Species Report for the Rota Blue Damselfly
(*Ischnura luta*)

A Rota blue damselfly on vegetation along Okgok Stream, Rota. (Photo by Lainie Zarones)

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Executive Summary

The Rota blue damselfly (*Ischnura luta*) is a small, blue-colored damselfly endemic to the 33 mi^2 (85 km^2) island of Rota, the third largest island in the Commonwealth of the Northern Mariana Islands (CNMI) in the western Pacific Ocean. In 2014, the United States Fish & Wildlife Service (Service) listed the Rota blue damselfly as an endangered species under the Endangered Species Act (Act). This species report assesses the damselfly's ecology, current condition, and future condition under various scenarios. This report will serve as the foundational science for informing the Service's approach to recovery for the Rota blue damselfly.

The Rota blue damselfly is a stream-obligate insect that inhabits one confirmed stream system on the island. This stream occurs within a forested portion of an area known as Talakhaya that contains the entirety of available stream habitat on Rota, limited by geology. With no studies of the ecology or life history of this insect to-date, we identified the basic needs of individuals and for the population and species based upon the biology of related stream-obligate damselflies and the *Ischnura* genus in general as follows:

Individual Needs
• Cool stream water that is relatively free of silt, pollution, and predators • Shelter, insect prey for foraging, and breeding sites provided by Okgok Stream and the native forest in which occurs.
Population/ Species Needs
• Cool stream water that is relatively free of silt and pollution as provided by Okgok Stream, and seasonally, nearby springs • Stream habitat of sufficient area and continuity to accommodate home range and breeding territories. • Forest habitat on the Sabana Plateau of sufficient quality, area, and continuity to provide for the aquifer that feeds stream flow emanating from Sonson Water Cave (Matan Hanum) and the other springs feeding several intermittent streams in the Talakhaya. • Forest habitat of sufficient quality, area, and continuity to maintain existing, cool, shaded forest understory conditions surrounding Okgok Stream. • Low abundance of existing predators and prevention of the establishment of new, invasive predators including nonnative fish and insect species.

Impacts from human activities have altered habitat important for the Rota blue damselfly, both directly and indirectly. Historical impacts to the landscape of Rota began with the arrival of the original Chamorro people 3,000-4000 ago and increased following European colonization in the 1500s. By the conclusion of the Second World War (WWII), human activities on the island had culminated in stream diversions and large alterations to forest habitat reducing the potential for

stream habitat to exist on the island. Reductions and changes to Rota's forest landscape has likely reduced size and quality of the aquifer that feeds the island's streams, while stream diversions for municipal water supplies have directly reduced the amount and annual duration of available stream habitat annually. Despite historical impacts to its habitat, the Rota blue damselfly has thus far demonstrated an apparent resiliency to overcome stochastic changes that affected the habitat upon which it depends.

Currently, several stressors directly and indirectly threaten the forest habitat of the Rota blue damselfly, including loss and degradation due to impacts from feral ungulates, nonnative plants, wildfire, and development. The primary direct stressor to the species is the ongoing municipal extraction of water from the Talakhaya stream systems. Additional potential stressors include predation by nonnative fish and insects that may establish on Rota. Ongoing conservation actions likely benefit the species, particularly revegetation efforts in the Talakhaya and associated outreach as well as identification and management of the Talakhaya and the Sabana Plateau as conservation areas.

The overall current viability of Rota blue damselfly is low due to low to moderate resiliency, and low representation and redundancy. When assessing possible future conditions of the Rota blue damselfly, we particularly considered potential impacts from:

1) The introduction of potential invasive stream predators to Rota, including for example *Gambusia* spp.;
2) future civilian activities that may also further degrade or reduce forest habitat and consequently reduce the capacity of the Sabana plateau to replenish the aquifer water available for stream habitat;
3) and of most serious concern to the viability of the Rota blue damselfly, future civilian activities on Rota that may require additional water extraction from Okgok Stream.

The Service expects conservation measures that include strong biosecurity, careful planning for balanced conservation and municipal water needs, and protection and management of forest on the Sabana Plateau to provide the greatest future potential benefit to damselfly.

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INTRODUCTION

The Rota blue damselfly (*Ischnura luta*) is a small, blue-colored narrow-winged damselfly endemic to the island of Rota, the third largest island in the Commonwealth of the Northern Mariana Islands (CNMI) in the western Pacific Ocean (**Figure 4**). First described in 2000 from specimens collected in 1996, the species is the only single island endemic stream insect recorded from the Mariana Archipelago, including Guam. Several stressors indirectly threaten the habitat of the Rota blue damselfly, including forest habitat loss and degradation due to impacts from feral ungulates, nonnative plants, and human activities. Additionally, water extraction for the island's municipal water supply directly threatens the viability of damselfly through loss of stream habitat. The several potential primary direct stressors to the damselfly likely include predation by nonnative fish and insects, as well as competition from nonnative insects – however we lack evidence of impact from these threats. The overall current viability of Rota blue damselfly is low due to low to moderate resiliency, and low representation and redundancy. The Service expects conservation measures that include strong biosecurity, careful planning for balanced conservation and municipal water needs, and protection and management of forest on the Sabana Plateau to provide the greatest future potential benefit to damselfly.

Prepared by the Pacific Islands Fish and Wildlife Office, this Species Report provides an in-depth review of Rota blue damselfly's biology, factors influencing viability (threats and conservation actions), and an evaluation of its current status and viability. The intent is for the Species Report to be easily updated as new information becomes available, and to support the functions of the Service's Endangered Species Program. As such, the Species Report will be a living document upon which the Service will base other documents such as recovery plans and 5-year reviews.

Regulatory History

After spending 18 years as a candidate species for Federal listing, the Rota blue damselfly was finally listed as endangered under the Endangered Species Act in 2015 (USFWS 2015, 73 pp.) . The species is included in the Draft Recovery Plan for 23 Species in the Marianas Islands, published on November 8, 2022 (USFWS 2022, entire). To date, the Service has not designated critical habitat for the Rota blue damselfly.

This document is one portion of a larger Pacific Islands Office-wide effort to assess the current and future viability of several listed species in the Mariana Islands as well as the main habitat types found within the archipelago including marine, forest, stream, and wetland habitats. To streamline this effort, we attempted to include the most relevant and recent information in this species report regarding the specific habitat and stressors pertaining to the Rota blue damselfly. For general information including geography, climate, geology, demographics, and an historical overview of human-caused impacts to the Mariana Islands, we direct the reader to our 2015 final listing rule for the damselfly (USFWS 2015, entire) and the recently completed biogeography assessment for the Mariana Islands (Harrington et al. 2019, entire). Likewise, for a general overview of the forest and stream habitats in the Mariana Islands including their historical and current stressors, we refer the reader to Willsey et al. (2019, entire) and Polhemus and Richardson (2020, entire), respectively.

Methodology

In preparing this Species Report, we used the best scientific and commercial data available to us, including peer-reviewed literature, grey literature (government and academic reports), and expert elicitation. This Species Report assesses the ability of the Rota blue damselfly to maintain viability over time, i.e., the species ability or likelihood to maintain populations over time, and thus avoid extinction. To assess the viability of the Rota blue damselfly, we used the three conservation biology principles of resiliency, redundancy, and representation, or the "3Rs" (**Figure 1**; USFWS 2016). We evaluated the viability of this species by describing what it needs to be resilient, redundant, and represented, and compared that to the status of the Rota blue damselfly based on the most recent information available to us.

Resiliency

Resiliency is the capacity of a population or a species to withstand the more extreme limits of normal year-to-year variation in environmental conditions such as temperature and rainfall extremes, and unpredictable but seasonally frequent perturbations such as fire, flooding, and storms (i.e., environmental stochasticity). Quantitative information on the resiliency of a population or species is often unavailable. However, in the most general sense, a population or species that can be found within a known area over an extended period of time (e.g., seasons or years) is likely to be resilient to current environmental stochasticity. If quantitative information is available, a resilient population or species will show enough reproduction and recruitment to maintain or increase the numbers of individuals in the population or species, and possibly expand the range of occupancy. Thus, resiliency is positively related to population size and growth rate, and may also influence the connectivity among populations.

Redundancy

Redundancy is the inherent ability of particular species that avoid extinction through existence as multiple resilient populations across a landscape. Such species occur across a geographic range that exceeds the area of impact of any given catastrophic event that would otherwise overwhelm the resilient capacity of individual populations of a species. In this Species Report, catastrophic events are distinguished from stochastic events-in that they are relatively unpredictable and infrequent and exceed the more extreme limits of normal year-to-year variation in environmental conditions (*i.e.,* environmental stochasticity). Because catastrophic events expose populations to an elevated extinction risk within a respective area of impact, redundancy exists when the geographic range of a species exceeds that area of impact. In general, a wider range of habitat types, greater geographic distribution, and connectivity across the geographic range will increase the redundancy of a species and its ability to survive a catastrophic event.

Representation
Representation exists when one or more populations of a species occurs across the full range of habitat types used by the species. Alternatively, representation can be viewed as maintaining the breadth of genetic diversity within and among populations, in order to allow the species to adapt to changing environmental conditions over time. Because the historic biogeographical range of a species is tied to a species' current habitat and genetic diversity, conservation of a species' range should take into account both current and historic latitudinal and longitudinal ranges, elevation gradients, climatic gradients, soil types, habitat types, seasonal condition, etc. Connectivity among populations and habitats is also an important consideration in evaluating representation.

The viability of a species is an assessment derived from a combined analysis of the 3Rs. A species is considered viable when there are a sufficient number of self-sustaining populations (resiliency) distributed over a large enough area across the range of the species (redundancy) and occupying a range of habitats to maintain environmental and genetic diversity (representation) to allow the species to persist indefinitely when faced with annual environmental stochasticity and infrequent catastrophic events. Common ecological features are an integral part of each of the 3Rs. This is especially true of connectivity between habitats across the range of the species. Connectivity sustains dispersal of individuals, which may affect genetic diversity within and among populations. Connectivity also sustains access to the full range of habitats normally and historically used by the species and is essential for re-establishing occupancy of habitats following severe environmental stochasticity or catastrophic events (see **Figure 1** for more examples of overlap among the 3Rs).

Population resiliency is the foundation of the 3Rs principles. While redundancy and representation are assessed at the species level, resilient populations are the necessary foundation to attain sustained or increasing representation and redundancy within the species. For example, a species cannot have high redundancy if the populations have low resiliency. This assessment of viability is not binary, in which a species is either viable or not, but measured rather on a continual scale of degrees of viability, from low to high. The health, number and distribution of populations were analyzed to determine "the three Rs" and the viability of the Rota blue damselfly. In broad terms, the more resilient, represented, and redundant a species is, the more viable the species is. The current and future understanding of factors, including threats and conservation actions, will influence how the "the three Rs" and viability are interpreted for the Rota blue damselfly. While this report focuses on the Rota blue damselfly in particular, we direct the reader to a more general discussion regarding the current and future scenarios for the Marianas forest habitat in Willsey et al. (2019, entire) and Miller (2019, entire) respectively.

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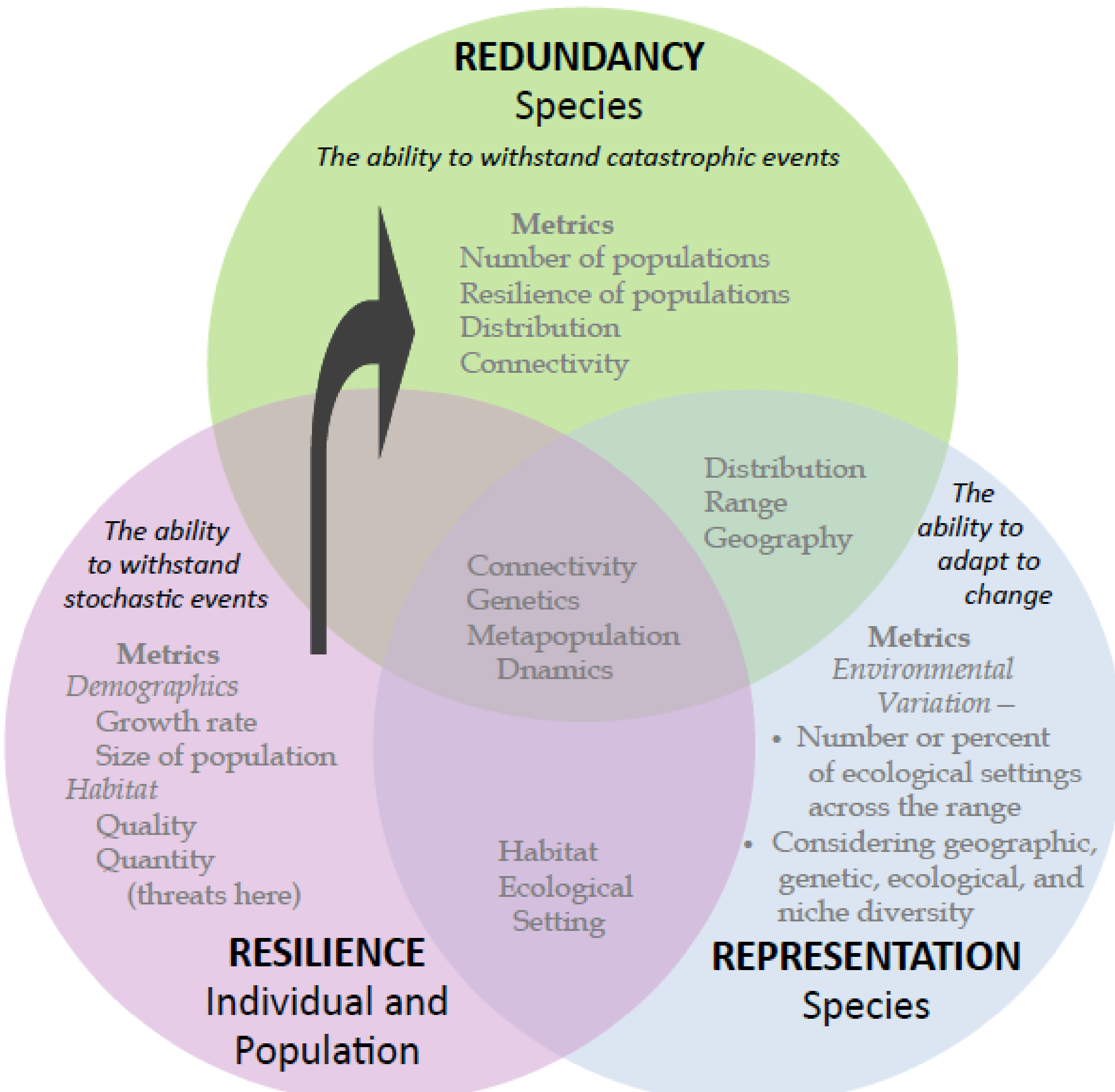

Figure 1. The three conservation biology principles of resiliency, redundancy, and representation, or the "3Rs"

SPECIES NEEDS / ECOLOGY

Species Description and Appearance

The Rota blue damselfly (*Ischnura luta*) is relatively small in size, with males measuring 1.3 in (34 mm) in body length, with forewings and hindwings 0.7 in (18 mm) and 0.67 in (17 mm) in length, respectively (Polhemus et al. 2000, p. 6). The species is average for the *Ischnura* genus, which are among the world's smallest damselflies. Adults of both sexes also exhibit compound eyes with a dark upper region and contrasting lighter color on the lower portion of the eye, another trait of the genus. Characteristic for the genus, both sexes are predominantly blue in color, particularly the thorax and portions of the male's abdomen are brilliant, iridescent blue. Both sexes have a yellow and black head with some yellow coloration on the abdomen. One may differentiate females of this species by their slightly smaller size and somewhat paler blue body color (Polhemus et al. 2000, p. 6) (**Figure 2**). Among the three other non-endemic *Ischnura* spp. present in Micronesia, including *I. aurora* (**Figure 3**), *I. senegalensis*, and *I. heterosticta*, males of the Rota blue damselfly can be distinguished by the their thoracic color and size, thoracic and wing color, or the shape of their cerci respectively (Polhemus et al. 2000, pp. 7-8).

