creatinine kinase levels also had among the highest white blood cell counts, which in combination suggest these two individuals were stressed.

The slightly higher concentration of phosphorus in the plasma of giant gartersnakes in this study (5.3 mg/dL) compared to giant gartersnakes examined in 2008 and reported by Wack and others (2012) (3.8 mg/dL) could be a sign of better nutritional status or dehydration. However, other plasma solutes such as sodium, total protein, uric acid, potassium, and calcium were found to be at nearly equal concentrations in the two studies. Presumably if snakes were dehydrated in the current study, all these plasma solutes would be at elevated concentrations, not just phosphorus. Phosphorus concentration in the plasma exhibited a slight seasonal pattern, with higher concentrations in the spring and lower concentrations in late summer. It is possible that the difference in phosphorus concentrations between the two studies is in part driven by this seasonal pattern. Both Wack and others (2012) and this study sampled snakes from April to September; however, it is possible that a greater proportion of snakes had blood drawn in the spring in this study, while in Wack and others (2012) a greater proportion of giant gartersnakes had blood drawn later in the summer, when phosphorus concentrations are lower overall. Along with plasma phosphorus concentrations, there was also a weak effect of season on uric acid concentration, which again could reflect seasonal patterns of dehydration related to periods of activity, foraging, and brumation. Uric acid concentration is also influenced by the time since a snake last consumed prey.

There was no effect of the proportion of rice agriculture within a snake’s buffered home range (MCP) on any of the hematological or plasma biochemistry parameters we measured. We hypothesized that the decreased availability of wetland habitat, due to the recent drought for example, may cause increased stress and, therefore, poor health in giant gartersnakes, which depend on wetlands. Although there was substantial variability among individual giant gartersnakes in the proportion of their buffered home range composed of rice, this did not seem to result in differences in their blood parameters, hydration levels, or overall health status. Indeed, very few of our proposed explanatory variables were strongly related to the hematological and plasma parameters we measured. One notable exception was a difference in hemoglobin concentrations between males and females. Male giant gartersnakes had higher hemoglobin levels than females. Although we do not know for certain what may drive this difference, sex differences in hemoglobin are common in mammals, with males having higher hemoglobin levels than females (Murphy, 2014). Sex differences in hemoglobin levels have been observed in reptiles as well, with male captive New Guinea snapping turtles (*Elseya novaeguineae*) having higher hemoglobin concentrations than females (Anderson and others, 1997). In gopher tortoises (*Gopherus polyphemus*) and eastern gartersnakes (*Thamnophis sirtalis sirtalis*), researchers have found no difference in hemoglobin concentrations between males and females (Taylor and Jacobson, 1982; Birchard and others, 1984). Our study thus contributes to a relatively unknown area of reptile health and physiology. Still, because of our small sample size for male snakes (n=4), there is much uncertainty around our estimate of male hemoglobin levels, and we should be cautious about concluding that male giant gartersnakes consistently have higher hemoglobin levels in their blood than females. Wack and others (2012) did not find any differences in blood parameters between male and female giant gartersnakes. Because our current study was based on giant gartersnakes tracked with radio-telemetry, we only sampled blood from snakes large enough to have a radio transmitter implanted. Because giant gartersnakes are characterized by sexual size dimorphism, with females much larger than males (Wylie and others 2010), this meant that most of the snakes we sampled were females. It would be beneficial in a future study to collect blood samples from equal numbers of male and female snakes and test again for differences in blood parameters among the sexes to establish if this is a consistent trend.

The weak positive relation between giant gartersnake snout-vent length and albumin concentration in blood plasma lacks any obvious explanation. Albumin is a protein involved in maintaining blood pressure and transporting various minerals, proteins, and fatty acids throughout the body. Therefore, we can speculate that larger giant gartersnakes may have higher albumin concentrations because they need to transport larger amounts of these nutrients in and out of tissues where they are stored to support growth and reproductive activities. Because the median and range of albumin levels in this study are nearly equal to those reported by Wack and others (2012), we do not think that the relation between albumin concentration and giant gartersnake snout-vent length is an indication of the relative health of larger compared to smaller snakes.

Although the amount of rice on the landscape did not influence the health or home range sizes of giant gartersnakes, and giant gartersnakes avoided cultivated rice itself, increased mobility of female giant gartersnakes and especially improved survival when rice is abundant indicate that cultivated rice is an essential component of giant gartersnake habitat in the contemporary landscape. In our study, decreased availability of rice, which is strongly correlated with a decrease in the extent of aquatic habitat available on the landscape, had direct negative consequences for giant gartersnakes through decreased survival rates. Results indicate that although most individuals did not use rice, and those that did only ventured into the fields between mid-June and early September, maintaining water in canals alone would not adequately support giant gartersnakes. Alternatives to rice production including habitat restoration or expansion of natural wetlands may benefit giant gartersnake populations in the absence of rice agriculture. However, because all of our study sites occurred in a matrix of rice agriculture, these alternatives were beyond the scope of this research. Nonetheless, maintaining canals that support the habitat components giant gartersnakes select most (terrestrial vegetation on banks, tules and other emergent vegetation in canals) and maximizing the extent of rice agriculture will likely benefit giant gartersnake populations in the rice-growing regions of the Sacramento Valley.

Summary

Most extant giant gartersnake populations persist in an agro-ecosystem dominated by rice, which serves as a surrogate to the expansive marshes lost to flood control projects and development of the Great Central Valley of California. Although our study indicated that giant gartersnakes make little use of rice fields themselves, and avoid cultivated rice relative to its availability on the landscape, rice is a crucial component of the modern landscape for giant gartersnakes. Giant gartersnakes are strongly associated with the canals that supply water to and drain water from rice fields; these canals provide much more stable habitat than rice fields because they maintain water longer and support marsh-like conditions for most of the giant gartersnake active season. Nonetheless, our results suggest that maintaining canals without neighboring rice fields would be detrimental to giant gartersnake populations, with decreases in giant gartersnake survival rates associated with less rice production in the surrounding landscape. Increased productivity of prey populations, dispersion of potential predators across a larger landscape, and a more secure water supply are just some of the mechanisms by which rice fields might benefit giant gartersnakes in adjacent canals. Results indicate that identifying how rice benefits giant gartersnakes in canals and the extent to which the rice agro-ecosystem could provide these benefits when rice is fallowed would inform the use of water for other purposes without harm to giant gartersnakes. Our study also suggests that without such understanding, maintaining rice and associated canals in the Sacramento Valley is critical for the sustainability of giant gartersnake populations.

Acknowledgments

We are indebted to the 11 private landowners that allowed us access to their lands to conduct this study; without their cooperation, this study would not have been possible. We thank E. Matchett and M. Nafus for their insightful comments and review. We thank L. Parker for administrative assistance, and many biological technicians, including C. Abeles, K. Anderson, L. Belo-Rex, R. Bhatt, M. Cook, J. Demianew, N. Dotson, G. Ferber, R. Fichman, C. Garbark, B. Graevs, A. Green, R. Hill, R. Kim, D. Knapp, B. Larsen, R. Lee, B. Lowe, D. Macias, D. Mackell, S. McNally, A. Merritt, A. Mott, M. Munn, D. Munoz, C. Murphy, G. Napolitano, B. O'Brien, K. Ober, E. Parsons, A. Prang, C. Scriven, J. Shepherd, J. Vargas, P. Waldron, and T. Wisneski, for their assistance with this project. Snakes were handled in accordance with IACUC protocol WERC-2014-01 and as stipulated in U.S. Fish and Wildlife Service Recovery Permit TE-157216-2 and California Scientific Collecting Permit SC-10779.

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Glossary

Abundance: The number of individuals of a population in the sampled area.
Bayesian analysis: A method of statistical inference in which Bayes' rule is used to update probability distributions as data are acquired.
Body condition: Any of a number of indices that relate body mass to structural body size.
Brumation: A state of dormancy in reptiles and amphibians similar to hibernation, but involving different metabolic processes.
Centrarchidae: A family of freshwater ray-finned fishes in the order Perciformes that includes the sunfish (for example, largemouth bass, bluegill, pumpkinseed, and crappie).
Coefficient: A parameter of a statistical (regression) model that indicates how the response variable changes with the predictor variable; analogous to the slope of a line.
Confidence interval: A statistical interval estimate of a parameter such that, if constructed across many replicated experiments, the proportion of such intervals that contain the true fixed value of the parameter equals the given confidence level.
Convergence: The meeting and overlapping of independent Markov chains in a Markov-chain Monte Carlo simulation, used to assess whether the stationary posterior distribution has been reached.
Covariate: A (predictor) variable thought to be correlated with another (response) variable used in a regression analysis.
Credible interval (CI): A specified domain of the posterior probability distribution used for interval estimation. Credible intervals can be interpreted as the probability, confidence, or belief that a parameter or value falls within the specified region.
Cyprinidae: A large family of freshwater fishes containing the carps, minnows, and their relatives.
Demography: The scientific study of populations, especially with regard to their size, structure, distribution, and dynamics.
Density: The number of individuals in a population per unit area or volume.
Dimorphic: Having two forms.
Extirpate: To cause a species to go extinct within a portion of its range.
Forage: To search for food.
Full model: The model containing the entire set of predictors (and their potential interactions) considered.
Gravid: Pregnant.
Hazard: The risk of mortality faced by an individual during a specified time period.
Home range: The area within which an animal carries out foraging, mating, and other normal activities.
Litter: The number of young brought forth by an iteroparous animal at one parturition.
Local convex hull (LoCoh): A method for calculating the home range of an animal that distinguishes high use areas from rarely used areas on the periphery of the home range.
Markov-chain Monte Carlo (MCMC): A class of algorithms for sampling from a probability distribution based on constructing a Markov chain that has the desired distribution as its equilibrium distribution.
Metabolic: Of, relating to, or affected by metabolism.
Minimum convex polygon (MCP): The smallest polygon that encloses all of an animal's locations.
Morphology: The form and structure of an organism.
Natricinae: A subfamily of the family Colubridae of snakes, which includes European grass snakes and North American watersnakes and gartersnakes.
Neonate: A newborn.
Occurrence: The state of a site, habitat, etc. being occupied by a species.
Parturition: The act or process of giving birth to offspring.

Posterior distribution: The probability distribution of an unknown quantity conditional on the evidence obtained from an experiment or survey, possibly taking into account relevant information available prior to the experiment or survey.

Posterior probability: The conditional probability assigned to a random event after relevant evidence or background has been taken into account.

Precinctive: Restricted to a defined geographic area.

Prior probability: The probability distribution that expresses one's uncertainty about an unknown quantity before some evidence (experiment, survey, observation, etc.) is taken into account.

Quadratic: Involving the square of a predictor variable in a regression model.

Range: The geographic limits within which all individuals of a species are found, excluding those in captivity.

Species: The basic category of biological classification, ranking below a genus and consisting of related individuals capable of interbreeding.

Subspecies: A subdivision of a species, especially a geographical or ecological subdivision.

Subterranean: Existing, situated, or operating below the surface of the earth; underground.

Survival: The rate or probability at which individuals alive at time t remain alive until time $t + 1$.

Uninformative prior: A prior probability distribution that expresses vague or general information about a variable, typically with the goal of assigning equal probabilities to all possibilities.

Appendix A. Home Range Figures

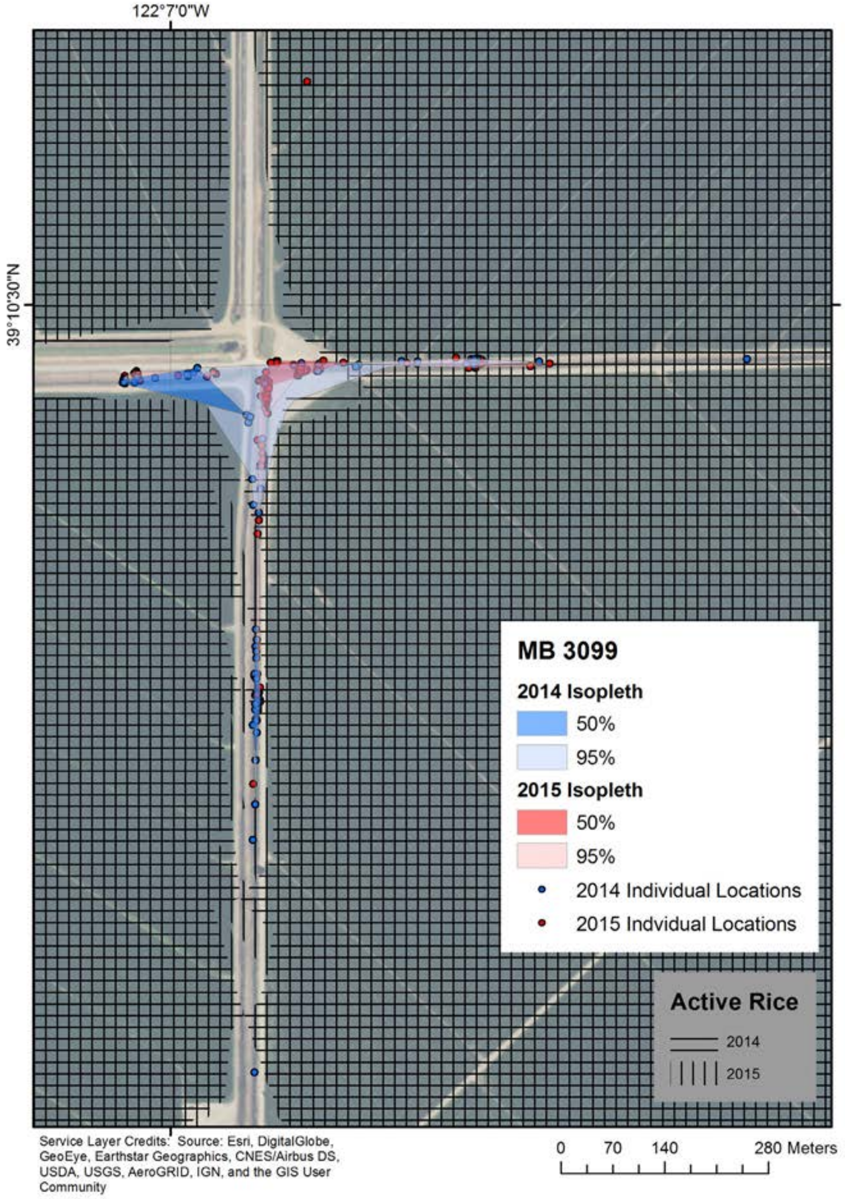
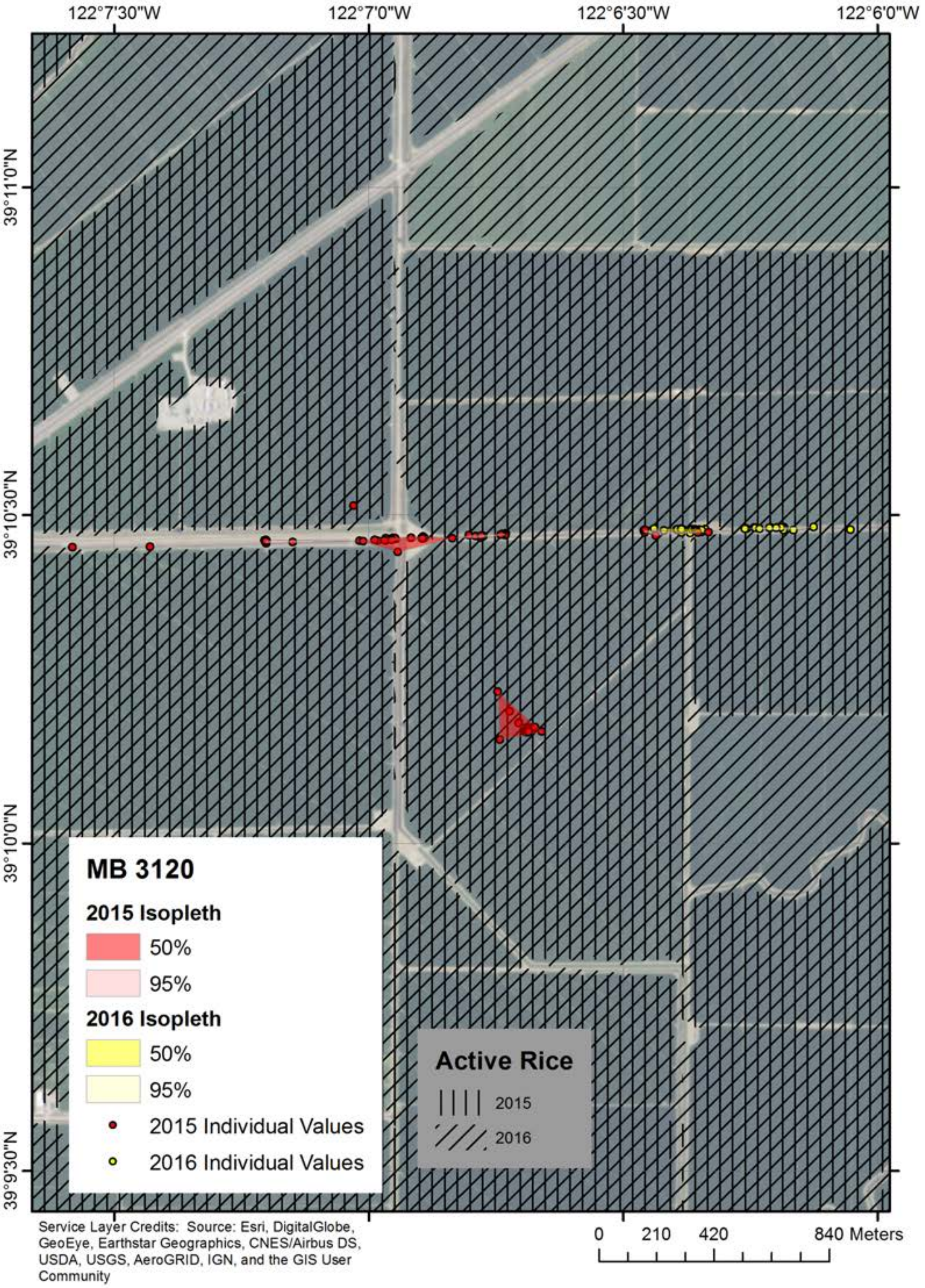


Figure A1. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3099 at site 1, Sacramento Valley, California. For detailed information on snake, see table 5.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A2. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3120 at site 1, Sacramento Valley, California. For detailed information on snake, see table 5.

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A3. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3158 at site 1, Sacramento Valley, California. For detailed information on snake, see table 5.

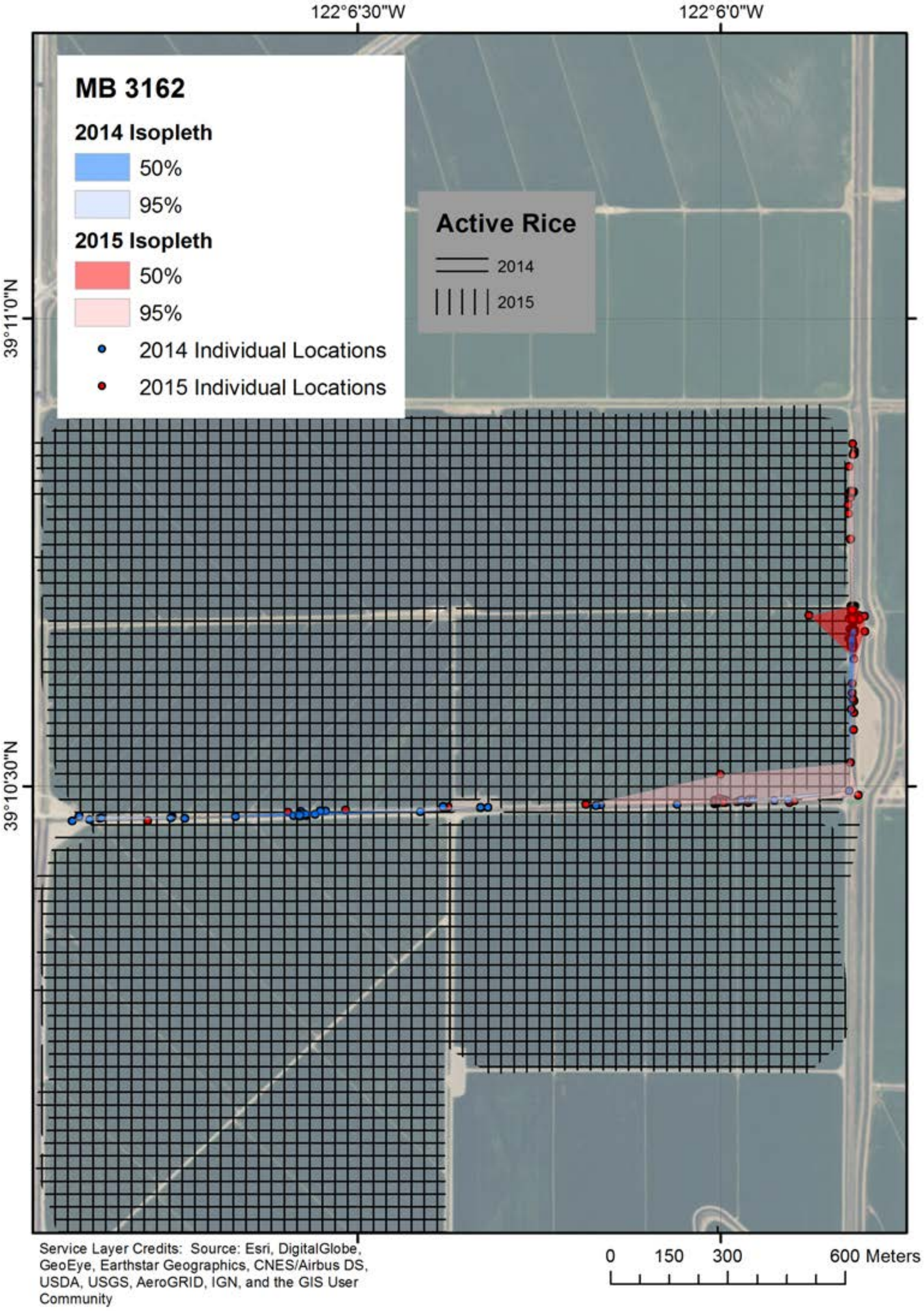


Figure A4. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3162 at site 1, Sacramento Valley, California. For detailed information on snake, see table 5.

