A GIS Approach to Habitat Suitability and Conflict Between the Giant Garter Snake (Thamnophis Gigas) and Southern Water Snake (Nerodia Fasciata)

By
Omri Cahn
Department of Environmental Science
Allegheny College
Meadville, Pennsylvania

April, 2019

GIS-based Suitability Analysis of Conflict Between the Giant Garter Snake (Thamnophis Gigas) and Southern Water Snake (Nerodia Fasciata) in California's Central Valley

By
Omri Cahn
Department of Environmental Science
Allegheny College
Meadville, Pennsylvania

April, 2019

Submitted in fulfillment of the senior thesis requirements of the Department of Environmental Science at Allegheny College and approved by the senior thesis committee.

Christopher J. Shaffer 4/25/19 C. Bradshaw-Wilson 4/25/19

Prof. Chris Shaffer **Date** **Dr. Casey Bradshaw-Wilson** **Date**

Omri Cahn

Pledge

Table of Contents

Abstract 2
Introduction 3
Methods 6
Results 11
Discussion 13
Implications 15
References 17

Name: Omri Cahn Date: Spring, 2019

Major: Environmental Science
Thesis Committee: Prof. Chris Shaffer, Dr. Casey Bradshaw-Wilson

Title: A GIS Approach to Habitat Suitability and Conflict Between the Giant Garter Snake (Thamnophis Gigas) and Southern Water Snake (Nerodia Fasciata)

Abstract

The giant garter snake (*Thamnophis gigas*) is currently listed as a threatened species and is at risk of becoming endangered according to the U.S. Department of Fish and Wildlife. Historically, the giant garter snake has faced significant habitat loss as California's central valley has been developed for agriculture. Another possible threat has come in the form of an invasive species, the southern water snake (*Nerodia fasciata*). The southern water snake's native range resides in the southern United States and Texas and does not naturally occur west of the Rocky Mountains. Both species favor wetland habitats and have similar dietary habits. The goal of this study is to determine habitat suitability and areas of competition for both the giant garter snake and the southern water snake. This was done using a GIS-based fuzzy logic designed to identify suitable habitats for both species as well as identifying areas of habitat conflict. The results generated can be used to inform decision makers on what actions to take to help preserve the giant garter snake and defend against further spreading of the southern water snake.

Introduction

The giant garter snake (*Thamnophis gigas*) is one of the native fauna of California's central valley (Dickert, 2005; Czech, 2006). Its original range encompasses most of the Sacramento and San Joaquin Valley. The snake resided within the wetland habitats of the valley. However, development of the central valley for agricultural use reduced the wetlands by 93% (Halstead, Wylie, & Casazza, 2013). This in turn resulted in a significant reduction of the species range as their habitat was destroyed (Hammerson, 2007). This is significant as one of the primary factors of reptile endangerment is a reduction in its native range and other factors like species specialization (Böhm et al., 2016). Today the giant garter snake is listed as a threatened species by both state and federal governments (California Department of Fish and Game Commission, 1971; U.S. Fish and Wildlife Service, 1993). The threats the giant garter snake faces include habitat degradation, habitat fragmentation, and the presence of an invasive species.

Habitat degradation is a considerable threat as reduced habitat availability limits the size of species populations that can be supported. In the central valley a common form of habitat degradation comes in the form of agricultural land use. The majority of the central valley's wetlands were converted into agricultural lands. Historically, as human population grows the need for more agricultural land increases (Green, 2005). This usually results in humans developing on previously undeveloped land to meet their needs. The need for high yield agriculture and desire to maintain biodiversity often cannot be simultaneously achieved (Lindenmayer, Young, & Saul, 2012). In addition, the giant garter snake faces issues with habitat fragmentation, which has been found to impair gene flow, causing genetic bottlenecking in many of the known populations as they are becoming more isolated (Paquin, Wylie, &

Routman, 2006; Wood et al., 2015). Habitat fragmentation also poses risks for other wildlife. Increased rates of extinction might have negative impacts at different trophic levels (Krauss et al., 2010; Cardinale et al., 2012). Invasive species as a conservation concern are also of importance to address. While the threats posed by invasive mammalian species, which are better known as they are more frequently studied and monitored species reptilian invasive species impacts are often less well known as they are generally studied less (Doherty et al., 2016). They also propose a threat to biodiversity, as invasive species might prey upon native species or out compete for resources.

