

Species Status Assessment Report
for the
Key ring-necked Snake (*Diadophis punctatus acricus*)



Key ring-necked snake

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Species Status Assessment Report for the Key ring-necked Snake (*Diadophis punctatus acricus*)

Prepared by the
U.S. Fish and Wildlife Service

EXECUTIVE SUMMARY

This species status assessment (SSA) reports the results of the comprehensive status review for the Key ring-necked snake (*Diadophis punctatus acricus*), documenting the subspecies' historical condition and providing estimates of current and future condition under a range of different scenarios. The Key ring-necked snake is one of the smallest subspecies of the family Dipsadidae and has only been documented on Key West, Big Pine Key, Little Torch Key, Middle Torch Key, No Name Key, Cudjoe Key, and Stock Island in the lower Florida Keys.

The SSA process can be categorized into three sequential stages. During the first stage, we used the conservation biology principles of resiliency, redundancy, and representation (together, the 3Rs) to evaluate individual Key ring-necked snake life history needs. The next stage involved an assessment of the historical and current condition of subspecies' demographics and habitat characteristics, including an explanation of how the subspecies arrived at its current condition. The final stage of the SSA involved making predictions about the subspecies' future response to positive and negative environmental and anthropogenic influences. This process used the best available information to characterize viability as the ability of a species to sustain populations in the wild over time.

The purpose of the SSA is to assess the viability of a species over time. To do this a species must have a sufficient number and distribution of healthy populations to withstand changes in its biological (*e.g.*, predators, disease) and physical (*e.g.*, habitat loss, climate change) environment, and to withstand environmental stochasticity (*e.g.*, flooding, drought, and storm surge). Viability is not a specific state, but rather a continuous measure of the likelihood that the species will sustain populations over time. Generally, the more resiliency, redundancy, and representation a species and its habitat have, the more protected the species is against changes to its environment, the more it can tolerate threats (one of the factors that may be acting on the species or its habitat, causing a negative effect), the better able it is to adapt to future changes, and thus, the more viable it is. For the purpose of this assessment, we define viability as the ability of a species to sustain populations in the wild. Using the SSA framework, we describe a species' viability by characterizing the status of a species in terms of its 3Rs (Shaffer and Stein 2000, pp. 305–310). Using various time frames and the current and projected levels of the 3Rs, we describe the subspecies' level of viability over time.

To evaluate the current and future viability of the Key ring-necked snake, we assessed a range of conditions to allow us to consider the subspecies' 3Rs. Together, the 3Rs comprise the key characteristics that contribute to a species' ability to sustain populations in the wild over time (*i.e.*, viability). Using the principles of the 3Rs, we characterized both the subspecies' current

viability and forecasted its future viability based on threats and over a range of plausible future scenarios.

Multiple threats are currently impacting the Key ring-necked snake and its habitat, and these impacts are occurring at the individual and population level. The most significant threats to the Key ring-necked snake is habitat loss due to residential and commercial development, climate change and sea level rise. The effects of storm events (*e.g.*, storm surge, high tide) and sea level rise (SLR) outweigh all other threats, and has the greatest influence on population resiliency. Storm event-related effects will become more frequent and intense which will accelerate habitat modification, and therefore reduce population resiliency. The Florida Keys will face increased sea level rise which will cause irreversible habitat modification and loss.

The viability of the Key ring-necked snake will depend on maintaining multiple resilient populations over time. Given our uncertainty regarding if or when habitat occupied by the Key ring-necked snake will be lost or otherwise impacted, we have forecasted what the Key ring-necked snake may have in terms of resiliency, redundancy and representation under four future scenarios which focus on a range of conditions based on climate change and land development projections. Given this, the population of Key ring-necked snakes in the Lower Florida Keys may begin experiencing significant losses in the next 10-20 years, may potentially be extirpated as early as 2040, and depending on the rate of SLR, will very likely become extirpated by 2080.

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1. INTRODUCTION

The Key ring-necked snake (*Diadophis punctatus acricus*) is one of the smallest subspecies of the family Dipsadidae documented in the lower Florida Keys. It is found on seven islands: Key West, Big Pine Key, Little Torch Key, Middle Torch Key, No Name Key, Cudjoe Key and Stock Island (Auth and Scott 1996, p. 33; Florida Fish and Wildlife Conservation Commission [FWC] 2011, p. 3; 2013, p.1; Mays and Enge 2016, p. 11, 13; J. Mays, personal communication, February 4, 2020). Within this limited range, the Key ring-necked snake is found in pine rocklands, tropical hardwood hammocks and limestone outcroppings. The slender snake attains a mean adult length of 6 to 10 inches (in) (15.2 to 25.4 centimeters [cm]), has a grayish-black dorsal surface, a yellow to red ventral surface, and the neck ring is indistinct or completely absent.

The Species Status Assessment (SSA) framework [U.S. Fish and Wildlife Service (Service) 2016, entire] is intended to be an in-depth review of a species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA Report to be easily updated as new information becomes available and (if a species is listed) to support all functions of the Endangered Species Program from Candidate Assessment, to Listing, to Consultations and to Recovery. As such, the SSA Report will be a living document that may be used to inform the Endangered Species Act of 1973, as amended (Act) decision making, such as listing, recovery, section 7, section 10 and reclassification decisions (the former four decision types are only relevant should a species warrant listing under the Act).

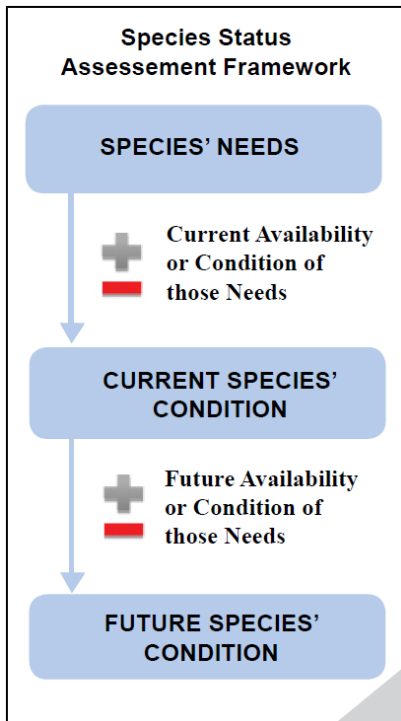
The Key ring-necked snake SSA is intended to provide the biological support for the decision on whether to propose to list the subspecies as threatened or endangered and, if so, to determine whether it is prudent to designate critical habitat in certain areas. Importantly, the SSA Report is not a decisional document by the Service; rather, it provides a review of available information strictly related to the biological status of the Key ring-necked snake. The listing decision will be made by the Service after reviewing this document and all relevant laws, regulations and policies. The results of a proposed decision will be announced in the *Federal Register* with appropriate opportunities for public input.

For the purpose of this assessment, we define viability as the ability of the subspecies to sustain resilient populations in the lower Florida Keys for at least 60 years. Using the SSA framework (Figure 1), we consider what the subspecies needs to maintain viability by characterizing the status of the subspecies in terms of its 3Rs (Wolf et al. 2015, entire; Service 2016, entire).

- Resiliency is assessed at the level of populations and reflects a species' ability to withstand stochastic events (events arising from random factors). Demographic measures that reflect population health, such as fecundity, survival, and population size, are the metrics used to evaluate resiliency. Resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity) and the effects of anthropogenic activities.
- Representation is assessed at the species' level and characterizes the ability of a species to adapt to changing environmental conditions. Metrics that speak to a species' adaptive potential, such as genetic and ecological variability, can be used to assess representation.

Representation is directly correlated to a species' ability to adapt to changes (natural or human-caused) in its environment.

- Redundancy is also assessed at the level of the species and reflects a species' ability to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk of such an event across multiple, resilient populations. As such, redundancy can be measured by the number and distribution of resilient populations across the range of the species.



To evaluate the current and future viability of the Key ring-necked snake, we assessed a range of conditions to characterize the subspecies' 3Rs. This SSA Report provides a thorough account of known biology and natural history and assesses the risk of threats and limiting factors affecting the future viability of the subspecies.

This SSA Report includes: (1) A description of Key ring-necked resource needs at both individual and population levels; (2) A characterization of the historic and current distribution of populations across the subspecies' range; (3) An assessment of the factors that contributed to the current and future status of the subspecies and the degree to which various factors influenced viability; and (4) A synopsis of the factors characterized.

Figure 1. Species Status Assessment Framework.

2. SUBSPECIES ECOLOGY

In this section, we provide basic biological information about the Key ring-necked snake, including its physical environment, taxonomic history and relationships, morphological description, other life history traits and range and distribution. We then outline the resource needs of individuals and populations. Here we report those aspects of the life histories that are important to our analyses.

2.1. Taxonomy

The Key ring-necked snake is one of 14 distinct subspecies of ring-necked snakes in North America, all of which are subspecies of *D. punctatus*. The other 13 subspecies are the Pacific (*D. p. amabilis*), Todos Santos Island (*D. p. anthonyi*), prairie (*D. p. arnyi*), Dugès (*D. p. dugesi*), northern (*D. p. edwardsii*), San Bernardino (*D. p. modestus*), northwestern (*D. p. occidentalis*), coralbelly (*D. p. pulchellus*), southern (*D. p. punctatus*), regal (*D. p. regalis*), San Diego (*D. p. similis*), Mississippi (*D. p. stictogenys*), and Monterey (*D. p. vandenburgii*) ring-

necked snakes. The distinguishing feature of the species *D. punctatus* is the presence of smooth scales with 15–17 scale rows along the midsection. Representatives of the species are found throughout much of North America extending into southeastern Canada and central Mexico.

The Key ring-necked snake was described and recognized as a new subspecies in 1968 based on four specimens collected on Big Pine Key, Monroe County, Florida (Paulson 1968, pp. 295–301). The Key ring-necked snake was similar to other ring-necked snakes in having 15 scale rows, 8 supralabials (scales that border the upper jaw) and a single row of large midventral spots, but differed based on a pale grayish-brown head, obscurely spotted chin and labials scales (scales that border the jaw) with little contrast, and a very faint to almost non-existent neck ring (Paulson 1968, p. 296).

Some herpetologists suggest that several subspecies including the Key ring-necked snake may not represent unique evolutionary lineages while others suggest that the genus *Diadophis* may comprise at least two genetically distinct species. In 2019, a study was conducted to determine whether the phylogenetic data of the Key ring-necked snake taxon supported the current taxonomic classification (Hoffman 2019, entire). This study concluded that the results were consistent with previous reports that the Key ring-necked snake should continue to be listed as a subspecies of the ring-necked snake, and that it does not warrant further splitting into a unique species.

The currently accepted classification for the Key ring-necked snake is as follows:

Phylum: Chordata
Class: Reptilia
Order: Squamata
Family: Dipsadidae
Genus: *Diadophis* (Baird and Girard 1853)
Species: *Diadophis punctatus* (Linnaeus 1766)
Subspecies: *Diadophis punctatus acricus* (Paulson 1968, p. 296)

Currently, this subspecies is a valid entity under the Act.

2.2. Morphology

The Key ring-necked snake is one of the smallest subspecies of the Family Dipsadidae. Body length can range from 3.5 to 12 in (8.9 to 30.4 cm); however, an adult specimen will average between 6 and 10 in (15.2 to 25.4 cm). The slender snake has a pale grayish-brown head, grayish-black dorsal surface, and a yellow, orange, or bright red abdomen which fades to orange/red underneath the tail (FWC 2013, p. 1). The dorsal surface of the head is spotted and there is a single row of half-moon spots down the center of the belly (Ernst and Ernst 2003, p. 92; FWC 2013, p. 1). The scales are smooth with 15–17 dorsal scale rows along the mid-section, and the anal scale (the scale just in front of and covering the cloacal/anal opening) is divided (McDiarmid 1978, p. 41; Ernst and Ernst 2003, p. 92). The dark pigment on the upper labials (scales that border the upper jaw) is diffuse and not confined to discrete spots as in mainland ring-necked snakes (McDiarmid 1978, p. 41). The pupil is round and the juvenile color is

similar to that of the adult (Ernst and Ernst 2003, p. 92; FWC 2013, p. 1). The characteristic neck ring is indistinct or virtually absent in both juveniles and adults.