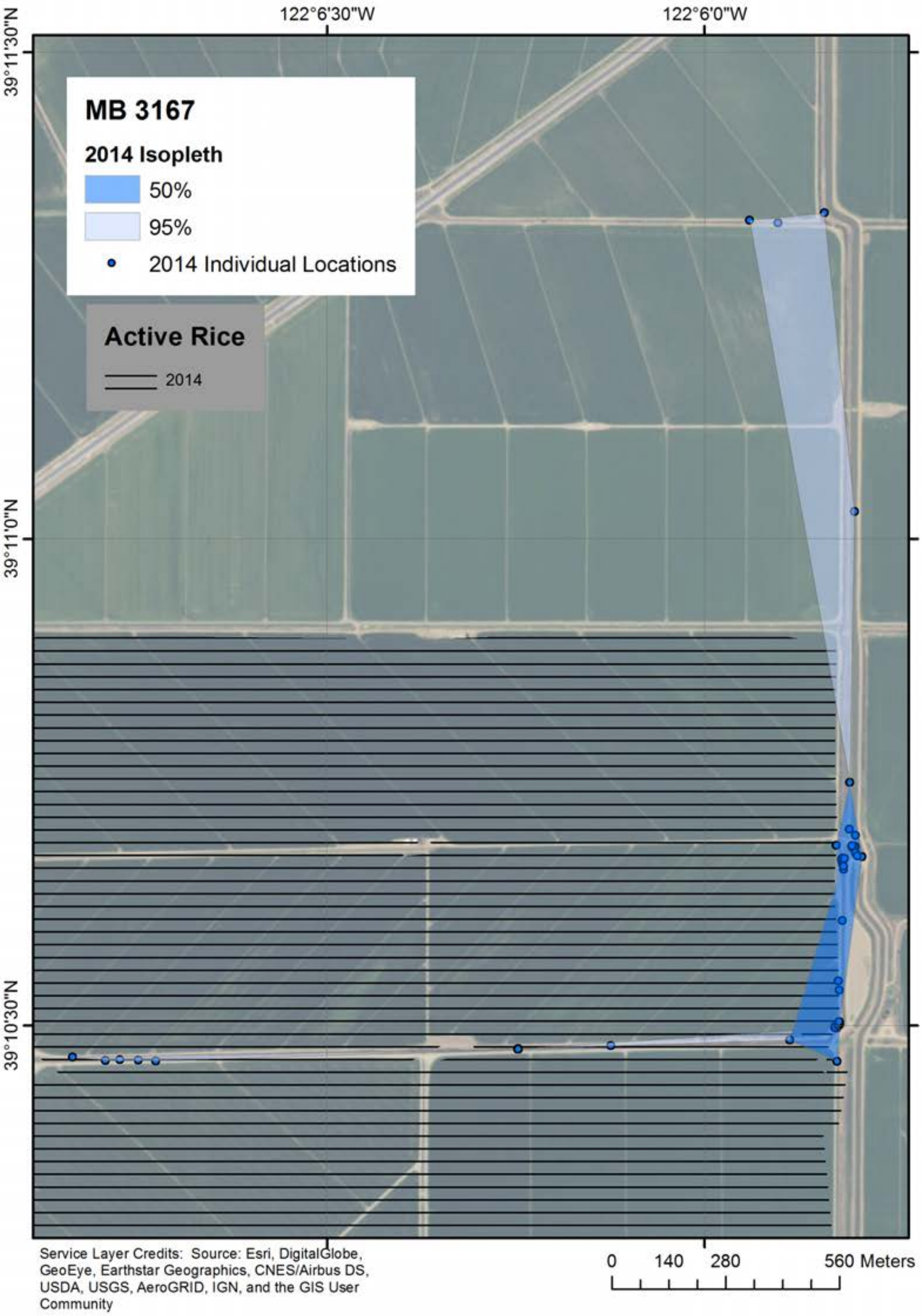
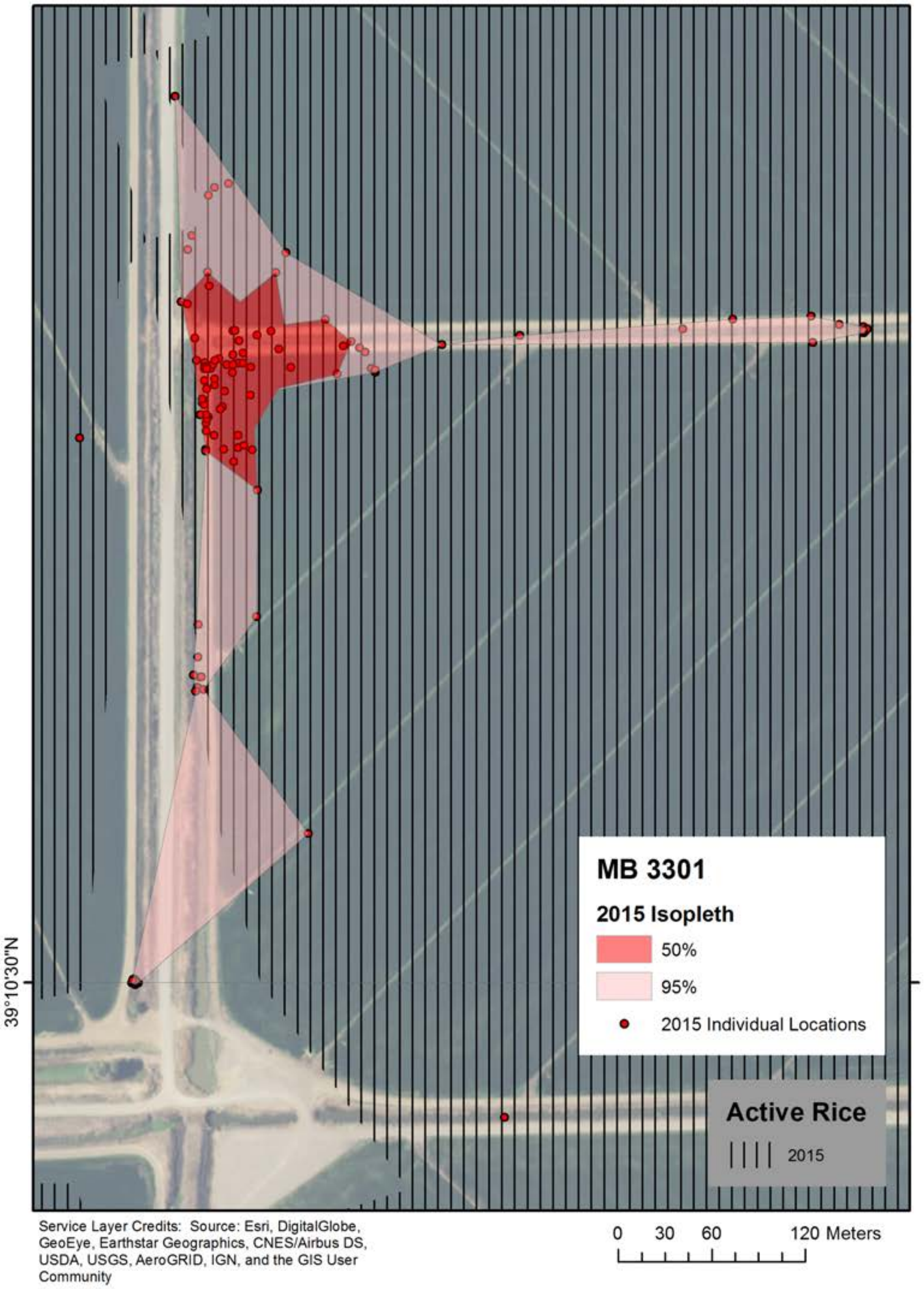
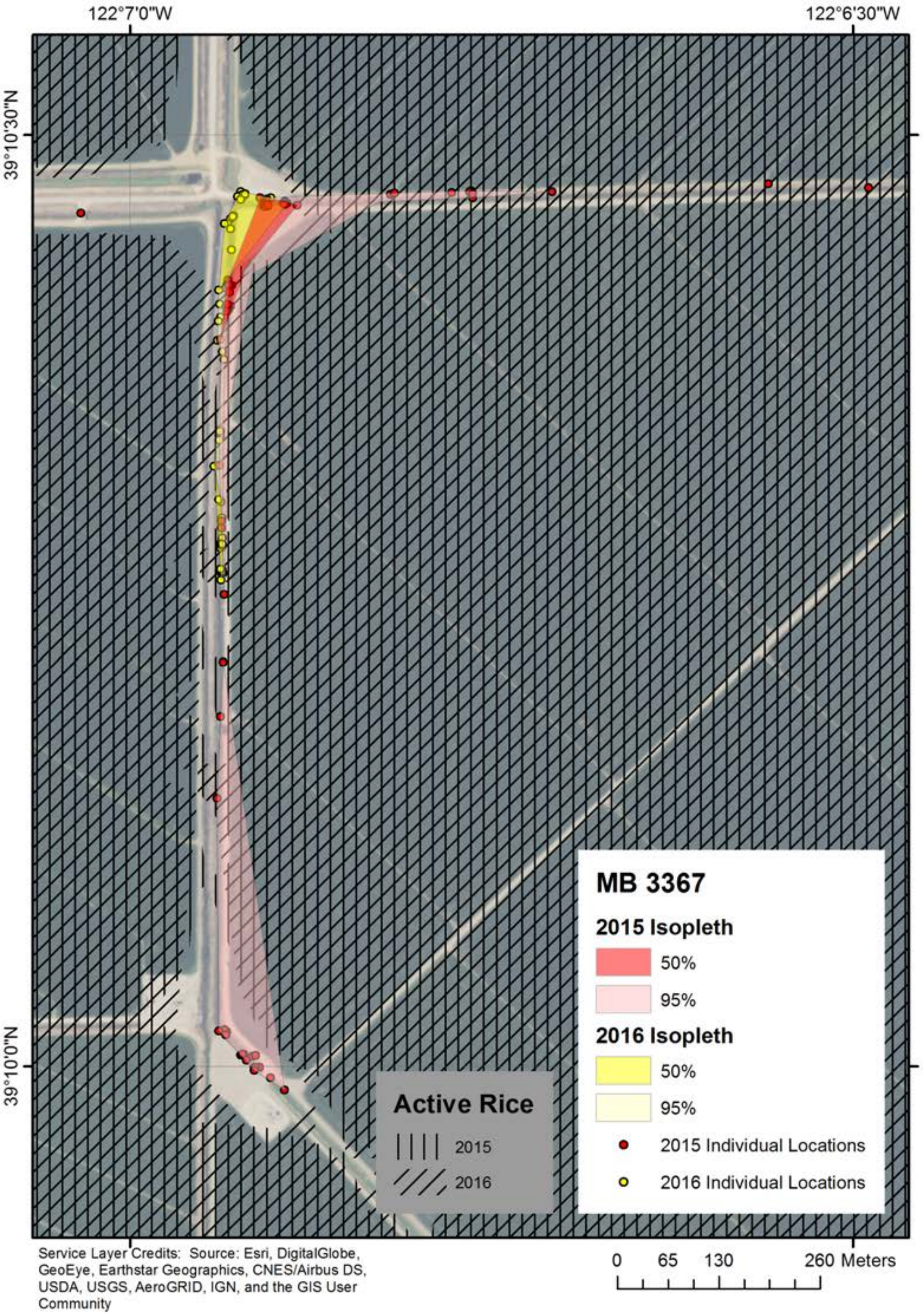


Figure A5. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3167 at site 1, Sacramento Valley, California. For detailed information on snake, see table 5.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A6. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3301 at site 1, Sacramento Valley, California. For detailed information on snake, see table 5.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A7. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3367 at site 1, Sacramento Valley, California. For detailed information on snake, see table 5.

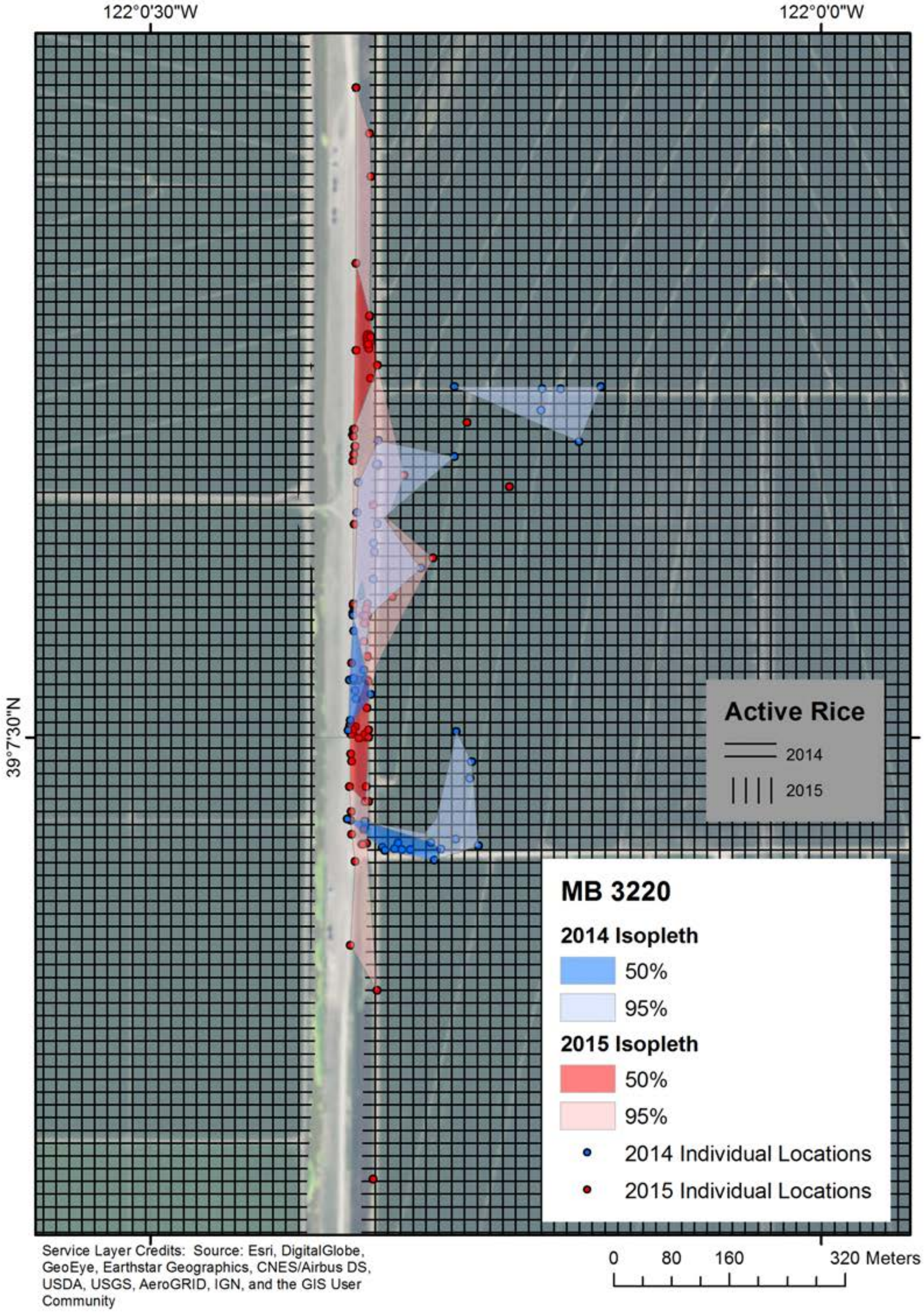
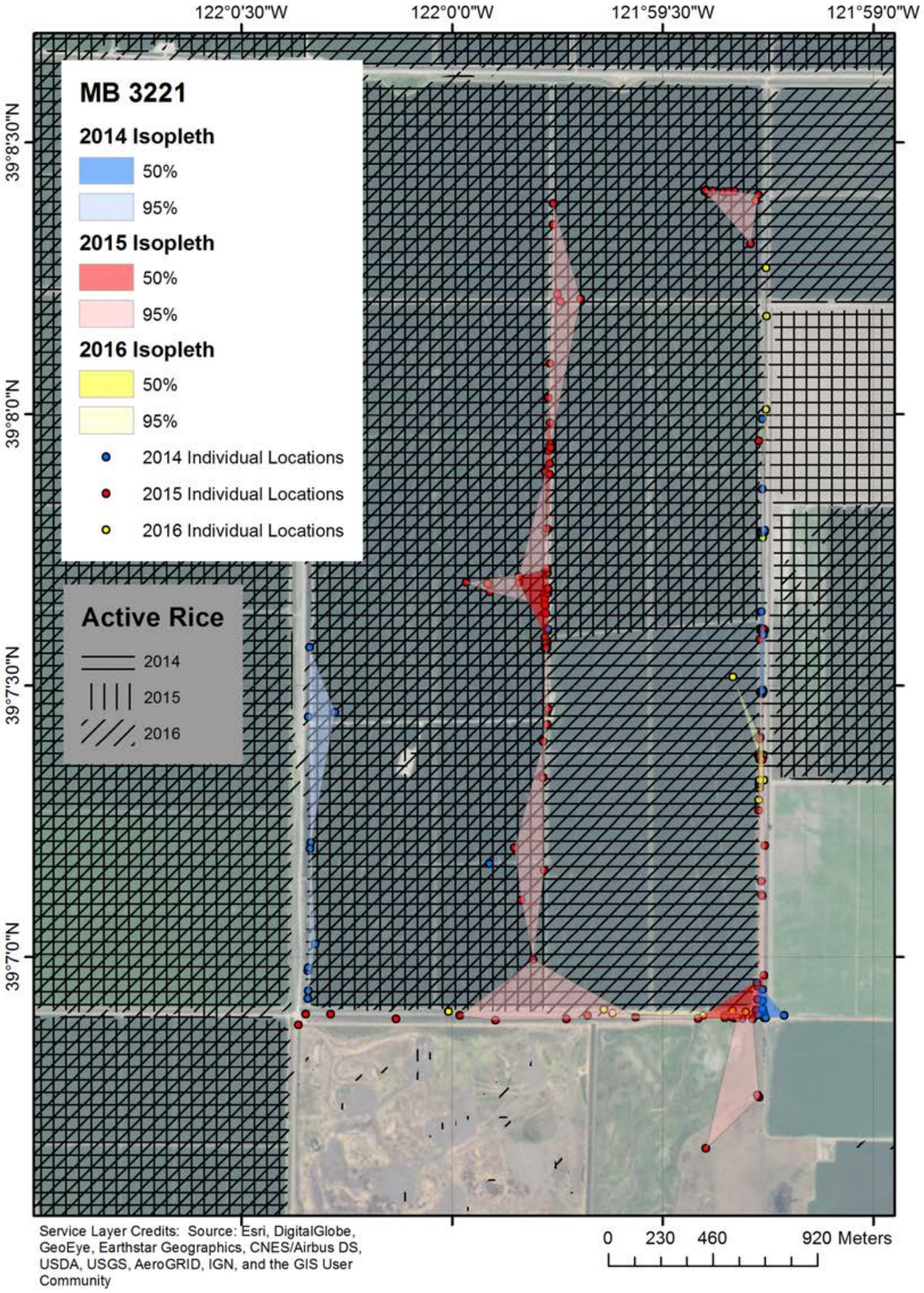


Figure A8. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3220 at site 2, Sacramento Valley, California. For detailed information on snake, see table 5.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A9. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3221 at site 2, Sacramento Valley, California. For detailed information on snake, see table 5.