The southern water snake (*Nerodia fasciata*) has reproductive populations in the central valley. They were first reported in Folsom, CA in 1992 and later again in Harbor City in 2007 (Rose & Todd, 2014). The southern water snake is native to the southeastern United States and is not naturally found west of the Rocky Mountains (CAFWS, 2009). The southern water snake poses several risks for native threatened and endangered species in California. It is a generalist predator (Reed et al., 2016) that can eat anything smaller than the width of its head (Vincent et al., 2005). Southern water snakes can thrive in the central valley because like the giant garter snake, its natural diet consists of small amphibians, fish, and mammals. Both species also give live birth and have similar litter sizes with the mean litter size for garter snakes being 17 (Brian et al., 2011), and the mean litter size for the southern water snake at 21 (Reed et al., 2016). The climate in the central valley is also appropriate for southern water snakes (Rose & Todd, 2014) as climate matching is essential for the success of an invasive reptile (Mahoney et al., 2014). In context to the central valley, southern water snakes pose as possible competition to the threatened San Francisco garter snake and the giant garter snake as they both inhabit wetland habitats and prey upon similar species (Rose, 2016). Southern water snakes not only pose a

threat to giant garter snakes but to many species found within California's central valley. Southern water snakes are a possible predatory threat to the following endangered or threatened species: Santa Cruz Long-toed Salamander, California Tiger Salamander, and Steelhead fish within the central valley (Rose & Todd, 2014).

The threat that the southern water snake possess to biodiversity is of significant concern. Invasive species can out compete species in the same niche, and prey upon native species, thus disrupting the ecosystem (Stigall, 2010). Current data suggests that we might be going through a sixth mass extinction brought on by climate change and other human-made ecological stressors (Barnosky et al. 2011; Mendenhall, Daily, & Ehrlich, 2012). It is important to maintain biodiversity within ecosystems as biologically diverse ecosystems function more efficiently and increase ecosystem stability (Cardinale et al., 2012). With the loss of species due to extinction comes the repercussions of loss of biodiversity including accelerated degradation of an ecosystem. Loss of diversity can also impact other species within the ecosystem and different tropic levels (Cardinale et al. 2012). The central valley's wetlands have already shrunk significantly as the land has been developed. This has put stress on species that specifically live in that region and are not found elsewhere. Species like the giant garter snake that are threatened may become endangered or go extinct if their habitat is not adequately protected.

The goal of this project is to use geographic information systems (GIS) to conduct habitat suitability analysis and identify possible habitat overlap for giant garter snakes and southern water snakes within the giant garter snakes' native range. The results from this study can be used by decision-makers to determine how to remove or reduce the spread of the invasive species as it poses a potential threat to endemic wildlife. Current possible strategies include removing *N. fasciata* with traps. While current trapping methods do succeed in capturing snakes of the desired

population placement, use of the traps until the invasive species is removed is time consuming and potentially costly (Reed et al. 2016; Nafus et al 2018). With more information on possible locations on the species in question there might be alternative conservation approaches for protecting the wetlands and mitigating the southern water snakes' impact.

Methods

The region analyzed was the central valley of California. This region contains the majority of the state's agriculture as well at its wetlands. The valley is adjacent to the Sierra Nevada mountain range to the east, and the Southern and Northern Coast ranges to the west. The state capital of Sacramento is also within the valley. Large portions of land have been developed for agriculture within the valley as well as a few cities. The valley also hosts several wetlands and a few wildlife conservancies.

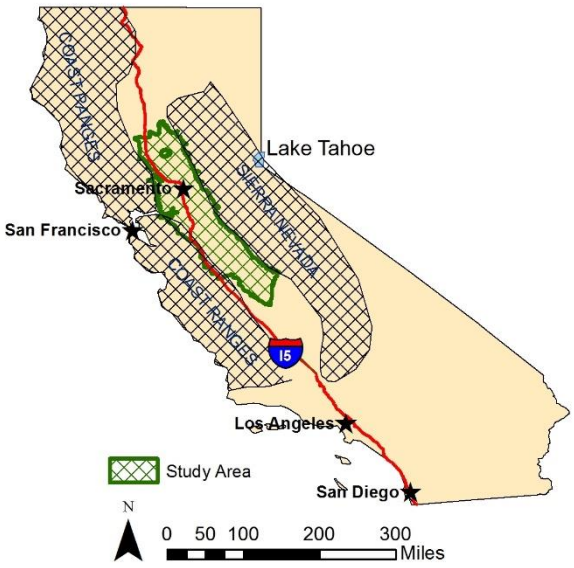


Figure 1. Map of California and the current estimated range of the giant garter snake

Landcover can be used to assess habitat suitability as both snakes favor wetland habitats and prefer being close to bodies of fresh water, including wetlands. (Reed et al. 2016). Distance from rice farms are also included in this analysis as rice fields are flooded providing a suitable habitat most of the year when the crop is being grown (Czech 2006). Temperature was used as snakes thermoregulate to control their metabolic rate during the year and thrive in favorable temperature ranges (Glen et al. 2009).