Figure 2. Photographs comparing of the Rota blue damselfly male (left) and female (right) (Photos by Dan Polhemus)

Figure 3. Photographs comparing the male Rota blue damselfly (left) to the similarly sized male *Ischnura aurora* (right). (Photos by Lainie Zarones)

Taxonomy

The Rota blue damselfly was first described in 2000 (Polhemus et al. 2000, pp. 5-7) based upon specimens collected in 1996. The species occurs within the order Odonata, a taxonomic grouping that includes damselflies (suborder Zygoptera) and dragonflies (suborder Epiprocta, formerly Anisoptera). Within Zygoptera, the Rota blue damselfly belongs to the superfamily Coenagrionoidea (closed-wing damselflies) and more specifically within the subfamily Coenagrionidae, commonly known as ‘pond’ or ‘narrow-winged damselflies. Also referred to as forktails, species within the *Ischnura* genus possess a fork-shaped appendage on the tip of the male’s abdomen. Relatively small in size, *Ischnura* spp. occur worldwide and across the Pacific region with many endemic island species (Polhemus et al. 2000, p. 9), including many ranked by the IUCN (IUCN 2019). Besides two endemic dragonflies, it is the only other odonate and the only endemic damselfly species recorded from the Mariana Islands. Named for the Chamorro word for Rota, “Luta”, the species is also the only single island endemic stream insect recorded from the archipelago (Polhemus et al. 2000, p. 6).

Table 1. Rota blue damselfly systematics.

Systematics	Rota blue damselfly
Class	Insecta
Order	Odonata (damselflies and dragonflies)
Suborder	Zygoptera (damselflies)
Super-Family	Coenagrionoidea (closed-wing damselflies)

Subfamily	Coenagrionidae (pond or narrow-wingled damselflies
Genus	*Ischnura*
species	*luta* ("of Rota"

Life History
This section briefly describes the life history of the Rota blue damselfly and includes information on habitat requirements, diet, foraging, longevity, and breeding biology including fecundity. Due to a lack of biological studies of the Rota blue damselfly specifically, we based the following section on the biology of related damselfly species in the *Ischnura* genus and the Coenagrionidae subfamily.

Aquatic Life Stage
With few exceptions including one known narrow-wing damselfly species that inhabits water-filled leaf axils in the Caroline Islands, the vast majority of coenagrionid damselflies including all recorded *Ischnura* spp. require true aquatic habitat during the larval stage of their life cycle (Lieftinck 1962, p. 3). While we lack recorded observations of the larvae, researchers have only observed Rota blue damselfly adults in association with the island's single perennial stream, indicating that the larval stage of the species is likely aquatic-obligate. Often referred to as nymphs or naiads, the larvae are capable of breathing underwater with flattened abdominal gills, and feed generally on small aquatic insects and other invertebrates (Williams 1936, p. 303; Polhemus and Asquith 1996, p. 4; Triplehorn and Johnson 2005, p. 193). Damselfly larvae may take many months to develop underwater, with some temperate species capable of overwintering for two or more years of development (Williams 1936, p. 309; Triplehorn and Johnson 2005, p. 195).

In addition to a sufficient amount of water, the specific habitat requirements of odonates, particularly coenagrionid damselflies fall within a very narrow range of water quality parameters (Córdoba-Aguilar and Rocha-Ortega 2019, pp. 1, 4-5). Generally intolerant of high temperatures, pollutants, hypoxic conditions, and silted water among other factors, ecologists have long identified damselflies and dragonflies as reliable indicators of overall water quality (Moore 1997, entire; Solimini et al. 1997, p. 21). It is because of their stringent water requirements that so many odonates have become imperiled worldwide as aquatic habitats disappear or become degraded due to human activities and other events such as climate change (Polhemus 1993, entire; Moore 1997, entire; Xerces Society 2019, entire).

Foraging and Breeding
Although research in general has not quantified feeding behavior and food intake for most damselflies and the Zygoptera overall, adult damselflies are predaceous and feed on small flying insects such as midges, small flies, and similarly sized insects (Westfall & May 1996). There is evidence that feeding occurs predominantly away from mating territories for some species

(Higashi et al. 1979), therefore the amount of vegetation immediately along the stream itself may not strictly correlate with feeding success. With their arms outstretched to form a basket, damselflies typically catch prey mid-air, or ambushed on vegetation. In addition to aerial interception, *Ischura* species in particular are known specialists at picking small insects off vegetation (Miller 1987; Westfall and May 1996).

The general biology of the adult narrow-winged damselflies includes territorial behavior by the males during which they guard areas of habitat where females will lay eggs (Polhemus and Asquith 1996, pp. 2–7). During copulation, the male grasps the female behind the head with terminal abdominal appendages to guard against rival males. This precautionary behavior may continue while the female lays eggs and thus males and females are often seen flying in tandem (Polhemus and Asquith 1996, p. 7; Triplehorn and Johnson 2005, p. 195).

Like most damselflies, narrow wing damselfly species show strong breeding site fidelity and both sexes typically remain in relatively close proximity to the aquatic environment where they lived as naiads and return to that same site to mate and lay eggs (Finke 1992, p. 449; Guillermo-Ferreira and Del-Claro 2011, p. 275). To large extent, a given species site fidelity is driven by a complex relationship between ideal oviposition sites, males seeking the highest density of females, and the likelihood of a very specific portion of the habitat to produce the highest number of quality offspring (Finke 1992, p. 449). During foraging however, adult narrow wing damselflies may fly widely over a large range of habitat to seek prey before maturing and returning to their selected breeding site (Polhemus and Asquith 1996, p. 7). Although there are no recorded observations of the Rota blue damselfly's naiad life stage, we may presume that at least seasonally suitable (and desirable) aquatic breeding sites exist within a certain range of the three sites where adults were recorded (**Figure 4**).

Using an ovipositor, recently fertilized female damselflies typically lay eggs by inserting them into small slits in aquatic vegetation below the water surface, while some species may lay eggs on rocks, algal mats, moss, or vegetation either below or above the water line (Williams 1936, p. 309; Guillermo-Ferreira and Del-Claro 2011, p. 275). Selection of suitability of oviposition sites is fundamental to a successful life history, and thus, reproductive success of damselflies. Many Zygoptera are known to be fairly strict specialists in regard to breeding, utilizing specific microhabitats. As an example, the species in the endemic Hawaiian genus *Megalagrion* includes different species that breed in diverse, but specific habitats including in stream pools, stream runs and cascades, on seeps, in leaf axis, or even terrestrially (Polhemus & Asquith 1996). Therefore, the existence of stream water is only one of many criteria, as females will reject habitat for a wide variety of reasons including inadequate or insufficient water quality, substrates, or plants for oviposition (Guillermo-Ferreira and Del-Claro 2011, pp. 278-279).

Adult damselflies do not guard their oviposition site, but continue to feed and mate afterward for a few weeks. The eggs require about 10 days to hatch into a naiad, which noted above, may take months to mature. Occurring in a tropical climate, the Rota blue damselfly naiad likely completes its development within approximately 2 to 4 months (Polhemus and Asquith 1996 p. 4), a trait that probably affords the species some adaptability given the seasonally ephemeral nature of many of the springs that occur in the Talakhaya. Naiads quickly develop into voracious predators and feed upon a variety of prey including water fleas, mosquito larvae, and other small aquatic organisms. Compared to larger, related dragonfly larvae, damselfly naiads show less variation in form, usually slender and elongate, many having morphological adaptations for holding their position in fast flowing water. Damselfly naiads are also more sensitive than dragonfly larvae to oxygen levels, silt, and other suspended fine particulate matter. Damselfly naiads also do not bury themselves in the mud, instead spend most of their time waiting to ambush prey, occasionally propelling themselves with their gills through the water or crawling on the substrate (Polhemus and Asquith 1996, p. 4).

To reach maturity the naiad requires up to 12 molts or more, a process that allows the young damselfly to grow by shedding successively larger skins (Williams 1936, pp. 303, 306, 318; Evenhuis et al. 1995, p. 18). Like all insects that molt, the damselfly naiad is essentially helpless for a short period of time and is vulnerable to predation by fish and a variety of other aquatic insects including other naiads. In the absence of abundant prey, naiads may exhibit territorial behavior toward naiads of the same species with measurable effects on growth (Nilsson-Örtman et al. 2014, p. 1,394). Many species that co-evolved with fish and other predators modify their foraging behavior to balance the risk of exposing themselves vs. possibly catching more prey, sometimes resulting in longer developmental times (McPeek 1995, p. 749; McPeek 1998, p. 1; Brodin and Johansson 2004, p. 2,927). This behavior is of relevance for island endemic damselflies that evolved in the absence of certain fish predators and are therefore susceptible to such predation pressure (Polhemus and Asquith 1996, pp. 24-25).

During the final molt, most damselflies crawl up onto nearby vegetation to pull their adult body out a split on the back of their larval skin. The adult damselfly emerges with a soft body and crumpled wings that require an air-swallowing process to expand and fully open. This endeavor may take several hours after which the adult flies away to hide in nearby vegetation. It is during the final molt that damselflies are most vulnerable to predation by a variety of predators due to their soft skin, the amount of time involved, and an inability to fly or crawl away during or immediately following the process (Polhemus and Asquith 1996, p. 4; Triplehorn and Johnson 2005, p. 194). Up to seven days may be necessary before the adult damselfly gains full use of its flight capability and begin its life seeking prey and eventually, a mate near the same stream where they emerged (Williams 1936, pp. 303, 306, 309, 318; Triplehorn and Johnson 2005, p. 194). The average lifespan of the adult damselfly is approximately three to four weeks (Triplehorn and Johnson 2005, p. 194).

INDIVIDUAL, POPULATION, AND SPECIES NEEDS

Individual Needs

Other than the limited amount of information available in the literature regarding distribution (see discussion below), and what can be extrapolated from related species biology as presented above, we lack specific details regarding the Rota blue damselfly's individual needs. Like all stream-obligate damselflies, the larval or naiad life stage requires stream water of sufficient duration and an adequate abundance of aquatic prey to complete its development to the adult stage. Based upon the biology of related narrow-wing damselflies, the Rota blue damselfly requires adequate stream flow for approximately 3 to 4 months in duration. Additionally, the stream water must be sufficiently cool, and relatively free of pollution, silt, and other particulate matter. Following its metamorphosis into the adult stage, the damselfly requires sufficiently complex forest understory to support an abundance of prey and provide places to evade predators.

Population Needs

Very little information is available regarding the structure and size of the Rota blue damselfly population, or whether the species exists as a single or multiple populations. Studies of related and similarly rare *Ischnura* damselflies indicate that as many as hundreds of individuals can be supported by portions of streams in areas measuring less than 5 acres (ac) (2 hectares (ha)) (Garrison and Hafernik 1981, p 377). A thorough delineation of the habitat and a mark-recapture study of adults could facilitate determination of the size and distribution of the Rota blue damselfly population (Garrison and Hafernik 1981, p. 377; Pollack 2016, p. 8; National Park Service in litt. 2019). Because damselflies in general, particularly rare species, do not persist in low quality habitats (Suhonen et al. 2010, pp. 1,151-1,152), we can assume that existing habitat conditions are sufficient to sustain the needs of the Rota blue damselfly population at the current (unknown) level. Based on studies of other rare damselflies, we can also assume that the habitat currently available to the species meets the needs of individuals and is sufficiently large, contiguous, and robust to support a population of at least several hundred interbreeding individuals. Lastly, we assume that the Rota blue damselfly population likely requires aquatic habitat that is sufficiently below some threshold of predator density and possibly absent of certain predators including nonnative fish species.

Species' Needs / Ecology

Assuming that all Rota blue damselflies on the island represent a single interbreeding population, we believe it is reasonable to assume that species needs are similar to population needs. For example, its species requirements may include: sufficient quantity and quality of forest habitat on the Sabana Plateau to help capture precipitation to feed the Talakhaya streams; sufficient density and distribution of forest along the Talakhaya stream channels to provide for cool water temperatures, refugia and shelter, and habitat for prey; an absence of certain predators, particularly nonnative fish; conditions below certain thresholds of predation pressure in general; and most importantly, sufficient stream flow to support development of the naiad larval stage.