2.3. Life history

Very little life history information is available on the Key ring-necked snake, especially as it relates to microhabitat, feeding and reproduction. Key ring-necked snakes have been documented in the lower Florida Keys including Key West, Big Pine Key, Little Torch Key, Middle Torch Key, No Name Key, Cudjoe Key and Stock Island (Auth and Scott 1996, p. 33; FWC 2011, p. 3; 2013, p. 1; Mays and Enge 2016, pp. 11, 13; J. Mays, personal communication, February 4, 2020) (Figure 2). Based on a 2015–2016 study to collect updated occurrence records, 8 individuals were documented on Middle Torch Key, Big Pine Key, Key West and a new occurrence on Cudjoe Key (Mays and Enge 2016, pp. 5, 10, 13; J. Mays, personal communication, February 4, 2020). Other than these very limited observations, no other quantitative data exists. Unfortunately, surveying for fossorial snakes in the Florida Keys is incredibly difficult due to the oolitic limestone substrate.

A unique characteristic of the Florida Keys is the thin (< 3.94 in [10 cm]) layer of sediment on the islands where lies a bed of limestone, and below that a shallow layer of freshwater referred to as a freshwater lens (U.S. Geological Survey [USGS] 2019a, p. 1). The freshwater lens is critically important for humans, flora, fauna and a variety of habitats. Because the density of freshwater is less than the underlying saltwater, it floats to the top and into the limestone rock formations where it becomes available to the island's biota. The volume of a freshwater lens fluctuates in response to rainfall, evapotranspiration, and human use (local wells).

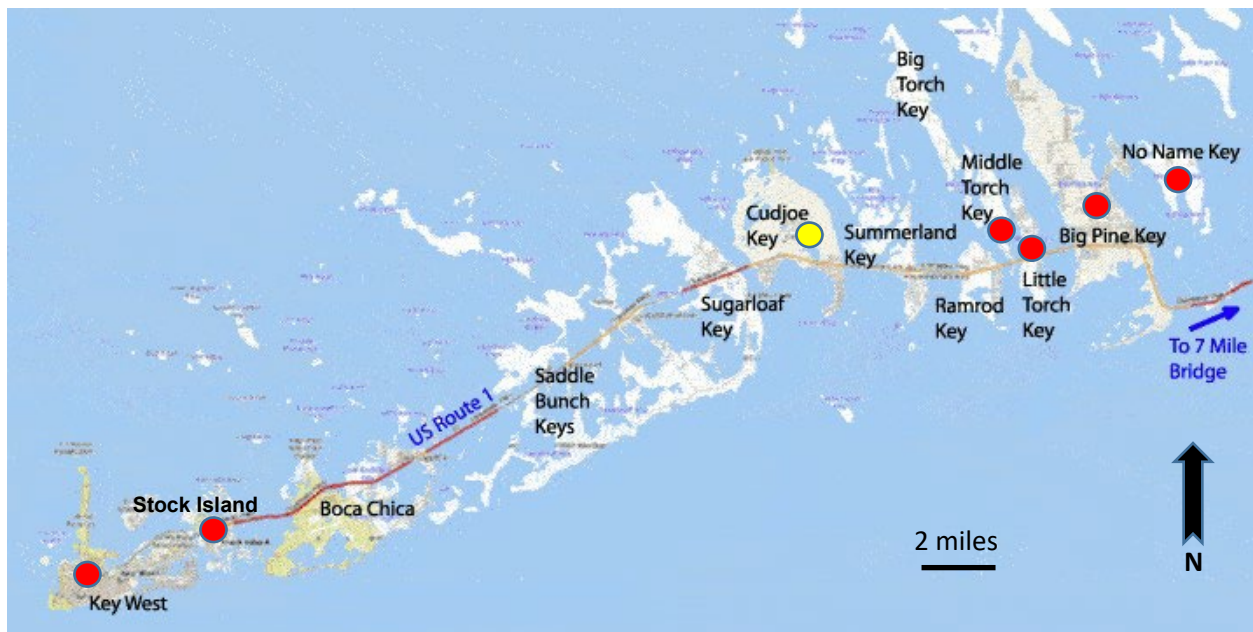


Figure 2. Historical (pre-2015, ●) and other documented records (2015-2016, ●) of Key ring-necked snakes in the lower Florida Keys.

Based on limited information, suitable habitat appears to consist of pinelands, pine rocklands, tropical hammock, rockland hammock, limestone outcroppings and rocky pine scrub areas (McDiarmid 1978, p. 41; Lazell 1989, p. 134; Auth and Scott 1996, p. 33; Enge et al. 2003, pp. 26–28). Most of the observations in the Florida Keys were from pine rocklands or nearby rockland hammocks. This subspecies appears to be restricted to areas near permanent freshwater that often occur as small holes in the limestone (Lazell 1989, pp. 134, 136). All *Diadophis* apparently require moist microhabitats to balance evaporative water loss from the body (Myers 1965, p. 4; Clark 1967, pp. 492–494). In addition, this subspecies has been found crossing roads at night and under flat rocks and boards (Paulson 1968, p. 300; Lazell 1989, p. 134; FWC 2013, p. 2).

The diet of the Key ring-necked snake is assumed to be similar to other *Diadophis* species which consists of small insects, snakes, lizards (*e.g.*, anoles, geckos), slugs, amphibians (*e.g.*, frogs, tadpoles) and earthworms (Ernst and Ernst 2003, p. 96; FWC 2013, p. 2).

There is virtually no information concerning the life cycle of the Key ring-necked snake. That said, life history characteristics are thought to be similar to the southern ring-necked snake. In general, mating of ring-necked snakes can occur in the spring or fall, delayed fertilization is possible and eggs are laid in June or early July. Females lay 1 to 10 eggs at one time each year (1 clutch/year) in covered, moist locations (Ernst and Ernst 2003, p. 95). Juveniles are thought to hatch in August and September.

2.4. Range and distribution

Based on historical records (pre-2015), the Key ring-necked snake had only been documented on No Name Key, Big Pine Key, Middle Torch Key, Little Torch Key, Stock Island and Key West (Auth and Scott 1996, p. 33; FWC 2011, p. 3; Mays and Enge 2016, pp. 11, 13; J. Mays, personal communication, February 4, 2020). Over the course of 14 months (January 2015, and July 2015 to July 2016), the FWC conducted a study in part to visit historical localities of the Key ring-necked snake to assess habitat suitability and population persistence and to conduct coverboard surveys to collect updated occurrence records (Mays and Enge 2016, p. 9). The results of the study revealed a new record on Cudjoe Key, as well as confirming the continuing presence of Key ring-necked snakes on three historical localities (Big Pine Key, Key West, and Middle Torch Key). In addition, local residents on Big Pine Key reported seeing fewer Key ring-necked snakes since Hurricane Wilma, suggesting this subspecies likely experienced a population decline due to storm surge induced overwash (Mays and Enge 2016, p. 13). The study also concluded that the efficacy of coverboard, pedestrian and driving surveys was very poor which explains why so little is known concerning the range, distribution and abundance of this subspecies.

3. POPULATION AND SUBSPECIES NEEDS

In this section, we outline the resource needs of individuals and populations of the Key ring-necked snake. Due to the relative rarity of this subspecies and its secretive nature, many aspects of the life history of this taxon as well as information on population status and trends are poorly known. The relative scarcity of this taxon makes it extremely difficult to collect sufficient high-

quality data using traditional survey and inventory techniques in order to produce a clear picture of its population status. In spite of the difficulties, active pursuit of research into aspects of the life history and population trends will be critical to providing information necessary to guide management decisions intended to ensure its long-term conservation. In the interim, conclusions on the conservation status of this taxon will be based on indirect observations of existing habitat, as well as less robust survey methodology.

3.1. Subspecies needs

In order to assess the current and future condition of the subspecies, it is necessary to identify the ecological needs at the population and individual level. As part of the assessment, we first identify and describe the four most influential factors (prey, refugia, water and available suitable habitat) representing the individual and population needs for the subspecies.

3.1.1. Individual needs

3.1.1.a. Prey

The Key ring-necked snake is assumed to be similar to other *Diadophis* species (*e.g.*, southern ring-necked) which prey upon small insects, snakes, lizards (*e.g.*, anoles, geckos), slugs, amphibians (*e.g.*, frogs, tadpoles), and earthworms (Ernst and Ernst 2003, p. 96; FWC 2013, p. 2). We do not know what the prey-related requirements (abundance, variety, range, etc.) are to sustain a viable population.

3.1.1.b. Refugia

Key ring-necked snakes require refugia to escape and hide from predators and regulate body temperature. Currently, we have no specific information on the exact requirement needs for suitable refugia. Refugia in pine rocklands and rockland hammock are likely provided by holes and crevices in the limestone, piles of rock rubble and pockets of organic matter accumulating in solution holes and shallow depressions in the oolitic limestone (Enge et al. 2003, p. 28). Snakes are ectothermic organisms which require an external heat source to warm its body in order to increase body function and productivity. Snakes can also become too hot, leading to desiccation. Therefore, a warm moist habitat, typically subterranean or shielded from the sun, is likely preferred refugia to escape from predators and to properly maintain suitable internal temperature and moisture levels.

3.1.1.c. Water

Water is essential for Key ring-necked snake survival. We have no specific information on the amount of water they require; however, this subspecies appears to be restricted to areas near permanent freshwater sources that often occur as small holes in the limestone (Lazell 1989, pp. 134, 136). The extensive network of holes, tunnels, and cavities in the limestone substrate most likely assists in creating more permanent water sources. During time of drought, these sources may become scarce and the Key ring-necked snake may need to seek out other fresh water

sources. Consequently, it is important for the Key ring-necked snake to have multiple fresh water sources in case one becomes depleted, contaminated, or unavailable. If all local water sources within a snakes' home range become dry, the snake may need to expend more energy and time in search of new water sources.

Home range is defined as the area a snake traverses for its normal daily activities (Burt 1943, pp. 350-351; Miller 2008, p. 16). The specific acreage associated with the Key ring-necked snake's home range is unknown; however, Lazell (1989, p. 134) documented an individual traveling a distance of 154.2 feet (ft) (47 meters [m]) between coverboards. In other studies, Blanchard et al. (1979, p. 382) documented individual snake travel distances varying between 20 ft (6.1 m) and 400 ft (121.9 m), and Fitch (1975, p. 25) 32.8 ft (10 m) and 5,577 ft (1,700 m).

3.1.2. Population needs

3.1.2.a. Habitat

We do not know how much suitable habitat and habitat connectivity is required to sustain a viable population. That said, the Key ring-necked snake's most influential need at a population level is available suitable habitat. There may be (a) distinct, non-interbreeding populations at each Key, or (b) some level of dispersal from rafting between Keys providing at least a small level of connectivity between individual populations. The minimum number of viable (resilient) populations necessary to sustain the subspecies is unknown. Because the Key ring-necked snake appears to be isolated to the Keys, the relatively small, patchy distributed islands can each support only a small number of individuals (or separate populations). The distribution and quantity of available suitable habitat across the subspecies' range necessary to support Key ring-necked populations is unknown.

3.1.3. Population resiliency

As defined earlier, resiliency is the ability to withstand stochastic disturbances and is measured by fecundity, survival, abundance of suitable habitat and population size. Generally, larger areas of suitable habitat support greater resiliency than smaller areas. In addition, resiliency is reflected by the quality of the above referenced factors, as well as genetic diversity, population abundance and demography.