Euclidean distance functions were used to measure the distance from each of the suitable features. In addition, the landcover data was reclassified. To reduce and simplify categories of

landcover. Landcover data types that were similar were consolidated into a larger group (Ex. River, lake data types could be reclassified to both be called “water”).

Fuzzy logic works on a gradient instead of separate distinct ranks and is an effective method for habitat suitability analysis. In fuzzy logic, Rach output is provided a membership value between 1 and 0. In the case of this study 1 indicates high favorability and 0 no favorability with 0.5 being in the midpoint. Using these data, a model for habitat suitability for the two species was constructed then compared.

A habitat suitability analysis was preformed using a fuzzy logic approach to GIS-based multi-criteria evaluation. Fuzzy logic approach was described first by mathematician and computer scientist Lotfi Zadeh. Fuzzy logic describes a condition in terms of truth or likelihood between the values of 1 and 0. In Boolean analysis 1 is considered true and 0 is considered false. Unlike Boolean fuzzy includes all real numbers between 1 and 0. This allows fuzzy to describe the likelihood of a criteria or condition being present (Zadeh, 2008). In the case of this analysis the conditions were habitat suitability and conflict. This method takes geospatial data and assigns a likelihood based on the habitat criteria of the species being studied. The application of fuzzy logic can be used to evaluate the suitability of a habitat by overlaying multiple criteria that constitutes ideal habitat conditions. In the case of this study, it can provide an output of the likelihood of suitable habitat and the likelihood of habitat conflict. A large likelihood indicates a greater probability of snakes being present, the places with the highest likelihood values are the most suitable for this analysis. Variables to be considered include land cover type, distance to streams and wetlands, distance to rice farms, and temperature. The data layers for this analysis have been summarized in table 1.

Table 1: Digital data input and their sources.

Criteria	Year	Source
Streams	2017	National Hydrography Dataset (USGS)
Rice Agriculture	2017	National Cropland Database (NRCS)
Land cover	2011	National Land Cover Database (USGS)
Temperature	2017	Prism Climate Group (Oregon State)

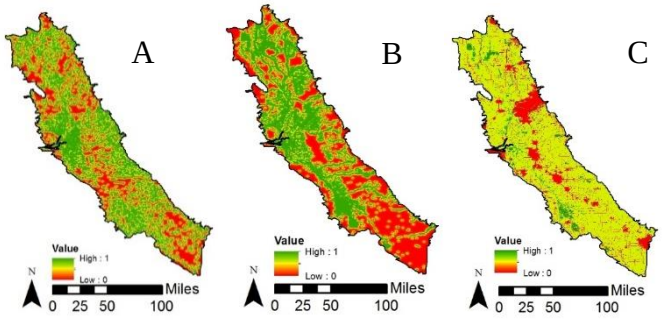
Each species was assigned individual fuzzy memberships as seen in table 2. The distances were derived by taking the mean and adding two standard deviations of each snake's average daily movement for a week with 162 meters a day for the giant garter snake (Reyes et al., 2017) and 93 meters a day for the southern water snake (Camper & Chick, 2010). The time span of a week was chosen as snakes' metabolic rate is partially determined by temperature (McCue, Lillywhite, & Beaupre, 2012). This means snakes can go long lengths of time without food or water depending on how they manage their temperature. With some species of snakes capable of going without food for months, the time span of a week was chosen, as ideally these snakes would want to stay within a close range of food and water as distances that would require a slowed metabolic rate would be less desired. For the output the small function was used as high values are most suitable and decline rapidly past the midpoint (Mitchell, 2012). This was used as the probability that the snakes would move further beyond two standard deviations of the mean would be exceedingly low. The steep decline in likelihood provided by the small function represents this.

Suitable temperature was based on the ideal average body temperature of each snake respectively. The giant garters snake's ideal body temperature was found to be 26.7 degrees Celsius with the lowest recorded value at 7 degrees (Wylie et al. 2009). For the southern water snake its average body temperature at 20 degrees Celsius with a steep increase in body

temperature past 10 degrees (Rose & Todd, 2014). The MSLarge function was used as the mean multiplier cuts off values that are too low then rises rapidly similar to a log function to the membership value of one (Mitchell, 2012). MSLarge was used as temperatures in the study area did not exceed habitable temperatures and higher basking temperatures were preferred. The mean multiplier values determined at what value suitability would begin to increase past zero.