Figure A10. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3254 at site 2, Sacramento Valley, California. For detailed information on snake, see table 5.

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Figure A11. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3255 at site 2, Sacramento Valley, California. For detailed information on snake, see table 5.

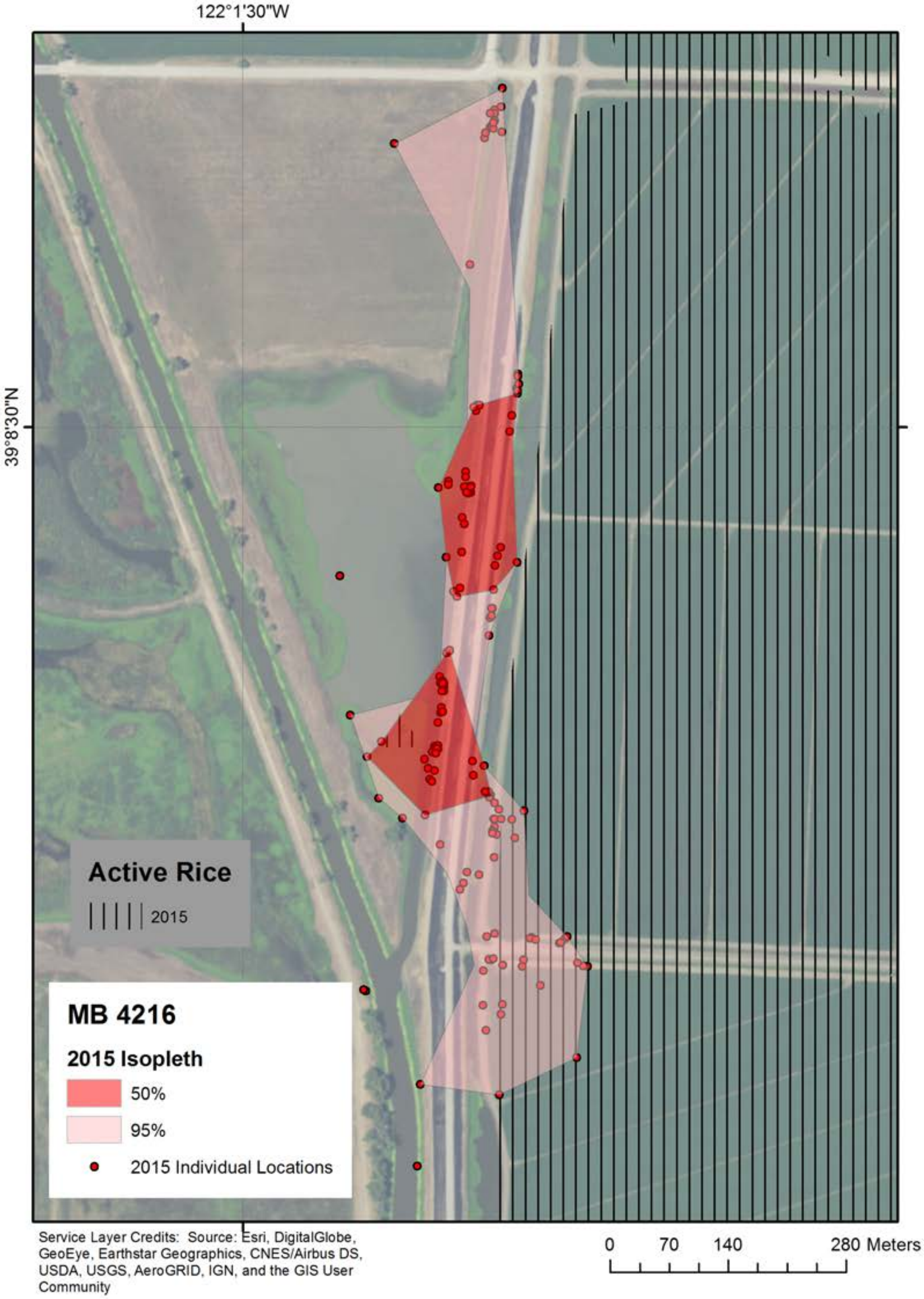
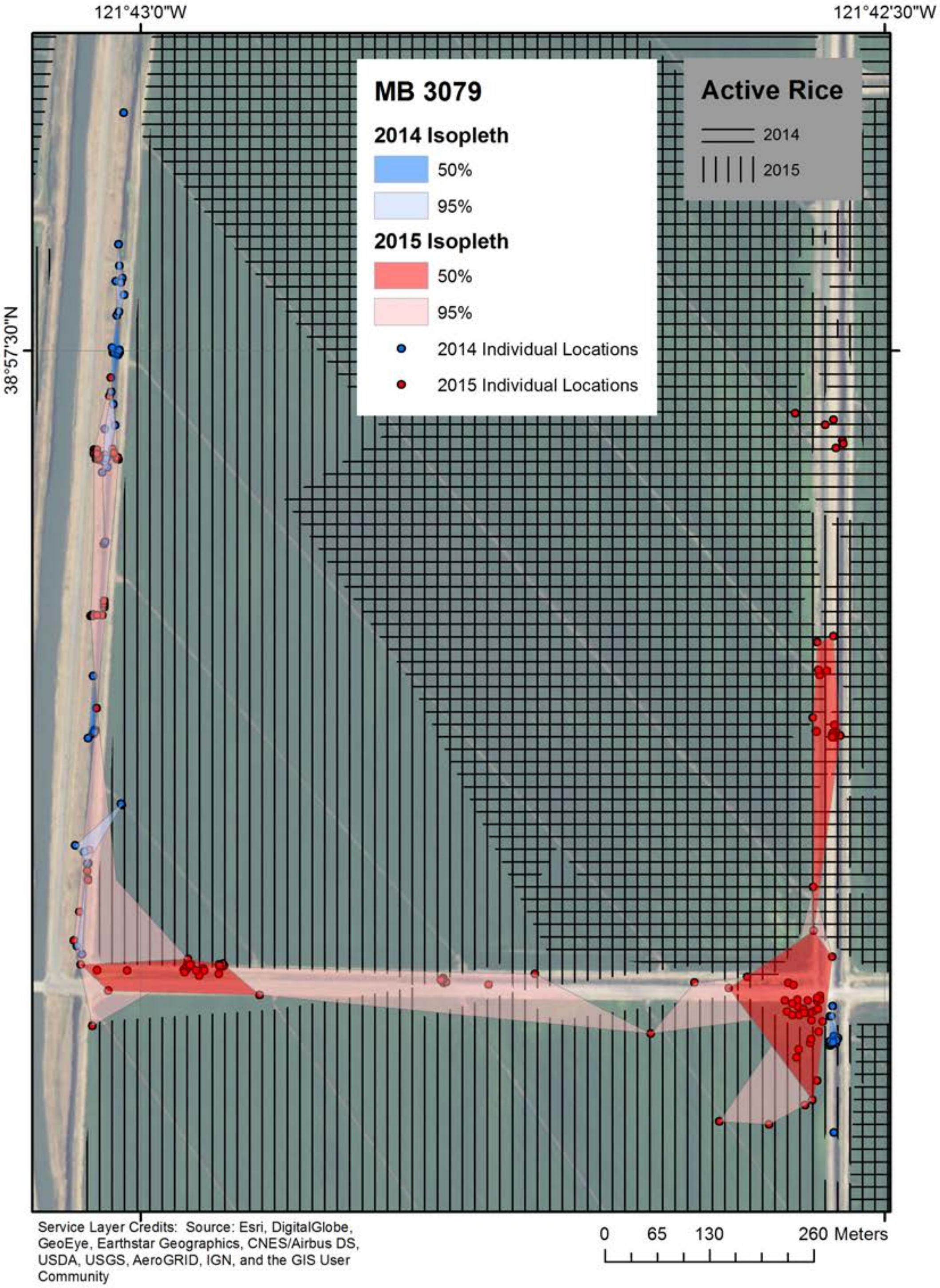
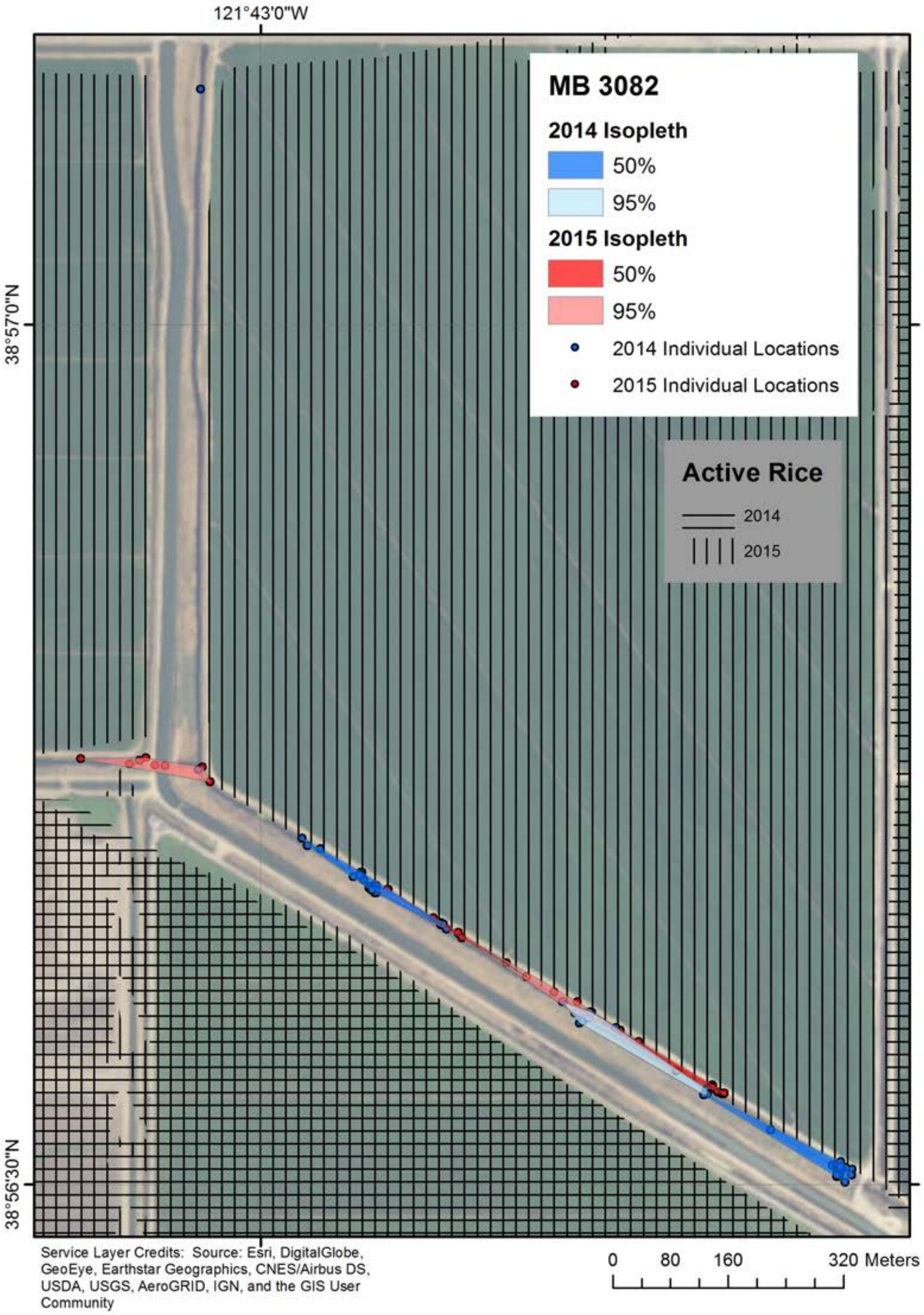


Figure A12. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 4216 at site 2, Sacramento Valley, California. For detailed information on snake, see table 5.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A13. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3079 at site 3, Sacramento Valley, California. For detailed information on snake, see table 5.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

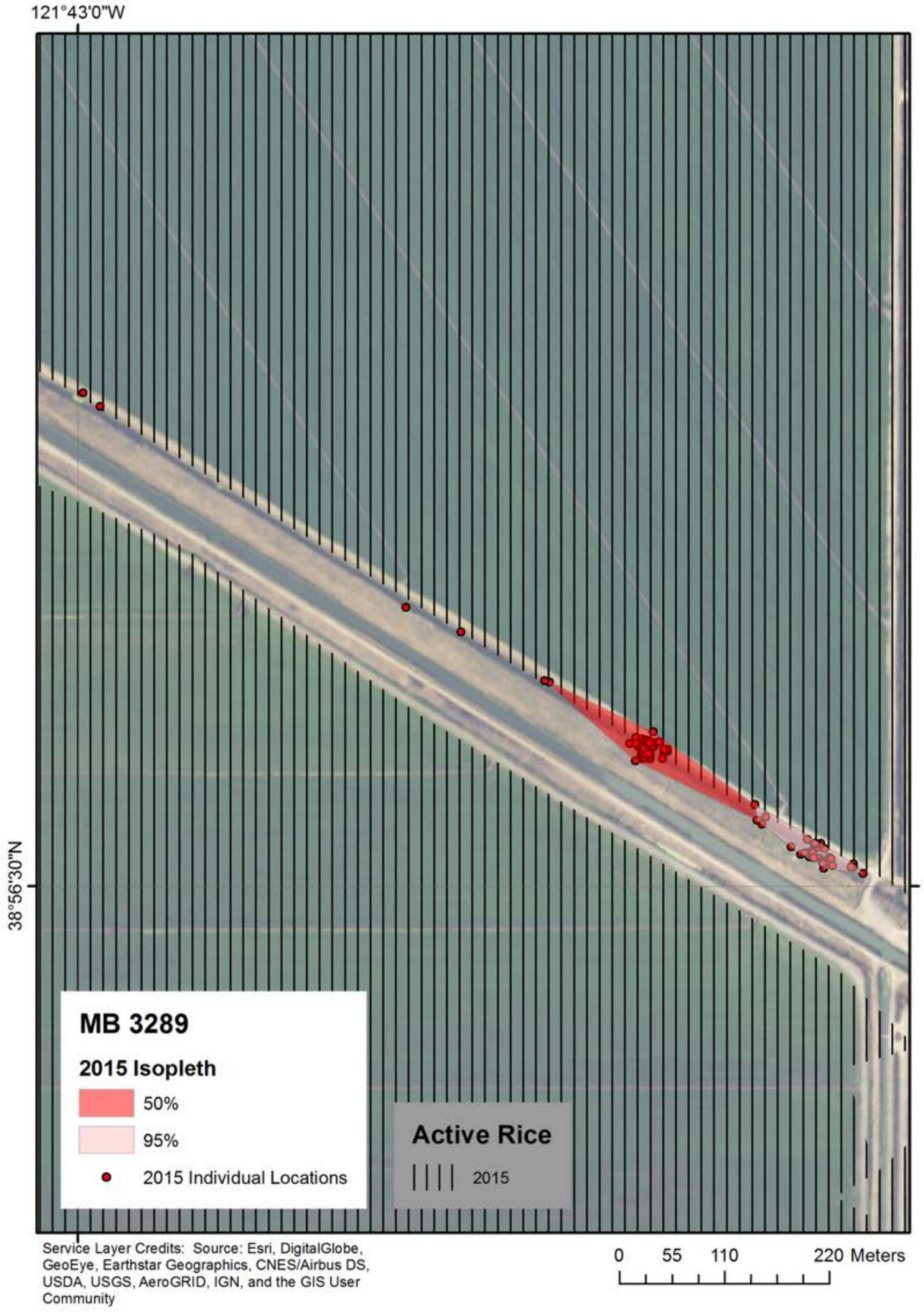
Figure A14. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3082 at site 3, Sacramento Valley, California. For detailed information on snake, see table 5.

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A15. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3103 at site 3, Sacramento Valley, California. For detailed information on snake, see table 5.

Figure A16. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3137 at site 3, Sacramento Valley, California. For detailed information on snake, see table 5.

Figure A17. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3237 at site 3, Sacramento Valley, California. For detailed information on snake, see table 5.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A18. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3289 at site 3, Sacramento Valley, California. For detailed information on snake, see table 5.

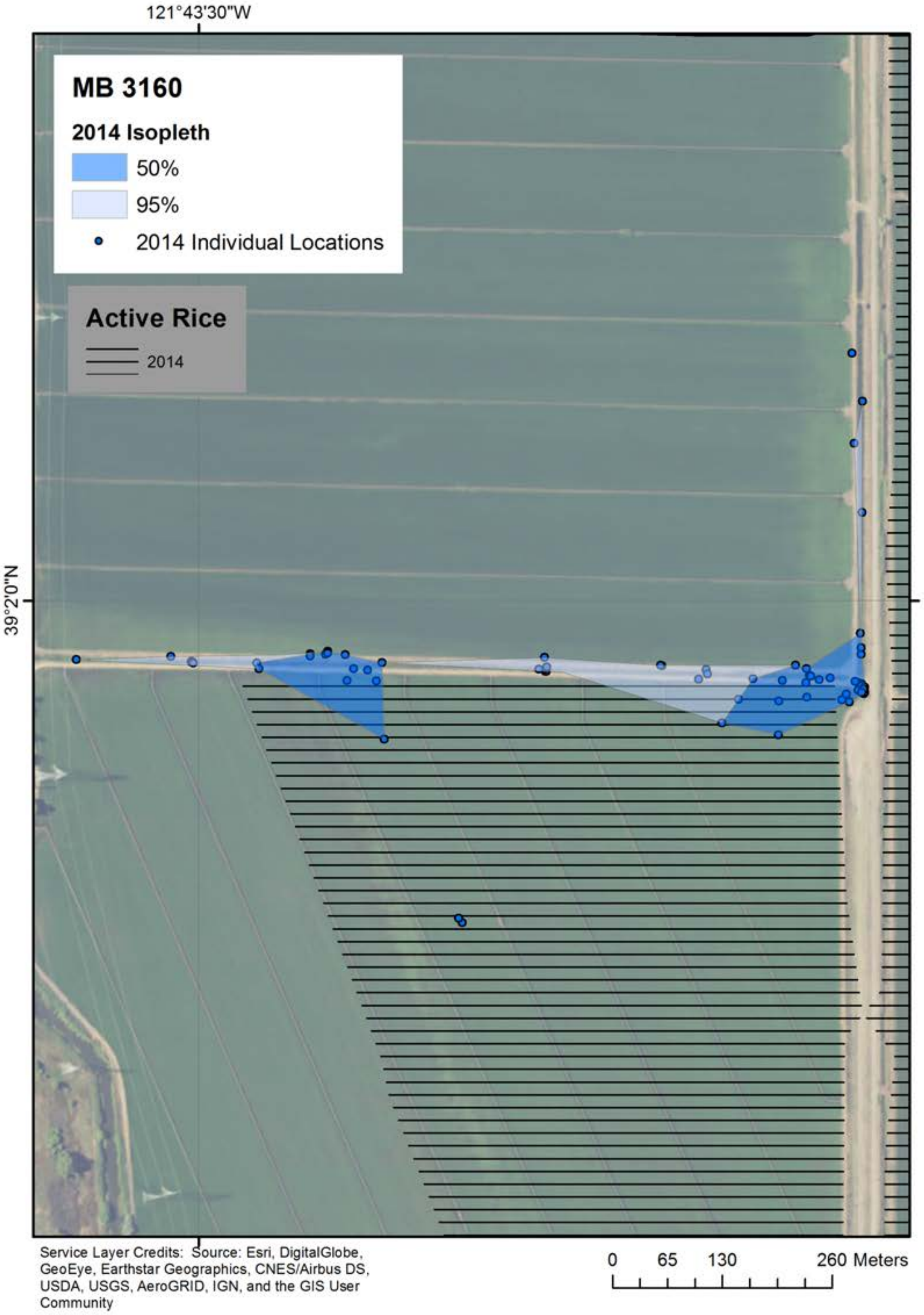


Figure A19. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3160 at site 4, Sacramento Valley, California. For detailed information on snake, see table 5.