Due to the cryptic nature of the Key ring-necked snake and very limited research, there is virtually no information concerning the population structure and demographics exhibited by this subspecies. In addition, no information exists on the abundance (number of individuals) or growth rate of these populations. Therefore, the health and resiliency of these populations is uncertain. That said, persistence of populations at historical locations suggest the presence of some resilient populations on the Keys.

Populations of the Key ring-necked snake are supported by the existence of suitable available habitat (*e.g.* pine rocklands, rockland hammock) across the subspecies' range. Therefore, a strong correlation to habitat availability and Key ring-necked snake populations can be assumed,

but not at a level of certainty in which habitat can be used as a surrogate for Key ring-necked snake presence.

The factor reducing population resiliency is the limited and patchy distribution of suitable habitat available across the subspecies' range. The Florida Keys are naturally limited in their land mass, and much of the Key ring-necked snake's native habitat has been developed and is highly used by human activities. Threats primarily associated with climate change and land development are currently adversely impacting these habitats required by Key ring-necked snake populations.

Passive dispersal of individual Key ring-necked snakes among the Florida Keys is likely occurring, but is expected to be taking place on a limited and random basis. The level to which immigration and emigration via dispersal acts as a factor towards population resiliency and prevention against extinction for this subspecies is unknown. Many of the Florida Keys have yet to be searched, and if occupied, they could act as "stepping stones" in the random dispersal of individual snakes. That said, due to the limited size of the Florida Keys, the distance between the keys, and the fact that swimming has not been documented in ring-necked snakes, dispersal is not likely, and thus, it has a limited influence on population dynamics. However, it cannot be completely ruled out as a contributing factor.

We lack detailed scientific information on the extent of the Key ring-necked snake's individual populations and population structure. Thus, our understanding of the factors influencing Key ring-necked snake resiliency is limited.

3.1.4. Subspecies redundancy

Redundancy describes the ability of a species to withstand catastrophic events; it's about spreading risk among multiple populations to minimize the potential loss of the species from catastrophic events. Redundancy is often characterized by having multiple, resilient populations distributed within the species' ecological settings and across the species' range. Distributed populations offer better redundancy than if the populations all occur in very close proximity and vulnerable to similar threats to the same intensity or timing. This latter case is true for the Key ring-necked snake. Because of its limited geographic range, similar threats are experienced with similar timing and intensity across its range. For example, the entire subspecies maybe vulnerable to the effects of a hurricane passing over the Florida Keys.

Limited acreage of suitable habitat remains in the Keys. Consequently, there is little redundancy or "backup" for the available habitat and natural expansion or movement of the subspecies to new areas is not probable.

Systematic recent surveys have not been conducted for the Key ring-necked snake across all of the Florida Keys; therefore, the true spatial distribution of populations throughout the Florida Keys is unclear and our current understanding of the subspecies' distribution is primarily based on historical records. Consequently, this subspecies may very well occur on Florida Keys other than those reported, and the importance of the other Keys (other than those with identified populations) to the overall population resiliency for the subspecies is unclear.

Subspecies redundancy for the Key ring-necked snake is provided by individuals being distributed across the lower Florida Keys. That said, based on the presence of pine rocklands and rockland hammock habitat (total acreage 7005.62 acres (ac) [2,835.07 hectares (ha)]) in the upper Florida Keys, the level of redundancy could be higher if discrete populations and individuals of this subspecies were documented across the upper Florida Keys. However, based on recent surveys the range of this subspecies appears to be restricted to the lower Florida Keys (J. Mays, personal communication, February 4, 2020).

Despite a level of redundancy provided by the discrete populations and individuals found dispersed across the lower Florida Keys, the Florida ring-necked snake lacks redundancy because of its small endemic range. For some large-scale threats (*e.g.*, storm events/hurricanes, sea level rise) that affect the entire Florida Keys archipelago, the entire subspecies is vulnerable to the timing and intensity of impacts.

3.1.5. Subspecies representation

Representation describes the ability of a species to adapt to changing environmental conditions and is measured by the breadth of genetic or environmental diversity within and among populations. Representation gauges the probability that a species is capable of adapting to environmental change. Hence, it is the evolutionary capacity or flexibility of the species. Representation is the range of variation found in the species, and this variation (called adaptive diversity) is the source of the species' adaptive capabilities.

In 2019, a study was conducted to determine whether the phylogenetic data of the Key ring-necked snake taxon supported the current taxonomic classification (Hoffman 2019). Prior to this study, it was unknown whether or not there existed genetically discrete populations on the seven Florida Keys (Key West, Big Pine Key, Little Torch Key, Middle Torch Key, No Name Key, Cudjoe Key and Stock Island) where this subspecies has been reported. This study concluded that the results were consistent with previous reports that the Key ring-necked snake should continue to be listed as a subspecies of the ring-necked snake, and that it does not warrant further splitting into a unique species.

In addition, the Key ring-necked snake occurs across a narrow geographic and ecological range. Consequently, there is no variation in habitat types across distance or elevation as there is for other wider-ranging and more abundant species. The amount of suitable habitat (pine rocklands and rockland hammock) which is threatened in the Florida Keys, is limited and patchily distributed throughout the Keys. Also, the Key ring-necked snake does not occur across different ecosystems or have access to different systems in which to adapt. Therefore, the Key ring-necked snake has a narrow breadth of genetic and environmental diversity within and among populations. Thus, the Key ring-necked snake currently has and historically has had a naturally low level of representation.

4. CURRENT CONDITION AND FACTORS INFLUENCING VIABILITY (THREATS)

After identifying the most influential individual, population and subspecies needs for the Key ring-necked snake, the current condition of the subspecies was evaluated. To determine the Key

ring-necked snake's current condition based on the threats discussed below, we (1) examined the risk level of each threat, (2) analyzed the subspecies by dividing it up by island, given that we do not have any information about population divisions by island, and (3) determined the level of risk associated with each threat in order to analyze the current condition of each population. In addition, we considered all regulatory mechanisms and conservation measures currently enacted. Currently, there are no regulatory mechanisms or conservation measures in place to address the threats of climate change. We also investigated threats associated with overutilization for commercial, recreational, scientific or educational purposes, and found no evidence that overutilization is impacting the subspecies.

In this SSA, we analyzed nine potential threats affecting the Key ring-necked snake and its overall population condition including: development, disease, fire suppression, predation, invasive species, sea level rise, saltwater intrusion, shifts in seasonal patterns of rainfall and temperature, and storm events. Each threat is considered in terms of the scale, intensity, duration, and the impacts it is having on the subspecies and habitat across its life history stages. Some threats may be affecting the subspecies at all life stages or all individuals or populations across the subspecies' range, while others may be specifically affecting a single subspecies need, such as the amount of suitable habitat. Some threats, while present and acting on individuals of the subspecies, may not rise to the level of affecting the subspecies or a population(s). Consideration and analysis was also given to the cumulative effects of these threats on viability. The most influential population resiliency factors were identified earlier under the "Population Needs" section. Threats and their cause and effect upon these factors and the subspecies as a whole were primarily identified through (1) FWC's Key ring-necked snake biological status review report (FWC 2011, entire), (2) FWC's species action plan for the Key ring-necked snake (FWC 2013, entire), and other published and unpublished reports.

4.1. Development

The Key ring-necked snake inhabits a variety of rockland habitat that is also desirable for residential and commercial development (Service 1999, pp. 3–174). Most rockland habitat within the Florida Keys has been impacted or destroyed for residential and commercial development (Hodges and Bradley 2006, pp. 8–9). Currently, total habitat area (pine rocklands and rockland hammock combined) potentially used by Key ring-necked snakes in the lower Florida Keys, is 5,704.97 ac [2,308.72 ha], where pine rocklands consists of 1,899.37 ac (768.65 ha) and rockland hammock 3,805.60 ac (1,540.07 ha) (USGS 2019b, p. 4). While the hammock habitats are widespread across many islands in various sizes, pine rocklands remains on only five islands in the lower Florida Keys (Table 1). One of these islands, Big Pine Key, has 1,480.43 ac (599.12 ha) (78 percent of total pine rocklands area), while other Keys (*e.g.*, Little Pine Key, No Name Key, Cudjoe Key and Sugarloaf Key) contain small areas of hardwood-invaded pine rocklands.

Although individual snakes show some tolerance of habitat alteration, development and conversion of suitable snake habitat are capable of impacting all life stages of the Key ring-necked snake. In addition to direct impacts from loss of soils for nesting and movement, ground cover and availability of ground invertebrate food sources can be reduced, and the loss of habitat reduces shelter and shade for adults. Habitat fragmentation can reduce connectivity indirectly or

Table 1. Current pine rocklands habitat distributed in the lower Florida Keys.

Island	Area (acres)
Big Pine Key	1,480.43
Cudjoe Key	84.18
Little Pine Key	126.51
No Name Key	125.87
Sugarloaf Key	82.38
Total Area	1,899.37

directly and further decrease population dynamics in finding mates and juvenile dispersal.

Past land clearing activities for human population growth and development in Monroe County has altered, degraded or destroyed hundreds of acres of rockland habitat for Key ring-necked snakes. Most rockland habitat within the Florida Keys has been impacted or destroyed for residential and commercial development.

Monroe County implemented a Habitat Conservation Plan (HCP) for Big Pine Key and No Name Key in 2006. The primary goal of the HCP is to maintain and implement a system which directs future growth in order to (1) maintain and enhance the character of the community, (2) protect natural resources, (3) encourage a compact pattern of development, (4) encourage the development of affordable housing, (5) direct future growth to appropriate infill areas and away from inappropriate locations not suitable for development, and (6) encourage development in areas served by central wastewater systems. Subsequently, development on these islands has to meet the requirements of the HCP in regard to future development. Furthermore, in order to fulfill the HCP's mitigation requirement, Monroe County has been actively acquiring parcels of high-quality habitat for listed species and managing them for conservation, including pine rocklands habitat on Big Pine and No Name Key.

In addition to the requirements outlined in the HCP, suitable habitat is protected within preserves such as the Key Deer National Wildlife Refuge, Florida Keys National Wildlife Refuge Complex, Crocodile Lake National Wildlife Refuge, Florida State Parks, and other parcels within Monroe County protected by the Environmentally Endangered Lands Program. Other than these avenues to protect suitable habitat, there are no current regulatory mechanisms or conservation measures that address the impacts of development. In addition, the Florida Keys Carrying Capacity Study conducted in 2003 (Monroe County 2016, entire), concluded that: (1) development in the Florida Keys has surpassed the carrying capacity of upland habitats to maintain their ecological integrity, (2) any further development in the Florida Keys would exacerbate secondary and indirect impacts to remaining habitat, and (3) any further encroachment into areas dominated by native vegetation would exacerbate habitat loss and fragmentation. Consequently, the study recommended that Monroe County continue its land acquisition and restoration programs and suggested the following actions to guide future development: (1) prevent encroachment into native habitat, (2) continue and intensify existing land acquisition programs, (3) focus on redevelopment and infill if further development occurs, and (4) increase efforts to manage the resources to effectively preserve and improve the ecological values of the remaining terrestrial ecosystems (Monroe County 2016, entire).

The effects of development has the potential to reduce individual survival (feed, breed, and shelter); therefore, causing a decrease in resiliency of the Key ring-necked snake. Resiliency may be further reduced due to loss of connectivity between populations. Overall, because the Key ring-necked snake is endemic to only a few lower Florida Key islands, losing even a few populations to the effects of development would result in a substantial reduction in subspecies redundancy. The Monroe County HCP could prevent further pine rocklands from being developed, though resiliency could continue to decline as habitats remain degraded due to development impacts.