Table 2: Fuzzy membership functions with midpoints and landcover membership scores

Input Variable	Giant Garter Midpoint/ Mean Multiplier	Southern Water Midpoint/ Mean Multiplier	Function/ Membership
Distance from Rice (m)	1134	649	Small
Distance from Streams (m)	1134	649	Small
Distance from Wetlands (m)	1134	649	Small
Temperature (C)	.401	.58	MS Large
Landcover			1.0: Wetlands, Open Water 0.6: Agriculture, Grassland 0.4: Forest 0.00: Developed, Barren



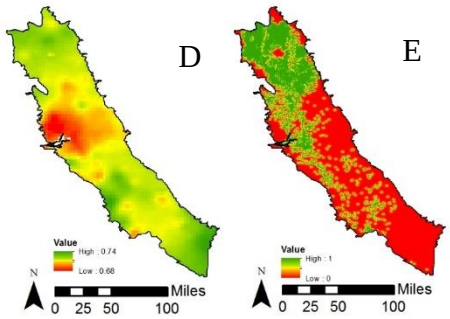


Figure 2: Fuzzy membership outputs for the giant garter snake A: Distance from streams, B: Distance from wetlands, C: Landcover, D: Temperature, and E: Distance from rice agriculture.

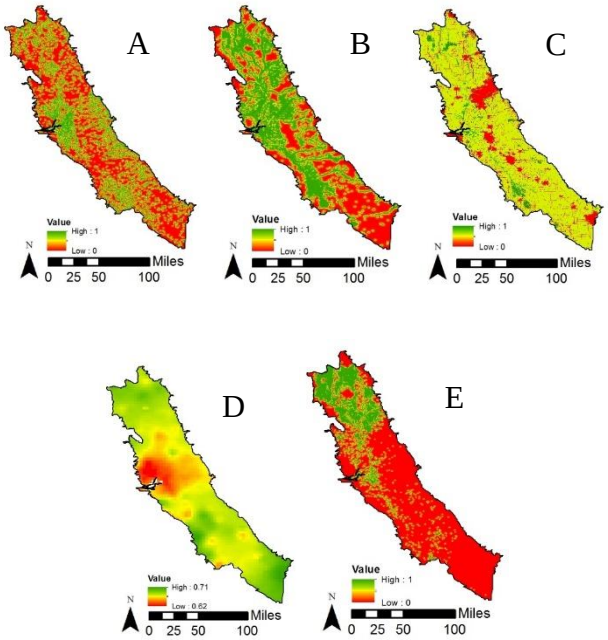


Figure 3: Fuzzy membership outputs for the southern water snake A: Distance from streams, B: Distance from wetlands, C: Landcover, D: Temperature, and E: Distance from rice agriculture.

Landcover membership values were assigned based off of habitat preference of both snakes. Both preferred wetland habitats and other areas near water sources most so they received a membership value of 1 (Reed et al. 2016). Agricultural land was given a slightly lower membership value of 0.6 as water intensive crops irrigation systems can provide habitat for the snakes, especially rice agriculture (Czech 2006). Forests were not considered highly suitable nor

highly unsuitable and were assigned the membership value of 0.4. Developed land like cities and other industrial areas was given a membership of 0 as that landcover type does not provide the necessary resources to successfully support these wild snakes. These outputs were used as the inputs to create the fuzzy overlays for each species.

For the fuzzy overlay the AND function was used as it selects the lowest likelihood values for each cell. This creates an output that best highlights the areas that are highly suitable and meet all the criteria (Mitchell, 2012). When looking for habitat overlap, instances of overlap will occur most over the most suitable areas. By using an operator that provides the lowest output areas that still have high suitability will be more pronounced in the output. To highlight areas of overlap the SUM function was used combining the outputs of the suitability maps. SUM provides an output that highlights increases in values and areas of high likelihood. It increases the output by subtracting then multiplying each input by one. The product is then used to take the difference of one. This method results in an increase but also prevents the output from exceeding 1 or going below 0. As a result, inputs that both have high values will be amplified indicating areas where conflict occurs most.

Results

The study region is approximately 27,602 km^2 in size. The results of this analysis have produced an output for both species of snakes. Both outputs appear similar with the giant garter snake displaying higher likelihood values than the southern water snake (Figure 4 & Table 3). For both species, the area within the study region that had likelihood values above 0.5 made up less than 15% of the whole study region. Each of the quantiles had higher values for the giant garter snake compared to the southern water snake.

Table 3: Quantiles and their range of likelihood values.