Table 2. Summary of Rota blue damselfly individual, population, and species needs

Individual Needs
• Cool stream water that is relatively free of silt, pollution, and predators • Shelter, insect prey for foraging, and breeding sites provided by Okgok Stream and the native forest in which occurs.
Population/ Species Needs
• Cool stream water that is relatively free of silt and pollution as provided by Okgok Stream, and seasonally, nearby springs • Stream habitat of sufficient area and continuity to accommodate home range and breeding territories. • Forest habitat on the Sabana Plateau of sufficient quality, area, and continuity to provide for the aquifer that feeds stream flow emanating from Sonson Water Cave and the other springs feeding several intermittent streams in the Talakhaya. • Forest habitat of sufficient quality, area, and continuity to maintain existing, cool, shaded forest understory conditions surrounding Okgok Stream. • Low abundance of existing predators and prevention of the establishment of new, invasive predators including nonnative fish and insect species.

ROTA LAND COVER, GEOLOGY, AND HYDROLOGY

Island of Rota

Lying at 14°09'N, 145°13'E and located approximately 36 miles (mi) (58 kilometers (km)) northeast of Guam and 47 mi (76 km) southwest of Aguiguan, Rota is the fourth largest island in the Mariana archipelago, measuring 33 mi^2 (96 km^2) (Mueller-Dombois and Fosberg 1998, p. 265; CNMI Statewide Assessment and Resource Strategy Council (CNMI-SWARS) 2010, p. 6). The island measures 32.97 mi^2 (85.4 km^2) in land area, and the highest point on the island is Mount Manira at 1,611 feet (ft) (491 meters (m)) in elevation. The island is the southernmost within the Commonwealth of the Northern Mariana Islands (CNMI). Based upon the 2010 census, Rota has a population of approximately 2,400 residents.

Rota Vegetation and Forest Cover

Within the Mariana Archipelago, Rota is among the most forested, and notably possesses both the highest percentage, (47% or 10,052 ac (4,068 ha)) of native forest cover relative to its size (**Figure 4**) (Amidon and Reeves 2019). As defined by Amidon and Reeves (2019), Rota's surface includes ten very different land cover classifications as summarized in **Table 3**. In all, approximately, six percent of the island has been developed for human use including urban and agricultural areas.

Table 3. Approximate percentage of land cover on Rota in descending order.

Land Cover	Acreage	Percent of Rota
native forest	10,052	47
scrub	5,903	28
secondary-mixed forest	2,096	10
developed lands	1,181	6
monoculture forest	735	3
barren	399	2
coastal	373	2
Leucaena (tangantangan) forest	229	1
savanna	225	1
wetland	9	<1

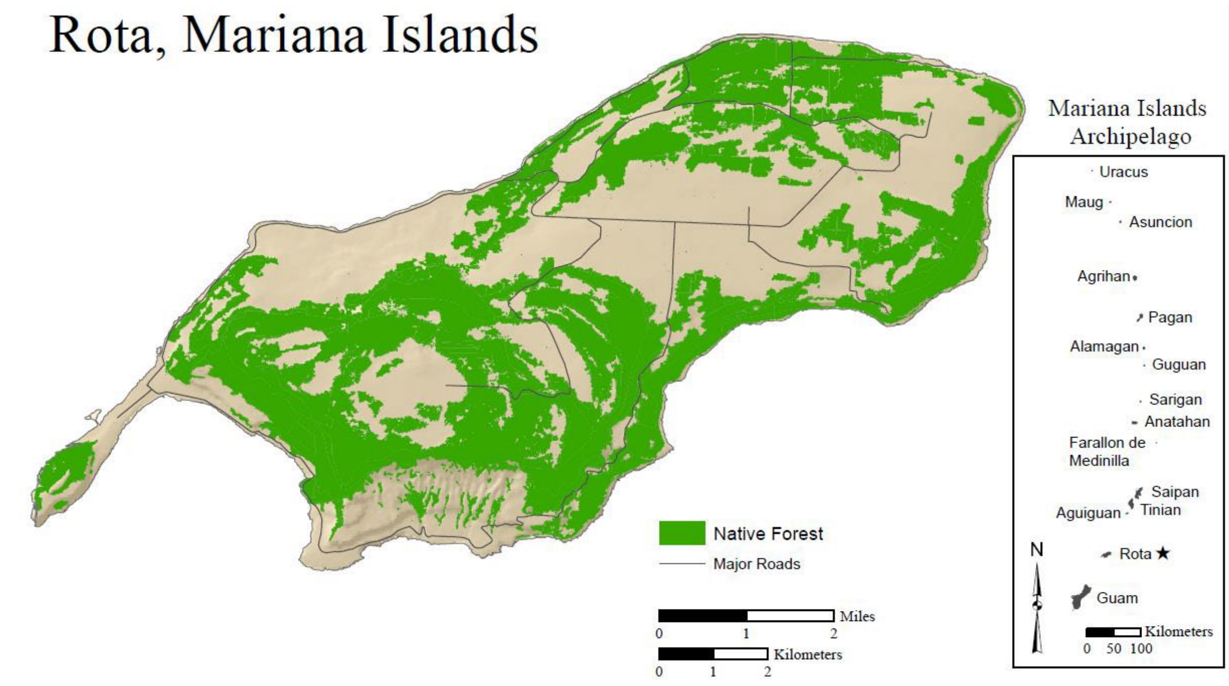

Figure 4. Map of Rota indicating the location of native forest remaining on the island

Rota Geology

Rota's complex geological composition includes plateaus of ancient limestone seabed pushed up with the tectonic plate, volcanic intrusions, and more recently, coral limestone formations (Ohba 1994, p. 14; Mueller-Dombois and Fosberg 1998, p. 241; Carruth 2003, p. 3; Gingerich 2003, p. 1; Taborosi 2004, pp. 8-13; Berger et al. 2005, p. 9). The island resembles a wedding cake-like assemblage of limestone terraces separated by dramatically vertical cliffs and surrounding a volcanic core that protrudes from its topmost, irregular plateau, known as the Sabana Plateau. Approximately ten percent of the surface geology of Rota is volcanic rock and soils, largely located in the southern Talakhaya region and one peak on the Sabana Plateau (**Figure 5**) (Carruth 2005, p. 4).

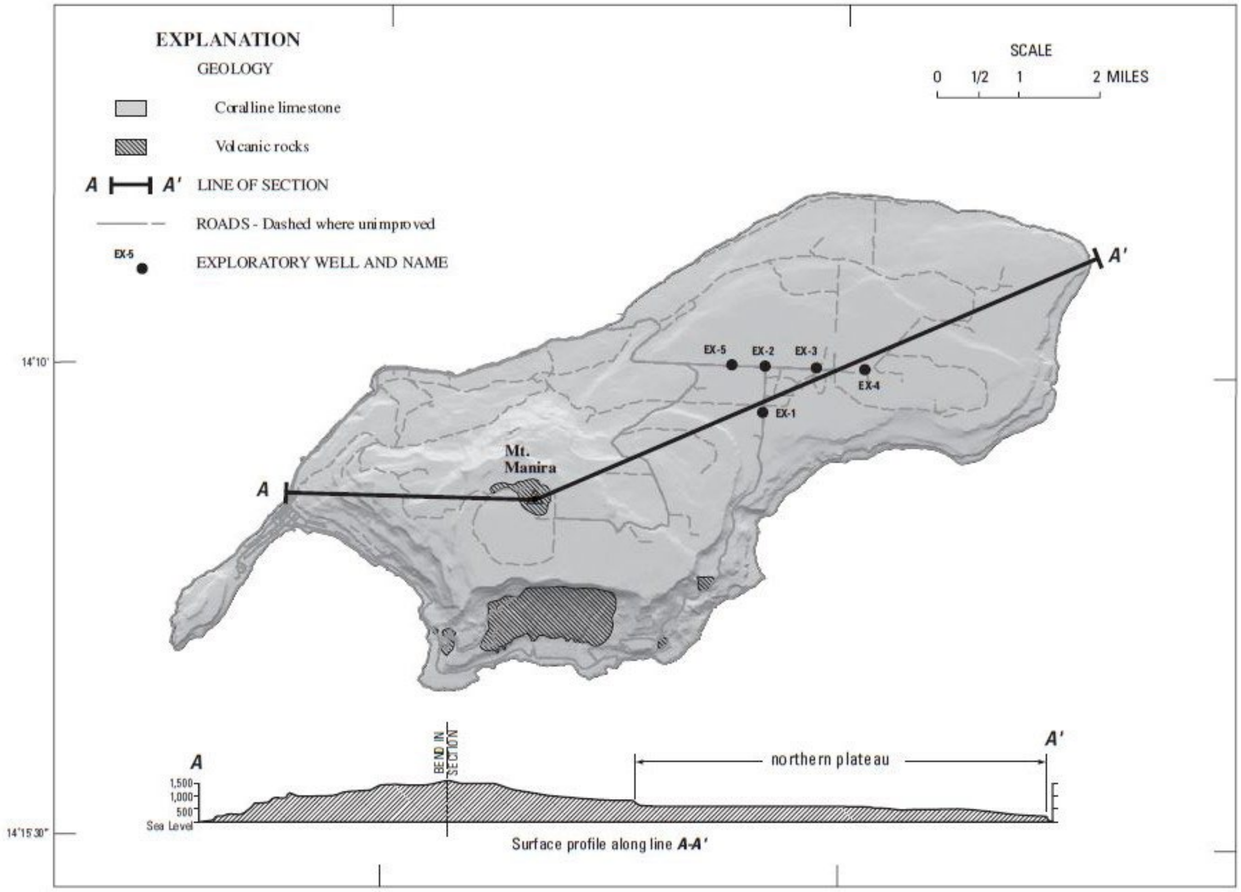

Figure 5. Generalized surface geology map of Rota highlighting the abundance of limestone substrate on the island and restriction of volcanic soils to the southern region of Talakhaya (from Carruth 2005, p. 5)

Rota Hydrology

Ultimately, seasonally variable rainfall is the source of all surface waters, which exists as a handful of seasonal streams and a single perennial stream on Rota. Due to the monsoon season in the western Pacific, the island's wet season occurs between July and October, while the dry season occurs between November and June. April is typically the driest month of the year (Ohba 1994, p. 16; Mueller-Dombois and Fosberg 1998, p. 241). With no permanent, long-term rainfall gauging records on the island, scientific understanding of Rota's hydrology is incomplete. However, approximate annual precipitation is likely about 96 inches (in) (218 centimeters (cm)) per year, similar to the nearest comparable islands, Guam and Saipan. Additionally and based on rainfall data from neighboring islands, approximately 70 percent of Rota's rainfall occurs during the wet season with significant variation from year to year (Keel et al. 2007, p. 6). According to the same data, drought conditions during a given dry year occurs evenly distributed throughout that year, resulting in drier wet seasons and drier dry seasons (Keel et al. 2007, p. 6). Historically, drought years on Rota, have typically followed a year with an El Nino Southern Oscillation (ENSO) event (Pacific ENSO Applications Climate Center in litt. 2019; Miller 2019).

Similar to its neighboring southern islands, Rota captures a high volume of rainwater due to its predominately limestone composition (Ward et al. 1965, p. H5; Carruth 2005, p. 4; Keel et al. 2005, p 15; Keel et al. 2007, p. 3). The permeable limestone that comprises approximately 90 percent of the island above sea level (Carruth 2005, p. 4), allows rain to percolate quickly into the ground instead of flowing on the surface (Taborosi 2004, p. 15) or being lost to evapotranspiration. Driven by gravity, the water moves underground through air-filled fractures, voids, and conduits to join a freshwater lens that ‘floats’ within the island above rock saturated with denser seawater (Taborosi 2004, p. 15). An unknown amount of freshwater exits the lens at the interchange between seawater, typically at the shoreline in the form of seeps and springs. However, freshwater also exits the lens, often well above sea level in areas where the water-saturated and permeable limestone contacts impermeable volcanic soils and rock.

Sabana Plateau and Talakhaya

Measuring approximately 1,300 ft (400 m) in height and 2,470 ac (1,000 ha) in area, the Sabana Plateau dominates the western side of the island and includes its highest point, Mount Sabana or Mount Manira at 1,611 ft (491 m) and (Mueller-Dombois and Fosberg 1998, p. 265). Largely comprised of limestone with some older volcanic outcrops (**Figure 5**), the plateau contains numerous caverns and is very porous in general (Keel et al. 2005, p. 15; Keel et al. 2007, p. 6; Polhemus and Richardson 2020, p. 19). While the east, north and west sides of the Sabana Plateau gradually drop off in a series of natural terraces, the southern slopes of the plateau are particularly steep, with vertical cliffs dropping precipitously to an area known at the Talakaya (Keel et al. 2007, p. 3).

Land cover on the Sabana plateau includes scrub-like grasslands intermixed with ferns and trees (30%), barren areas (1%), ringed by forest (69%) that extends onto the surrounding karst limestone cliffs and the rugged slopes that encircle all sides the plateau (Mueller-Dombois and Fosberg 1998, pp. 265–266; Keel et al. 2007, p. 10; Amidon and Reeves 2019). Although the area lacks a rain gauge, the top of the plateau appears to receive more precipitation and cloud cover than the rest of the island, an observation supported by data from the island of Saipan (Lander 2004 as cited by Keel et al. 2007, p. 7). It is also the only location known to support certain plant species including several federally listed orchids as well as other plants (Harrington et al. in litt. 2012, pp. 18-19; USFWS 2015, p. 59,437; Harrington et al. 2019, p. 9).

Similar to other areas with comparable geology, including southern Guam and portions of Saipan, the Sabana Plateau captures a proportion of annual rainfall subsurface as perched groundwater several hundred feet above sea level (Gingerich 2003, p. 1). This groundwater emerges at the contact between the overlying limestone and the underlying basalt substrates, forming numerous perennial and seasonal seeps and springs in the Talakhaya region. These seeps and springs occur along the interface between the two rock types, which stretches across the top of the Talakhaya for approximately 2.4 mi (3.9 km) (Keel et al. 2007, p. 3). Like springs in southern Guam, the springs in the Talakhaya exhibit a direct response to rainfall deficits. For example, the two largest springs on the island, Sonson Water Cave (Matan Hanum) and As Onan, together the major municipal water sources for Rota (see further discussion below), release reduced flow volumes from April through June, particularly during drought years (Carruth 2005, p. 1).

Comprised of older, weathered, and relatively impermeable volcanic substrates, the steep topography of the Talakaya (**Figure 9**) contains several streams, including one perennial, fed by the aforementioned springs (Keel et al. 2007, p. 3). The Talakhaya is the only portion of Rota capable of supporting streams due to the combination of its volcanic soils, topography, and reliable recharge source provided by the Sabana Platea (Polhemus et al. 2000, p. 8). Comprising less than 10 percent of island's surface area, the region measures approximately 1,370 ac (550 ha) in size and contains approximately five larger stream channels and several additional discernable tributary channels. Land cover within the Talakhaya area includes native and mixed forest (54%), grasslands and scrub (41%), and barren hardpan areas (5%) (Amidon and Reeves 2019).