4.2. Disease

Snake fungal disease (SFD) (*Ophidiomyces ophiodiicola*) is an emerging disease that has infected snakes throughout the eastern United States, including Florida. There is no evidence to suggest that Key ring-necked snakes are affected by SFD or other fungal diseases. Snake fungal disease has predominately been documented in larger snake species (Allender et al. 2015, pp. 187–196). The protozoa *Cryptosporidium serpentis* is a significant cause of parasitic disease in snakes (Upton et al. 1989, pp. 20–30). Reported prevalence and fate of snakes with *Cryptosporidium* spp. in captive and wild populations is not well studied. There is no evidence to suggest Key ring-necked snakes are affected by this or other parasites, or other diseases.

4.3. Fire suppression

Urban development and agriculture has greatly reduced the extent of pine rocklands in the Florida Keys. In addition, the quality of some pine rocklands has declined in the Keys because they are isolated and confined by surrounding urban development that restricts the use of prescribed fire which is the principal management tool. Prescribed fire must be periodically introduced to sustain the pine rocklands community structure. In the absence of fire, pine rocklands are invaded by many of the species found in hardwood hammocks, they lose their herbaceous flora and they move along a successional trajectory toward hammock (Service 1999, pp. 3–173). These rockland hammocks are generally present where pine rocklands were not burned for a long period of time, creating more pine rocklands fragmentation. This fragmentation of pine rocklands in the Florida Keys increases the risk of invasion by exotic vegetation along the interface with disturbed or developed areas, further altering, degrading or destroying suitable habitat for the Key ring-necked snake.

Though Key ring-necked snakes can still persist in areas where fire has been suppressed, pine rocklands habitat quality is reduced by lack of fire. Thus, the effects of fire suppression has the potential to reduce population resiliency through ongoing habitat degradation that impacts Key ring-necked snake needs.

4.4. Predation

No natural predators have been documented for the Key ring-necked snake; however, some potential predators may be similar to other ring-necked snake subspecies, which include wild hogs, frogs, toads, raccoons (*Procyon lotor*), owls, opossums (*Didelphis marsupialis*), larger snakes, centipedes and large spiders. Although unknown, the occurrence and abundance of the

above referenced predators is thought to be limited on the seven Florida Keys where the Key ring-necked snake has been documented. Consequently, it's thought that these predators present little to no significant threat at the population or subspecies level for the Key ring-necked snake. A more likely and significant predator of the Key ring-necked snake are the thousands of feral cats (*Felis catus*) in the Florida Keys. Feral cats are natural predators and it has been estimated that every year hundreds of millions of birds, small mammals, amphibians and reptiles are killed by feral cats in the United States (Service 2011, p. 1). Feral cats and possibly other domesticated animals present a significant threat to all life stages of the Key ring-necked snake where they are present in snake habitat. That said, direct evidence is lacking on the current level of impact feral cats and other domesticated animals have on the Key ring-necked snake. Given the limited dispersal and possible clumped distribution, feral cat and other domesticated animal predation could negatively reduce or eliminate a snake population.

The Service developed a Florida Keys National Wildlife Refuges Complex Integrated Pest Management Plan (IPMP) (Service 2012, entire) which included a variety of methods for managing several non-native species (e.g., free-roaming cats) that have invaded lands managed by the Service as part of the Florida Keys National Wildlife Refuges Complex. However, since the IPMP has only been implemented in the Key Deer, Key West, Great White Heron and Crocodile Lake National Wildlife Refuges, and there are no historical records indicating the presence of the Key ring-necked snake in these refuges, we can only assume that the efficacy of the IPMP in reducing feral cat predation on the Key ring-necked snake is negligible. Other attempts to manage populations of feral cats have been implemented over the past years which consisted of trapping, sterilizing and vaccinating them; however, they are then released back into the wild. Consequently, such programs are assumed to have little effect in reducing the level of feral cat predation on Key ring-necked snakes. Therefore, if feral cats are preying on Key ring-necked snakes, it is assumed that the IPMP has little effect in eliminating this threat.

Currently, there are no additional conservation measures other than the IPMP that addresses the impacts of feral cats or other potential predators. Predators, particularly feral cats, have the potential to negatively impact snake populations; however, because there is no documented incidences of predation of the Key ring-necked snake, the actual effects of predation are unknown.

4.5. Invasive species

South Florida is home to a large number of invasive nonnative species which could directly and/or indirectly affect the survival of the subspecies. Specifically, invasive species could potentially affect prey availability, predation rates and habitat suitability of the subspecies. As discussed in the Predation section, nonnative predators could be preying on the snake, increasing predation beyond the natural levels experienced by the subspecies.

The red imported fire ant (*Solenopsis invicta*) has thoroughly invaded a wide range of habitats in south Florida and the Florida Keys. The fossorial (primarily underground) nature and small size of the Key ring-necked snake makes all life stages, particularly the eggs, susceptible to the red imported fire ant. Fire ants have been documented killing numerous reptile species eggs and hatchlings. Fire ants may also indirectly impact adults by affecting survival and weight gain,

behavioral changes, changes in foraging patterns and habitat use and reduced food availability (Allen et al. 2004, pp. 90–91).

Non-native species dominate herpetofaunal communities in both native habitat in Miami-Dade County (Clements et al. 2019, pp. 1783–1784) and this scenario is likely in the Florida Keys as well. The brown anole (*Anoles sagrei*), tropical house gecko (*Hemidactylus mabouria*), Cuban treefrog (*Osteopilus septentrionalis*), cane toad (*Rhinella marina*) and tegu lizards (*Tupinambis teguixin*, *Salvator merianae*, *S. rufescens*) are non-native, invasive species that may be potential predators of Key ring-necked snakes. Populations of these and other invasive species appear to be increasing throughout the Miami area and on some of the Keys (Meshaka et al. 2004, pp. 149–154; Meshaka 2011, entire). The nonnative ashy gecko (*Sphaerodactylus elegans*) forages in leaf litter and under debris, and may compete with the Key ring-necked snake for food resources. The level of predation or resource competition that the Key ring-necked snake is experiencing from these invasive species is unknown, but could be threats at the population, subspecies, or individual level.

Native snakes would be expected to occasionally prey on Key ring-necked snakes, but the extent to which they do is unknown. Larger snakes could potentially prey upon the Key ring-necked snake, but it is unlikely and has never been documented.

The non-native brahminy blind snake (*Indotyphlops braminus*) is the most widely introduced snake in the world and has been observed throughout Miami-Dade and Monroe counties. Since the brahminy blind snake is smaller than the Key ring-necked snake, it likely does not compete with it for food resources as it preys on smaller items such as ants and termites.

We are not aware of any eradication programs specifically focusing on the brown anole, tropical house gecko or the Cuban treefrog. There have been past efforts to eradicate the cane toad; however, they still persist throughout south Florida. The priority level to continue and/or revive eradication efforts for cane toads are unknown at this time. Ongoing efforts to eradicate large snakes, as discussed above, are a high priority in south Florida; however, as discussed, negative impacts to Key ring-necked snakes by these large exotic snakes are not likely.

Nonnative plants have significantly impacted native habitats in south Florida (Bradley and Gann 1999, pp. 15, 72). Nonnative, invasive plants compete with native plants for space, light, water, and nutrients, and can make habitat conditions unsuitable for Key ring-necked snakes by changing or reducing leaf ground cover, increasing root masses in friable soils as well as loss of shade and protective cover. If nonnative vegetation cover is not as dense as native vegetation, changes in soil temperature could result and negatively impacting the Key ring-necked snake (Service 2017a, p. 32).

Invasive plant management and eradication programs are ongoing and have proven successful on a preliminary level. The Miami-Dade County Environmentally Endangered Lands Program, Institute for Regional Conservation along with Federal and State partners contribute to pine rocklands habitat management and restoration, which largely focuses on invasive and exotic plant removal. In addition, the habitat restoration program implemented at the Key Deer National Wildlife Refuge also contributes to exotic and invasive plant eradication.

Other than the conservation measures outlined above, there are no additional regulatory mechanisms or conservation measures to address the potential impacts of invasive species. There are no documented incidences of invasive species-related impacts on the Key ring-necked snake; therefore, the potential impact on resiliency, redundancy, and representation of this snake is unknown.

4.6. Climate change

The terms “climate” and “climate change” are defined by the Intergovernmental Panel on Climate Change (IPCC). The term “climate” refers to the mean and variability of different types of weather conditions over time, with 30 years being a typical period for such measurements. The term “climate change” thus refers to a change in the mean or variability of one or more measures of climate (*e.g.*, temperature or precipitation) that persists for an extended period, whether the change is due to natural variability or human activity (IPCC 2013, p. 1450).

The following scientific and ecological information on climate change includes summarized work from the 2018 publication entitled *Impacts, Risks, and Adaptation in the United States: The Fourth National Climate Assessment* (U.S. Global Change Research Program [USGCRP] 2018, entire). Also summarized is information from the 2018 publication from the IPCC entitled *Global Warming of 1.5°C: Summary for Policymakers* (IPCC 2018, entire). This information is being further condensed with a primary focus on Florida (Service 2019, entire).

Of all threats, the predominant threat currently affecting the Key ring-necked snake and its habitat are the rapid and intense shifts in climate occurring as a result of increasing greenhouse gas (GHG) emissions. The entire Florida Keys archipelago is being challenged by increases in sea level, saltwater intrusion, increases in tide and tidal flooding and shifts in seasonal climate pattern.

Currently, there are no regulatory mechanisms or conservation measures that address the impacts of climate change, sea level rise and saltwater intrusion. The effects of saltwater intrusion has the potential to degrade existing habitat that supports the Key ring-necked snake, leading to reductions in subspecies needs, and thus to population resiliency. The effects of saltwater intrusion are primarily habitat-based, but some individual snakes could also be lost. Signs of saltwater intrusion impacts are currently documented on Big Pine Key, where pine trees have been replaced by salt tolerant mangrove. The magnitude of this threat has the potential to greatly increase in the future depending on the severity of sea level rise.

4.6.1. Sea level rise

The Key ring-necked snake is vulnerable to current and predicted sea level rise across its entire range because it is located only in the Florida Keys. The Florida Keys are among the most vulnerable areas to the effects of sea level rise due to their low mean elevation of less than 4 ft (1.2 m) (Service 2019, p. 9). Consequently, the Florida Keys are highly susceptible to flooding, with lands further upland at risk of inundation and saltwater intrusion. The effects of increasing sea levels, higher tidal surges, increased coastal and inland flooding and saltwater intrusion are currently being experienced in south Florida and the Florida Keys (Benedict et al. 2018, pp. 9, 13, 31, 7-i; Service 2019, p. 1).

Global sea level has increased by 8 to 9 in (0.20 to 0.23 m) since 1880, with the rate of increase over the past 20 years doubling (Service 2017b, p. 5). This is equivalent to the Florida coastline subsiding at a rate of 0.04 in (0.10 cm) per year (Service 2017b, p. 6). Sea level rise in the Florida Keys has been documented based on the long term trend in sea level rise at the National Oceanic and Atmospheric Administration (NOAA) Key West Station which shows a 0.09 in (0.23 cm) increase per year from 1913 to 2018 of the mean high water line (NOAA 2019; Figure 3). In addition, the NOAA Vaca Key Station (City of Marathon) shows a 0.14 in (0.36 cm) per year sea level rise between 1971 (start of data collection) and 2018 (NOAA 2019, Figure 3). In both of these figures, the blue and red lines represent the actual timeline trend and the projected timeline trend, respectively. Although there is some variability in the blue projected timeline trend, it exhibits a consistent upward current trend and above the projected timeline trend.

While the sea level rise rate for Florida has been equivalent to that experienced globally, recent analysis is now indicating an accelerated rate for the eastern United States above that of the global rate (Park and Sweet 2015, entire; Sweet et al. 2017, pp. 39–41). The global trend is currently on the higher end trajectory of the scenarios, projecting a sea level rise of 8.20–9.84 ft (2.5–3.0 m) by 2100. The accelerated sea level rise in south Florida is being attributed to shifts in the Florida Current due to: (1) added ocean mass brought on by the melting Antarctic and Greenland ice packs, and (2) thermal expansion from the warming ocean (Park and Sweet 2015, entire; Rahmstorf et al. 2015, entire; Deconto and Pollard 2016, p. 596; Sweet et al. 2017, pp. vi, 14, 15, 18). For this reason, adding approximately 15 percent to the earlier global mean sea level rise projections when using projections for southeast Florida (including the Florida Keys) is recommended if the projections used do not yet model the accelerated rate (Park and Sweet 2015, entire; Southeast Florida Regional Climate Change Compact 2012, p. 35).