Quantile	Giant Garter Snake	Southern Water Snake	Conflict
Q0	0	0	0
Q1	0.0-0.037	0.0-0.016	0.0-0.047
Q2	0.037-0.280	0.016-0.105	0.047-0.346
Q3	0.280-0.736	0.105-0.708	0.346-0.923

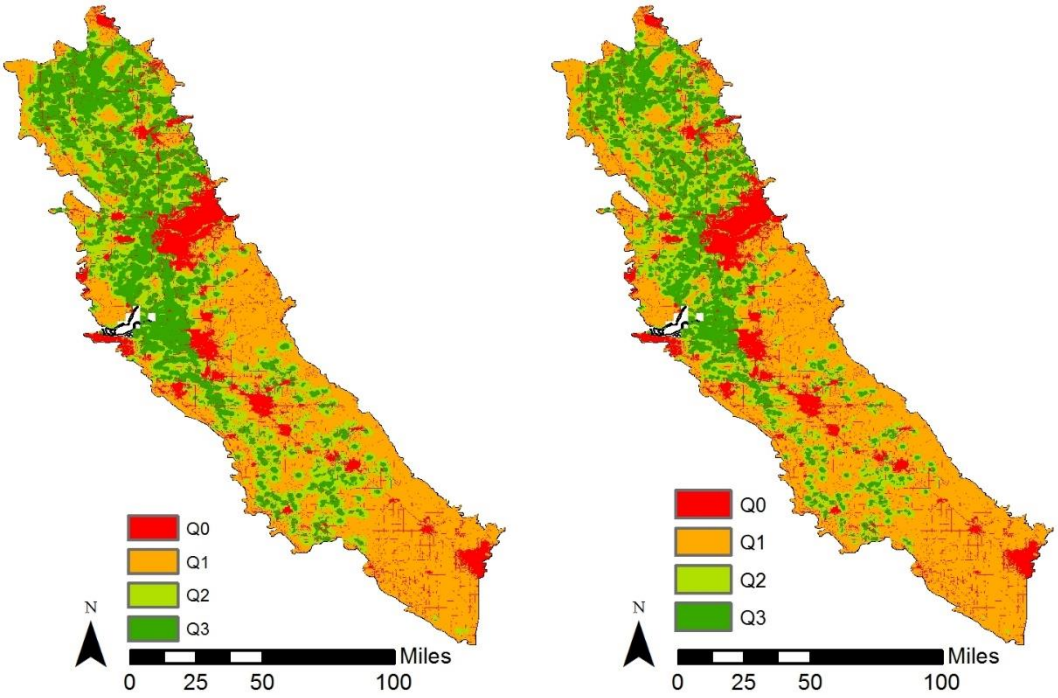


Figure 4: Giant garter snake Fuzzy Overlay output (left) Southern water snake Fuzzy Overlay output (right) with Q4 being the upper quantile and Q0 as the bottom

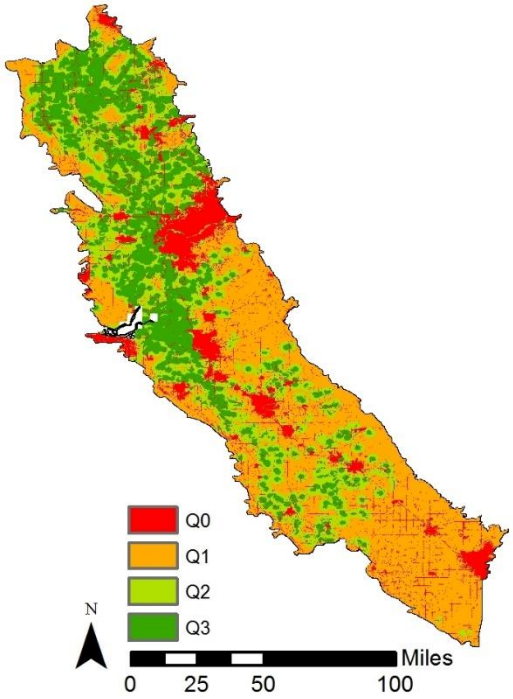


Figure 5: Habitat conflict between the giant garter snake and southern water snake with Q4 being the upper quantile and Q0 as the bottom

The regions of the map that are in the upper quantiles across both species and the habitat conflict mostly occur in the northern region of the study area. High suitability also occurs east of the Bay Area where San Francisco is located. Areas in the lowest quantile are around Sacramento in the upper left portion and the lower portions of the study area.