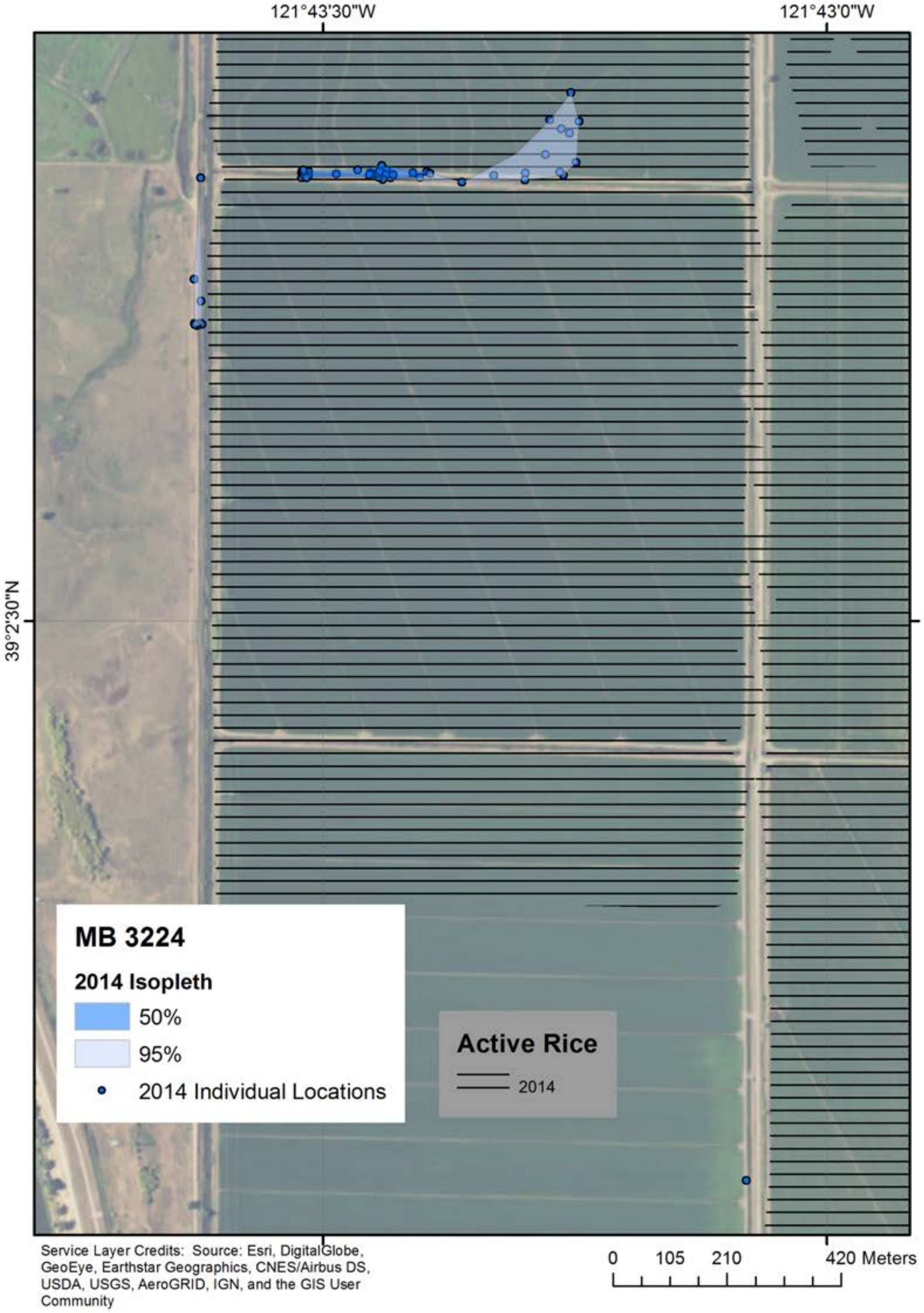


Figure A20. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3224 at site 4, Sacramento Valley, California. For detailed information on snake, see table 5.

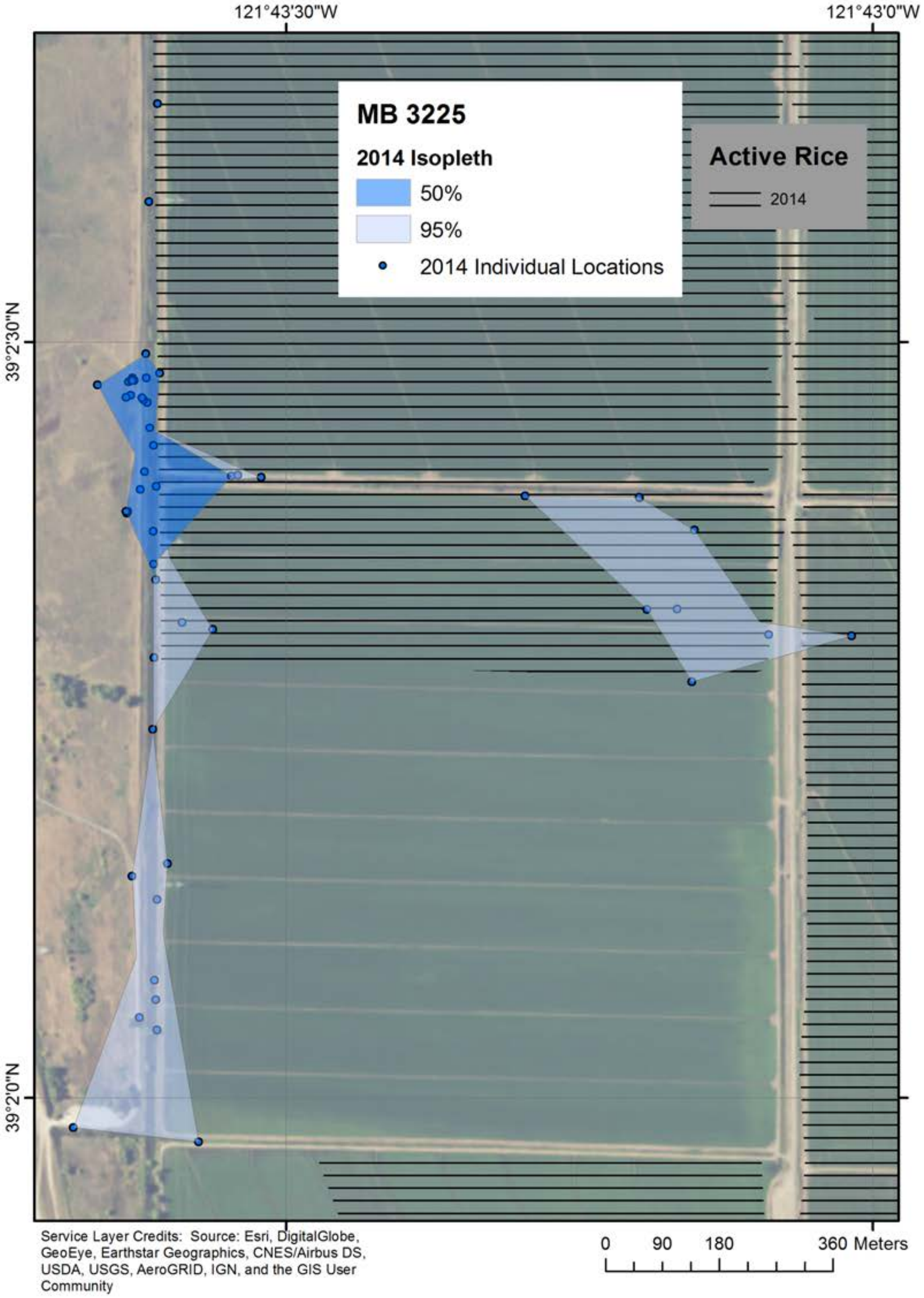
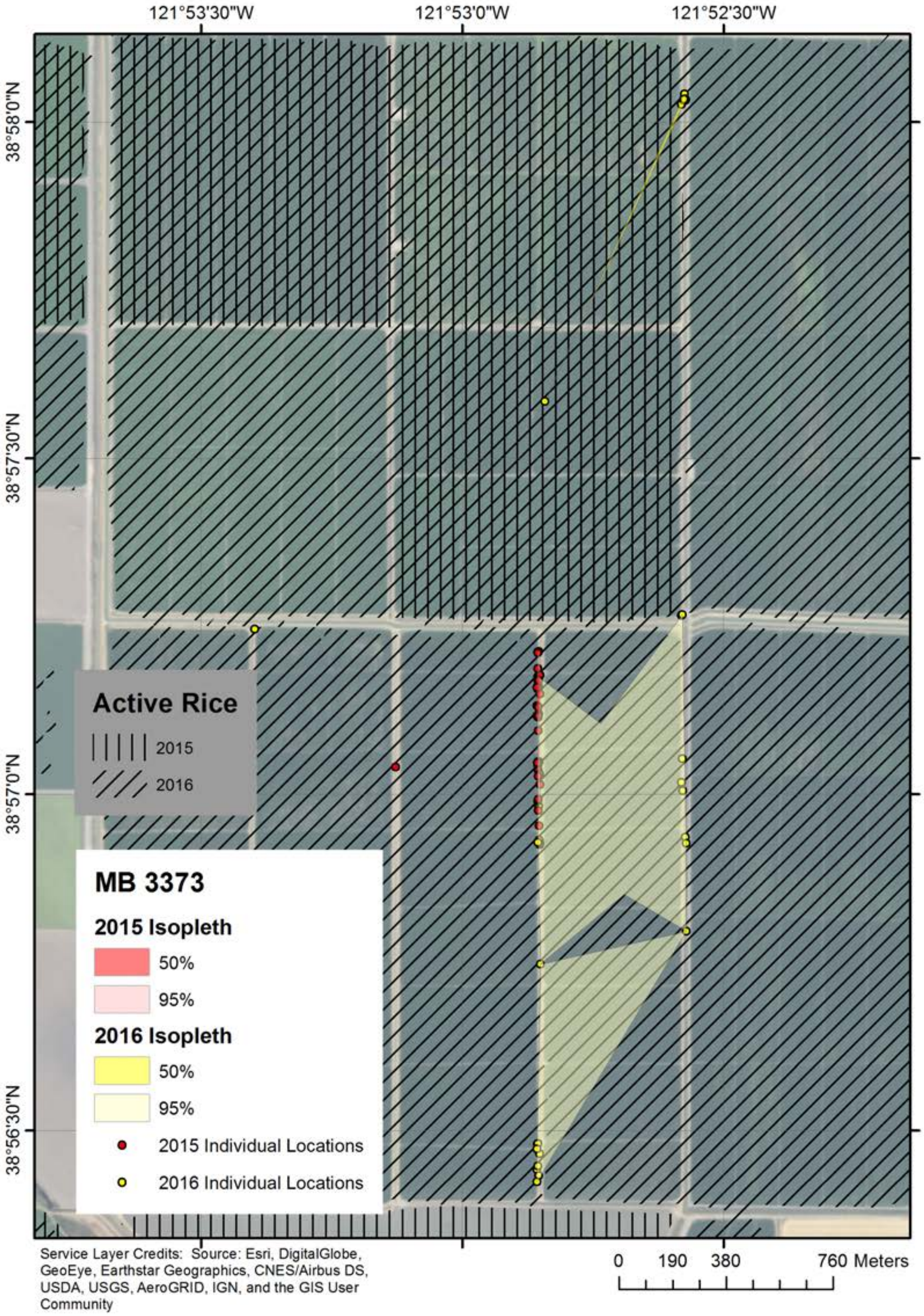


Figure A21. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3225 at site 4, Sacramento Valley, California. For detailed information on snake, see table 5.

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A22. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3238 at site 4, Sacramento Valley, California. For detailed information on snake, see table 5.



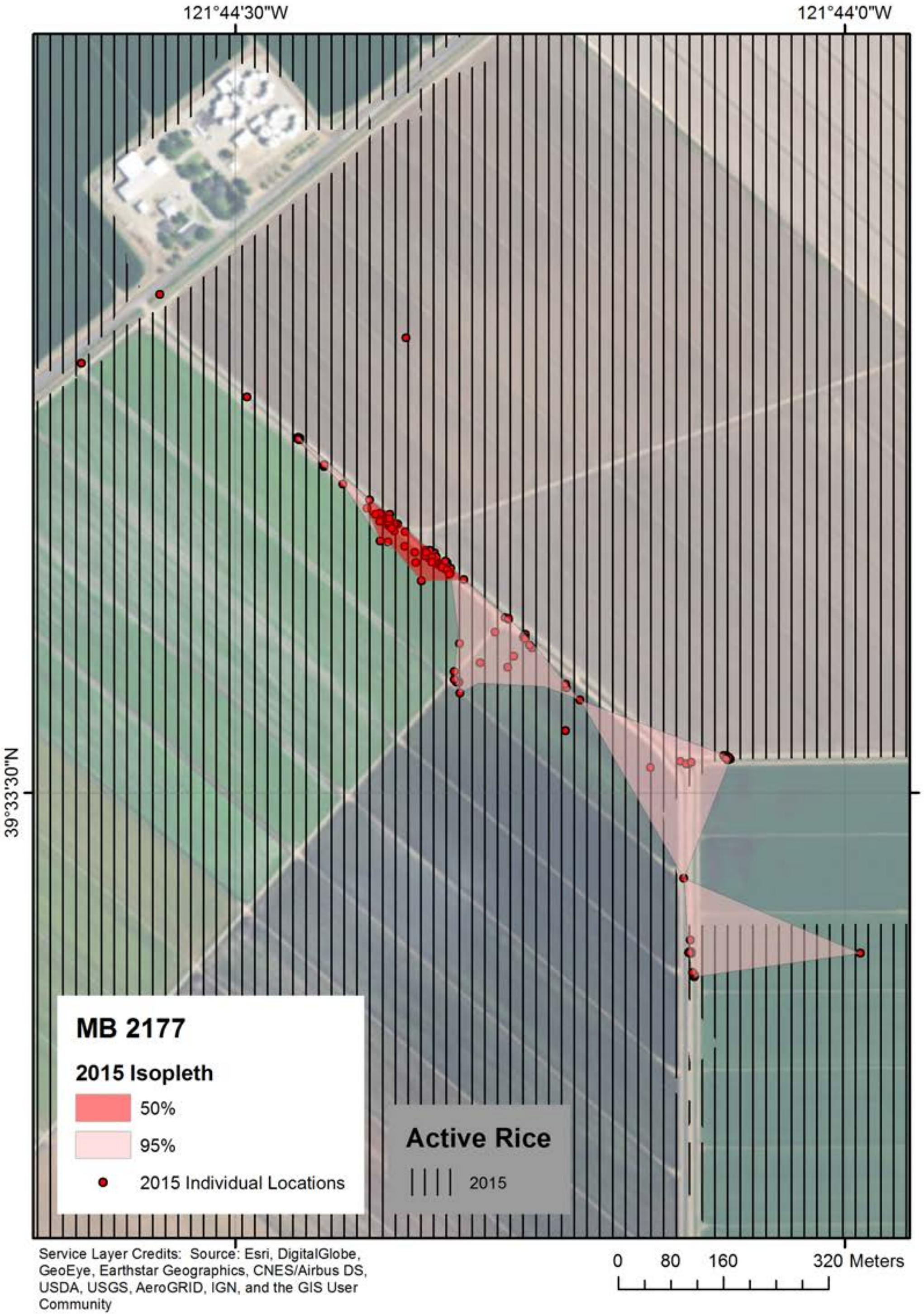
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A23. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3373 at site 5, Sacramento Valley, California. For detailed information on snake, see table 5.

Figure A24. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3376 at site 5, Sacramento Valley, California. For detailed information on snake, see table 5.

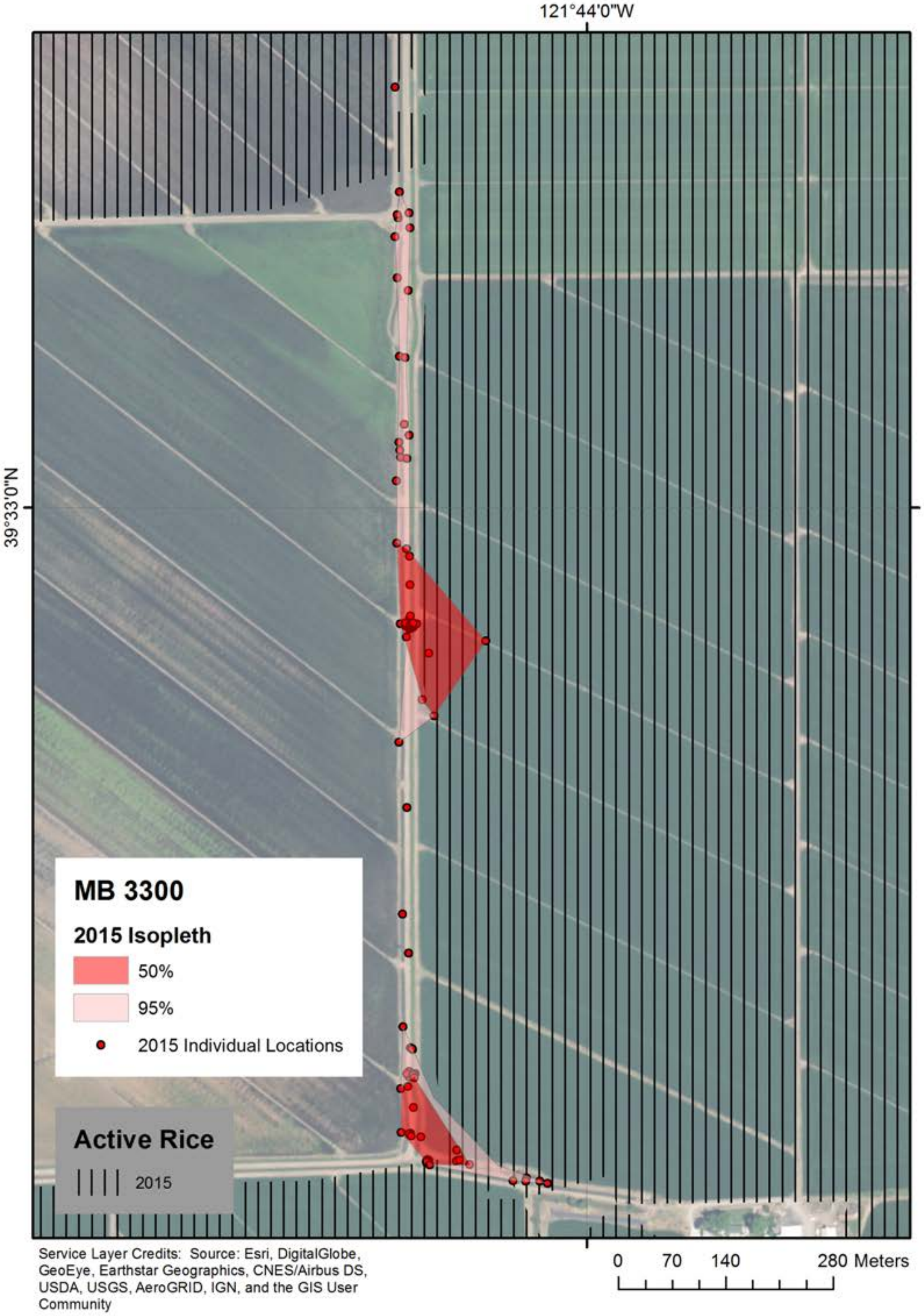
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A25. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3263 at site 6, Sacramento Valley, California. For detailed information on snake, see table 5.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A26. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 2177 at site 7, Sacramento Valley, California. For detailed information on snake, see table 5.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A27. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3300 at site 7, Sacramento Valley, California. For detailed information on snake, see table 5.

Figure A28. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3326 at site 7, Sacramento Valley, California. For detailed information on snake, see table 5.