The effects of sea level rise could impact the Key ring-necked snake by loss of individuals during flooding events, causing a loss in population resiliency. If flooding is severe enough, it could extirpate entire populations, leading to a substantial loss of redundancy of the subspecies.

4.6.2. Saltwater intrusion

Higher tidal surges, coastal and inland flooding and saltwater intrusion due to increasing sea levels are currently being experienced in south Florida and the Florida Keys. With worsening storms and extreme tidal events, storm surges along the Florida Keys will increase in frequency and severity over time, and will impact habitats further inland. Salt from ocean water deposited during these high-water events (surface inundation of seawater) has the potential to remain in place in and under the soil for long periods of time, which will negatively impact vegetative growth. For forest production to be sustained in such an ecosystem, nutrient cycling must be extremely efficient (*i.e.*, there can be little leaching of nutrients beyond the root zone). In other instances, the effects of more powerful storm surges have attributed to the conversion and loss of pine forest habitat in the Florida Keys to more halophilic (salt-loving) vegetation (Ross et al. 1994, pp. 151–154).

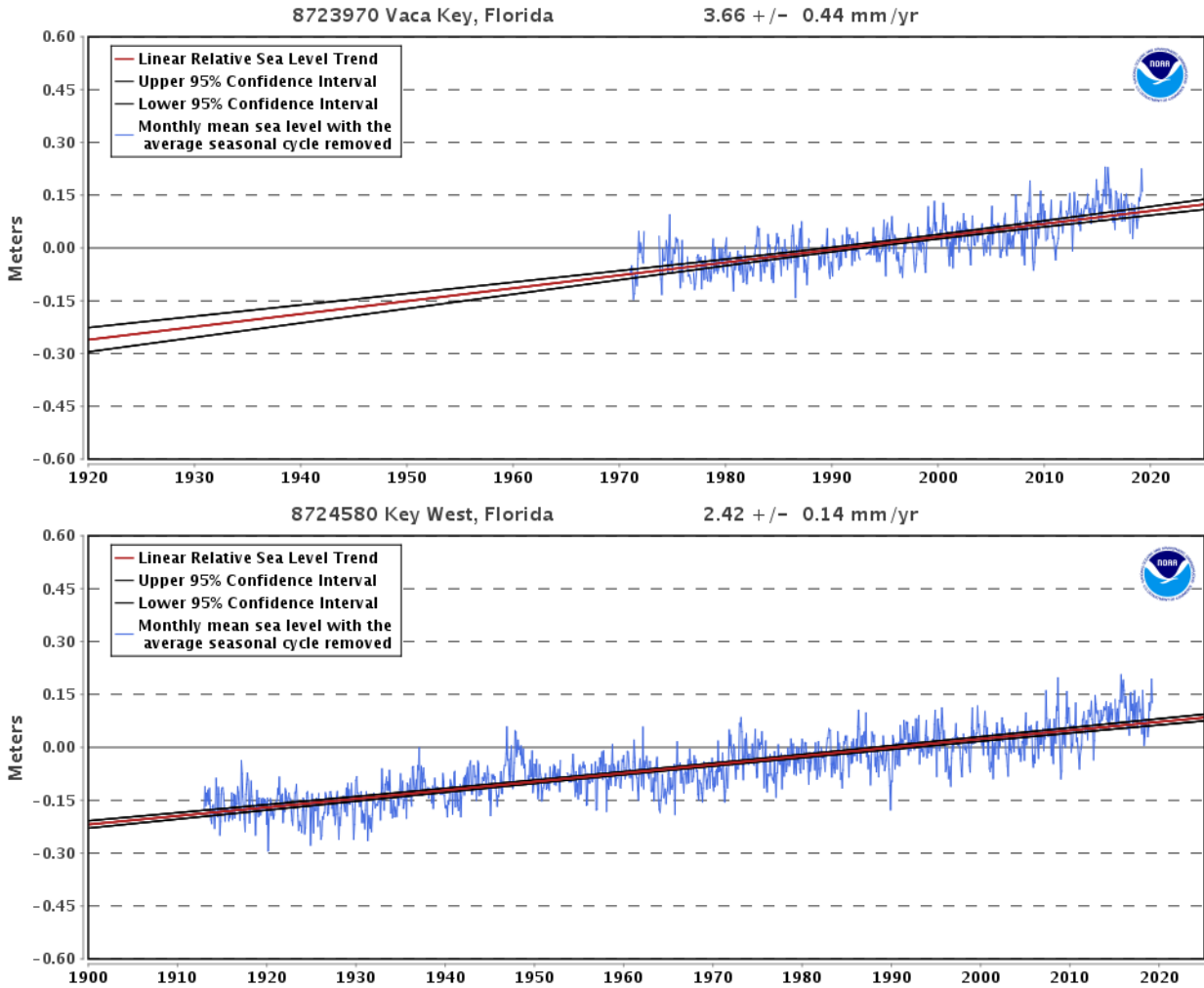


Figure 3. Vaca Key (1970 to 2018) and Key West (1913 to 2018) NOAA tidal gauges (NOAA 2019).

The results of saltwater intrusion from storm surge and flooding (*e.g.*, loss of habitat, habitat conversion, reduction in the capacity of freshwater storage and freshwater resources) will result in displacement landward to less suitable habitat, the loss of suitable habitat, and the loss of individual Key ring-necked snakes.

4.6.3. Shifts in seasonal patterns of rainfall and temperature

In the United States, the average temperatures have increased by 1.3 to 1.9°F (0.77 to 1.1°C) since recordkeeping began in 1895 (Service 2017b, p. 2). The decade from 2000 to 2009 is documented as the warmest on record (Service 2017b, p. 2). Average temperatures in south Florida have increased 1.5°F (0.83°C) or more since 1991 (Service 2017b, p. 2). Because of the current condition of human-induced emissions (that is, the pattern of continued release of GHG added to those already occurring in the atmosphere), increases in surface air temperature continue to rise. Even if there was an immediate and aggressive reduction in human produced

GHG emissions, there would still be expected continued increases in surface air temperature (IPCC 2018, pp. 1–11).

The Key ring-necked snake is a subterranean ectotherm and therefore dependent on gaining heat from its microhabitat or by coming in contact with the undersides of warm surfaces (*e.g.*, rocks) that are exposed to direct sunlight. We assume that the Key ring-necked snake uses a variety of surfaces for thermoregulation. Although the activity temperature range (*i.e.*, normal range of temperatures in which activity occurs) of the Key ring-necked snake is unknown, it is thought to be consistent with that of a tropical ecosystem. Therefore, any continuously higher average number of hot days out of the Key ring-necked snake's optimum range or a permanent shift in average air temperature out of this range, has the potential to stress them physiologically. Physiological stress can manifest into a variety of risks including predation and reduced reproductive performance, and/or foraging success. In more extreme cases, once an ectothermic organism is exposed to a temperature outside of its activity temperature range, it is closer to reaching a critical thermal maximum/minimum, in which locomotion becomes uncoordinated and the animal loses its ability to escape conditions that will lead to its death (Zug et al. 2001, pp.179–188). Key ring-necked snakes may become more vulnerable to situations involving critical thermal maximum when it is unable to escape conditions due to habitat loss and fragmentation. In addition, ambient temperature out of the optimal range will physically influence the environment of the nests which may modify incubation periods, embryo temperatures, egg survival and hatching times.

Precipitation patterns are also changing. Annual average precipitation has increased by 4 percent since 1901 across the entire United States (USGCRP 2018, pp. 745–808) and 5 to 10 percent since 1900 in south Florida (Service 2017b, p. 4). Shifts in seasonal rainfall events as well as increases in average precipitation are currently being documented (USGCRP 2018, pp. 745–808). The south Florida dry season (November through April) has become wetter, the rainy season (May through October) has become drier, and current projections show that this trend will continue. This could have detrimental effects on the Key ring-necked snake's seasonal feeding, breeding and sheltering patterns based on their ability to adapt. Heavy downpours are currently increasing and have especially increased over the last 30 to 50 years. The frequency and intensity of heavy precipitation events across the United States have increased and are expected to continue to increase over the coming century. There is currently a 27 percent increase in the frequency and intensity of heavy downpours since the 1970s (Service 2017b, p. 4). Increased inland flooding is predicted during heavy rain events in low-lying areas. With worsening storms, storm surges along coastlines become stronger and push inland further. Consequently, more powerful storm surges will exacerbate the effects of the increased sea level along the Florida Keys' shorelines.

Currently, there are no regulatory mechanisms or conservation measures that address the impacts of shifting seasonal patterns of rainfall and temperature. Although changes in seasonal weather patterns in south Florida have been documented (Service 2017b, entire), direct impact on the Key ring-necked snake or its habitat have not been observed. However, with increased flooding events associated with climate change and sea level rise, the magnitude of this threat could increase into the future, decreasing population resiliency across the range of the subspecies.

4.7. Storm events

There has been a substantial increase of Atlantic hurricane activity by most measures since the early 1980s, the period during which high-quality satellite data first became available. These include measures of intensity, frequency and duration as well as the number of strongest (Category 4 and 5) storms (Walsh et.al. 2014, p. 20). Strong rainstorms, tropical storms, and hurricanes are all natural parts of a tropical ecosystem. However, although these events are common occurrences, the health of the Key ring-necked snake becomes vulnerable when the quantity and quality of their resources (*e.g.*, food, cover/nesting) are compromised. This is especially true in the case of storm surges and when their frequency increases in the number of incidences (being impacted repeatedly without time to recover).

Hurricane activity has been above normal since the Atlantic Multi-Decadal Oscillation (AMO) (the natural variability of the sea surface temperature in the Atlantic Ocean) went into its warm phase around 1992. Currently, while the incidence of tropical storms in southeast Florida (including the Keys) is above normal, this frequency is expected to decrease with climate change, but the intensity of the storms is expected to increase by approximately 20 percent (Service 2017b, p. 7). This increased intensity results in larger tidal storm surge and greater destruction than historically documented. Ecosystem resiliency is reduced when impacts by extreme events such as floods or storms occur (Service 2017b, p. 7). Saltwater intrusion from storm surge and flooding results in displacement landward to less suitable habitat and the loss of individual Key ring-necked snakes. The limestone substrate, of which snakes likely rely on for cover, prey and nesting will become flooded more frequently which will promote a higher frequency and longevity of displacement and stress. The recent increases in storm strength are linked, in part, to higher sea surface temperatures occurring in the equatorial regions of the Atlantic Ocean where hurricanes form and move. Numerous factors have been shown to influence these local sea surface temperatures, including natural variability of the AMO, human-induced emissions of heat-trapping gases and particulate pollution (Service 2017b, p. 7).

Long-term monitoring of the Key ring-necked snake and information on strong storm impacts to this subspecies are lacking. However, information does exist on the impacts to habitat from hurricanes and other strong storms that have occurred in the region that can provide some insight of the potential damage and loss to the Key ring-necked snake from such storms. These events most likely disturb and reduce the quantity and quality of their resources (*e.g.*, food, cover/nesting) and may do so significantly depending upon the severity and proximity of the storm center. This is particularly the case of storm surges which bring in nutrient-rich sediment that exacerbate soil accretion, salt deposition and vegetation loss (Dingler et al. 1995, p. 296; Jackson et al. 1995, p. 321).