Discussion

The results of this study show that giant garter snakes are generally more suited to the habitat within the study region than the southern water snake (Table 3). In all quantiles the values for the giant garter snake's highest values are higher than that of the southern water snake. Both species' quantiles are visually similar (Figure 4). This is due to the similar habitat criteria for each of the snakes. The main differentiating factor for each snake is the mean distance it can travel, which was used to calculate membership values (Table 2). Each snake had higher favorability near streams, wetland, and rice fields. The suitability outputs highlight this clearly. These features were all common in the norther portion of the study region and near San

Francisco (Figures 2 & 3). Areas of lowest suitability appear to be closely related to developed land. This outcome is to be expected because land that was developed replaced and built over wetlands and streams. Additionally, the use of the AND function outputs the lowest value for each pixel, as developed land was ranked as 0 (Table 2) its impact on the output can easily be observed.

The output of the habitat conflict layer (Figure 5) is visually similar to previous outputs for each of the snake species as the two habitat suitability maps were overlaid. The combination of the two layers using the SUM function highlights areas with high likelihood values. This results in a layer with higher likelihood values than either of the inputs (Table 3). Areas of the highest conflict occur where both species' upper quantiles overlap, which is the intended result. These areas occur mostly east of the bay where the costal mountain ranges are split. Areas of conflict are also present in the north above and around Sacramento. Few areas of conflict occur in the southern portion of the study area, likely a result of the land not being very suitable for each species.

Previous studies on habitat suitability of the southern water snake show that much of the central valley is suitable (Rose & Todd, 2014). This particular study looks for habitat suitability across the contiguous United States. The researches also looked at native species range where the southern water snakes predicted suitable habitat overlaps with the giant garter snake. A study on giant garter snake suitability also resulted in outputs that indicated the giant garter favors streams, wetlands, and rice agriculture within the central valley (Halstead, Wylie, & Casazza, 2010). These results agree with the observations made in this study.

The method of fuzzy logic for habitat suitability is well supported. Multi-criteria decision making is often used for suitability analysis, particularly the use of fuzzy logic methods in

combination with GIS (Khedrigharibvand et al., 2019; Olivero, Marques, & Real, 2012). The use of these methods is common, as models can be constructed from previously recorded data and literature. Depending on the quality of data and the understanding of habitat preferences, accurate models of habitat suitability have been able to be constructed and used for informative policy-making.

This analysis used the USGS 2011 land cover data set. Originally, data from 2016 was intended for use. Due to the government shutdown, the USGS was unable to publish the 2016 landcover data before this analysis was performed. An improvement would be using the updated data set to better represent the study regions landcover. Another consideration in the temperature data used, the cell size for that data was much larger as temperature data is not recorded with high precision. Temperature data is usually recorded in 4km cell resolution while the rest of the data used for this study was at a cell size of 30m. While more precise temperature data would be ideal, it is difficult to produce and acquire.

Implications

Moving forward in protecting the giant garter snake, we must consider the threat of species that can compete. Southern water snakes are capable and can inhabit much of the same land as giant garter snakes. If southern water snake populations are able to establish themselves the risk the likelihood of competition is high. Both species are incredibly reliant on wetland habitat (Roe, Kingsbury, & Herbert, 2003). To combat this, the protection of wetlands and streams is essential. Historically, wetlands have declined in the central valley. The continuation of their protection is key. In terms of controlling southern water snakes' populations and their spread little can be done. Methods of trapping are not successful in capturing enough snakes to diminish or remove established populations (Reed et al., 2016). Another possibility is the use of

biological control. This can be done by introducing a species that is a natural predator to the introduced species (Messing & Wright, 2006). However, this could be the source of further problems. In the past, some introduced species intended for biological control have gone out of control and became invasive themselves (De Clereq, Mason, & Babendreier, 2011; Simberloff, 2012). Although, if done properly there is little risk. Additionally, the similarities between the giant garter and southern water snake might result in the giant garter being negatively impacted by biological as well. Given these circumstances, preventing the further spread and introduction of additional southern water snake individuals should be a priority.

Further understanding of the southern water snake's movement within the central valley could also be important. With current technology we can use radio telemetry or GPS based telemetry to better understand the movements of individuals of both giant garter and southern water snake populations. These methods have been previously used to estimate the ranges and movement habits of various species including ratsnakes and Burmese pythons (Ward, Sperry, & Weatherhead, 2013; Smith et al., 2018). Data that shows current locations of populations can be used to better protect the giant garter and to help control the spread of southern water snakes.