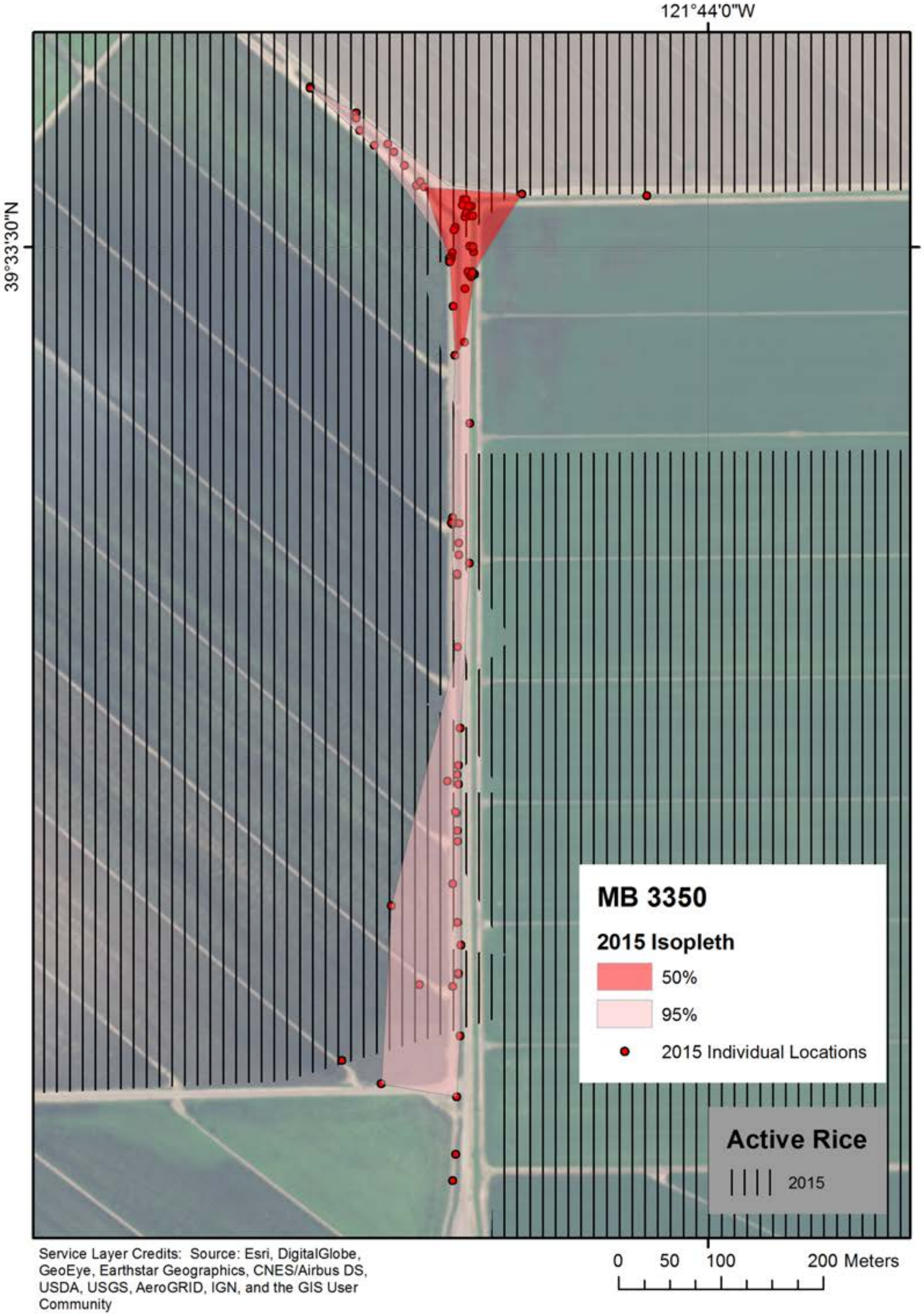


Figure A29. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3350 at site 7, Sacramento Valley, California. For detailed information on snake, see table 5.

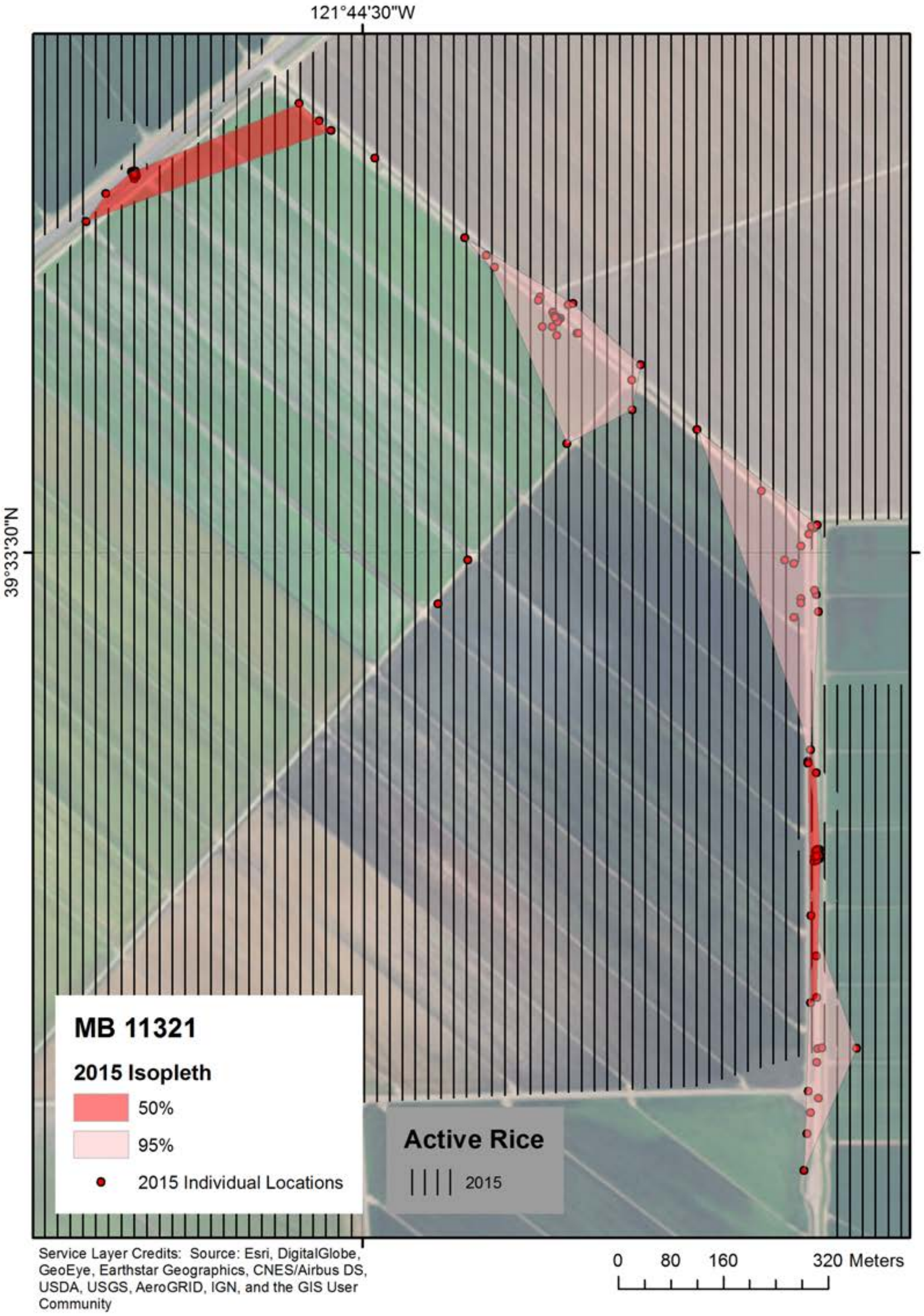


Figure A30. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 11321 at site 7, Sacramento Valley, California. For detailed information on snake, see table 5.

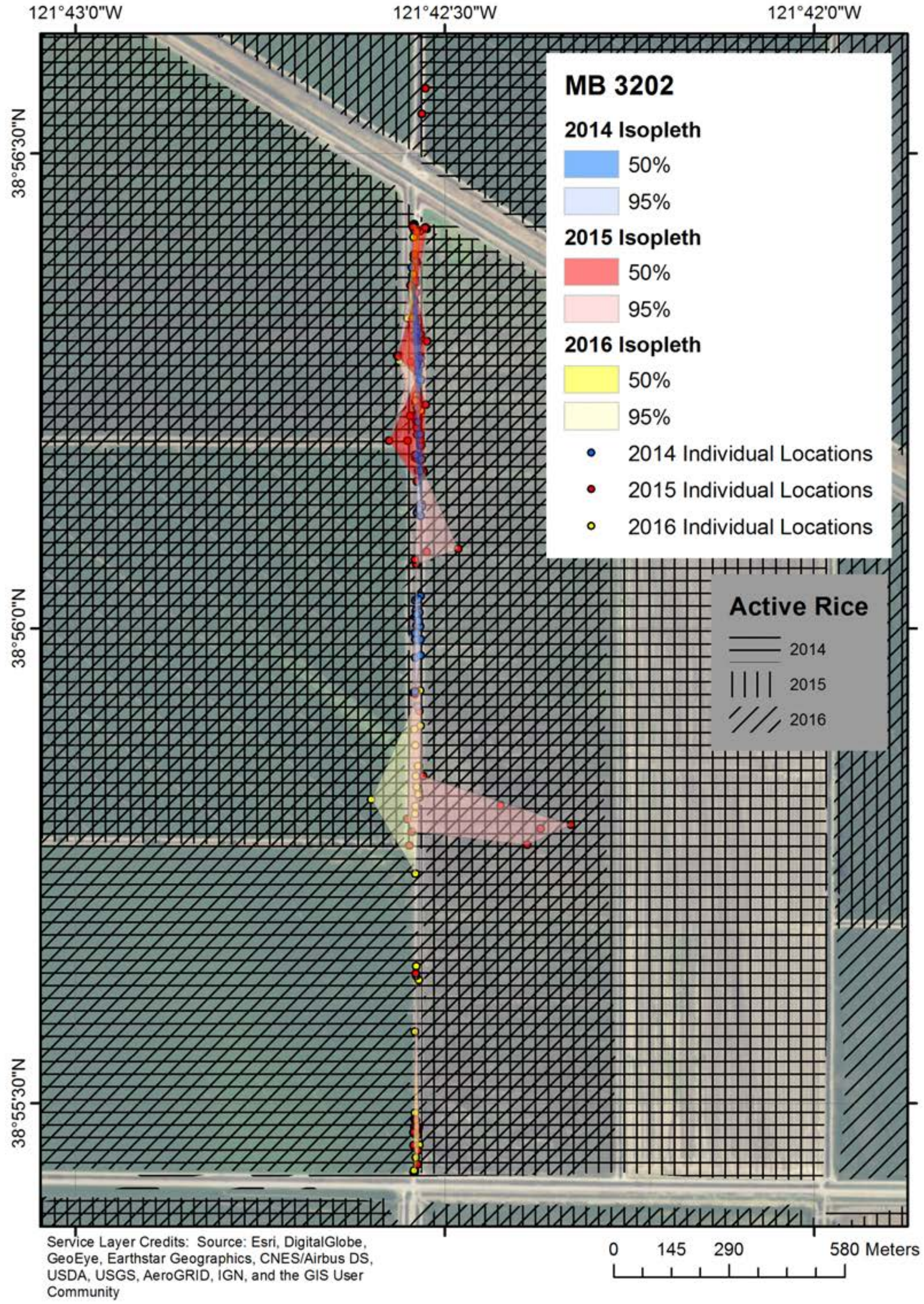


Figure A31. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3202 at site 8, Sacramento Valley, California. For detailed information on snake, see table 5.

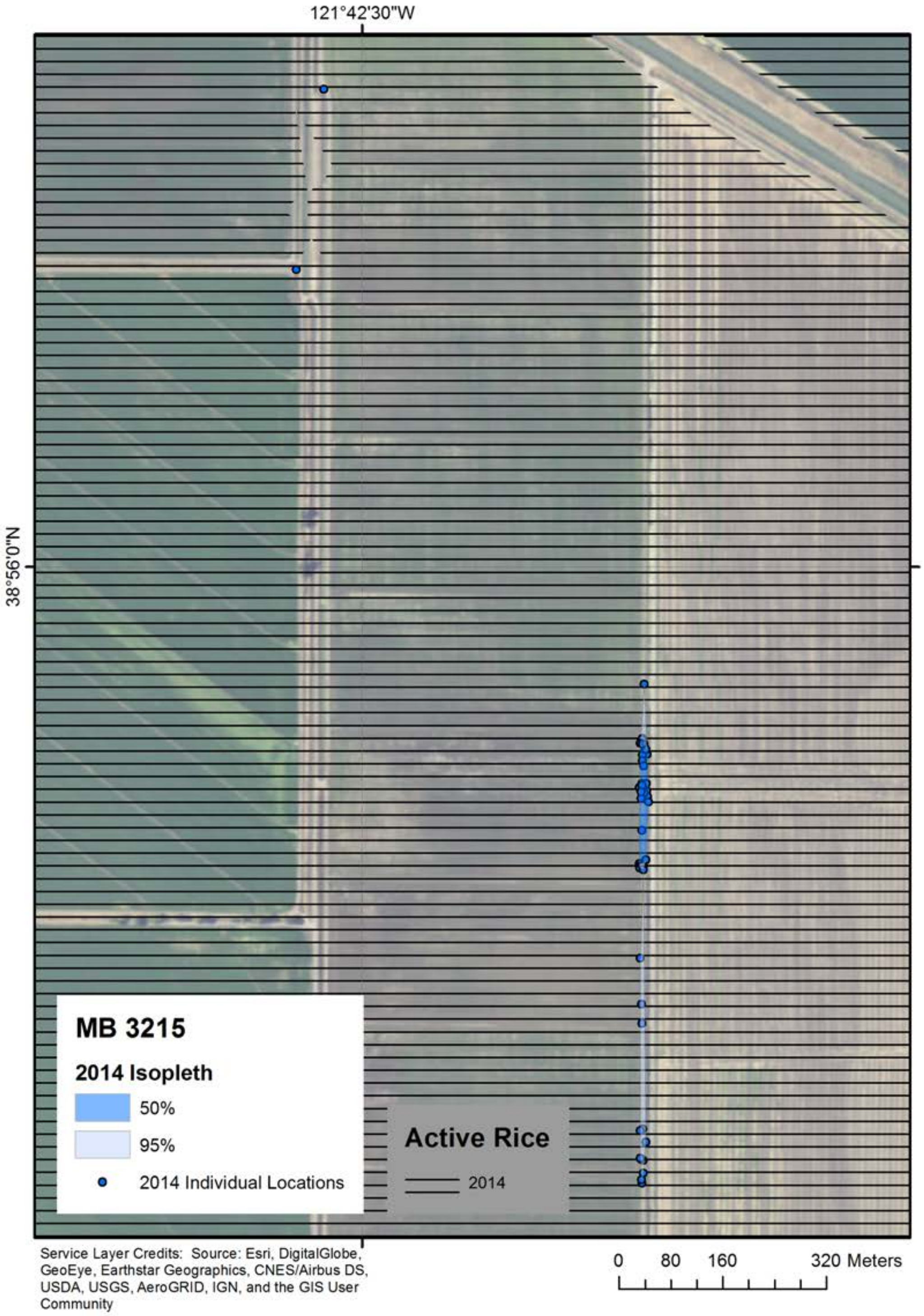


Figure A32. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3215 at site 8, Sacramento Valley, California. For detailed information on snake, see table 5.

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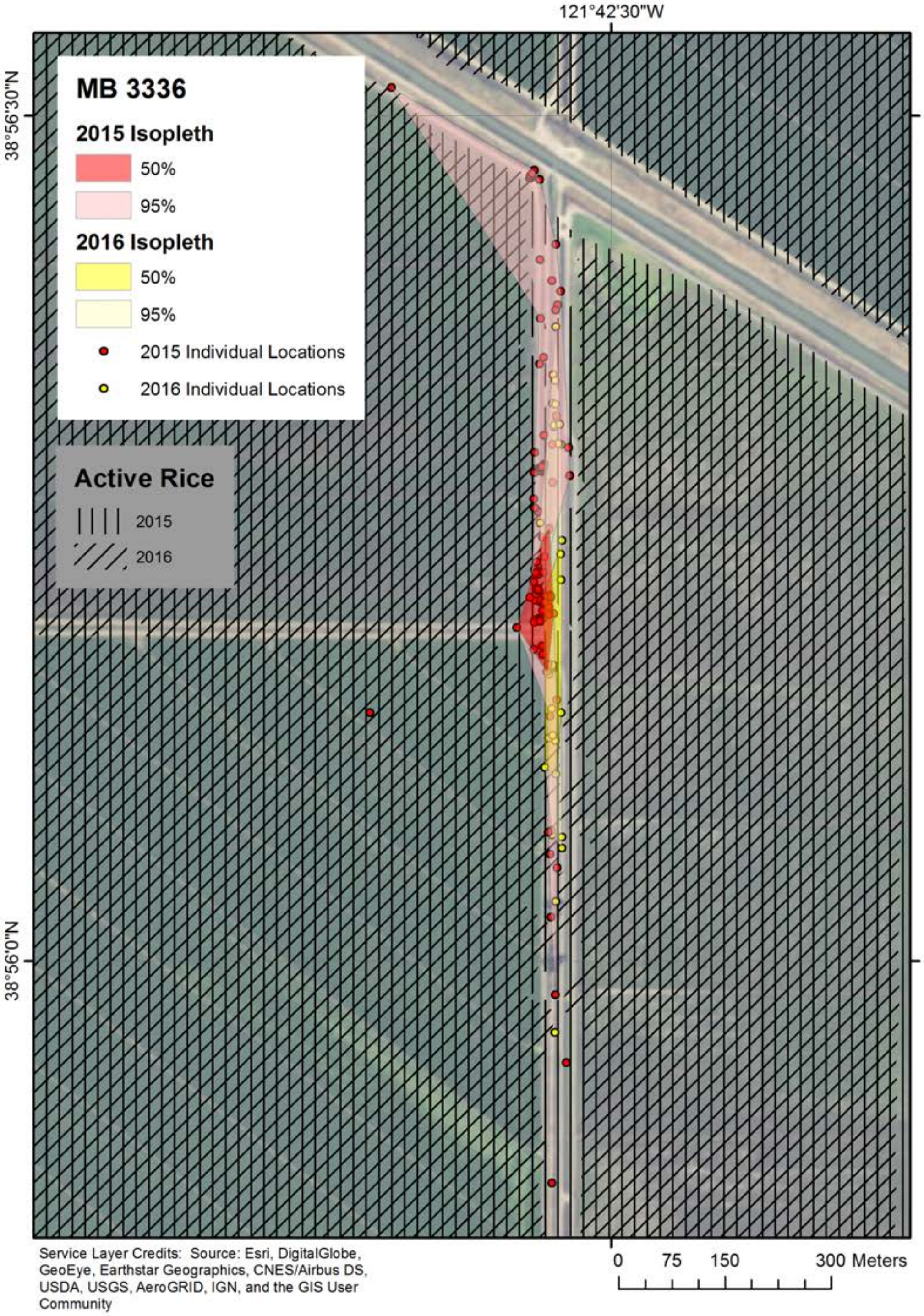
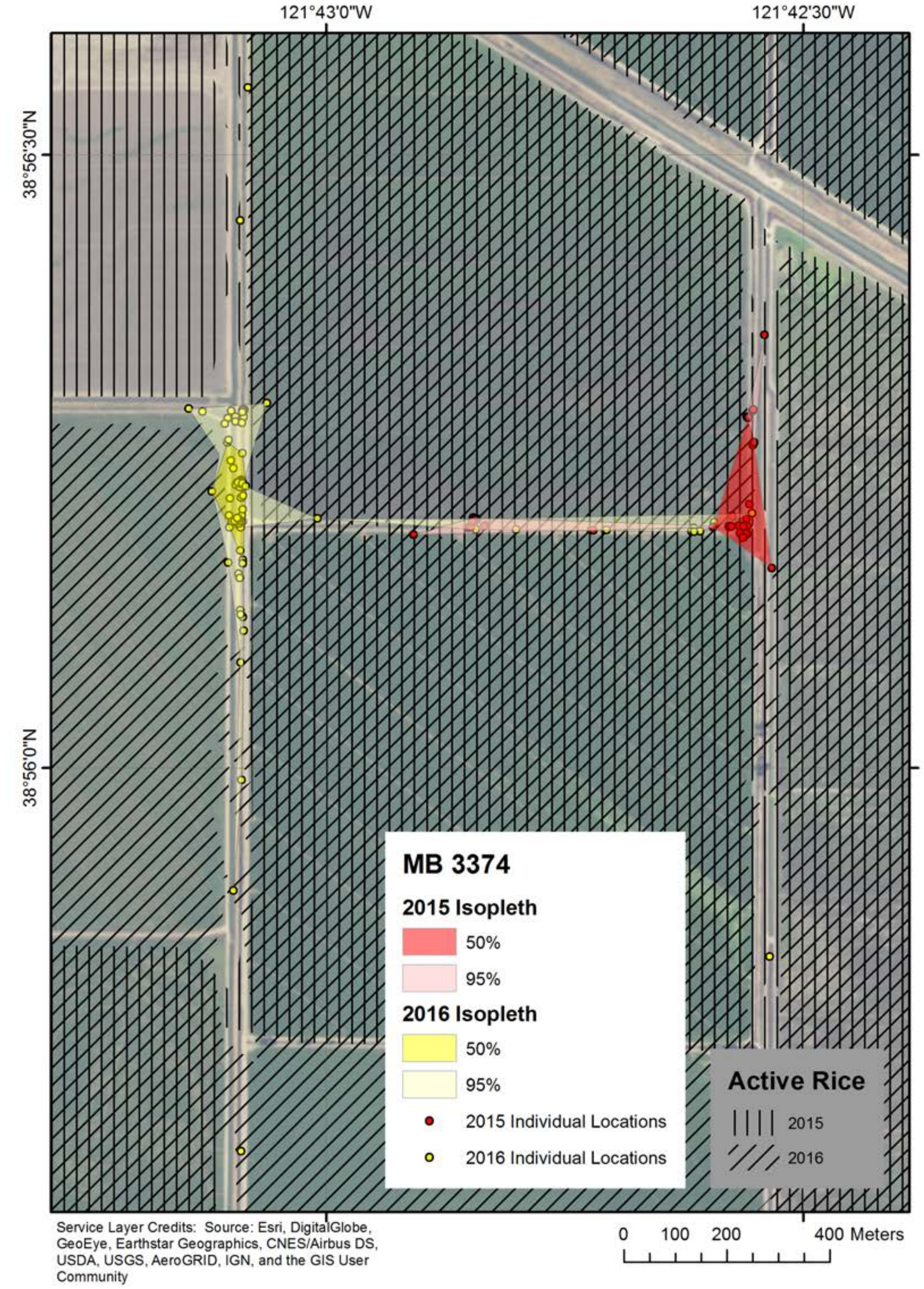
Figure A33. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3235 at site 8, Sacramento Valley, California. For detailed information on snake, see table 5.