Saltwater surges and short-term flooding of upland habitats from strong storms and hurricanes in the Keys has the potential to kill some Key ring-necked snakes and their prey. In 2005, Hurricane Wilma (Category 3) passed just north of the Florida Keys causing maximum storm tides 5 to 6 ft (1.5 to 1.8 m) above mean sea level in Key West and flooding approximately 60 percent of the city. On Boca Chica and Big Pine Keys, Hurricane Wilma caused a storm surge of 5 to 8 ft (1.5 to 2.4 m) (Kasper 2007, pp. 10–16). In 2017, the combined effect of storm surge and the tide from Hurricane Irma produced maximum inundation levels of 5 to 8 ft (1.5 to

2.4 m) above ground level for portions of the lower Florida Keys from Cudjoe Key eastward to Big Pine Key and Bahia Honda Key, near and to the east of where Irma's center made landfall (Cangialosi et al. 2018, pp. 8–9). A storm surge of 13 ft (4 m) would result in the complete submersion of Big Pine Key (Lopez et al. 2004, p. 284). Key ring-necked snakes have been documented on Key West based on historical records prior to 2014, and Big Pine Key (most recent sighting as of August 2019). It is unknown whether Key ring-necked snakes can swim.

Currently, there are no regulatory mechanisms or conservation measures that address the impacts of storm events. The effects of storm events has the potential to reduce individual survival (feed, breed, and shelter), which could then lead to a reduction in the snake's resiliency and redundancy. While past storms have not resulted in complete inundation of islands, an increase in the intensity and frequency of storms or a direct hit from a strong hurricane could cause significant reductions in subspecies numbers, further limiting its population resiliency and making it even more vulnerable to all other threats.

4.8. Summary of threats

Multiple threats are currently impacting the Key ring-necked snake and its habitat, and these impacts are occurring at the individual (moderate risk) and population (high risk) level (Table 2). The risk of each threat using the risk scoring criteria in Table 3, was applied to each population and used to assess the overall population condition (Table 4). As expected, each population received similar scores which is due to limited information for the subspecies and its small endemic range.

Threats brought on by the occurrence of more severe storms include the increased incidence and intensity of storm surge that accompanies these storms. This surge exacerbates the level of flooding and inundation. Increased rainfall, along with the threats of SLR and higher than average storm surges, further reduces the amount of available habitat due to inundation. This in turn negatively affects snake movement, reproduction and food availability. That said, before the effects of inundation are documented, vegetation succession will result in mangrove dominant habitat conversion due to saltwater intrusion which will further reduce the amount of suitable habitat. In addition, habitat is being lost or converted due to SLR, but also through human development. Each of these threats alone affects the overall health of the subspecies and its habitat, but combined produce synergistic or worsening effects on the subspecies.

The result is that freshwater-dependent flora and fauna which comprise much of the island's biota will disappear. Over time, vegetation succession will result in mangrove dominance on the remaining land and more expansive estuaries across much of the island.

Though individual populations are no longer likely to be lost to development, ongoing habitat degradation associated with urbanization of both pine rocklands and rockland hammock habitat, and fire suppression of pine rocklands are continuing to reduce the availability of Key ring-necked snake needs, thus decreasing population resiliency. In addition, all effects associated with climate change are interrelated, with shifts in the magnitude of severe storms contributing to increased flooding events that have the potential to extirpate entire populations of the Key ring-necked snake. Although a severe hurricane is unlikely to flood all populations at once, if a

hurricane were to extirpate most populations, it would leave the remainder of the subspecies significantly more vulnerable to other threats.

Even minor threats which impact just a few individuals in a population need to be considered for their additive effects. For example, threats like predation and invasive species may have low impacts on their own, but combined with impacts of other threats, they are further reducing already low numbers of Key ring-necked snakes. These minor threats were considered cumulatively for their effects to the Key ring-necked snake and were currently found not to impose negative effects at the population level or to the subspecies.

Additionally, various threats can originate from a similar cause, but produce a set of interdependent effects on the subspecies. For example, GHG emissions increase the rate and severity of climactic changes which act in combination as threats on the subspecies. These include: (1) SLR, (2) seasonal shifts in timing and amounts of precipitation, (3) shifts in temperature patterns, and (4) increased storm intensities which affect the subspecies. SLR (increased mean [average] high water line) reduces available habitat. Because the average high water line is now higher than historic levels, areas not typically flooded are now flooded on a more regular basis.

The severity of threats may also be exacerbated by the Key ring-necked snake's limited distribution and small population size. There are no records that demonstrate that the Key ring-necked snake was ever distributed beyond the lower Florida Keys. Thus, it has, and probably has always had, low natural representation and redundancy. Currently, it is found only on seven lower Florida Key islands. Rarity is not in itself a threat; however, small population size can exacerbate the effects of ongoing threats, making the subspecies more vulnerable to extirpation. As discussed previously, the Key ring-necked snake is a narrow endemic, meaning it has naturally low redundancy and representation to help it buffer against stochastic and catastrophic events.

5. FUTURE CONDITIONS AND SCENARIOS

5.1. Introduction

To analyze species' viability, we considered the current and future availability or condition of resources. To examine the potential future condition of the Key ring-necked snake, four future scenarios were developed. The scenarios focused on a range of conditions based on climate change scenarios and projections for land development. The range of what is likely to happen in each scenario is described based on current condition and how resiliency, representation, and redundancy would be expected to change. The levels of certainty or uncertainty are addressed in each scenario. Given that there is uncertainty as to exact future trends of many threats, these future scenarios are meant to explore the range of uncertainty and examine the subspecies' response across the range of likely future conditions.

Table 2. Current conditions of the Key ring-necked snake based on threats.

THREAT	LOW RISK (Risk of Threat 1)	MODERATE RISK (Risk of Threat 2)	HIGH RISK (Risk of Threat 3)
Development	Development occurrence protected by land management plan.	The level of development would affect suitable habitat and displace some individual snakes, but not at an extent to affect snake populations.	A significant amount of suitable habitat would be lost due to development such that snake populations would be impacted.
Disease	No impacts.	Some individual snakes would exhibit signs of disease, but impacts would not be widespread enough in the snake population to affect resiliency.	Disease would be prevalent in populations across the range of the subspecies, decreasing population resiliency.
Fire suppression of pine rocklands habitat	Ongoing, regular fire maintenance.	The level of fire suppression would affect some suitable habitat and displace some individual snakes, but not at an extent to affect population resiliency.	A significant amount of suitable habitat would be lost due to fire suppression such that snake population resiliency would be impacted.
Predation	No impacts.	Some individual snakes would be predated, but impacts would not be widespread throughout snake populations.	Predation would be prevalent in populations across the range of the subspecies, decreasing population resiliency.
Invasive species	No impacts.	Invasive plants would not outcompete native plants to the extent that a significant amount of suitable snake habitat is altered. Nonnative fauna would outcompete some individual snakes for food, or prey on some snakes, but the effects would not be widespread in the snake population.	Invasive plants would outcompete native plants altering habitat so it is no longer suitable for the snake. Nonnative fauna may outcompete snakes for food, or prey on snakes such that populations are impacted.
Sea level rise	No impacts.	Individual snakes will be affected by increasing sea levels, higher tidal surges, and increased coastal and inland flooding.	The severity of increasing sea levels, higher tidal surges and increased coastal and inland flooding would impact snake populations and possibly extirpate areas.
Saltwater intrusion	No impacts.	Some individual snakes will be displaced by the frequency and severity of saltwater intrusion and its impact to suitable snake habitat.	The frequency and severity of saltwater intrusion and its impact to suitable snake habitat would impact snake populations, decreasing population resiliency.
Shifts in seasonal patterns of rainfall and temperature	No impacts	Individual snakes would be affected by the frequency and intensity in these seasonal pattern changes, but not to the extent that population resiliency would be affected.	The frequency and intensity in these seasonal pattern changes would impact snake populations.
Storm events	No impacts.	The intensity, frequency, and duration of storm events would be at a level in which the quantity and quality of individual snake needs are compromised and some snakes would be displaced landward to less suitable habitat.	The intensity, frequency and duration of storm events would be at a significant level such that the quantity and quality of snake resources and snake populations would be displaced.

Table 3. Risk and overall population condition scoring criteria.

Overall Population Condition	Risk of Threat	Population Persistence over 60 years	Probability of Persistence
High (9–13 points)	1	Very Likely	91-100%
Moderate (14–18 points)	2	Likely	51-90%
Low (19–24 points)	3	Unlikely to likely as not	0-50%

For the purpose of this assessment, we generally defined viability as the ability to sustain populations over time. For this to occur, a species must have a sufficient number and distribution of healthy populations to withstand changes in its biological (*e.g.*, predators, disease) and physical (*e.g.*, habitat loss, climate change) environment, and environmental stochasticity (*e.g.*, flooding, storm surge). We looked at expected changes in development (up through 2070), shifts in seasonal patterns of rainfall and temperature (up through 2100), and climate change (sea level rise and saltwater intrusion) from 2030 to 2100. That said, we focused on changes that are expected in the next 60 years, and more specifically at the years 2040, 2060, and 2080; because at 2100, there is virtually no habitat forecasted to be present in the lower Florida Keys.

We chose four plausible scenarios to examine the potential impacts to Key ring-necked snake populations from development, fire suppression of pine rocklands habitat, climate impacts (sea level rise and saltwater intrusion), storm events, and shifts in seasonal patterns of rainfall and temperature. Population resiliency for each scenario was measured based on the scale outlined in Table 3.

5.1.1. Development and fire suppression – future impacts

Possible future development is very likely to continue across the range of the Key ring-necked snake. Suitable habitat that is projected to be lost is privately owned and not currently under conservation. In the *Mapping Florida’s Future – Alternative Patterns of Development in 2070* report, Carr and Zwick (2016, pp. 20–22) did not predict Monroe County to experience the most dramatic potential changes out of all counties in southern Florida. This is likely because most land in Monroe County is already allocated to development, agriculture or conservation. Currently, there are 5,704.97 ac (2,308.72 ha) of existing pine rocklands and rockland hammock in the lower Florida Keys, of which 4,711.36 ac (1,906.62 ha) (82.58 percent) are protected/under conservation (Florida Natural Areas Inventory 2019). Consequently, it is likely that any remaining suitable unprotected habitat for the Key ring-necked snake is extremely vulnerable to development if left unprotected. In addition, fire suppression has had considerable negative impacts on pine rocklands communities. The condition of some extant pine rocklands has declined and become degraded because of inadequate management or because they are

Table 4. The risk of threats and their effect on the population condition of the Key ring-necked snake. The subspecies was analyzed by dividing it up by island, given that we do not have any information about population divisions by island.

Area	Development	Fire Suppression of Pine Rocklands	Disease	Predation	Invasive Species	Sea Level Rise	Saltwater Intrusion	Shifts in seasonal patterns of rainfall and temperature	Storms	Population Condition
Big Pine Key	Moderate	Moderate	Low	Low	Low	High	High	High	High	Low
Cudjoe Key	Moderate	Moderate	Low	Low	Low	High	High	High	High	Low
Key West	Moderate	Moderate	Low	Low	Low	High	High	High	High	Low
Little Torch Key	Moderate	Moderate	Low	Low	Low	High	High	High	High	Low
Middle Torch Key	Moderate	Moderate	Low	Low	Low	High	High	High	High	Low
No Name Key	Moderate	Moderate	Low	Low	Low	High	High	High	High	Low
Stock Island	Moderate	Moderate	Low	Low	Low	High	High	High	High	Low

isolated and confined by surrounding development that restricts the use of prescribed fire which is the primary management tool.

As of July 1, 2018, the U.S. Census Bureau estimated the population of Monroe County at 75,027 people, an increase of almost 3 percent from 2010 (73,090 people) (U.S. Census Bureau 2018). The projected population in Monroe County by 2040, 2060, and 2070, is 75,500, 77,038 and 77,748 people, respectively (Carr and Zwick 2016, p. 27). Although the expected population growth in Monroe County is relatively modest, all vacant/private owned land is projected to be developed, including lands currently inaccessible for development such as islands not attached to the Overseas Highway (U.S. 1) (Zwick and Carr 2006, pp. 14–15). This development will have the potential to further reduce the amount of suitable habitat.