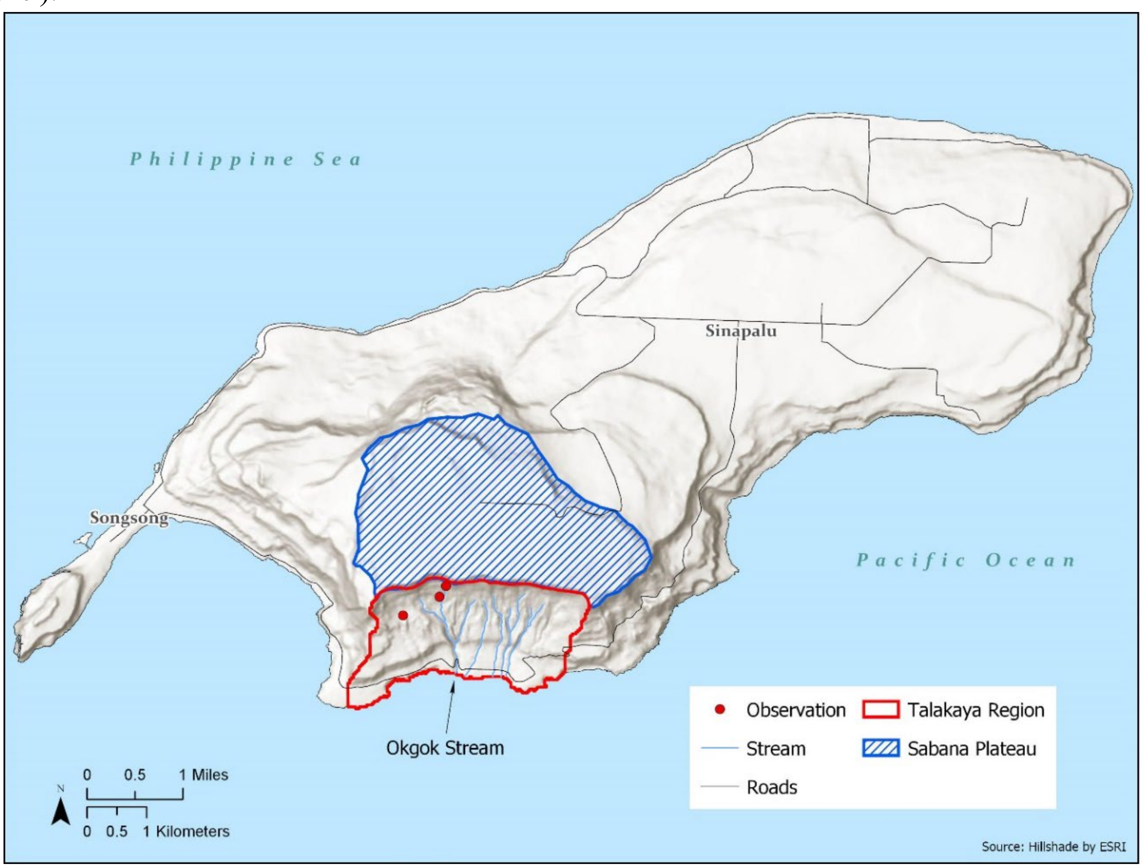

Figure 6. Topographical hill-shade map of Rota illustrating the broad, flat terrain, well suited to capture rainfall and showing the confinement of stream channels to the southern Talakhaya region. Only the Okgok Stream is perennial with all the other channels shown supporting only intermittent

flow during the wet season or after heavy rains. The three known observations of the Rota blue damselfly are also indicated (see further discussion below).

Beginning in 2003, the USGS began hydrological studies on Rota as part of a larger effort to project for future water supply on the island (Carruth 2003; Keel et al. 2005; Keel et al. 2007). While investigating the relationship between the Sabana Plateau and the Talakhaya springs, researchers determined that the majority of the rainfall captured on the plateau discharges at the springs, and is therefore, the source for the region's streams (Keel et al. 2007, p. ii, 8, 23). Although lacking a rainfall gauge on the plateau at the time of the study, and thus, a true water budget to measure the relationship, the USGS report based its hypothesis upon an assortment of hydrological evidence. The study documented hydrological recharge on the plateau (i.e., short streams on the volcanic outcrop that drain into the limestone substrate), lack of evidence of surface discharge from any Sabana Plateau perimeter locations, and absence of surface runoff during storms on the plateau summit. Also part of the analysis were estimated rates of water discharge from the two largest Talakhaya springs (Keel et al. 2007, pp. 19, 23). Based upon an estimated daily discharge of between 700,000 and one million gallons (2.7 to 3.8 million liters), Keel et al. (2007, pp. 19, 23) hypothesized that Sonson Water Cave's recharge area on the Sabana Plateau is approximately 1,088 ac (544 ha) in size or about 45 percent of the plateau area (**Figure 6** and **Figure 7**).

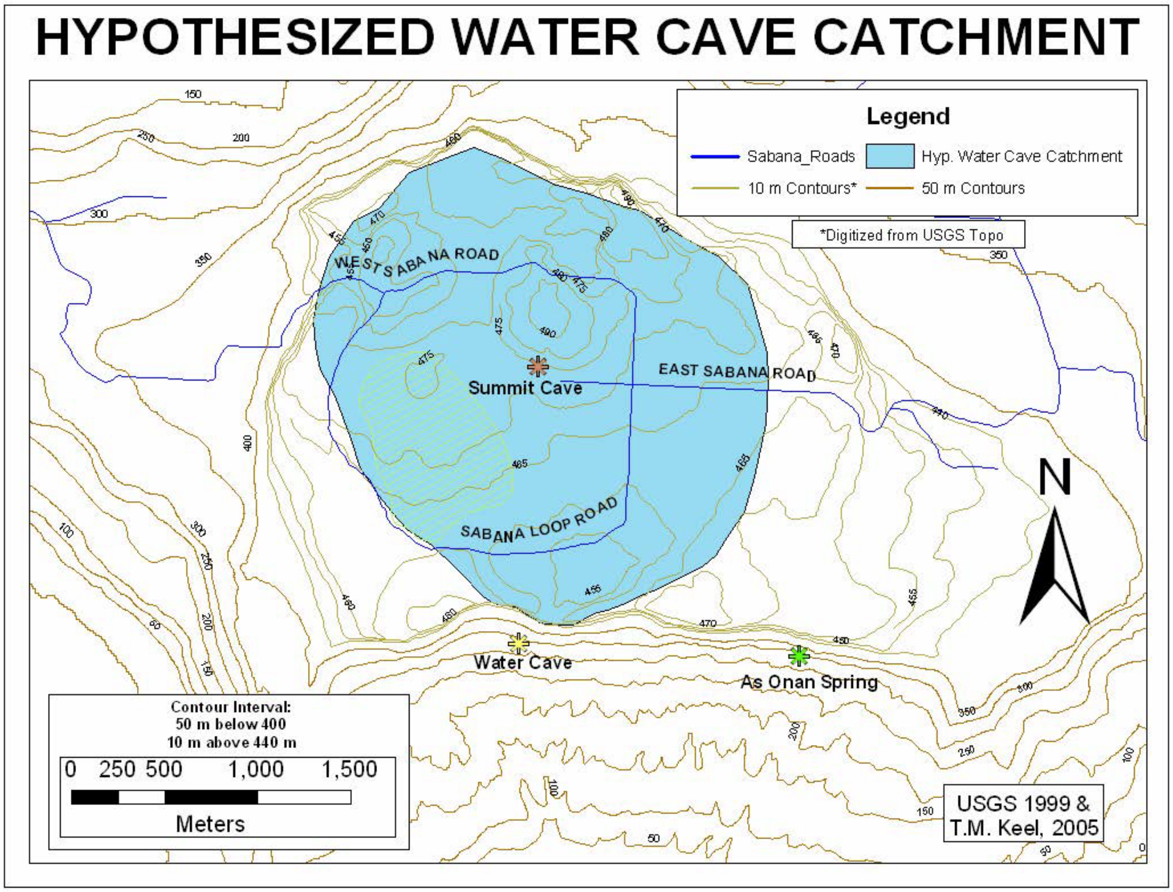

Figure 7. Map of the hypothesized Sonson Water Cave recharge area on the Sabana Plateau (from Keel et al. 2007, p. 24)

Historical and Current Habitat and Distribution

The Rota blue damselfly was only first documented in the scientific literature in the year 2000 based upon specimens observed and collected in 1996 (Polhemus et al. 2000, entire), and only observed twice since its discovery. Consequently, we know very little about the species' historical habitat and distribution. According to Polhemus et al. (2000, p. 8) and Polhemus and Richardson (2020, p. 21), the species is not recorded from any other islands in the archipelago, including Guam, located 40 mi (64 km) to the south, nor Saipan, located 79 mi (127 km) to the north. Despite the fact that narrow-winged damselflies are considered feeble fliers among the Odonata (Triplehorn and Johnson 2005, p. 205), this fact remains perplexing given the great abundance of streams, rivers, and springs in southern Guam (Polhemus et al. 2000, p. 8).

Historical Range and Distribution

Other than three informal visits to Okgok Stream that resulted in circumstantial observations of the Rota blue damselfly, we are aware of few other surveys on Rota for aquatic insects, formal or informal. While it is also possible that researchers visiting the island have to-date failed to observe either naiads or adults at a few other potential sites including human-made ponds and pools, the species' historical and current habitat range and entire distribution appear limited to the Talakhaya if not to Okgok Stream alone (**Figure 5**). However, the presence of several dry and intermittently dry stream channels located to the east of Okgok Stream (**Figure 6** and **Figure 9**), also presents the possibility that the Rota blue damselfly once inhabited a larger distribution that included all of the Talakhaya – assuming that presence of the channels indicates that the streams were once more perennial in nature. It is also possible that the species seasonally inhabits some or all of the numerous Talakhaya springs when they are flowing with water, and during drier months, retreats to perennial water in and around the Okgok Stream. Without additional surveys of the springs and all of the stream channels, it is not possible to know the full extent of the Rota blue damselfly's distribution in the Talakhaya.

Recorded Observations of the Rota blue damselfly

U.S. Fish and Wildlife Service biologists first discovered the Rota blue damselfly in April 1996 during a brief and incomplete survey of Okgok Stream. Biologists observed a few individuals and collected one male and one female specimen outside the Sonson Water Cave located below the Sabana plateau (Polhemus et al. 2000, pp. 1–8). Biologists estimated the size of the population at the time of discovery as "small" and limited to the stream area near the mouth of the cave. During a subsequent and more thorough survey of Okgok Stream later in the same year, (see below, "Current Habitat and Distribution – Okgok Stream"), Camacho et al. (1997, entire), examined the entire length of the river from the cave to the ocean, but did not record observations of insects in their report, perhaps due to a stated focus on fish and macroinvertebrates.

Eighteen years elapsed between the original discovery of the species in 1996 and the next known survey specifically for the Rota blue damselfly in January 2014. During a brief reconnaissance conducted to confirm the status of the species and its habitat, USFWS biologists observed two male specimens flying above a portion of the stream that overran the Sonson Water Cave access road at approximately 770 ft (235 m) in elevation (Richardson in litt. 2014). Weather conditions were not ideal during this survey date, with intermittent rain possibly reducing the number of foraging adults observed (Richardson in litt. 2014). Unlike the 1996 survey of Okgok Stream, biologists did not observe damselflies near or below the water cave entrance. However, surveys of the cave vicinity occurred very late in the day when damselflies typically begin to seek refuge for the night (Polhemus and Asquith 1996, p. 7). This portion of the stream was absent of fish as well (Richardson in litt. 2014), notable because of the susceptibility of naiads of many Pacific damselfly species that succumb to predation by nonnative fish species (see "Predation by nonnative fish").

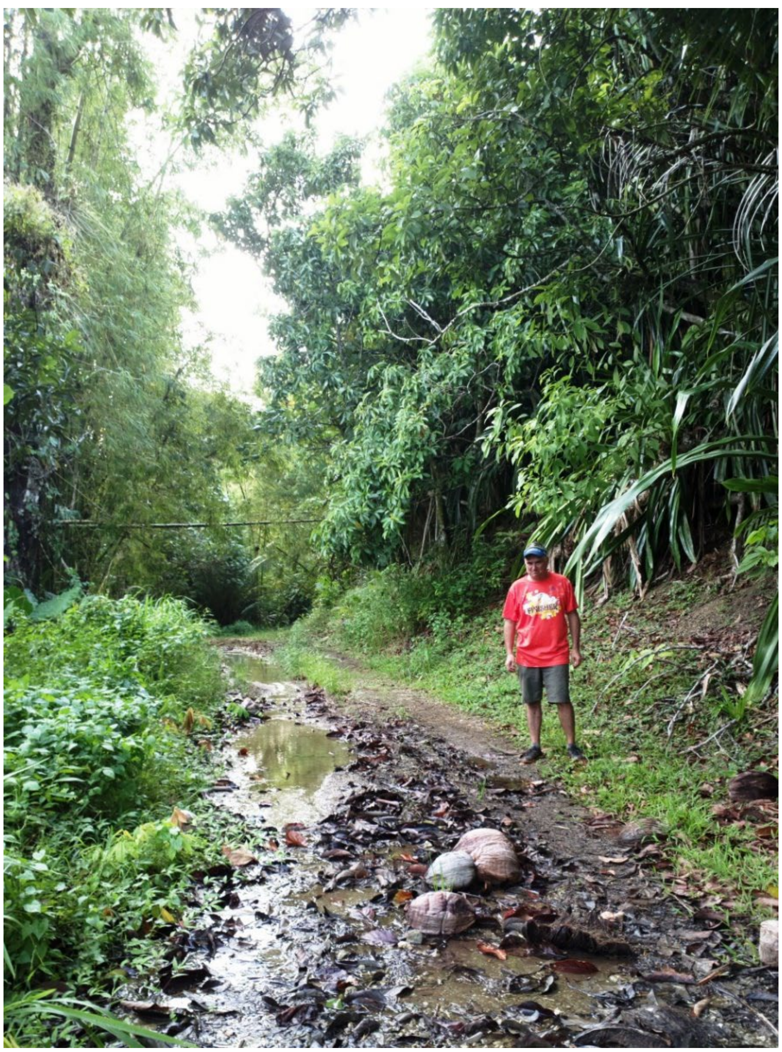

Figure 8. January 2014 photograph of the area where USFWS biologists observed adult Rota blue damselflies flying over a streamlet overflowing the Sonson Water Cave access road. (Photo by Mike Richardson)

Subsequently in November 2015, biologists with the CNMI Division of Forestry and Wildlife conducted a brief follow-up survey of Okgok Stream in an attempt to gauge distribution of the species (Zarones et al.in litt. 2015). Similar to the 2014 survey biologists located the species, one individual this case, in a small rivulet of water running down the Sonson Water Cave access road. According to the report, this observation occurred 2,230 ft (680 m) to the southwest of Sonson Water Cave area, and the survey team indicated that the water source did not connect to the stream from Sonson Water Cave. Zarones et al. (in litt. 2015) suggested this observation may represent an expanded distribution for the species, but concluded that additional surveys were necessary to determine the Rota blue damselfly's true distribution.