Figure A34. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3239 at site 8, Sacramento Valley, California. For detailed information on snake, see table 5.



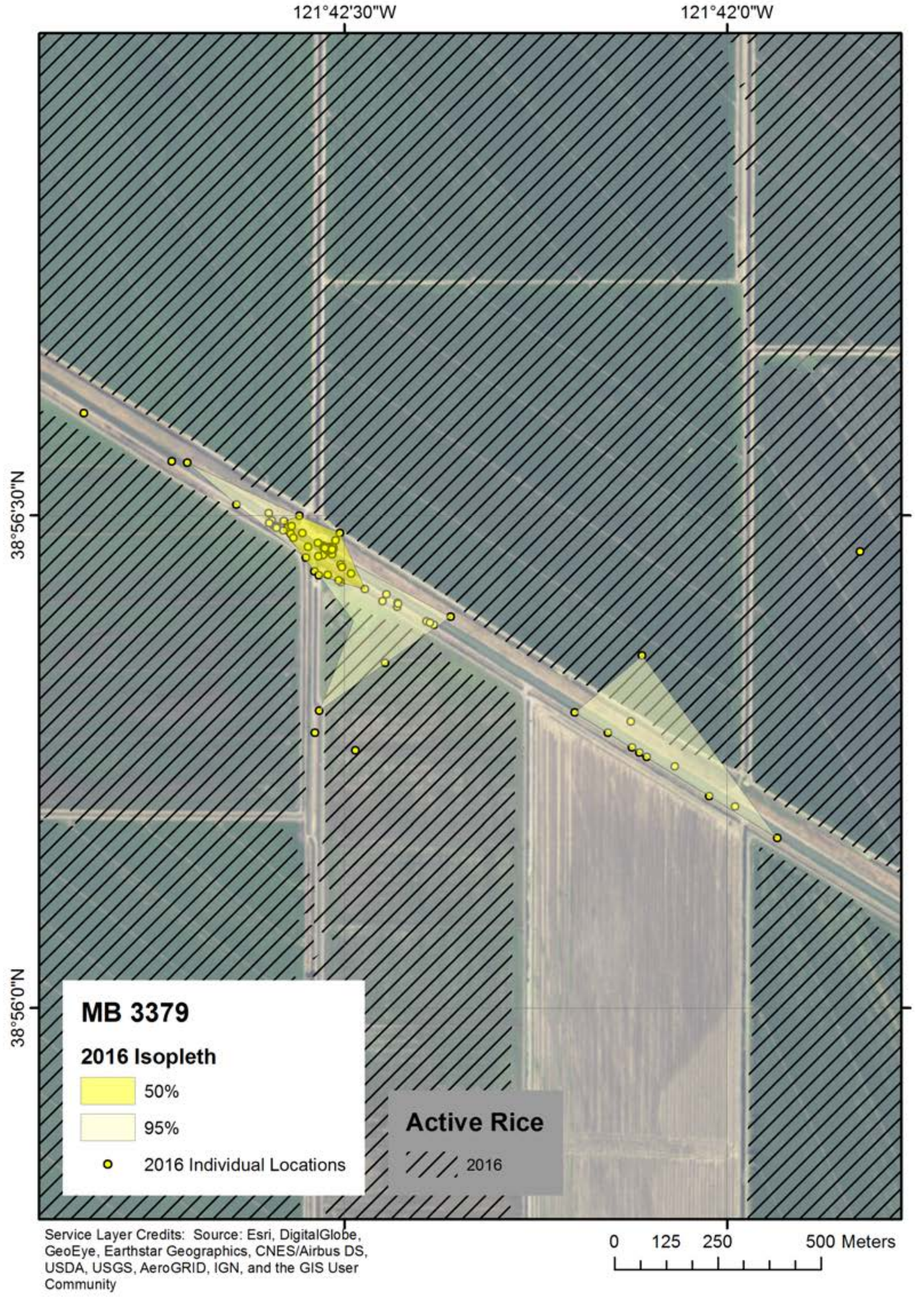
Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A35. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3336 at site 8, Sacramento Valley, California. For detailed information on snake, see table 5.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A36. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3374 at site 8, Sacramento Valley, California. For detailed information on snake, see table 5.

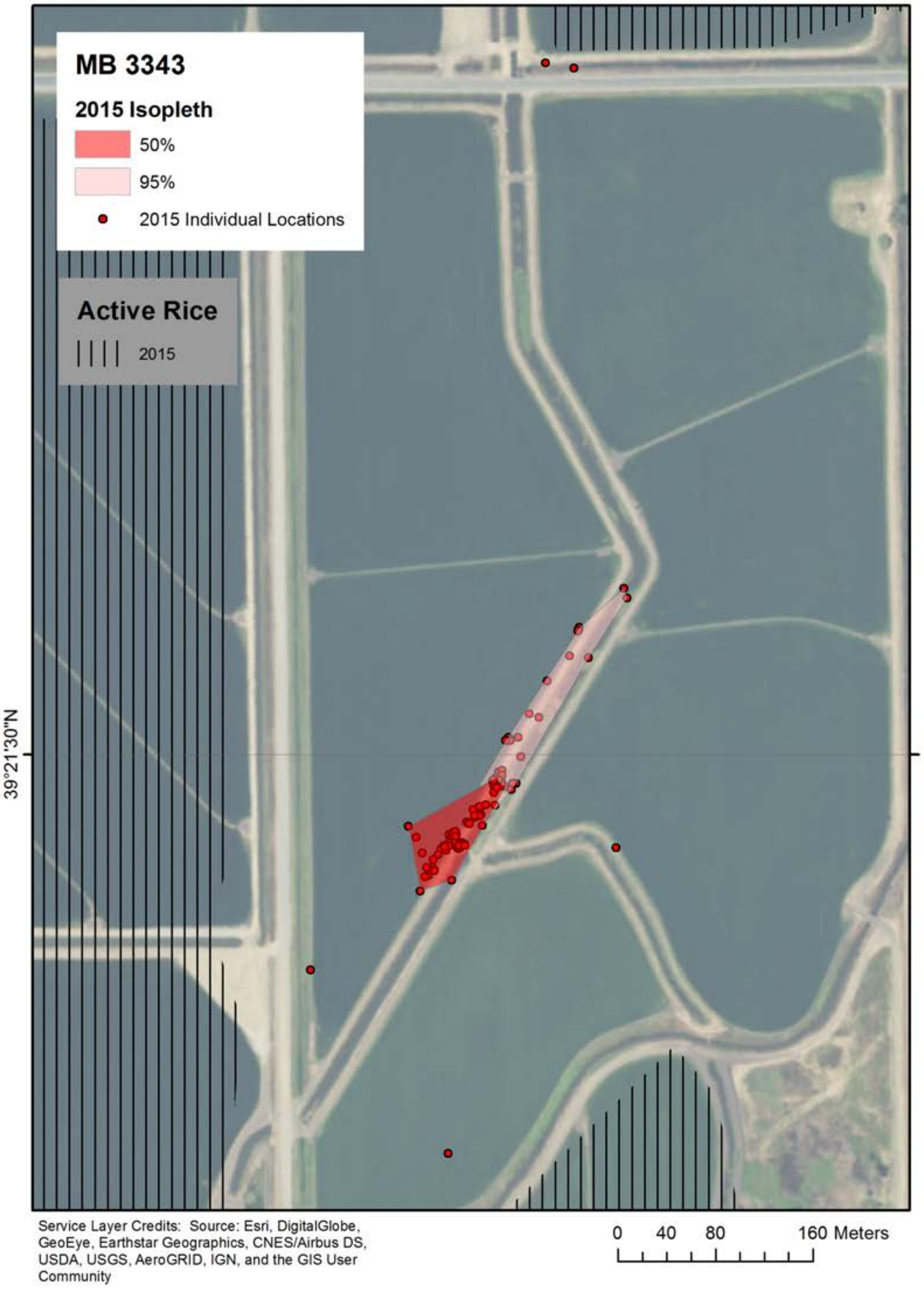


Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A37. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3379 at site 8, Sacramento Valley, California. For detailed information on snake, see table 5.

Figure A38. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3311 at site 9, Sacramento Valley, California. For detailed information on snake, see table 5.

Figure A39. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3322 at site 9, Sacramento Valley, California. For detailed information on snake, see table 5.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A40. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3343 at site 9, Sacramento Valley, California. For detailed information on snake, see table 5.

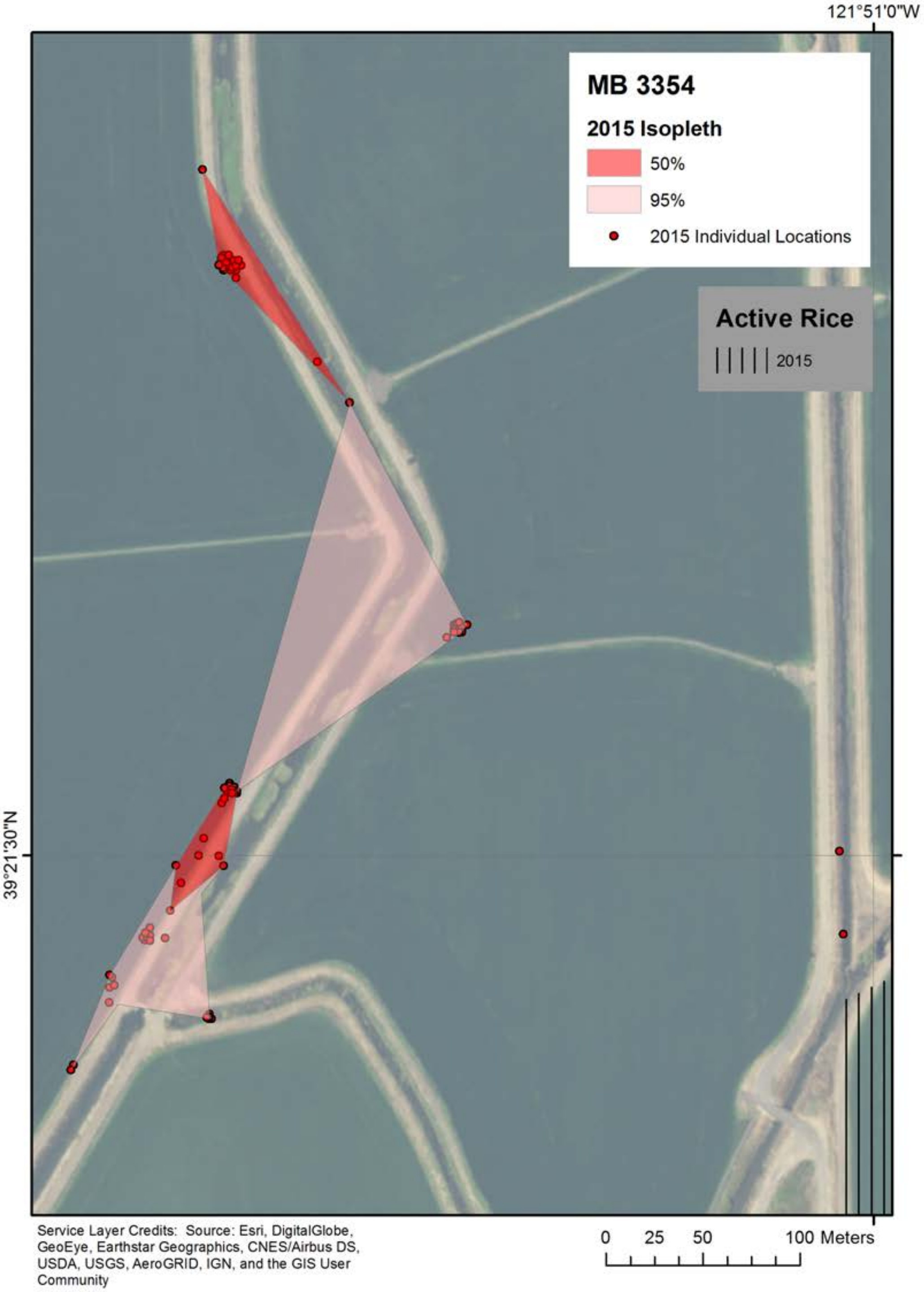


Figure A41. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3354 at site 9, Sacramento Valley, California. For detailed information on snake, see table 5.

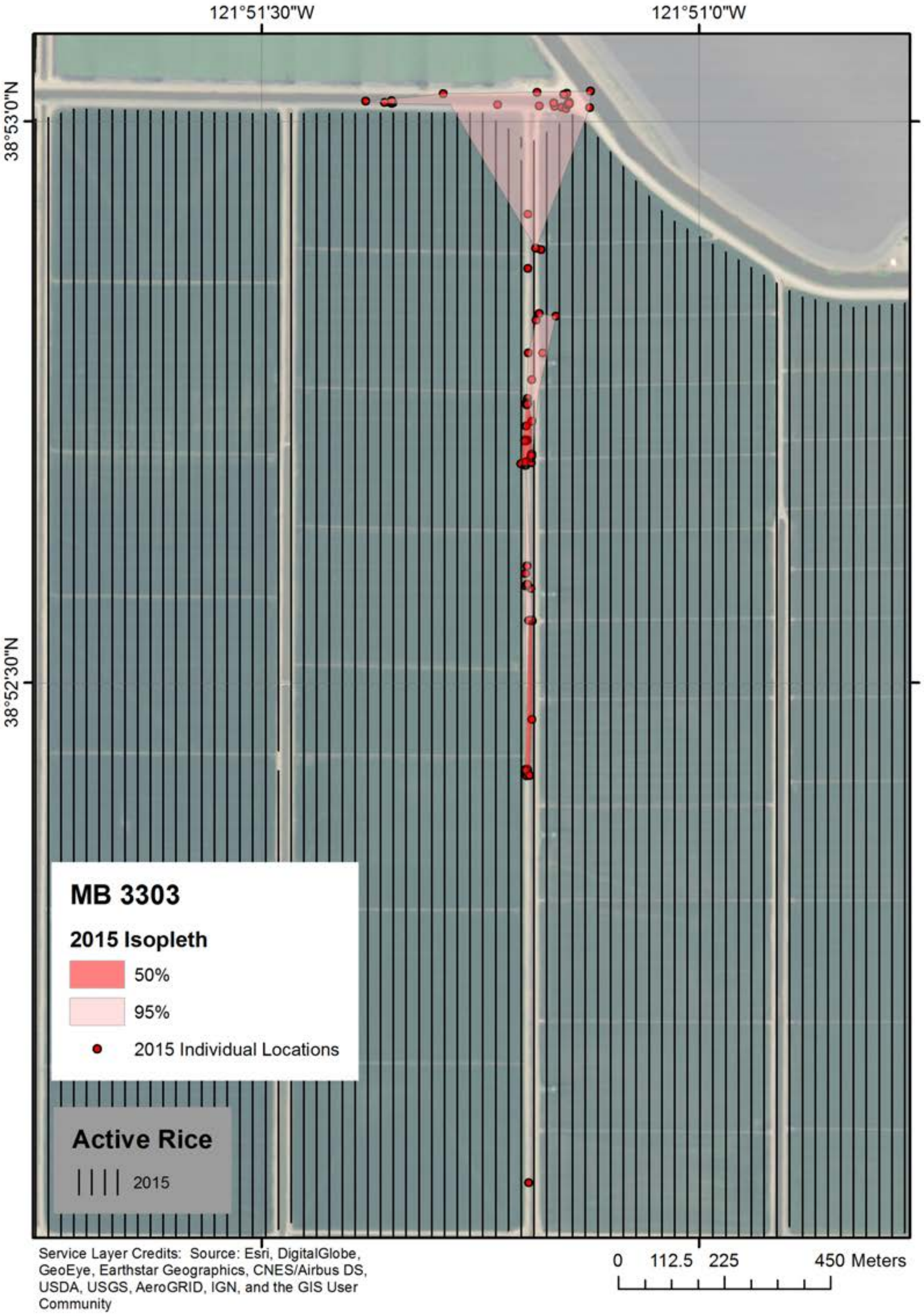
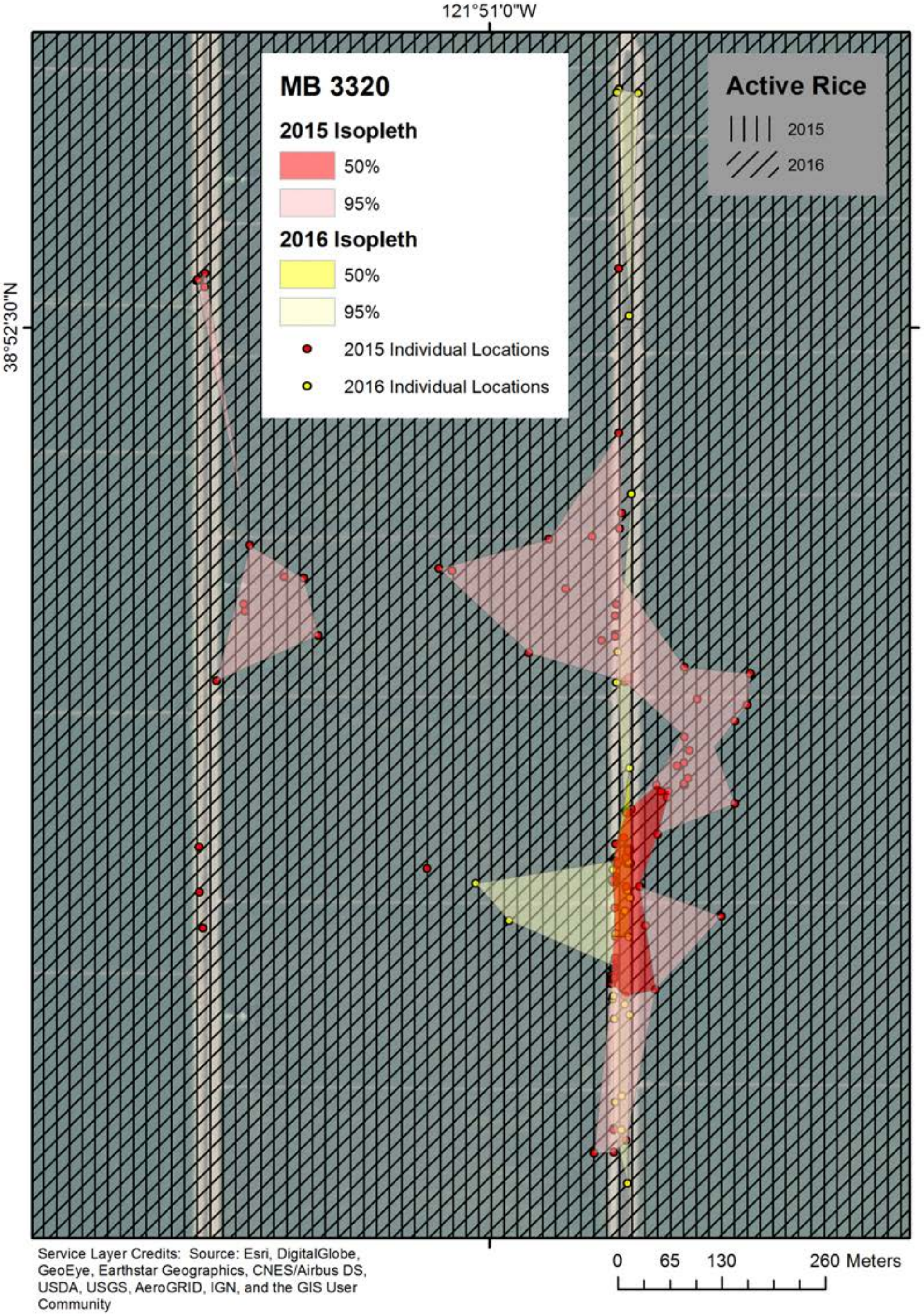
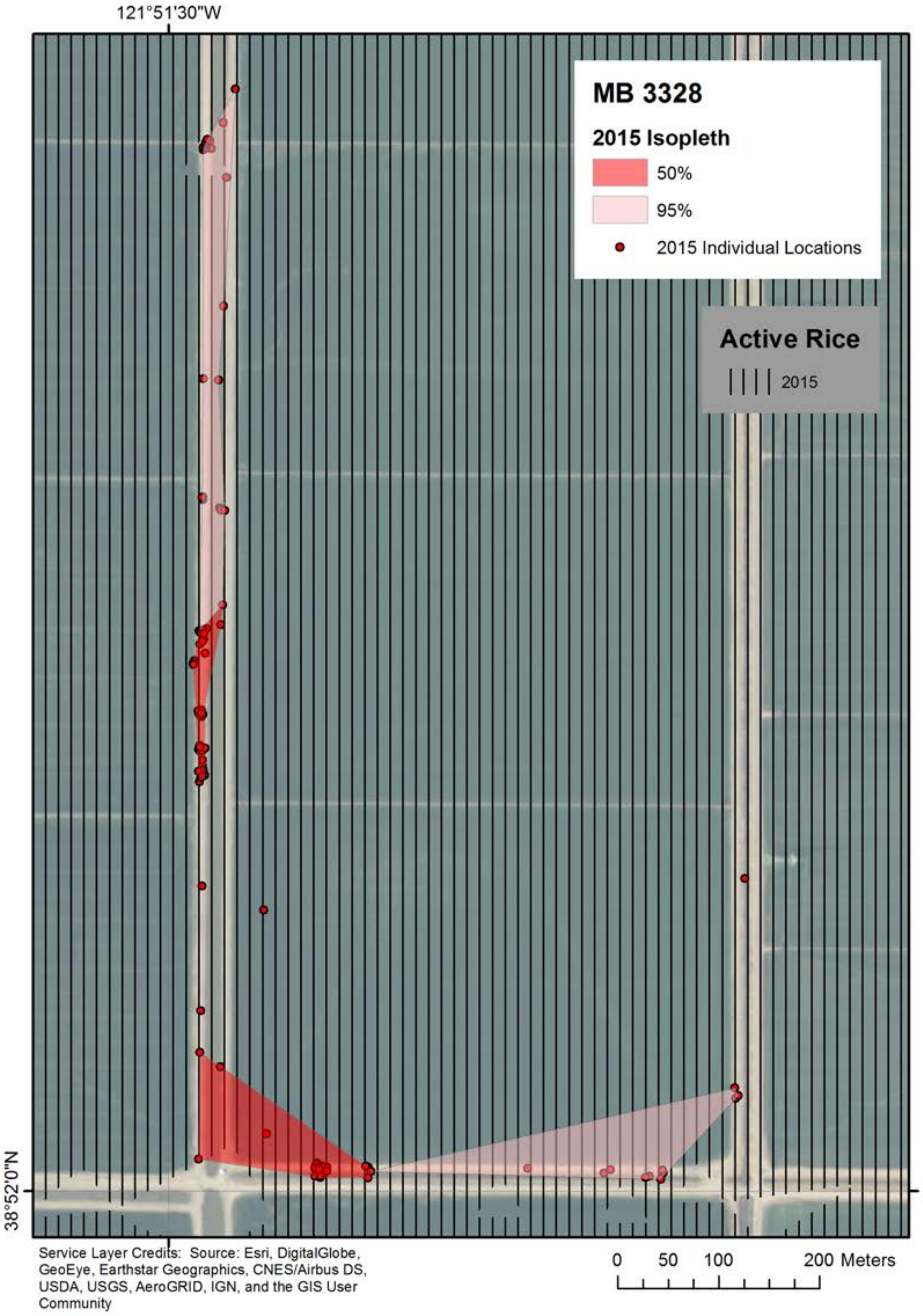