5.1.2. Climate change (sea level rise and saltwater intrusion) – future impacts

In Florida, sea level is projected to rise between 1 ft (0.4 m) at the low end and to 8.4 ft (3.2 m) at the high end by 2100 (USGS 2019b, p. 1). Due to SLR, low-lying islands and coastal areas have increasingly become more vulnerable to high tide flooding which is rapidly increasing in frequency, depth, and extent (Sweet et al. 2018, p. 3). In south Florida and the Florida Keys, high tide flooding events primarily affect low-lying coastal areas and exposed critical Key ring-necked snake habitats such as pine rocklands and rockland hammocks. With continued increase in SLR, high tide/king tide flood frequencies are also expected to rapidly increase, with potentially severe damage to remaining rockland habitat because pine rocklands species, particularly the dominant canopy species (slash pine, *Pinus elliottii* var. *densa*) has little ability to tolerate saltwater (<2 ppt) (USGS 2019b, p. 2). Consequently, pine rocklands habitat has undergone a significant reduction in the Florida Keys due to SLR (Ross et al. 1994, p. 154). Currently, some of these areas are occupied by halophytic vegetation such as mangroves and buttonwood (Alexander 1976, pp. 219–222) owing to high tide flooding as a result of rising sea level, but also due to saltwater intrusion of the islands' freshwater lens. As stated earlier, a unique characteristic of the Florida Keys is the existence of a freshwater lens below each island that is critically important for humans, flora, fauna and a variety of habitats.

Based on a case study of Big Pine Key in the lower Florida Keys, USGS concluded that saltwater by sea level rise alone, will begin to negatively affect the root zone of the island's upland vegetation as early as 2030 (USGS 2019a, p. 3). The result is that freshwater-dependent flora and fauna which comprise much of the island's biota will disappear. Over time, vegetation succession will result in mangrove dominance on the remaining land and more expansive estuaries across much of the island.

In a study conducted by the USGS, they determined that there is a total of 1,899.37 and 3,805.60 ac (768.65 and 1,540.07 ha) of pine rocklands and rockland hammock, respectively (USGS 2019b, p. 4). In addition, while rockland hammocks are distributed across many of the islands, pine rocklands only exists on five islands within the lower Keys including Big Pine Key, Little Pine Key, No Name Key, Cudjoe Key, and Sugarloaf Key. Using regional sea level rise (RSLR) scenarios (low, intermediate, and extreme; Sweet et al. 2017, pp. vi, vii, 12, 21), USGS (2019b; entire) calculated the change in pine rocklands and rockland hammock habitat (total area and percent of current extent) in 10-year intervals from 2030 and 2100. In addition, the high tide

effect (minor, moderate, and major) on pine rocklands and rockland hammock habitat was assessed by calculating the area impacted due to high tide on top of the RSLR effect.

Pine rocklands and rockland hammock habitats were analyzed separately according to expected losses from projected RSLR scenarios with an intermediate (I) RSLR (Sweet et al. 2017, pp. vi, vii, 12, 21), and moderate high tide effect (2.69 ft [0.82] m) for the years 2040, 2060, and 2080, for the lower Florida Keys (Tables 5 and 6). In addition, we considered forecasted losses from projected RSLR scenarios with an extreme (E) RSLR (Sweet et al. 2017, pp. vi, vii, 12, 21), in combination with a predicted moderate tide effect (2.69 ft [0.82 m]) to compare the range of expected impacts for the most immediate scenario, 2040 (Tables 5 and 6).

Similarly, predicted affects to pine rocklands and rockland hammock by root zone salinization with an intermediate (I) RSLR (Sweet et al. 2017, pp. vi, vii, 12, 21) for the years 2040, 2060, and 2080 were analyzed for the lower Florida Keys (Tables 7 and 8). In addition, we considered forecasted losses from projected RSLR scenarios with an extreme (E) RSLR (Sweet et al. 2017, pp. vi, vii, 12, 21), in combination with a predicted moderate tide effect (2.69 ft [0.82 m]) to compare the range of expected impacts for the most immediate scenario, 2040 (Tables 7 and 8).

Table 5. Predicted pine rocklands habitat changes with an intermediate (I) and extreme (E) RSLR (Sweet et al. 2017, pp. vi, vii, 12, 21), and moderate high tide effect (2.69 ft, [0.82 m]) in the lower Florida Keys, for the years 2040, 2060 and 2080.

Future Scenario	RSLR height (m)	Year	Current pine rocklands (ac) in the lower Florida Keys.	Area (ac) of pine rocklands affected by both RSLR and high tide	Percent (%) of pine rocklands affected by both RSLR and high tide.
1	0.31	2040I	1,899.35	1,674.44	88.16
2	0.54	2060I		1,834.88	96.61
3	0.83	2080I		1,898.90	99.98
4	0.60	2040E		1,864.90	98.19

Table 6. Predicted rockland hammock habitat changes with an intermediate (I) and extreme (E) RSLR (Sweet et al. 2017, pp. vi, vii, 12, 21), and moderate high tide effect (2.69 ft, [0.82 m]) in the lower Florida Keys, for the years 2040, 2060 and 2080.

Future Scenario	RSLR height (m)	Year	Current rockland hammock (ac) in the lower Florida Keys.	Area (ac) of rockland hammock affected by both RSLR and high tide.	Percent (%) of rockland hammock affected by both RSLR and high tide.
1	0.31	2040I	3,805.60	3,668.29	96.39
2	0.54	2060I		3,749.54	98.53
3	0.83	2080I		3,778.39	99.29
4	0.60	2040E		3,758.21	98.75

Table 7. Predicted pine rocklands habitat affected by root zone salinization based only on sea level rise predictions with an intermediate (I) and extreme (E) RSLR (Sweet et al. 2017, pp. vi, vii, 12, 21) in the lower Florida Keys, for the years 2040, 2060 and 2080.

Future Scenario	RSLR height (m)	Year	Current pine rocklands (ac) in the lower Florida Keys.	Area (ac) of pine rocklands affected by root salinization.	Percent (%) of pine rocklands affected by root zone salinization.
1	0.31	2040I	1,899.35	1,358.92	71.55
2	0.54	2060I		1,631.11	85.88
3	0.83	2080I		1,840.58	96.91
4	0.60	2040E		1,682.76	88.60

Table 8. Predicted rockland hammock habitat affected by root zone salinization based only on sea level rise predictions with an intermediate (I) and extreme (E) RSLR (Sweet et al. 2017, pp. vi, vii, 12, 21) in the lower Florida Keys, for the years 2040, 2060 and 2080.

Future Scenario	RSLR height (m)	Year	Current rockland hammock (ac) in the lower Florida Keys.	Area (ac) of rockland hammock affected by root salinization.	Percent (%) of rockland hammock affected by root zone salinization.
1	0.31	2040I	3,805.60	3,303.95	86.82
2	0.54	2060I		3,632.02	95.44
3	0.83	2080I		3,751.23	98.57
4	0.60	2040E		3,674.47	96.55

5.1.3. Storm events – future impacts

The intensity, frequency and duration of hurricane activity in the Atlantic Ocean has been increasing since the early 1980s. This increase in activity is linked to higher sea surface temperatures which are influenced by natural variability occurring in the North Atlantic Ocean, human-induced emissions of heat-trapping gases and particulate pollution (Service 2017b, p. 7). In addition, a 20 percent increase in rainfall rates associated with hurricanes is expected (Service 2017b, p. 7).

Extreme weather events are another aspect of climate change likely to impact pine rocklands and rockland hammock habitat. Plant species common to both habitats have little ability to tolerate salt stress due to saltwater intrusion or inundation owing to high tide events and sea level rise. Although the effects during severe storm events may be temporary, high mortality of pine rocklands and rockland hammock species may occur. In conclusion, climate change-induced storm events may reduce the resiliency of both pine rocklands and rockland hammock habitats.

5.1.4. Shifts in seasonal patterns of rainfall and temperature – future impacts

Annual average temperature over the contiguous United States is projected to rise. Increases of approximately 2.5°F (1.4°C) are projected for the period 2021–2050 relative to 1976–2005 in all Representative (emission) Concentration Pathway (RCP) scenarios, implying recent record-setting years may be common in the next few decades (high confidence). There are four RCPs (RCP8.5, RCP6, RCP4.5, and RCP2.6) and their primary function is to provide time-dependent projections of atmospheric GHG concentrations. Much larger rises are projected by late century (2071–2100): 2.8°–7.3°F (1.6°–4.1°C) in a lower scenario (RCP4.5) and 5.8°–11.9°F (3.2°–6.6°C) in the higher scenario (RCP8.5) (USGCRP 2018, p. 159). Extreme heat events in Florida are projected to increase relative to 1986–2005 (Service 2017b, p. 2). Due to the already released, human-induced emissions of GHGs present in the environment, another +0.5° F (-17.5° C) increase in surface air temperature would be expected, even if there was a sudden end to all human-induced GHG emissions (Carter et al. 2014, pp. 414–415). For the State of Florida, this would equate to an increase of more than 30 to 40 days of extreme heat events for Florida’s coastal areas (Service 2017b, p. 2). An increase in temperature also causes an increase in evapotranspiration in plants, which will change vegetation growth and survival, leading to changes in plant communities which could indirectly affect Key ring-necked snakes.

Extreme rainfall events have increased in frequency and intensity in the southeastern United States, and there is high confidence they will continue to increase in the future. Both the frequency and severity of extreme precipitation events are projected to continue increasing in the southeast region under both lower and higher scenarios (Easterling et al. 2017, p. 223). Future projections of average precipitation are uncertain, but an increase in intense rainfall is projected. Though average summer precipitation may not change, higher temperatures will increase the rate of soil moisture loss and thereby droughts will likely be more intense (USGCRP 2018, pp. 1004, 1134). Dry consecutive days are expected to increase up to 30 percent in south Florida by 2100 (Service 2017b, p. 7). While dry conditions may not necessarily harm the Key ring-necked snake, extreme conditions (lack of rainfall and increased temperatures) could be detrimental. Decreased water availability, exacerbated by population growth and land-use change, will continue to increase competition for water (USGCRP 2018, p. 1112). Increasing drought intensity will likely trigger more frequent wildfire events which may be beneficial to Key ring-necked snakes by increasing habitat quality. In addition, greater rainfall rates during hurricanes are expected with about a 20 percent increase near the center of storms, increasing risks of severe and damaging flooding (Service 2017b, pp. 4-5).

Shifts in seasonal patterns of rainfall and temperature are additional impacts of climate change likely to negatively affect suitable Key ring-necked snake habitat. Although temporary, these impacts are expected to work in conjunction with and possibly exacerbate other climate change impacts discussed above and are only predicted to increase in severity (USGCRP 2018, entire). Periods of extreme drought and/or heavy rainfall can cause losses and alteration in plant and animal communities which could affect the Key ring-necked snake directly and/or indirectly. For example, with an increase in flooding frequency, Key ring-necked snakes may be more frequently displaced from underground refugia, leading to higher mortality risk. Alternatively, more periods of extreme drought may reduce the abundance of prey, decreasing the ability of Key ring-necked snakes to feed. Climate change-induced shifts in seasonal patterns of rainfall

and temperature may reduce the Key ring-necked snake's overall resiliency, especially when extreme events occur within areas of multiple populations.

5.1.5. Minor threats (disease, invasive species, predation) – future impacts

In the case of minor threats (disease, predation, invasive species), we have no information that the magnitude of these threats will change from their current condition. If any one of these threats begin to increase and place pressure on the Key ring-necked snake, it will need to be assessed immediately because although these minor threats may have low impacts on their own, combined with impacts of other threats, they could further reduce the already low number of Key ring-necked snakes.