Table 4. Documented observations of the Rota blue damselfly and surveys of freshwater systems on Rota

Year / Month	Areas Surveyed	Recorded Observations	Source
1969	Sonson Water Cave vicinity and unspecified portions of Okgok Stream	No indication of damselflies recorded in the literature	Eldredge 1969
1989	coastal portion of Talakhaya Region	No indication of damselflies recorded in the literature	Smith et al. 1989
1996 (April)	Sonson Water Cave vicinity and unspecified portions of Okgok Stream	Several Rota blue damselflies were observed outside the cave	Polhemus et al. 2000
1996 (August)	Okgok Stream lower and middle reaches (below 130 m)	No indication of damselflies recorded in the literature	Camacho et al. 1997
1996 (September)	Sonson Water Cave and Western (Lupok) Tributary of Okgok Stream	No indication of damselflies recorded in the literature	Camacho et al. 1997
2014 (January)	Okgok Stream at about 700 ft to 800 ft elevation and vicinity outside Sonson Water Cave	Two damselflies observed at 771 ft (235 m; no damselflies recorded near the Sonson Water Cave	Richardson in litt. 2014
2015 (November)	Portions of Okgok Stream and vicinity	One damselfly observed at a new location SW of the Sonson Water Cave	Zarones et al. in litt. 2015

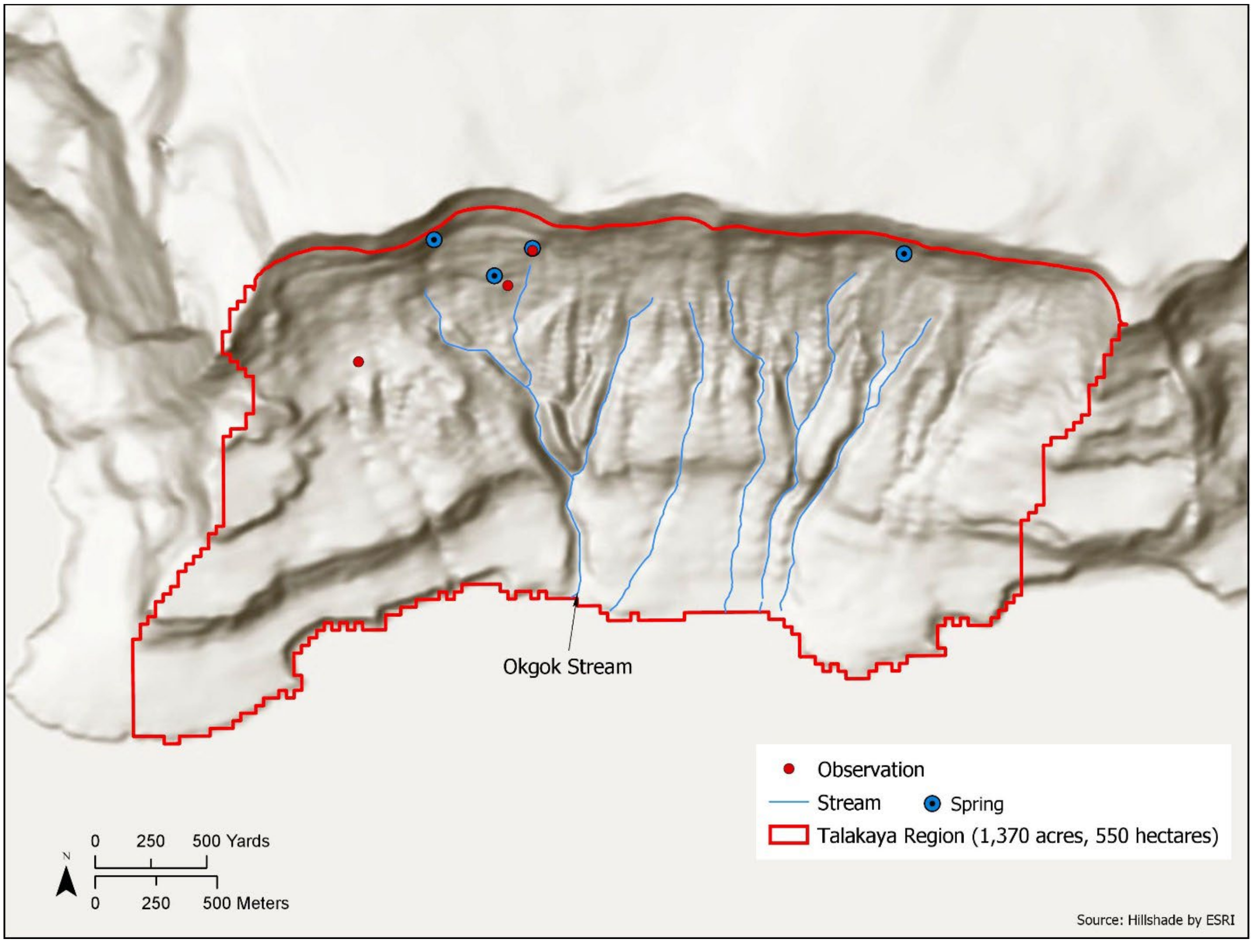

Figure 9. Topographical hill-shade map of the Talakhaya detailing location of the main springs, observations of the damselfly, and the location of Okgok Stream, and several intermittent streams in the eastern portion of the region. The apparent depth and relief of numerous stream channels to the east of Okgok Stream suggest that they may have been more consistently perennial in the past.

Current Habitat and Distribution – Okgok Stream

Based upon the available information, the Rota blue damselfly appears to be restricted to some still underdetermined portion of Okgok Stream (Polhemus and Richardson 2020), and as noted above, the species possibly takes advantage of other seasonally available habitat within the Talakhaya. According to the available literature and as noted above, (Camacho et al. 1997, entire; Carruth 2005, entire; Keel et al. 2007, entire; Golabi et al. 2018, p. 198), stream flow is intermittent in most of the streams in Talakhaya region, and occurs primarily during periods of heavy rainfall. The one exception is the Okgok Stream system, which drains approximately 40 percent of the Talakaya (**Figure 9**) (Camacho et al. 1997). p. 3). Approximately 0.87 mi (1.4 km) in length, Okgok Stream originates at the largest of the Talakhaya springs known as the Sonson Water Cave (**Figure 10** and **Figure 13**), located at approximately 1,138 ft (350 m) elevation. The vegetation along the headwater and midreach of Okgok Stream consists primarily mixed and native ravine native forest (Camacho et al. 1997, p. 8; U.S. Forest Service in litt. 2014), which provides dense canopy cover and shading for the majority of the stream's main channels. The less steep, terminal reach has riparian vegetation consisting largely of cultivars such as banana (*Musa* spp.), breadfruit (*Artocarpus altilis*), bamboo (*Bambusa* spp.), and coconut (*Cocos nucifera*) (Camacho et al. 1997, p. 8).

Figure 10. January 2014 photograph taken outside Sonson Water Cave showing the exterior of the catchment system and the excess water released into Okgok Stream during times of sufficient discharge from the cave. (Photo by Mike Richardson).

The most comprehensive biological study of Okgok Stream to date remains the work of Camacho et al. (1997, entire), funded by the U.S. Fish and Wildlife Service. This study characterized the aquatic macrofauna of the perennial Okgok Stream as well as the several other intermittent streams found within the Talakaya region. The study also assessed other biotic factors including substrate, surrounding vegetation, and mean canopy cover, the latter of which was reported to be among the highest recorded among any Micronesia streams surveyed by the authors (Camacho et al. 1997, pp. 5, 9, 12). The investigators also reported on the presence and distribution of four native fish species occurring in different portions of the stream as well as three native species of shrimp (Camacho et al. 1997, p. 9). The surveys did not assess the aquatic insect biota of Okgok Stream, and thus, the stream and Rota's aquatic insect fauna remains poorly studied.

Besides the Rota blue damselfly, researchers have observed one additional damselfly species on Rota and within the Talakhaya, the cosmo-tropical *Ischnura aurora* (Zarones et al. in litt. 2015). This species is also capable of breeding in ponds and wetlands, unlike the Rota blue damselfly, which appears to be an obligate stream-breeder (Polhemus and Richardson 2020, p. 21). At this time, it is unknown if *I. aurora* is a competitor of the Rota blue damselfly. Researchers believe other species of aquatic insects are undoubtedly present on Rota as well, but further survey work is necessary to confirm (Polhemus and Richardson 2020, p. 21).

According to Camacho et al. (1997 pp. 9-12) the stream contains a large waterfall located at an elevation of 131 ft (40 m), above which only two native gobies were detected and below which, other more aggressive native fish species occurred. When Fish and Wildlife Service biologists discovered the Rota blue damselfly in 1996, they observed the species just outside the Sonson Water Cave located at 1,148 ft (350 m). The adults have also been observed below and far to the southwest of the cave, on stream-overrun portions of the access road. Presumably, therefore the Rota blue damselfly may inhabit the entire stream length from the cave entrance to the lowest, large waterfall, but likely not below in the lower section of the stream.

Based upon observations of the adults on temporal-riparian habitat on roads near the water cave (Richardson in litt. 2014; Zarones et al. in litt. 2015), the species also appears to use surrounding habitat during sufficient spring seepage in the Talakhaya. Nevertheless, as our State partner has identified (Zarones et al. in litt. 2015) and as this species report acknowledges, much remains unknown about this species' habitat distribution and needs. These data gaps include, but not limited to (1) larval stage life history and foraging habitat requirements; (2) exact extent of Okgok Stream inhabited; (3) seasonal variation in habitat; and (4) definitively, whether any of the perennial seeps or seasonal streams in the Talakhaya support the species as well.

Figure 11. Topographical map of the Talakhaya detailing observations of the Rota blue damselfly in relation to several of the springs and regional names within the area.

Factors Affecting Viability

This section describes the various factors that may be affecting the viability of the (current) Rota blue damselfly population and that may have led to any (unverifiable) historical range decline. This assessment identifies loss and alteration of habitat as the stressors of most importance to the viability of damselfly. In particular, future increases in development of water resources in the Talakhaya for municipal use and loss and alteration of forested habitat on the Sabana Plateau and in the Talakhaya are plausible, relevant, and of serious potential concern. We address the history and present level of these habitat stressors in the section below, followed by a brief discussion of potential direct stressors to the species including predation by nonnative fish and insects. **Table 5** below summarizes the habitat and direct stressors to the Rota blue damselfly including documented stressors and potential, but undocumented stressors.

Table 5. Summary of possible and documented stressors to the Rota blue damselfly and its habitat.

Stressor	Possible Effects	Documented Impacts
Habitat Stressors		
water extraction (as a result of development / urbanization)	Stream dewatering during dry season and stream reduction during wet season	Very little perennial stream habitat remains in the Talakhaya, the only part of Rota geologically capable of supporting streams
Forest herbivores: (deer, and to a lesser extent, cattle)	Erosion & trampling may reduce stream water quality; Forest alteration and facilitated spread of nonnative plants	The Talakhaya includes large areas of eroded grasslands and badlands with very little canopy cover along portions of the former stream channels; Forest along stream channels in the Talakhaya experiences soil disturbance and forest alteration including reduced canopy cover; Alteration of Sabana Plateau forest by ungulate activity - may reduce water input into the aquifer feeding the Talakhaya streams
Nonnative plants	Forest alteration and exacerbation of fire regime on Rota	Much of the Talakhaya Region largely now eroded grasslands with very little canopy cover along most of the former stream channels; Alteration of forest along stream channels in the Talakhaya Region including reduced canopy cover; Alteration of Sabana Plateau forest by nonnative plants - may reduce water input into the aquifer feeding the Talakhaya region streams
Fire	Forest alteration and exacerbation of fire regime on Rota	Much of the Talakhaya Region is now grasslands or denuded and suffers from frequent fires and erosion, and very little canopy cover remains along most of the former stream channels
Activities associated with hunting	Carefully implemented hunting programs could actually reduce the deer population	Hunters frequent start fires in the Talakhaya Region to 'flush' deer, leading to impacts (see fire above)
Typhoons	Forest alteration including reduced canopy cover and facilitated spread of nonnative plants	Effects documented for impacts to forest habitat on the Sabana Plateau, but not specifically documented to affect the Rota blue damselfly
Potential Direct Stressors		
Predation by nonnative fish	Reduced abundance Exclusion from otherwise suitable habitat; Reduced fitness as a result of altered behavior	Impacts not documented to affect the Rota blue damselfly, although native flagtails likely exclude use of the lower Okgok Stream reach below the lower waterfall
Predation by nonnative insects	Reduced abundance as a result of reduced fitness and loss of individuals	No evidence. Impacts not documented to affect the Rota blue damselfly
Competition with nonnative insects	Reduced fitness as a result of altered behavior	No evidence. Impacts not documented to affect the Rota blue damselfly
Disease	Reduced abundance as a result of reduced fitness and loss of individuals	No evidence. Impacts not documented to affect the Rota blue damselfly

Habitat Stressors - Habitat Loss and Degradation

Many different stressors have historically affected forest habitat within the Mariana Islands, including development, wildfire, nonnative feral ungulates, nonnative plants, and climatic events such as typhoons (USFWS 2015; Willsey et al. 2019). Many of these same stressors continue to affect the native forest habitat necessary for the Rota blue damselfly. Some stressors, including nonnative plants, alter and degrade native forests slowly and incrementally, while development for example, completely removes forest habitat.