Figure A42. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3303 at site 10, Sacramento Valley, California. For detailed information on snake, see table 5.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A43. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3320 at site 10, Sacramento Valley, California. For detailed information on snake, see table 5.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A44. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3328 at site 10, Sacramento Valley, California. For detailed information on snake, see table 5.

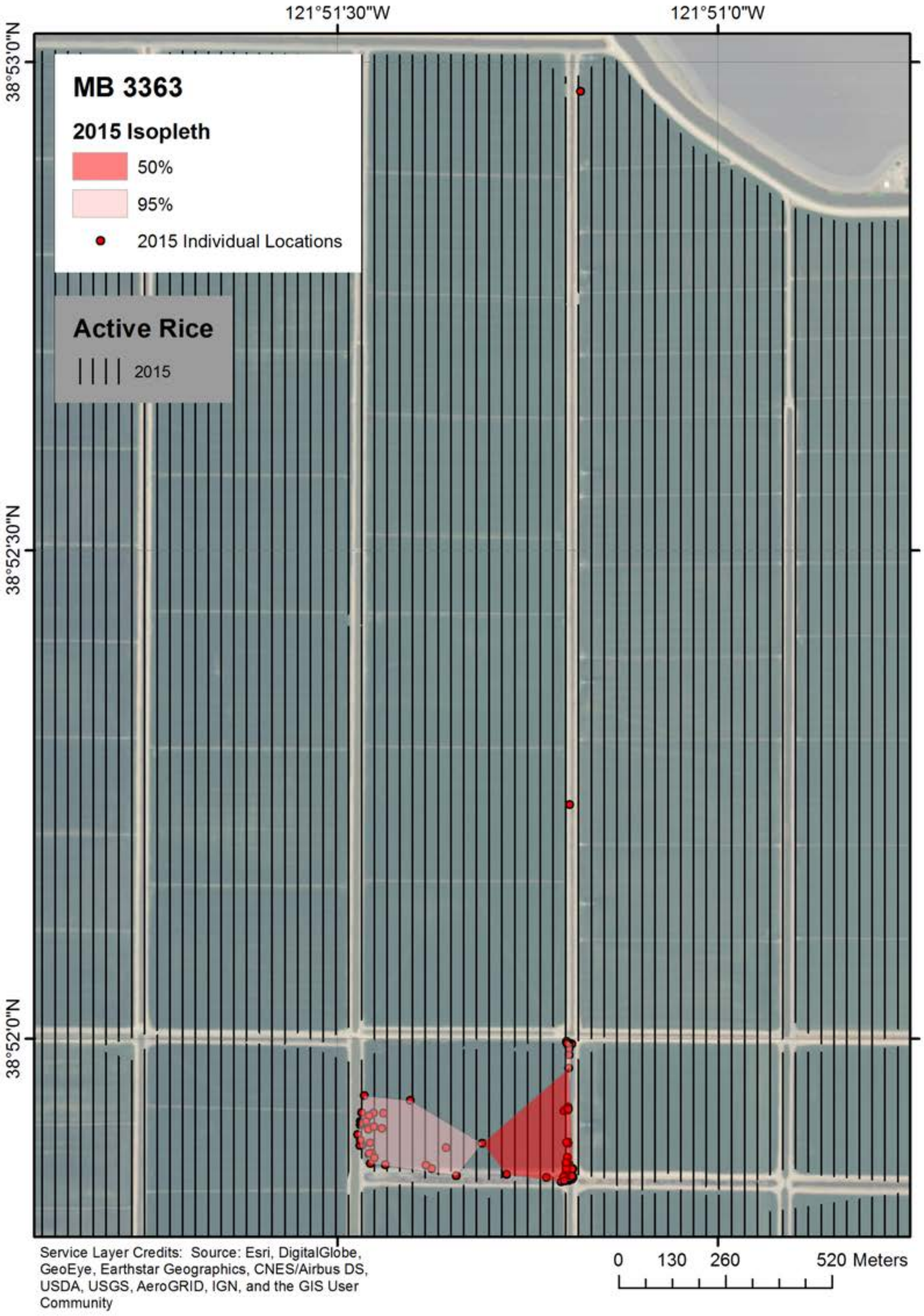
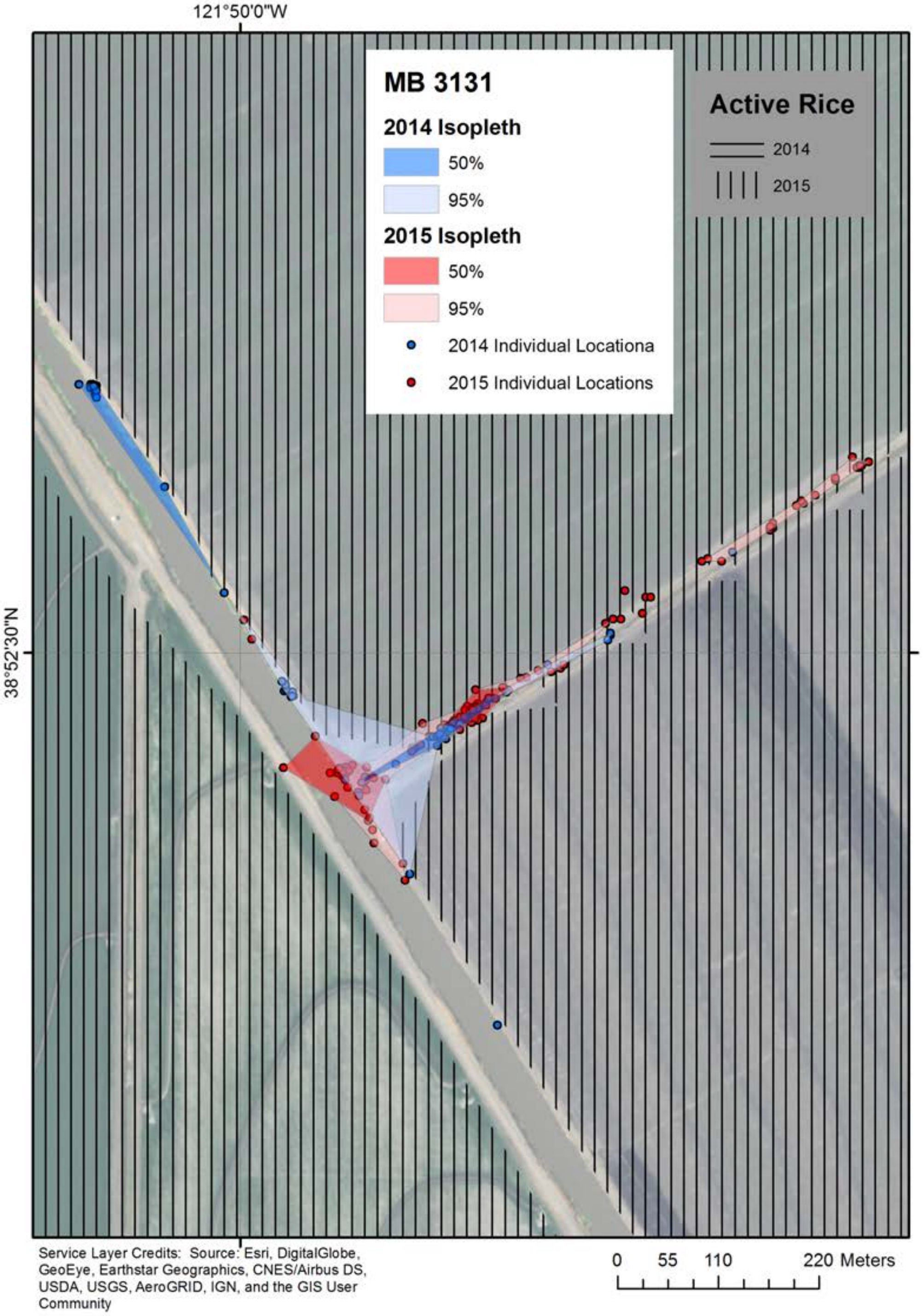


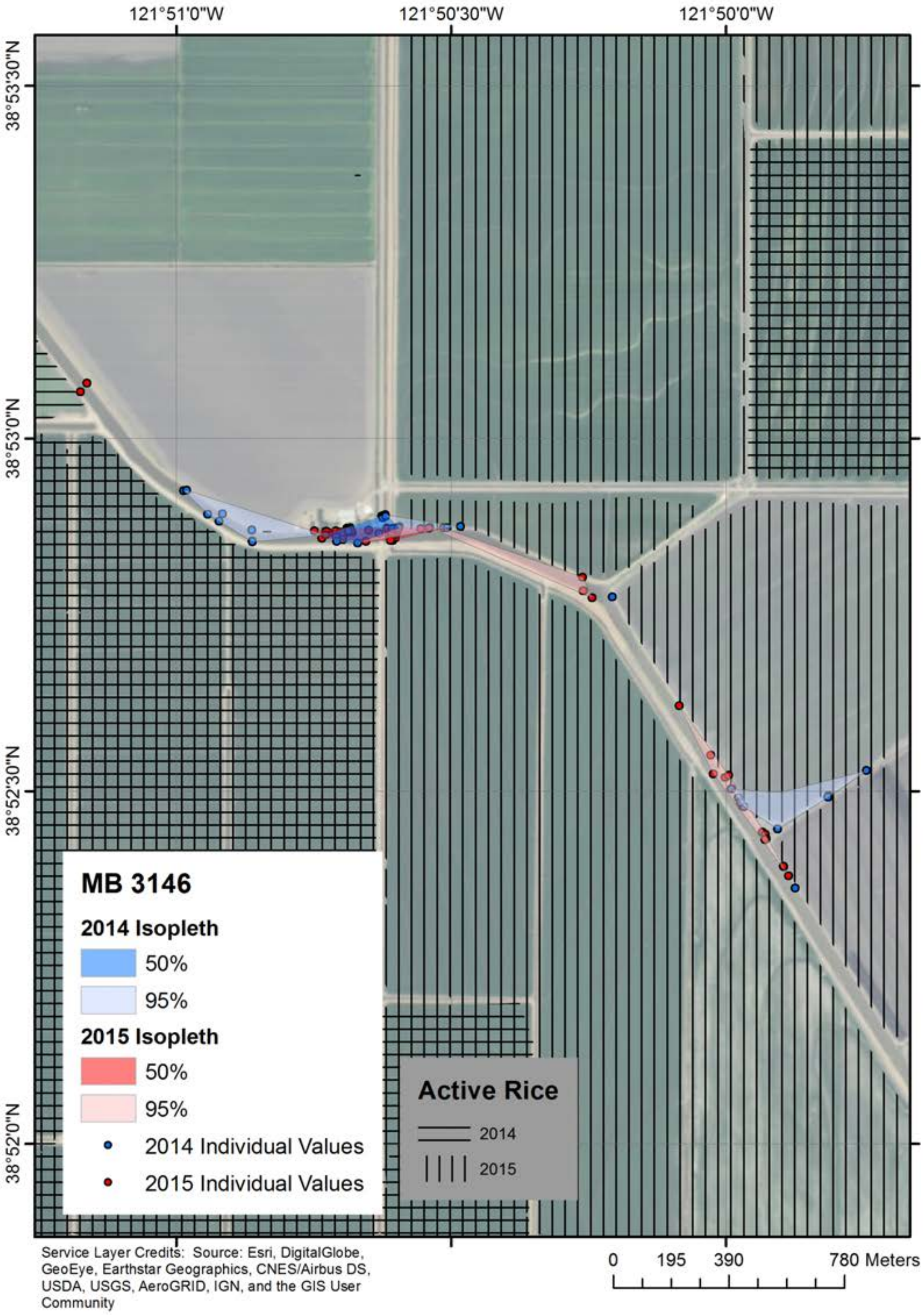
Figure A45. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3363 at site 10, Sacramento Valley, California. For detailed information on snake, see table 5.

Figure A46. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3378 at site 10, Sacramento Valley, California. For detailed information on snake, see table 5.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A47. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3131 at site 11, Sacramento Valley, California. For detailed information on snake, see table 5.



Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A48. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3146 at site 11, Sacramento Valley, California. For detailed information on snake, see table 5.

Figure A49. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3153 at site 11, Sacramento Valley, California. For detailed information on snake, see table 5.

Figure A50. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3258 at site 11, Sacramento Valley, California. For detailed information on snake, see table 5.

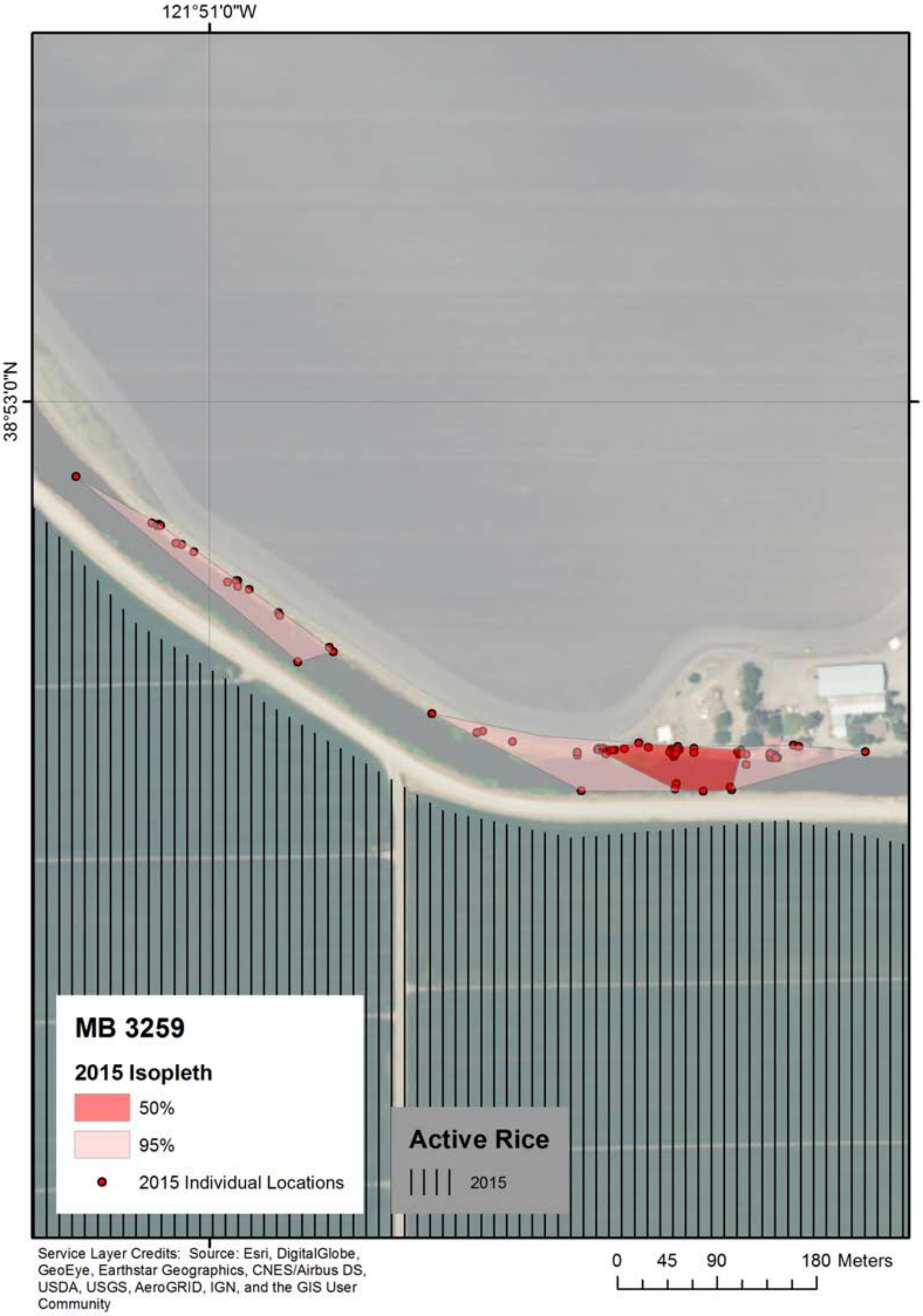


Figure A51. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3259 at site 11, Sacramento Valley, California. For detailed information on snake, see table 5.