5.2. Scenario 1 (2040I)

Scenario 1 outlines those factors having an influence on the Key ring-necked snake in 2040. For scenario 1 we focused on the predicted pine rocklands and rockland hammock habitat projections with a moderate high tide effect (2.69 ft [0.82 m]) and an intermediate RSLR (1.02 ft [0.31 m]) for 2040 (Tables 5 and 6).

Based on the SLR modeling scenario with the above referenced parameters, the pine rocklands habitat affected by both RSLR and high tide is 1,674.44 ac (677.62 ha) or 88.16 percent of the current pine rocklands habitat in the lower Florida Keys, and only 224.91 ac (91.02 ha) or 11.84 percent unaffected (Table 5). The rockland hammock habitat affected by similar RSLR and high tide parameters is 3,668.29 ac (1,484.50 ha) or 96.39 percent of the current rockland hammock habitat in the lower Florida Keys, and only 137.31 ac (55.57 ha) or 3.61 percent unaffected (Table 6). In addition, the pine rocklands and rockland hammock habitat affected by root zone salinization is 1,358.92 ac (549.94 ha) (71.55 percent) and 3,303.95 (1,337.06 ha) (86.82 percent), respectively (Tables 7 and 8).

5.2.1. Resiliency

Scenario 1 results in a loss of 88.16 and 96.39 percent of the pine rocklands and rockland hammock habitat, respectively, that currently supports the Key ring-necked snake (Tables 5 and 6). Consequently, this will very likely cause extirpation of the Key ring-necked snake population in the lower Florida Keys (Table 9).

Storm events and associated storm surges will be a greater source of mortality and habitat modification; therefore, reducing population resiliency. Projected SLR will increase the inland penetration and residence time of saltwater during storm surge events, and decrease the freshwater lens, both of which will accelerate habitat modification and loss. In addition, SLR in the Florida Keys will increase saltwater intrusion and inundation, and root zone salinity over the coming decades. This will result in the loss of habitat, changes in freshwater-dependent habitat and/or loss of individual snakes, creating a trend toward probable extirpation of the Key ring-necked snake population in the lower Florida Keys.

5.2.2. Representation

The environmental diversity of the Key ring-necked snake habitat is low. Consequently, the ability of this subspecies to adapt to changing environmental conditions among populations is extremely limited. Therefore, a reduction in subspecies representation is expected.

5.2.3. Redundancy

Redundancy has been low for the Key ring-necked snake and with the continued loss or modification to its habitat as outlined above, a reduction or the elimination in subspecies redundancy is expected.

5.3. Scenario 2 (2060I)

Scenario 2 outlines those factors having an influence on the Key ring-necked snake in 2060. For scenario 2, we focused on the predicted pine rocklands and rockland hammock habitat projections with a moderate high tide effect (2.69 ft [0.82 m]) and an intermediate RSLR (1.77 ft [0.54 m]) for 2060 (Tables 5 and 6).

Based on the SLR modeling scenario with the above referenced parameters, the pine rocklands habitat affected by both RSLR and high tide is 1,834.88 ac (742.55 ha) or 96.61 percent of the current pine rocklands habitat in the lower Florida Keys, and only 64.47 ac (26.09 ha) or 3.39 percent unaffected (Table 5). The rockland hammock habitat affected by similar RSLR and high tide parameters is 3,749.54 ac (1,517.38 ha) or 98.53 percent of the current rockland hammock habitat in the lower Florida Keys, and only 56.06 ac (22.69 ha) or 1.47 percent unaffected (Table 6). In addition, the pine rocklands and rockland hammock habitat affected by root zone salinization is 1,631.11 ac (660.09 ha) (85.88 percent) and 3,632.02ac (1,469.83 ha) (95.44 percent), respectively (Tables 7 and 8).

5.3.1 Resiliency

Scenario 2 results in a loss of 96.61 and 98.53 percent of the pine rocklands and rockland hammock habitat, respectively, that currently supports the Key ring-necked snake (Tables 5 and 6). Consequently, this will very likely cause extirpation of the Key ring-necked snake population in the lower Florida Keys (Table 9).

Storm events and associated storm surges will be a greater source of mortality and habitat modification; therefore, reducing population resiliency. Projected SLR will increase the inland penetration and residence time of saltwater during storm surge events, and decrease the freshwater lens, both of which will accelerate habitat modification and loss. In addition, SLR in the Florida Keys will increase saltwater intrusion and inundation, and root zone salinity over the coming decades. This will result in the loss of habitat, changes in freshwater-dependent habitat and/or loss of individual snakes, creating a trend toward probable extirpation of the Key ring-necked snake population in the lower Florida Keys.

5.3.2. Representation

The environmental diversity of the Key ring-necked snake habitat is low. Consequently, the ability of this subspecies to adapt to changing environmental conditions among populations is extremely limited. Therefore, a reduction in subspecies representation is expected.

5.3.3. Redundancy

Redundancy has been low for the Key ring-necked snake and with the continued loss or modification to its habitat as outlined above, a reduction or the elimination in subspecies redundancy is expected.

5.4. Scenario 3 (2080I)

Scenario 3 outlines those factors having an influence on the Key ring-necked snake in 2080. For scenario 3, we focused on the predicted pine rocklands and rockland hammock habitat projections with a moderate high tide effect (2.69 ft [0.82 m]) and an intermediate RSLR (2.72 ft [0.83 m]) for 2080 (Tables 5 and 6).

Based on the SLR modeling scenario with the above referenced parameters, the pine rocklands habitat affected by both RSLR and high tide is 1,898.90 ac (768.46 ha) or 99.98 percent of the current pine rocklands habitat in the lower Florida Keys, and only 0.45 ac (0.18 ha) or 0.02 percent unaffected (Table 5). On the other hand, the rockland hammock habitat affected by similar RSLR and high tide parameters is 3,778.39 ac (1,529.06 ha) or 99.29 percent of the current rockland hammock habitat in the lower Florida Keys, and only 27.21 ac (11.01 ha) or 0.71 percent unaffected (Table 6). In addition, the pine rocklands and rockland hammock habitat affected by root zone salinization is 1,840.58 ac (744.86 ha) (96.91 percent) and 3,751.23 (1,518.07 ha) (98.57 percent), respectively (Tables 7 and 8).

5.4.1. Resiliency

Scenario 3 results in a loss of 99.98 and 99.29 percent of the pine rocklands and rockland hammock habitat, respectively, that currently supports the Key ring-necked snake (Tables 5 and 6). Consequently, this will very likely cause extirpation of the Key ring-necked snake population in the lower Florida Keys (Table 9).

Storm events and associated storm surges will be a greater source of mortality and habitat modification; therefore, reducing population resiliency. Projected SLR will increase the inland penetration and residence time of saltwater during storm surge events, and decrease the freshwater lens, both of which will accelerate habitat modification and loss. In addition, SLR in the Florida Keys will increase saltwater intrusion and inundation, and root zone salinity over the coming decades. This will result in the loss of habitat, changes in freshwater-dependent habitat and/or loss of individual snakes, creating a trend toward probable extirpation of the Key ring-necked snake population in the lower Florida Keys.

5.4.2. Representation

The environmental diversity of the Key ring-necked snake habitat is low. Consequently, the ability of this subspecies to adapt to changing environmental conditions among populations is extremely limited. Therefore, a reduction in subspecies representation is expected.

5.4.3. Redundancy

Redundancy has been low for the Key ring-necked snake and with the continued loss or modification to its habitat as outlined above, a reduction or the elimination in subspecies redundancy is expected.

5.5. Scenario 4 (2040E)

Scenario 4 outlines those factors having an influence on the Key ring-necked snake in 2040. For scenario 4 we focused on the predicted pine rocklands and rockland hammock habitat projections with a moderate high tide effect (2.69 ft [0.82 m]) and an extreme RSLR (1.97 ft [0.60 m]) for 2040 (Tables 5 and 6).

Based on the SLR modeling scenario with the above referenced parameters, the pine rocklands habitat affected by both RSLR and high tide is 1,864.90 ac (754.70 ha) or 98.19 percent of the current pine rocklands habitat in the lower Florida Keys, and only 34.45 ac (13.94 ha) or 1.81 percent unaffected (Table 5). The rockland hammock habitat affected by similar RSLR and high tide parameters is 3,758.21 ac (1,520.89 ha) or 98.75 percent of the current rockland hammock habitat in the lower Florida Keys, and only 47.39 ac (19.18 ha) or 1.25 percent unaffected (Table 6). In addition, the pine rocklands and rockland hammock habitat affected by root zone salinization is 1,682.76 ac (680.99 ha) (88.60 percent) and 3,674.47 ac (1,487.01 ha) (96.55 percent), respectively (Tables 7 and 8).

5.5.1. Resiliency

Scenario 4 results in a loss of 98.19 and 98.75 percent of the pine rocklands and rockland hammock habitat, respectively, that currently supports the Key ring-necked snake (Tables 5 and 6). Consequently, this will very likely cause extirpation of the Key ring-necked snake population in the lower Florida Keys (Table 9).

Storm events and associated storm surges will be a greater source of mortality and habitat modification; therefore, reducing population resiliency. Projected SLR will increase the inland penetration and residence time of saltwater during storm surge events, and decrease the freshwater lens, both of which will accelerate habitat modification and loss. In addition, SLR in the Florida Keys will increase saltwater intrusion and inundation, and root zone salinity over the coming decades. This will result in the loss of habitat, changes in freshwater-dependent habitat and/or loss of individual snakes, creating a trend toward probable extirpation of the Key ring-necked snake population in the lower Florida Keys.

5.5.2. Representation

The genetic and environmental diversity of the Key ring-necked snake is low. Consequently, the ability of this subspecies to adapt to changing environmental conditions among populations is extremely limited. Therefore, a reduction in subspecies representation is expected.

5.5.3. Redundancy

Redundancy has been low for the Key ring-necked snake and with the continued loss or modification to its habitat as outlined above, a reduction or the elimination in subspecies redundancy is expected.

6. Summary and Conclusions

In the Florida Keys, the effects of storm events (*e.g.*, storm surges, high tide), saltwater intrusion and SLR outweigh all other threats in all four scenarios and has the greatest influence on population resiliency. Storm event-related effects will become more frequent and intense which will accelerate habitat modification, reducing population resiliency. In addition, the Florida Keys will face increased saltwater intrusion and SLR which will cause habitat modification and loss. Acting together, these threats will cause irreversible habitat modification and loss that will precede inundation. Given this, all Key ring-necked snake populations may begin experiencing significant losses across its narrow range in the next 10–20 years, may potentially be extirpated as early as 2040, and depending on the rate of SLR, will very likely become extirpated by 2080. (Table 9).

Table 9. Predicted population condition of the Key ring-necked snake under four scenarios.

Lower Florida Keys	Current	Scenario 1 (2040I)	Scenario 2 (2060I)	Scenario 3 (2080I)	Scenario 4 (2040E)
Big Pine Key	Low	Possibly extirpated	Presumed extirpated	Presumed extirpated	Presumed extirpated
Cudjoe Key	Low	Possibly extirpated	Presumed extirpated	Presumed extirpated	Presumed extirpated
Key West	Low	Possibly extirpated	Presumed extirpated	Presumed extirpated	Presumed extirpated
Little Torch Key	Low	Possibly extirpated	Presumed extirpated	Presumed extirpated	Presumed extirpated
Middle Torch Key	Low	Possibly extirpated	Presumed extirpated	Presumed extirpated	Presumed extirpated
No Name Key	Low	Possibly extirpated	Presumed extirpated	Presumed extirpated	Presumed extirpated
Stock Island	Low	Possibly extirpated	Presumed extirpated	Presumed extirpated	Presumed extirpated

*Possibly to mean that it may have gone from a low population condition to extirpation, but the timing is unknown.

*Presumed to mean that it has definitely happened at a set time, based on the results of our future scenarios.

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