Alteration of Forest and Stream Habitat on Rota - Overview

Before the arrival of the original Chamorro settlers approximately 4,000 years ago, forest likely covered much of Rota, excluding natural savanna areas (Mueller-Dombois and Fosberg 1998, p. 268). Although approximately 62 percent of the island remains forested with 47 percent native forest, Rota's natural environments have experienced significant alteration over time due to human activities including the introduction of nonnative species. Larger scale agriculture including rice production and other human impacts on the island began during the 400-year Spanish colonization beginning in the 1500s. Impacts to island and its habitats peaked during the Japanese colonization of the Mariana Islands from 1914−1944. On Rota, the Japanese cleared large areas of forest to plant sugarcane plantations, mined large amounts of phosphate on the Sabana Plateau, and began alteration of the island's limited hydrology (Stephenson and Moore 1980, p. 60; Amidon 2000, pp. 4−5; Engbring 1986, pp. 10, 27). Although never invaded during World War II, U.S. military forces heavily bombed Japanese infrastructure on the island (Engbring et al. 1986, pp. 8, 11). More recently, impacts to Rota's forest and stream habitat continue due to agriculture on the Sabana Plateau, water extraction from the Talakhaya springs, hunting practices including arson, and periodic development for tourism.

Among all possible indirect (habitat) and direct (predation) stressors to the species, we identify the loss and alteration of stream habitat and loss and degradation of forest habitat upon the Sabana Plateau and in the Talakhaya Region as the threats of greatest concern to the Rota blue damselfly. The remote and relatively inaccessible location of the Rota blue damselfly population within the Talakhaya watershed affords the species some protection from human impacts. However, a reduction or removal of stream flow in particular, due to increased interception for municipal usage or reduced aquifer recharge on the Sabana, and possibly in conjunction with the effects of climate change, could directly eliminate or reduce the amount of aquatic habitat available to the species.

Historical water development on Rota and alteration of the Talakhaya

A 1977-1980 effort by the USGS (Stephenson and Moore 1980, entire) provides the most comprehensive review and investigation of historical water use and development on Rota. Through literature review, field surveys, and extensive interviewing of the Rota population, their findings produced a detailed report illustrating water use on the island from the early Chamorro history through present day use (in the 1970s). According to the report, development of water resources in the Talakhaya began only after the arrival of the Japanese and their colonization of the island in 1915.

Based upon available archaeological evidence, the Chamorro did not settle villages near the Okgok Stream or even along the coast below the Talakhaya (Stephenson and Moore 1980, p. 27; NPS 2005, p. 61). With reliable springs in the foothills and even along the shoreline, where freshwater still bubbles out of the sand presently, the Chamorro apparently selected village sites for reasons other than proximity to the Talakhaya streams. The first recorded description of water use on Rota occurred after French explorer, Freycinet visited the island around 1811 during which his historian noted that the people of Songsong used partially brackish wells located in the village (Stephenson and Moore 1980, pp. 32-33). During the same account, Freycinet's historian noted that the Chamorro avoided use of "a stream" located east of the village due to difficult access. Near exclusive use of wells and springs continued through the 1800s and the brief German colonization of Rota between 1899 and 1915.

After WWI, Japan took possession of the Mariana Islands in 1915 and rapidly endeavored with the construction of infrastructure and sugarcane plantations on Rota. In approximately 1935, the Japanese constructed a water collection system that included catchments in both Sonson Water Cave and As Onan Cave in addition to gravity-fed piping to deliver the water and an access road to maintain the systems. The pipes from Sonson Water Cave delivered water to the village of Songsong, while a different pipe system delivered water from As Onan to the village of Sinapalu (Stephenson and Moore 1980, pp. 32-33). Songsong was the main population center at the time, and near Sinapalu, the Japanese had constructed an airport and various support structures. Water piped to Sinapalu also supplied the large surrounding areas under sugarcane cultivation (**Figure 12**). At a later unknown date, the US government upgraded and replaced both catchment systems to deliver water from the two caves. The upgraded systems at each cave included enhanced-efficiency ponding catchments built with newer materials, resulting in less water entering the respective stream systems.

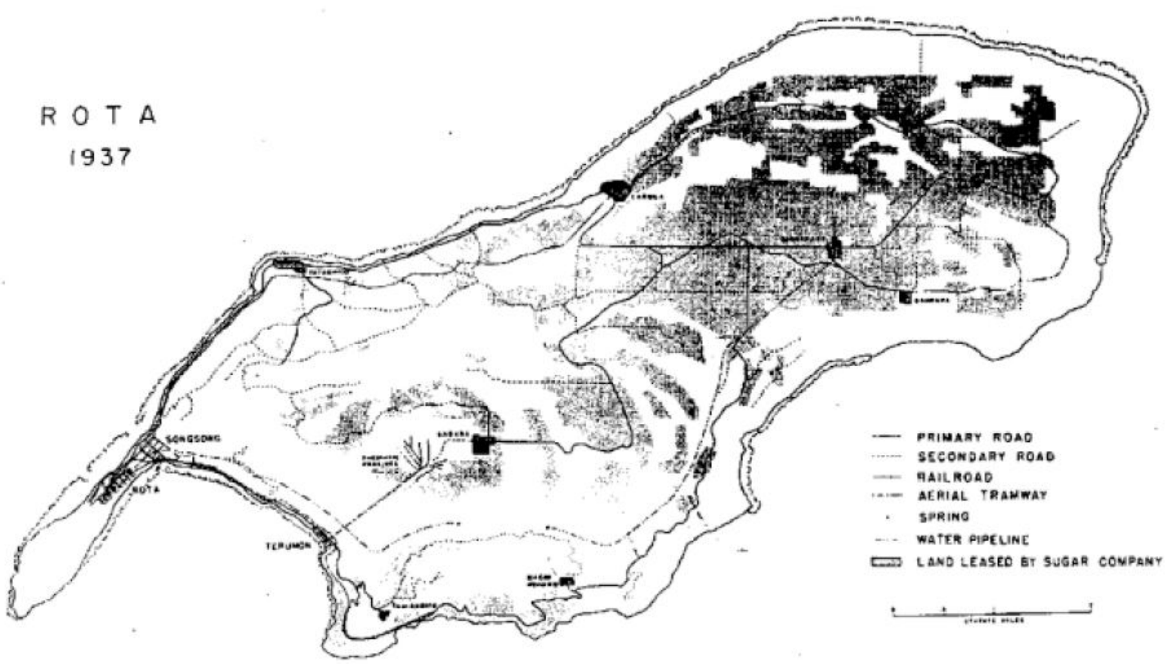

Figure 12. Map of Rota showing the extent of areas under Japanese sugarcane production in 1937 as well as the location of pipes from the Talakhaya springs and the aerial tramway from the Sabana Plateau phosphate mining operation. (From Bowers 1950)

Current water extraction and use on Rota

Rota is the only island in the archipelago that does not obtain the majority of its water from groundwater wells. The two largest Talakaya springs, Sonson Water Cave and As Onan Cave, continue to serve as the primary municipal water source for Rota as they have since the Japanese installed catchments in 1935 (Polhemus et al. 2000, p. 8; Berger et al. 2005, p. 347; and Keel et al. 2007, p. 3; Richardson in litt. 2014). The current concrete collection structure and associated piping erected into the entrance of Sonson Water Cave (**Figure 10** and **Figure 13**) delivers an estimated 2.7 to 3.8 million liters-per-day of water (1.8 Mgal/day) to Rota's municipal system, the majority to Songsong Village and a smaller amount to Sinapalu Village (Keel et al. 2007, p. 19). The USGS estimated that the present day catchment system located at As Onan Cave captures and delivers to Sinapalu Village roughly half the amount captured from Sonson Water Cave (Keel et al. 2007, p. 22).

Presently during normal weather years, water captured from these two springs exceeds demand of the relatively small Rota population. For example in the Village of Songsong, excess water is often visible spilling and streaming down the sides of the large holding tank erected to store the water (Keel et al. 2007, p. 6). However as noted previously, water discharge from all spring systems in the Mariana Islands can dramatically vary between the dry and wet seasons. Studies of the Sonson Water Cave in the early 1990s demonstrated the discharge amounts to vary between 5.4 Mgal/day in the wet season and .54 Mgal/day during the dry season (USDA SCS 1994 as cited in Golabi et al. 2018, p. 194). Keel et al. (2007, p. 6), noted that during periodic drought years water discharge is further reduced from these springs.

Following a strong ENSO event in 1997, Rota experienced a significant drought year in 1998 that reduced discharge from the springs during the dry season to the point that officials implemented water rationing on the island for several months (Carruth 2005, p. 1). In 1999 due to the 1998 drought, the USGS drilled five exploratory groundwater wells in the Sinapalu region of Rota to test the possibility of tapping into the underlying aquifer. Hydrological testing resulted in excessive drawdown results at two of the wells, but three wells produced satisfactory aquifer recovery results and were put into production to supplement the municipal water supply (Carruth 2005, p. 1). Meanwhile, water extraction continues at the same level at both Sonson Water Cave and As Onan, and researchers have suggested that under conditions similar to the 1998 drought, dewatering of the Okgok Stream is entirely plausible without concomitant changes to water use and conservation (Keel et al. 2007, p. 23).

While Berger et al. (2005, p. 346) reported that Rota residents believed water extraction from the spring at As Onan Cave leaves many of the streams in the Talakaya dry most of the year, we lack information to confirm that those stream channels contained more consistent stream flow prior to the construction of the catchment at the spring. Indeed, the literature indicates some disagreement about whether the now intermittent stream channels were once more perennial. Island residents interviewed as part of an ongoing restoration project at Talakhaya (see below, "Conservation Efforts to Reduce Habitat Loss and Degradation on Rota") recalled that many of the streams were once more perennial, while USGS research in the early 1990s suggested that all were mostly intermittent (USDA SCS 1994 as cited in Golabi et al. 2018, p. 194). However, given the large amount of water collected from both springs since 1935, we believe it is safe assume that all of the channels are drier for longer periods of time each year in addition to containing reduced average annual stream flow.

Figure 13. January 2014 photograph of the entrance of Sonson Water Cave showing catchment structures and public access barrier. (Photo by Mike Richardson)

Historical loss and alteration of forest habitat on Rota

As noted above, approximately 62 percent of Rota remains forested, although native forest habitat on the island has declined by approximately 53 percent as a result of human activities including agriculture, development, tourism, hunting practices, and wartime activities prior and during WWII. According to literature, the most significant impacts to Rota's forest occurred during Japanese administration and control of the island from 1915 to 1944 (Bowers 1950, p. 41-45; Stephenson and Moore 1980, pp. 45-60). Of greatest impact, the Japanese developed over 33 percent of the island into sugarcane plantations beginning in 1930 (Bowers 1950, p. 45).

Loss and alteration of forest habitat in the Talakhaya

Specific to habitat of the Rota blue damselfly's forest habitat within the Talakhaya, the systems installed in 1935 by the Japanese to extract water from the two large springs likely contributed to some amount of decline in the forest downstream within the region. More significantly, to make room for the large influx of Japanese for the sugar plantations and for soldiers during the buildup for WWII, the Japanese relocated many Chamorro residents of Rota along what is the present water cave access road. The residents were forced to live on dozens of farms where forest was cleared to plant a variety of crops, many of which are still present to this day (Bowers 1950, p. 56; Camacho et al. 1997, p. 7). According to old maps produced to document lands leased for sugar on the island, it is also possible sugar was grown in part of the Talakhaya as well (**Figure 12**) (Bowers 1950, p. 104).

Prior to these events, the literature indicates that the limited agriculture within the Talakhaya occurred primarily at lower elevations where residents grew rice and a few other crops beginning in the late 1800s (Stephenson and Moore 1980, p. 34). The development of agriculture along the water cave access road was likely the beginning of impacts to forest habitat in the Talakhaya leading to the interrelated present day problems including widespread erosion, cyclical wildfire, and loss of at least 46 percent of the forest habitat within the region. Although their source is not clear, according to the CNMI Bureau of Environmental and Coastal Quality (CNMI-BECQ) (2016, p. 142), the large swaths of barren badlands present on the Talakhaya's steep upper slopes are the result of clear cutting for agriculture purposes by the Japanese. Although the exact date is not clear, Stephenson and Moore (1980, p. 60) reported that the Japanese were sufficiently concerned about erosion in the Talakhaya that they built dikes across several of the channels between Okgok Stream and the stream originating at As Onan spring to control the problem of soil loss. Agricultural activities within the Talakhaya have continued through the present, although the vast majority occurs at lower elevations where the land is relatively flat (**Figure 15** and **Figure 16**). Additionally according to the CNMI-BECQ (2016, p. 142), some new areas residents have cleared some new agricultural plots in an area above the Sonson Water Cave. Current land cover within the Talakhaya consists approximately of forest (54 %) grassland/scrub (41 %), and developed and barren lands (5%) (Amidon and Reeves 2019).

Loss and alteration of forest habitat on the Sabana Plateau

As noted above – historically (and currently), forest habitat on the Sabana Plateau has likely played an important role in facilitating the capture and recharge of water into the perched aquifer that feeds the Talakhaya springs (see above **Figure 7** and discussion regarding recharge area). As with the Talakhaya, the Japanese were the first to implement large changes to the forests on the Sabana Plateau through the construction of numerous roads to and on the plateau and during development of sugarcane and the mining of phosphate (Bowers 1950, pp. 45, 104; Amidon 2000, pp. 4−5; Engbring 1986, pp. 10, 27). While we lack estimates for the total acreage of forest cleared on the plateau for sugarcane, the amount was substantial based on a 1946 aerial photograph of the area (**Figure 15**) and a map depicting sugar-leased lands during the time (Figure 12) (Bowers 1950, p. 104).

Besides sugarcane development, the Japanese initiated an extensive mining operation on the Sabana Plateau sometime between 1930 and 1938 (Russell 2002, p. 52), and between approximately 1938 and 1943, the Japanese mined an annual average of 37,000 tons of phosphate from the plateau (Stephenson and Moore 1980, p. 60). An aerial tramway constructed from the summit down to a plant outside Songsong, allowed transport of the mined phosphate. The relatively large footprint of the mined area is still depicted on the current USGS topographical map for Rota (see above, **Figure 11**). In 2007 USGS researchers mapped the area and estimated its size to exceed 247 ac (100 ha), even larger than shown on USGS maps (Keel et al. 2007, p. 9) (see below, **Figure 14**). However, their study was not able to investigate the effects if any on the ability of the affected portion of the plateau to recharge the underlying aquifer (Keel et al. 2007, p. 10).