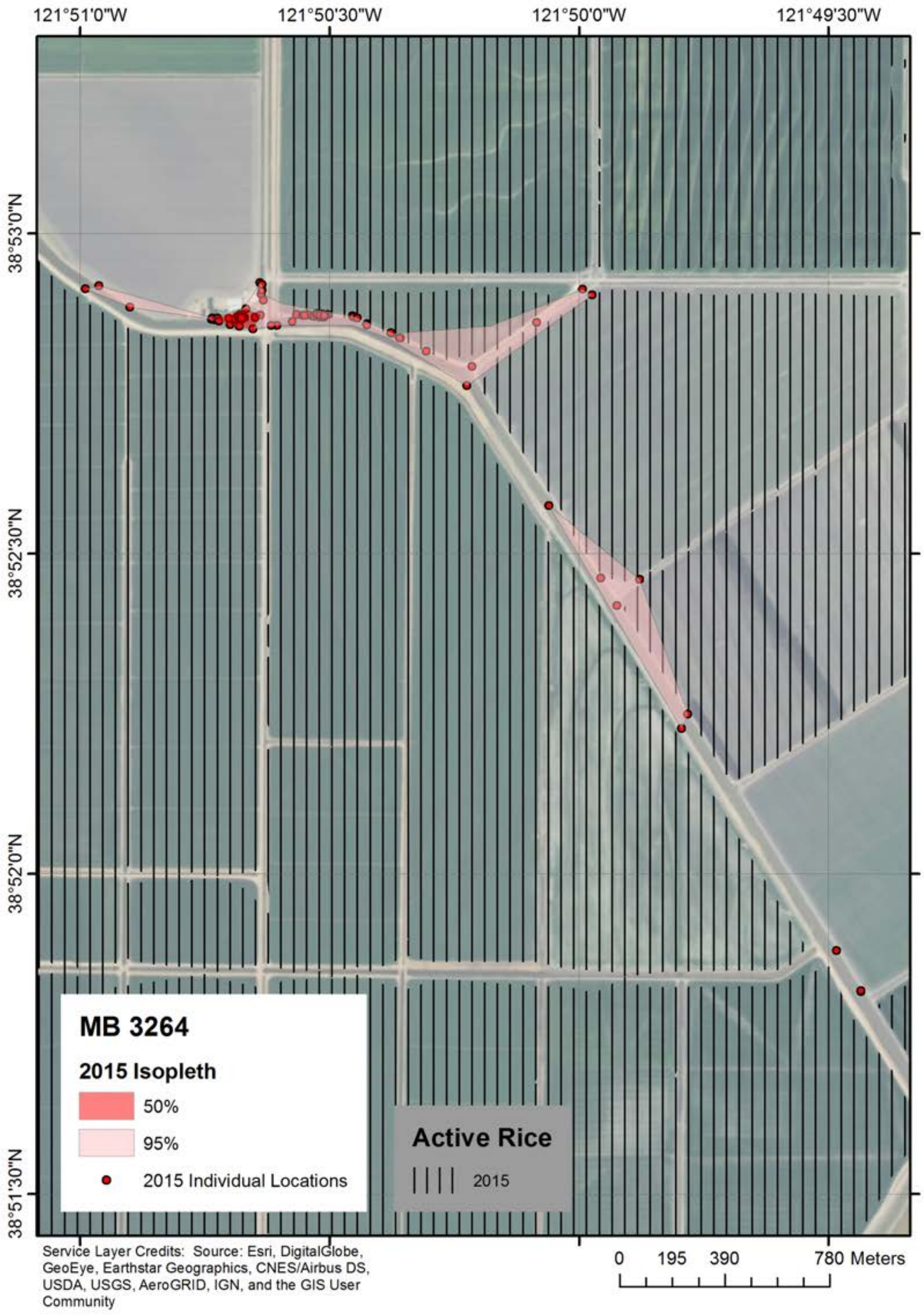


Figure A52. Adaptive Local Convex Hull (*a*-LoCoH) home range for snake 3264 at site 11, Sacramento Valley, California. For detailed information on snake, see table 5.

Appendix B. Health Assessment Model Results

Table B1. Summary of model results for blood parameters from giant gartersnakes that received health assessments.

[All models included random effects of individual (σ_{ind}) and site (σ_{site}) in addition to the fixed effects. σ represents any remaining variation in the response not accounted for by fixed or random effects]

	Mean	SD	2.5th percentile	97.5th percentile
	White blood cell count (× 10^3/ µL)			
α_0	6.96	0.89	5.21	8.70
β_{SVL}	0.31	0.66	-0.99	1.60
β_{sex}	-3.61	3.61	-10.85	3.59
$\beta_{sex\ x\ SVL}$	-2.91	3.80	-10.31	4.67
β_{date}	0.69	0.72	-0.70	2.10
β_{date}^2	0.68	0.52	-0.37	1.69
β_{rice}	-0.20	0.70	-1.59	1.19
β_{cap}	-0.33	0.65	-1.60	0.93
σ	5.31	0.46	4.49	6.26
σ_{ind}	0.77	0.68	0.01	2.52
σ_{site}	0.90	0.78	0.03	2.92
	Red blood cell count (× 10^6/uL)			
α_0	0.75	0.04	0.67	0.84
β_{SVL}	-0.06	0.03	-0.12	0.00
β_{sex}	-0.11	0.18	-0.46	0.24
$\beta_{sex\ x\ SVL}$	-0.06	0.19	-0.43	0.30
β_{date}	0.02	0.04	-0.05	0.10
β_{date}^2	0.01	0.03	-0.04	0.06
β_{rice}	0.04	0.03	-0.02	0.11
β_{cap}	-0.02	0.04	-0.10	0.06
σ	0.24	0.02	0.19	0.29
σ_{ind}	0.08	0.05	0.00	0.18
σ_{site}	0.05	0.04	0.00	0.15
	Hemoglobin (g/dL)			
α_0	8.24	0.38	7.48	8.99
β_{SVL}	-0.25	0.26	-0.76	0.26
β_{sex}	3.02	1.48	0.10	5.91
$\beta_{sex\ x\ SVL}$	1.75	1.51	-1.20	4.71
β_{date}	0.12	0.30	-0.46	0.73
β_{date}^2	0.34	0.20	-0.04	0.72
β_{rice}	0.33	0.27	-0.19	0.85
β_{cap}	-0.07	0.22	-0.51	0.36
σ	1.62	0.25	1.19	2.13
σ_{ind}	1.03	0.48	0.10	1.86
σ_{site}	0.57	0.40	0.02	1.52

	Mean	SD	2.5th percentile	97.5th percentile
	Pack cell volume (%)			
α_0	25.32	1.03	23.31	27.37
β_{SVL}	-1.04	0.75	-2.49	0.42
β_{sex}	7.76	4.13	-0.32	15.96
$\beta_{\text{sex x SVL}}$	4.20	4.32	-4.31	12.53
β_{date}	0.15	0.85	-1.48	1.89
β_{date}^{2}	1.15	0.59	-0.01	2.32
β_{rice}	1.10	0.79	-0.45	2.65
β_{cap}	-0.16	0.72	-1.56	1.23
σ	5.68	0.60	4.40	6.83
σ_{ind}	1.41	1.23	0.04	4.35
σ_{site}	1.17	0.98	0.04	3.58
	Heterophils (× 10^3/μL)			
α_0	0.77	0.13	0.50	1.04
β_{SVL}	-0.01	0.10	-0.20	0.19
β_{sex}	-0.14	0.59	-1.29	0.99
$\beta_{\text{sex x SVL}}$	-0.17	0.60	-1.35	1.01
β_{date}	-0.02	0.10	-0.23	0.18
β_{date}^{2}	0.05	0.07	-0.09	0.19
β_{rice}	0.05	0.10	-0.14	0.23
β_{cap}	0.02	0.08	-0.14	0.17
σ	0.54	0.08	0.42	0.72
σ_{ind}	0.50	0.12	0.22	0.71
σ_{site}	0.15	0.12	0.01	0.46
	Lymphocytes (× 10^3/μL)			
α_0	5.54	0.99	3.61	7.51
β_{SVL}	0.15	0.51	-0.84	1.15
β_{sex}	-3.71	2.70	-9.03	1.46
$\beta_{\text{sex x SVL}}$	-2.35	2.89	-7.99	3.31
β_{date}	0.43	0.56	-0.68	1.50
β_{date}^{2}	0.60	0.39	-0.17	1.37
β_{rice}	-0.16	0.54	-1.20	0.90
β_{cap}	-0.03	0.06	-0.16	0.09
σ	4.03	0.34	3.42	4.76
σ_{ind}	0.60	0.48	0.03	1.81
σ_{site}	0.78	0.61	0.03	2.28

	Mean	SD	2.5th percentile	97.5th percentile
	Basophils (× 10^3/μL)			
α_0	0.21	0.06	0.10	0.33
β_{SVL}	-0.01	0.03	-0.06	0.05
β_{sex}	-0.08	0.16	-0.39	0.23
$\beta_{sex\ x\ SVL}$	-0.16	0.17	-0.50	0.16
β_{date}	0.05	0.03	-0.01	0.11
β_{date}^2	0.00	0.02	-0.05	0.04
β_{rice}	-0.03	0.03	-0.09	0.03
β_{cap}	0.00	0.00	-0.01	0.00
σ	0.22	0.02	0.19	0.27
σ_{ind}	0.06	0.04	0.00	0.14
σ_{site}	0.04	0.04	0.00	0.13
	Azurophils (× 10^3/μL)			
α_0	0.85	0.25	0.37	1.33
β_{SVL}	0.19	0.13	-0.06	0.45
β_{sex}	0.09	0.72	-1.30	1.53
$\beta_{sex\ x\ SVL}$	-0.53	0.74	-2.04	0.92
β_{date}	0.27	0.14	-0.01	0.55
β_{date}^2	-0.05	0.10	-0.24	0.14
β_{rice}	0.02	0.13	-0.24	0.27
β_{cap}	-0.01	0.02	-0.04	0.02
σ	0.88	0.11	0.68	1.09
σ_{ind}	0.41	0.22	0.02	0.82
σ_{site}	0.26	0.18	0.01	0.68
	Monocytes (× 10^3/μL)			
α_0	0.09	0.05	-0.02	0.19
β_{SVL}	0.02	0.03	-0.03	0.07
β_{sex}	-0.03	0.15	-0.32	0.27
$\beta_{sex\ x\ SVL}$	-0.06	0.16	-0.37	0.26
β_{date}	-0.01	0.03	-0.07	0.05
β_{date}^2	0.03	0.02	-0.02	0.07
β_{rice}	-0.03	0.03	-0.08	0.03
β_{cap}	0.00	0.00	-0.01	0.00
σ	0.21	0.02	0.17	0.25
σ_{ind}	0.06	0.04	0.00	0.15
σ_{site}	0.04	0.03	0.00	0.12

	Mean	SD	2.5th percentile	97.5th percentile
Plasma protein (g/dL)				
α_0	5.29	0.22	4.87	5.72
β_{SVL}	0.27	0.15	-0.04	0.57
β_{sex}	-0.57	0.87	-2.28	1.10
$\beta_{sex\ x\ SVL}$	-0.81	0.90	-2.54	0.98
β_{date}	-0.25	0.17	-0.59	0.09
β_{date^2}	0.17	0.12	-0.07	0.41
β_{rice}	0.02	0.16	-0.30	0.32
β_{cap}	-0.01	0.14	-0.30	0.27
σ	1.12	0.13	0.86	1.37
σ_{ind}	0.41	0.27	0.02	0.97
σ_{site}	0.27	0.20	0.01	0.75
Aspartate aminotransferase (IU/L)				
α_0	16.10	3.14	9.88	22.32
β_{SVL}	1.22	1.63	-1.97	4.37
β_{sex}	-3.67	8.76	-20.86	13.64
$\beta_{sex\ x\ SVL}$	-3.44	9.37	-22.28	14.90
β_{date}	1.36	1.76	-2.15	4.83
β_{date^2}	-0.95	1.29	-3.47	1.56
β_{rice}	-0.60	1.70	-3.92	2.77
β_{cap}	0.49	0.21	0.07	0.89
σ	13.44	1.14	11.40	15.84
σ_{ind}	1.33	1.38	0.04	5.32
σ_{site}	1.13	1.13	0.03	4.18
Creatinine kinase (IU/L)				
α_0	360.58	78.04	199.18	507.53
β_{SVL}	29.09	63.33	-93.54	154.48
β_{sex}	-11.43	93.60	-195.46	166.60
$\beta_{sex\ x\ SVL}$	-2.58	96.47	-193.05	186.31
β_{date}	0.57	64.61	-123.74	127.78
β_{date^2}	57.37	50.84	-44.27	156.95
β_{rice}	-78.94	65.17	-205.75	51.61
β_{cap}	59.99	64.18	-65.41	187.50
σ	730.56	61.55	623.22	862.77
σ_{ind}	2.90	7.82	0.03	17.37
σ_{site}	13.17	65.30	0.05	156.58

	Mean	SD	2.5th percentile	97.5th percentile
Uric acid (mg/dL)				
α_0	4.91	0.78	3.36	6.45
β_{SVL}	0.33	0.40	-0.45	1.14
β_{sex}	3.59	2.17	-0.65	7.87
$\beta_{sex\ x\ SVL}$	2.94	2.29	-1.55	7.49
β_{date}	-1.04	0.44	-1.90	-0.16
β_{date^2}	0.77	0.32	0.16	1.40
β_{rice}	0.32	0.43	-0.53	1.15
β_{cap}	0.00	0.05	-0.10	0.10
σ	3.25	0.27	2.77	3.82
σ_{ind}	0.46	0.35	0.03	1.31
σ_{site}	0.65	0.47	0.03	1.75
Glucose (mg/dL)				
α_0	75.94	4.83	66.55	85.44
β_{SVL}	0.80	2.51	-4.12	5.76
β_{sex}	2.89	13.09	-22.87	28.57
$\beta_{sex\ x\ SVL}$	-22.51	13.90	-49.36	5.32
β_{date}	-0.53	2.67	-5.78	4.75
β_{date^2}	1.02	1.99	-2.92	4.91
β_{rice}	-0.63	2.61	-5.67	4.56
β_{cap}	-0.02	0.32	-0.65	0.61
σ	20.66	1.74	17.55	24.46
σ_{ind}	1.35	1.59	0.04	6.28
σ_{site}	1.66	1.96	0.03	7.31
Calcium (mg/dL)				
α_0	15.11	0.36	14.41	15.84
β_{SVL}	-0.22	0.26	-0.72	0.29
β_{sex}	-0.82	1.39	-3.50	1.97
$\beta_{sex\ x\ SVL}$	-0.21	1.45	-3.13	2.68
β_{date}	0.03	0.28	-0.52	0.57
β_{date^2}	-0.23	0.20	-0.63	0.16
β_{rice}	0.40	0.27	-0.12	0.93
β_{cap}	0.28	0.25	-0.21	0.76
σ	2.00	0.17	1.69	2.38
σ_{ind}	0.36	0.26	0.02	0.97
σ_{site}	0.48	0.34	0.02	1.28

	Mean	SD	2.5th percentile	97.5th percentile
Phosphorus (mg/dL)				
α_0	6.17	0.44	5.31	7.04
β_{SVL}	0.36	0.23	-0.07	0.82
β_{sex}	-2.19	1.25	-4.65	0.24
$\beta_{\text{sex x SVL}}$	-0.97	1.33	-3.61	1.69
β_{date}	-0.62	0.25	-1.11	-0.14
β_{date}^{2}	-0.10	0.18	-0.46	0.25
β_{rice}	-0.19	0.24	-0.65	0.28
β_{cap}	-0.02	0.03	-0.08	0.04
σ	1.79	0.16	1.51	2.13
σ_{ind}	0.38	0.27	0.02	1.00
σ_{site}	0.29	0.23	0.01	0.85
Total protein (g/dL)				
α_0	4.66	0.14	4.40	4.94
β_{SVL}	0.17	0.10	-0.03	0.37
β_{sex}	0.12	0.56	-0.96	1.23
$\beta_{\text{sex x SVL}}$	-0.23	0.59	-1.37	0.95
β_{date}	-0.03	0.11	-0.24	0.20
β_{date}^{2}	0.00	0.08	-0.15	0.16
β_{rice}	0.03	0.10	-0.17	0.23
β_{cap}	0.02	0.09	-0.17	0.20
σ	0.74	0.08	0.58	0.90
σ_{ind}	0.26	0.17	0.01	0.61
σ_{site}	0.14	0.12	0.01	0.43
Albumin (g/dL)				
α_0	1.26	0.05	1.18	1.36
β_{SVL}	0.06	0.03	0.01	0.12
β_{sex}	-0.07	0.16	-0.37	0.24
$\beta_{\text{sex x SVL}}$	-0.21	0.16	-0.51	0.10
β_{date}	-0.04	0.03	-0.10	0.02
β_{date}^{2}	0.01	0.02	-0.03	0.05
β_{rice}	-0.01	0.03	-0.06	0.05
β_{cap}	0.01	0.03	-0.04	0.06
σ	0.21	0.02	0.17	0.25
σ_{ind}	0.06	0.04	0.00	0.15
σ_{site}	0.09	0.05	0.01	0.20

	Mean	SD	2.5th percentile	97.5th percentile
Globulin (g/dL)				
α_0	2.80	0.31	2.21	3.41
β_{SVL}	0.16	0.15	-0.14	0.47
β_{sex}	0.28	0.85	-1.43	1.97
$\beta_{sex\ x\ SVL}$	-0.31	0.90	-2.06	1.50
β_{date}	-0.13	0.17	-0.47	0.21
$\beta_{date}{}^2$	0.11	0.12	-0.14	0.35
β_{rice}	-0.03	0.17	-0.36	0.30
β_{cap}	0.02	0.02	-0.02	0.06
σ	1.17	0.12	0.92	1.41
σ_{ind}	0.37	0.25	0.01	0.91
σ_{site}	0.24	0.18	0.01	0.68
Potassium (mmol/dL)				
α_0	4.76	0.26	4.26	5.28
β_{SVL}	-0.02	0.12	-0.25	0.21
β_{sex}	-0.70	0.64	-1.97	0.53
$\beta_{sex\ x\ SVL}$	-1.24	0.65	-2.52	0.05
β_{date}	-0.13	0.13	-0.40	0.13
$\beta_{date}{}^2$	0.21	0.09	0.03	0.39
β_{rice}	0.20	0.12	-0.04	0.45
β_{cap}	0.00	0.01	-0.03	0.03
σ	0.87	0.08	0.73	1.04
σ_{ind}	0.20	0.14	0.01	0.53
σ_{site}	0.40	0.21	0.05	0.87
Sodium (mmol/dL)				
α_0	158.64	0.91	156.86	160.46
β_{SVL}	0.49	0.63	-0.73	1.70
β_{sex}	-1.39	3.47	-8.22	5.46
$\beta_{sex\ x\ SVL}$	-1.08	3.56	-7.97	5.90
β_{date}	-0.37	0.70	-1.73	1.02
$\beta_{date}{}^2$	0.06	0.49	-0.88	1.06
β_{rice}	0.32	0.64	-0.95	1.60
β_{cap}	0.84	0.59	-0.31	2.00
σ	4.72	0.51	3.69	5.74
σ_{ind}	1.29	1.02	0.05	3.67
σ_{site}	1.16	0.82	0.06	3.09

Publishing support provided by the U.S. Geological Survey
Science Publishing Network, Tacoma Publishing Service Center

For more information concerning the research in this report, contact the
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Reyes and others—**Behavioral Response of Giant Gartersnakes (*Thamnophis gigas*) to the Relative Availability of Aquatic Habitat on the Landscape**—Open-File Report 2017–1141

ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20171141