References

Barnosky, A. D., Matzke, N., Tomiya, S., Wogan, G. O., Swartz, B., Quental, T. B., . . . Ferrer, E. A. (2011). Has the Earth's sixth mass extinction already arrived? *Nature,471*(7336), 51-57. doi:10.1038/nature09678

Böhm, M., Williams, R., Bramhall, H. R., Mcmillan, K. M., Davidson, A. D., Garcia, A., . . . Collen, B. (2016). Correlates of extinction risk in squamate reptiles: The relative importance of biology, geography, threat and range size. *Global Ecology and Biogeography,25*(4), 391-405. doi:10.1111/geb.12419d

Camper, J. D., & Chick, L. D. (2010). Seasonal Variation in the Spatial Ecology of the Banded Watersnake (Nerodia fasciata fasciata). *Herpetologica,66*(4), 464-475. doi:10.1655/09-029.1

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., . . . Naeem, S. (2012). Biodiversity loss and its impact on humanity. *Nature, 486*(7401), 59-67. Retrieved from https://search.proquest.com/docview/1020697424?accountid=8268

De Clercq, P., Mason, P. G., & Babendreier, D. (2011). Benefits and risks of exotic biological control agents. *Biocontrol, 56*(4), 681-698. doi:http://dx.doi.org.ezproxy1.allegheny.edu:2048/10.1007/s10526-011-9372-8

Dickert, C. (2005). Giant garter snake surveys at some areas of historic occupation in the grassland ecological area, merced co. and mendota wildlife area, fresno co., california. *California Fish and Game, 91*(4), 255-269.

Doherty, T. S., Glen, A. S., Nimmo, D. G., Ritchie, E. G., & Dickman, C. R. (2016). Invasive predators and global biodiversity loss. *Proceeding of the National Academy of Sciences of the United States of America,113*(40), 11261-11265. doi:10.1073/pnas.1602480113

Endangered and Threatened Wildlife and Plants; 5-Year Reviews of Species in California, Nevada, and the Klamath Basin of Oregon. (2011, May 25). Retrieved September 27, 2018, from https://www.federalregister.gov/documents/2011/05/25/2011-12861/endangered-and-threatened-wildlife-and-plants-5-year-reviews-of-species-in-california-nevada-and-the

Green, R. E. (2005). Farming and the Fate of Wild Nature. *Science,307*(5709), 550-555. doi:10.1126/science.1106049

Halstead, B. J., Wylie, G. D., & Casazza, M. L. (2013). Ghost of habitat past: Historic habitat affects the contemporary distribution of giant garter snakes in a modified landscape. *Animal Conservation,17*(2), 144-153. doi:10.1111/acv.12073

Halstead, B. J., Wylie, G. D., & Casazza, M. L. (2010). Habitat Suitability and Conservation of the Giant Gartersnake (Thamnophis gigas) in the Sacramento Valley of California. *Copeia,2010*(4), 591-599. doi:10.1643/ce-09-199

Hammerson, G.A. 2007. *Thamnophis gigas*. The IUCN Red List of Threatened Species 2007: e.T21706A9310655. http://dx.doi.org/10.2305/IUCN.UK.2007.RLTS.T21706A9310655.en. Do wnloaded on 28 September 2018.

Khedrigharibvand, H., Azadi, H., Teklemariam, D., Houshyar, E., Maeyer, P. D., & Witlox, F. (2017). Livelihood alternatives model for sustainable rangeland management: A review of multi-criteria decision-making techniques. *Environment, Development and Sustainability,21*(1), 11-36. doi:10.1007/s10668-017-0035-5

Krauss, J., Bommarco, R., Moises, G., Heikkinen, R. K., Helm, A., Kuussaari, M., . . . Steffan-Dewenter, I. (2010). Habitat fragmentation causes immediate and time-delayed biodiversity loss at different trophic levels. *Ecology Letters,13*, 597-605. doi:10.1111/j.1461-0248.2010.01457.x

Mahoney, P. J., Beard, K. H., Durso, A. M., Tallian, A. G., Long, A. L., Kindermann, R. J., . . . Mohn, H. E. (2014). Introduction effort, climate matching and species traits as predictors of global establishment success in non-native reptiles. *Diversity and Distributions,21*(1), 64-74. doi:10.1111/ddi.12240

Mccue, M. D., Lillywhite, H. B., & Beaupre, S. J. (2012). Physiological Responses to Starvation in Snakes: Low Energy Specialists. *Comparative Physiology of Fasting, Starvation, and Food Limitation,*103-131. doi:10.1007/978-3-642-29056-5_8

Mendenhall, C. D., Daily, G. C., & Ehrlich, P. R. (2012). Improving estimates of biodiversity loss. *Biological Conservation,151*(1), 32-34. doi:10.1016/j.biocon.2012.01.069

Messing, R., & Wright, M. (2006). Biological Control of Invasive Species: Solution or Pollution? *Frontiers in Ecology and the Environment, 4*(3), 132-140. Retrieved from http://www.jstor.org.ezproxy1.allegheny.edu:2048/stable/3868683