While the greatest extent of forest clearing on the Sabana plateau occurred between 1930 and the mid-1940s, many of these areas subsequently regrew forest although much of it not intact native forest (Keel et al. 2007, p. 10; USFWS 2015; Amidon and Reeves 2019). Agricultural activities on different parts of the plateau has continued during the ensuing decades through the present, with the result that area is now a complex matrix of grasslands, croplands, and native and mixed scrub forests (Berger et al. 2005, pp. 35-36). According to the CNMI-DEQ (2015, p. 13), the Sabana Plateau contains some of the more productive and economically important farms on the island, contributing to both commercial and subsidence agricultural. Regarding ongoing agriculture on the plateau, several reports have identified the potential for concomitant use of chemicals and fertilizers to contaminate the water municipal water supply (Keel et al. 2007, p. 23; CNMI-DEQ 2015, p. 26). The potential for contamination is also a possible threat to the Rota blue damselfly although we are unaware of any study demonstrating that this has happened or is occurring. The current land cover on the plateau consists approximately of forest (54 %) grassland/scrub (41 %), and developed and barren lands (5%).

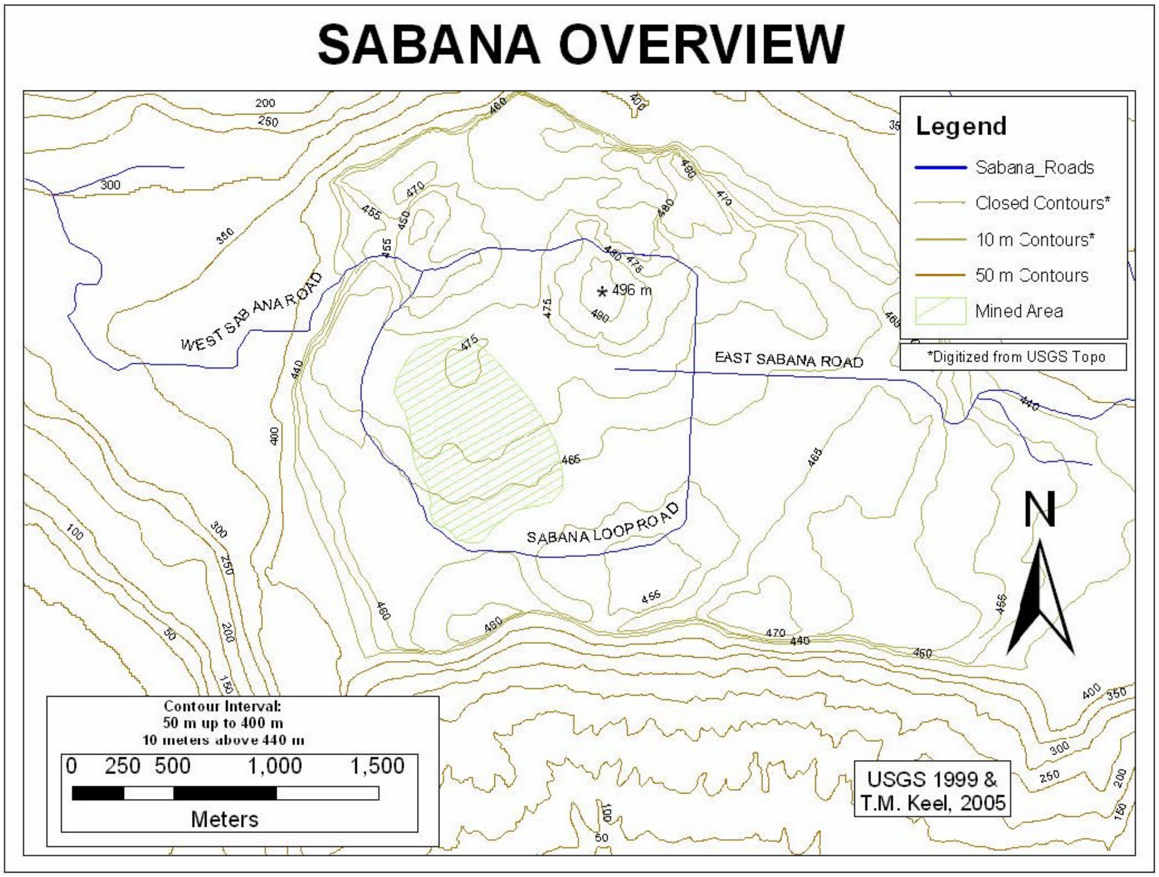

Figure 14. Map depicting the estimated area on the Sabana Plateau mined for phosphate by the Japanese between 1938 and 1943 (from Keel et al. 2007, p. 11)

Figure 15. Aerial photograph showing the extent of forest habitat loss on the Sabana Plateau and in the Talakhaya by 1946.

Forest alteration on Rota due to invasive plants

The native flora of the Mariana Islands (plant species that were present before humans arrived) consisted of no more than 500 taxa Mueller-Dombois and Fosberg 1998, p. 241). On Rota alone, over 200 plant species have since been introduced from elsewhere and at least one-third of these have become pests (Mueller-Dombois and Fosberg 1998, pp. 242–243, 249, 262–263; Costion and Lorence 2012, pp. 51−100). Of these non-native pest plants, several species present on Rota are known to be habitat-altering, including lantana (*Lantana camara*), fountain grass (*Pennisetum setaceum*), ivy or scarlet gourd (*Coccinia grandis*), molasses grass (*Melinis minutiflora*), and tangantangan (*Leucaena leucocephala*) among others (Wiles et al. 1990, pp. 168, 177; Space et al. 2000, entire). All of species continue to harm forest habitats on the island, and several, including lantana, molasses grass, and fountain grass alter fire ecology (Thaman 1974, p. 23; D'Antonio and Vitousek 1992, pp 63-87; Space and Falanruw 1999, p. 3) with detrimental effects on forest habitats, particularly in the fire-prone Talakhaya inhabited by the Rota blue damselfly.

In addition to increasing fire risk, nonnative plant species often exploit the disturbance caused by other factors such as hurricanes, agriculture and development, and feral ungulates. In combination, they reinforce or exacerbate their negative impacts to native habitats. Among the larger southern Mariana Islands, Rota contains the highest percentage (47%) of relatively intact native forest. However, nonnative plant impacts to the Sabana Plateau and the Talakhaya Region are currently ongoing and the threat of forest impacts from invasion and further spread by nonnative plant species on Rota remains a serious concern.

The adult Rota blue damselfly is likely able to forage in modified habitat that includes nonnative plant species. However, the exceptionally dense canopy cover provided by the remaining native forest in the Talakhaya Region (Camacho et al. 1997, pp. 9-10) provides shaded conditions along the Okgok Stream and cooler stream temperatures important to most stream fauna including damselflies (Polhemus and Richardson 2020, p. 9). Research has documented the ability of nonnative plant species to change native forest composition in the Marianas that result in impacts including reduced canopy cover that could lead to increased stream temperatures (UFWS 2015; Polhemus and Richardson 2020, p. 9).

These same impacts are of equal concern to the health of the perched aquifer fed by the Sabana Plateau. This aquifer is somewhat dependent upon the amount and type of forest vegetation on the plateau summit, which helps to captures water in form of passing mists and slowly release water into the porous substrate (USFWS 2001, 2006; Keel et al. 2007, entire; USFWS 2015). It is possible that a reduction in forest cover and quantity due to impacts from nonnative plants will also reduce the capacity for the Sabana Plateau to recharge the aquifer that is the source of the spring water feeding the Talakhaya streams (Keel et al. 2007, p. 10).

Forest loss and alteration on Rota due to ungulates

Where established in the Mariana Islands, Philippine deer (*Cervus mariannus*) often cause documented damage to the forest structure. Through their grazing activities, deer cause a wide range of impacts including erosion, spread of nonnative plants, and decimation of the understory (Schreiner 1997, pp. 179–180; Wiles et al.1999, pp. 193−215; Berger et al. 2005, pp. 36, 45–46, 100; CNMI-SWARS 2010, p. 24; JGPO-NavFac Pacific 2010, p. 3-33; SWCA 2011, pp. 35, 42). In addition to documented impacts to Okgok Stream by cattle (Camacho et al. 1997, p. 7), and pertaining to the Rota blue damselfly, Philippine deer can cause severe erosion of watersheds. Foraging and trampling by the deer destabilize soils that support native plant communities and bury or damage native plants, resulting in adverse effects on water quality due to runoff over exposed soils (Cuddihy and Stone 1990, p. 63; Berger et al. 2005, pp. 42, 44, 138, 156−157; CNMI-SWARS 2010, pp. 9−10; Kessler 2011, p. 323). Both the Sabana Plateau and the Talakhaya area contain some of the largest populations of Philippine deer in the Mariana Islands. With seasonal limits on hunting the deer in the CNMI, experts believe the large populations on Rota are contributing to the deterioration of the native forest understory in both regions (CNMI-DEQ 2015, p. 13). In particular, grazing deer greatly hamper the ongoing efforts to revegetate the slopes of the Talakhaya (see discussions below regarding hunting practices and conservation efforts) (CNMI Division of Coastal Resource Management (CNMI-DCRM) in litt. 2019, p. 1). Complicating the matter, many residents of Rota identify the continued health of the Rota deer populations as a conservation priority (CNMI-DEQ 2015, p. 3). While the impacts to forest habitat on the Sabana Plateau and in the Talakhaya from the effects of ungulates, and particularly Philippine deer, are ongoing, we are unable to quantify the level of the impact to the forest habitat of the Rota blue damselfly.

Forest loss and alteration on Rota due to wildfire

Fire is a human-exacerbated threat to native species ecosystems throughout the Mariana Islands, including on the island of Rota. Occurrence of wildfire is most common during the dry season despite the year-round humid climate (JGPO-NavFac Pacific 2010, p. 1-9). On Rota, deer hunters frequently create fires in order to lure deer to new growth for easier hunting on the Sabana Plateau and within the Talakhaya (CNMI-DEQ 2015, p. 13; Golabi et al. 2018, p. 198; CNMI-DCRM in litt. 2019, p. 1; NOAA in litt. 2019) (**Figure 16**). It is common for these fires to become wildfires that spread into adjacent forest habitats.

Fire can destroy dormant seeds of native species as well as plants themselves, even in steep or inaccessible areas. Successive fires that burn farther and farther into native forest habitat destroy native plants and remove habitat for native species by altering microclimate conditions to those favorable to nonnative plants. Nonnative plant species most likely to spread as a consequence of fire are those that produce a high fuel load, are adapted to survive and regenerate after fire, and establish rapidly in newly burned areas. For example, it is well-documented that nonnative grasses often invade and change the landscape of native tropical forests and shrublands. Many nonnative grasses and plants provide fuels that allow fire to burn areas not easily flammable and shift the ecological balance in their favor (Fujioka and Fujii 1980 in Cuddihy and Stone 1990, p. 93; National Park Service 1989 in Cuddihy and Stone 1990, p. 93; D'Antonio and Vitousek 1992, pp. 70, 73–74; Tunison et al. 2002, p. 122).

On both the Sabana Plateau and in the Talakhaya, wildfire present an ongoing threat to the remaining native forests in these regions and continues to hamper efforts to revegetate these efforts (see discussion below regarding conservation efforts). While the impacts to forest habitat on Rota from effects of wildfire are ongoing, particularly within the Talakhaya, we are unable to quantify the level of the impact to the forest habitat of the Rota blue damselfly.

Figure 16. Photograph of area that burned in the Talakhaya in 2017. (Photo by Malcolm Johnson)

Natural Events – Cyclones / Typhoons

Tropical cyclones and typhoons are a common natural disturbance in the Western Pacific and have impacted the Mariana Islands with varying frequency and intensity for millennia (see additional discussion in Willsey et al. 2019 and USFWS 2015). Besides the possibility of causing flooding or landslides, typhoons may exacerbate forest fragmentation and invasion of native forests by nonnative species, stressors that directly and indirectly reduce breeding and foraging habitat for the Rota blue damselfly. Although the Rota blue damselfly has likely coexisted with severe storms during its entire existence, these events exacerbate the other stressors that threaten its one remaining population. In addition to at least temporarily damaging forest and stream habitat, typhoons may certainly cause possible direct mortality of individual damselflies.

The forests on the Sabana Plateau have shown documented evidence of longterm conversion and decline due the effects of historically recent typhoons, and grazing deer often exacerbate these effects (Berger et al. 2005, p. 36). In 1988, typhoon Roy hit Rota with winds of over 150 mi (241 km) per hour and completely defoliated almost all of the forests of Rota (Fancy and Snetsinger 1996). On the Sabana Plateau and its clifflines, winds downed 50 percent of the trees, and 100 percent of the trees suffered limb damage. In December 1997, Rota was hit again by another super typhoon, Paka, which defoliated much of the Sabana Plateau (Fancy and Snetsinger 2001). These storms have resulted in lasting degradation and destruction of high-elevation wet forests on Rota that are important to the underlying aquifer that feeds Okgok Stream. While the impacts to forest habitat on Rota from effects of typhoons are ongoing, we are unable to quantify the level of the impact to the forest habitat of the Rota blue damselfly. However, we believe the viability of the Rota blue damselfly's current status is vulnerable to these types of catastrophic chance events.

Conservation Efforts to Reduce Habitat Loss and Degradation on Rota

In recent years, the CNMI government has designated several publically owned areas on Rota as protected lands under Rota Local Law 9-1 due to their high resource value. These areas include a marine sanctuary, sea bird sanctuaries, and conservation areas for forests and wildlife, two of which occur within the vicinity of the Talakhaya. Created in 1994, the Sasanhaya Bay Fish Reserve was the first established marine protected area in the CNMI. It is located below the Talakhaya in the Sasanhaya Bay between and including Pui'la Point and the Coral Gardens. The second protected area, also established in 1994, is called the Sabana Protected Area. The CNMI government established this preserve on the Sabana Plateau to provide watershed protection, wildlife and forest conservation, as well as for community farming and medicinal plant gathering. In 2007, CNMI added the Talakhaya region to the Sabana Conservation Area, providing it with the same status and protection (CNMI-DEQ 2015, pp. 10-11). The two area combined, known as the Sabana / Talakhaya Watershed, have been identified as a Coral Reef Management Priority site by the CNMI government (Golabi et al. 2018, p. 194).