Nafus, M. G., Adams, A. A., Klug, P. E., & Rodda, G. H. (2018). Habitat type and structure affect trap capture success of an invasive snake across variable densities. *Ecosphere,9*(8). doi:10.1002/ecs2.2339

Olivero, J., Márquez, A. L., & Real, R. (2012). Integrating Fuzzy Logic and Statistics to Improve the Reliable Delimitation of Biogeographic Regions and Transition Zones. *Systematic Biology,62*(1), 1-21. doi:10.1093/sysbio/sys061

Paquin, M. M., Wylie, G. D., & Routman, E. J. (2006). Population Structure of the Giant Garter Snake, Thamnophis gigas. *Conservation Genetics,7*(1), 25-36. doi:10.1007/s10592-005-7439-8

Reed, R. N., Todd, B. D., Miano, O. J., Canfield, M., Fisher, R. N., & Mcmartin, L. (2016). Ecology and Control of an Introduced Population of Southern Watersnakes (Nerodia fasciata) in Southern California. *Herpetologica,72*(2), 130-136. doi:10.1655/herpetologica-d-14-00061

Reyes, G. A., Halstead, B. J., Rose, J. P., Ersan, J. S., Jordan, A. C., Essert, A. M., . . . Casazza, M. L. (2017). Behavioral response of giant gartersnakes (Thamnophis gigas) to the relative availability of aquatic habitat on the landscape. *Open-File Report*. doi:10.3133/ofr20171141

Roe, J. H., Kingsbury, B. A., & Herbert, N. R. (2003). Wetland and upland use patterns in semi-aquatic snakes: Implications for wetland conservation. *Wetlands,23*(4), 1003-1014. doi:10.1672/0277-5212(2003)023[1003:wauupi]2.0.co;2

Rose, J. P., & Todd, B. D. (2014). Projecting Invasion Risk of Non-Native Watersnakes (Nerodia fasciata and Nerodia sipedon) in the Western United States. *PLoS ONE,9*(6). doi:10.1371/journal.pone.0100277

Smith, B. J., Hart, K. M., Mazzotti, F. J., Basille, M., & Romagosa, C. M. (2018). Evaluating GPS biologging technology for studying spatial ecology of large constricting snakes. *Animal Biotelemetry,6*(1). doi:10.1186/s40317-018-0145-3

Simberloff, D. (2012). Risks of biological control for conservation purposes.*Biocontrol, 57*(2), 263-276. doi:http://dx.doi.org.ezproxy1.allegheny.edu:2048/10.1007/s10526-011-9392-4

Stigall, A. L. (2010). Invasive Species and Biodiversity Crises: Testing the Link in the Late Devonian. *PLoS ONE,5*(12). doi:10.1371/journal.pone.0015584

Lindenmayer (Author), *Title: Land Use Intensification : Effects on Agriculture, Biodiversity and Ecological Processes*(pp. 7-15). Collingwood, VIC : CSIRO PUBLISHING.

Vincent, S. E., Moon, B. R., Shine, R., & Herrel, A. (2005). The functional meaning of “prey size” in water snakes (Nerodia fasciata, Colubridae). *Oecologia,147*(2), 204-211. doi:10.1007/s00442-005-0258-2

Ward, M. P., Sperry, J. H., & Weatherhead, P. J. (2013). Evaluation of Automated Radio

Telemetry for Quantifying Movements and Home Ranges of Snakes. *Journal of Herpetology,47*(2), 337-345. doi:10.1670/12-018

Wood, D. A., Halstead, B. J., Casazza, M. L., Hansen, E. C., Wylie, G. D., & Vandergast, A. G. (2015). Defining population structure and genetic signatures of decline in the giant gartersnake (Thamnophis gigas): Implications for conserving threatened species within highly altered landscapes. *Conservation Genetics,16*(5), 1025-1039. doi:10.1007/s10592-015-0720-6

Wylie, G. D., Casazza, M. L., Halstead, B. J., & Gregory, C. J. (2009). Sex, season, and time of day interact to affect body temperatures of the Giant Gartersnake. *Journal of Thermal Biology,34*(4), 183-189. doi:10.1016/j.jtherbio.2009.01.006\

Zadeh, L. A. (2008). Is there a need for fuzzy logic? *Information Sciences,178*(13), 2751-2779. doi:10.1016/j.ins.2008.02.012

§670.5(a). Animals of California Declared to Be Endangered ... (n.d.). Retrieved September 25, 2018, from http://www.fgc.ca.gov/regulations/2009/670_5apffregs.pdf