Supported through US Coral Reef Initiative funding, an ongoing multi-phase revegetation project in the Talakhaya began in 2007. Broadly, the goals of the project include the need to address the several interrelated problems facing the watershed ranging from fires from poaching by hunters, soil loss due to erosion, and the resulting impacts to the surrounding coral reef systems. The project's aim is to stabilize soils, prevent erosion, and enhance stream water quality and thus prevent sedimentation from entering coastal waters below the Talakhaya. Through the efforts of numerous Federal and CNMI partnering agencies as well as a large number of Rota resident volunteers, tremendous progress had been made toward protecting the watershed and the surrounding reef system. Developed from conservations plans originally began in the 1990s, and expanded in scope and scale through the 2010 development of a conservation action plan for the area initially completed in 2012 and revised in 2015 (CNMI-DEQ 2015, entire). A large component of the project has been education and outreach efforts to all Rota residents ranging from schoolchildren to adults. In particular, the project has focused on increasing community appreciation for stewardship of the land and reef and reducing the number of illegal fires set in the Talakhaya by hunters to flush out browsing deer (CNMI-DEQ 2015, pp. 13, 15; Golabi et al. 2018, p. 198). To reduce and eventually reverse ongoing soil erosion in the Talakhaya, volunteers have outplanted grasses and trees on several thousand acres (approximately 60 to 70 percent) of the Talakhaya since 2007 (**Figure 17**, **Figure 18**, and **Figure 19**). Initial research thus far indicates that more time is needed to assess the effects of the outplanting efforts on reducing sediment entering the streams and the ocean due to the variation in progress revegetating different areas of the Talakhaya (Golabi et al. 2018, p. 198).

Figure 17. Photograph of conservations efforts in the Talakhaya involving the planting of vetiver grass (*Chrysopogon zizanioides*). (CNMI Division of Coastal Resources Management 2019)

Figure 18. Photograph of rows of vetiver grass outplanted during conservations efforts in the Talakhaya. (Photo from CNMI Division of Coastal Resources Management 2019)

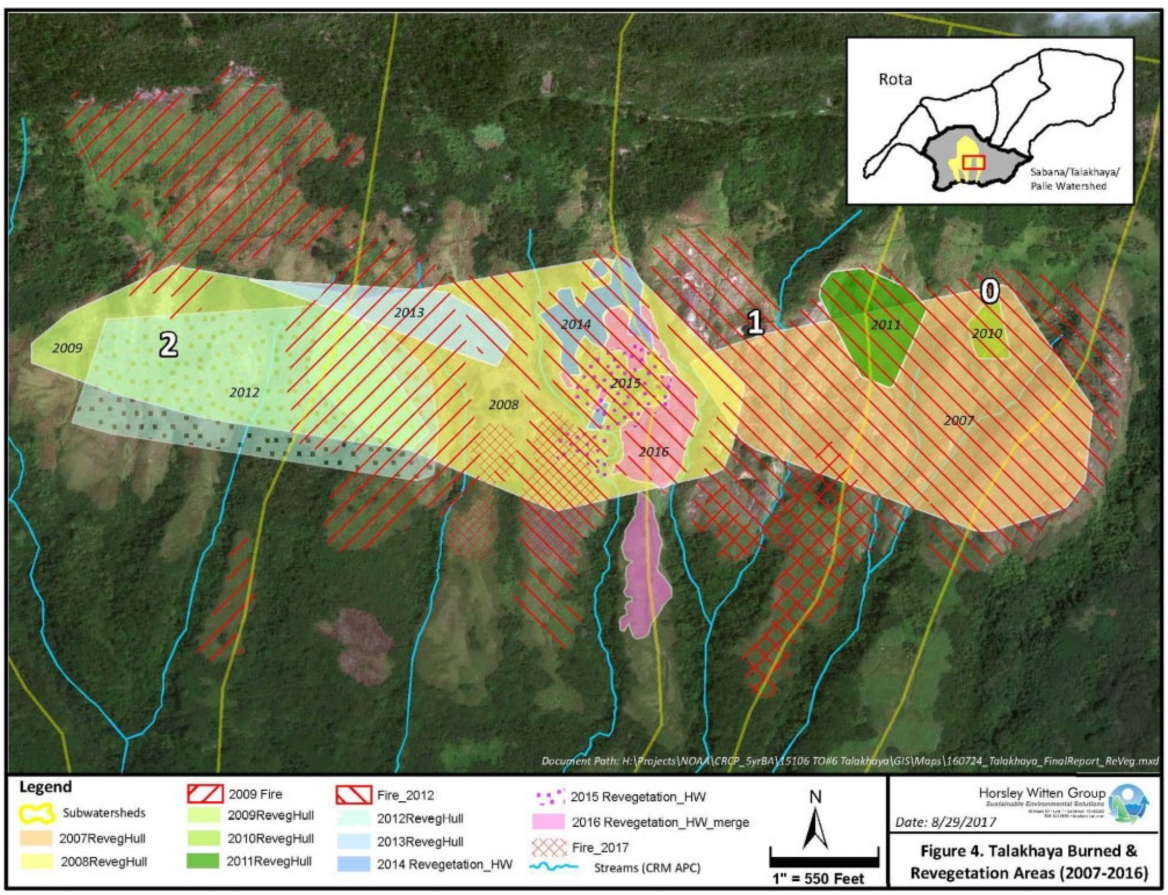

Figure 19. Map of the Talakhaya showing areas under restoration since 2007 and areas that have experienced recent wildfires. The project has revegetated between 60 and 70 percent of the Talakhaya with grasses and trees, although setbacks from the fires occurred in 2009, 2012, 2013, and 2017. (Photo from CNMI Division of Coastal Resources Management 2019)

In summary, a variety of stressors has historically affected the forest habitat that supports the Rota blue damselfly. Many of these stressors are ongoing, including agriculture on the Sabana Plateau, fires set by hunters, and the effects of feral ungulates, typhoons, and nonnative plants. Although the effects of these stressors on the viability of the Rota blue damselfly cannot be quantified, the impacts to forest habitat in the region are visibly obvious and of substantial concern. Healthy forest on the Sabana Plateau facilitates replenishment of water into the underlying aquifer and healthy forest within the Talakhaya prevents drying of substrates and keeps stream waters shaded, cool, and clear of silt – all factors biologically important to the viability of the Rota blue damselfly.

Figure 20. Recent aerial photograph showing the current state forest habitat on the Sabana Plateau and in the Talakhaya.

Direct Stressors – Predation, Disease, and Competition

The following section provides an overview on the potential of stressors such as predation and competition to directly impact the Rota blue damselfly. From all types of aquatic habitats, research has shown that the presence of predators including predatory fish and arthropods influences and alters damselfly behavior. In the case of aquatic habitats invaded by nonnative fish or insect predators, impacts to endemic damselflies can be devastating. As demonstrated by the decline of the Hawaiian *Megalagrion*, invasion by nonnative predators can lead to significant impacts including suppression, extirpation, and extinction (Polhemus 1993, pp. 343, 348). While we lack evidence of Rota blue damselfly predation by nonnative species, there is substantial risk through introduction of these organisms to Rota and the Okgok Stream system.

Predation by nonnative fish

A large body of research indicates that fish predation has factored tremendously in the evolution of damselfly naiad behavior including their distribution in continental aquatic systems (Johnson 1991, p. 8; McPeek 1990, entire; McPeek 1998, entire). Conversely, in the Pacific region freshwater systems, many damselfly groups lack adaptations for predator avoidance behavior due to their evolution in the absence of certain fish species. Consequently, predation by nonnative fish species introduced to these systems is widely implicated in the extirpation of many damselfly populations, including for example, several species of the related *Megalagrion* genus of narrow-wing damselflies endemic to the Hawaiian Islands (Polhemus 1993, entire; Polhemus and Asquith 1996, pp. 24-25; Englund 1999, pp. 235–236).

During the aforementioned 1996 survey of Okgok Stream (Camacho et al. 1997, entire) researchers reported the presence of four native fish species, including the marine itinerant flagtail (or mountain bass) (*Kuhlia rupestris*) in the terminal reach below the first waterfall, an eel (*Anguilla marmorata*), and two gobies (*Stiphodon elegans, Sicyopus leprurus*) inhabiting the swifter midreach waters above the first waterfall. According to their report, densities of these native fish were low, especially in areas above the first and main waterfall. In particular, the more aggressive predator among the four species, the flagtails, occurred only in the lower reach of the stream with the large, lower waterfall apparently acting as a barrier. Correspondingly, the biologists recorded two native shrimp species (susceptible to the flagtail) only in the stream above the same waterfall.

The two gobies were the only fish found above the large lower waterfall in Okgok Stream. Gobies are renowned for their ability to maneuver up steep channels in areas of rapidly flowing water by using ventral fins evolved to form a sucking disk (Ego 1956). Although less studied in the Marianas, freshwater gobies in Hawaii are primarily browsers and bottom feeders with midges and worms being their primary food items, but often eating algae off rocks and boulders (Ego 1956; Kido et al. 1993, p. 47). The relatively low total number and density of gobies counted during the study possibly correlates to the low abundance of algae detected during the stream, which likewise, may correspond to the very high canopy cover recorded at the time of the survey (Camacho et al. 1997, p. 12).

As a species in the genus *Ischnura* with its worldwide distribution, it is possible that the Rota blue damselfly has either retained or evolved behaviors to avoid the benthic feeding habitats of the native fish species recorded in Okgok Stream (Polhemus pers comm. 2014). However, it may not be adapted to avoid feeding behaviors of nonnative fish species not yet recorded on Rota. For example, several nonnative fish in the *Gambusia* genus were introduced to streams for on Guam mosquito control during the mid-1900s, as well as aggressive aquarium fish species including guppies, swordtails, mollies, betta, oscars, and koi. Currently, there are no records of these species occurring on Rota. Biologists believe that the species with the most potential for introduction to Rota include *Gambusia* sp. And guppies (Tibbatts in litt. 2014). If either group established in the upper portion of Okgok Stream, they could reduce the viability of the Rota blue damselfly by eating the naiad life stage, interrupting its life cycle, and possibly exclude portions of its habitat or worse.

Predation by nonnative insects

Backswimmers and other aquatic predators
Backswimmers are aquatic "true bugs" in the family Notonectidae within the Heteroptera insect order. Voracious predators, backswimmers frequently feed on prey much larger than themselves, such as tadpoles, small fish, and other aquatic insects, (Heads 1985, p. 559; Heads 1986, p. 369). Several species of backswimmers also prey on damselfly naiads, and their presence in the water can cause naiads to alter foraging behavior leading to a reduction of naiad growth, development, and survival (Heads 1985, p. 559; Heads 1986, p. 369). On many Pacific islands including the Mariana Islands, backswimmers are absent from aquatic systems (Englund 2011, entire), and in Hawaii for example, several species have become established with possibly deleterious effects upon the endemic damselfly fauna (Polhemus 1996, pp. 34-35). While we lack information to indicate whether backswimmers are present on Rota, the possibility is certainly plausible that any number of nonnative, aquatic insect predators may arrive and establish on the island, thereby further reducing the viability of the damselfly. Prior to 2007 for example, there was no record a backswimmer relative (Family Pleidae) in Micronesia until a predatory species from North American was discovered in a Guam stream system. Researchers speculated that the species, *Paraplea puella*, arrived accidentally via the aquaculture or aquarium trade, a common pathway for worldwide introductions of nonnative aquatic organisms (Zack et al. 2007, entire).

Predation by nonnative ants
The Mariana Islands contain approximately at least 57 ant species, the large majority apparently introduced by human activities (Clouse 2007, p. 186). Therefore, many native insects in the Mariana Islands evolved in the absence of predation pressure from most of the ant species now

established. Ants can be particularly destructive predators because of their high densities, recruitment behavior, aggressiveness, and broad range of diet (Reimer 1993, pp. 17-18). The ability of adult reproductive ants disperse by flight greatly exacerbates the threat of ants spreading into new habitats including that of the Rota blue damselfly (Borror et al. 1989, p. 738). Most invasive ant species can quickly establish new colonies in suitable habitats (Staples and Cowie 2001, p. 55), attributes that allow many ant species to impact otherwise geographically isolated populations of native arthropods (Nafus 1993, pp. 19, 22-23).

Several particularly aggressive species known to impact native Pacific islands insect fauna (Zimmerman 1948, p. 173; Reimer et al. 1990, pp. 40-43) are among the many nonnative ants established in the Mariana Islands (Clouse 2007, **Table 4**). These particularly aggressive species include the big-headed ant (*Pheidole megacephala*), the long-legged ant (also known as the yellow crazy ant) (*Anoplolepis gracilipes*), *Solenopsis papuana* (no common name), *Solenopsis geminata* (no common name), and little fire ant (*Wasmannia auropuncta*). Researchers recognize many other species of ants as threats to endemic invertebrates on Pacific islands, with a trend of new species of ants spreading and establishing every few years (Staples and Cowie 2001, pp. 53).

Due to a preference for drier habitats, ants are less likely to occur in high densities in the riparian and aquatic habitat currently occupied by the Rota blue damselfly. However, some species, including the long-legged ant (*Solenopsis papuana*) and the little fire ant, introduced to Guam in 2011, are increasingly found within habitats wetter than previously documented. As noted earlier regarding the life history of the Rota blue damselfly, naiads may be particularly susceptible to ant predation when they crawl out of the water or seek a terrestrial location for their metamorphosis into the adult stage. Based upon documented ant predation on other Pacific island endemic damselfly fauna (Englund in litt. 2008, pp. 56-57), the potential threat to the Rota blue damselfly is possible, although we lack evidence of this impact.

RESILIENCY, REPRESENTATION, AND REDUNDANCY OF THE SPECIES

Resiliency of Current Populations: Low
Resiliency is the capacity of a population to withstand stochastic disturbance events. Quantitative information on Resiliency is often unavailable for evaluating the status of a species. In the most general sense, a species showing good population growth is more likely to be resilient to an environmental perturbation. Additionally, occupying a larger landscape with viable migration corridors among habitats will greatly facilitate resilience, and sustain geographically dispersed populations.

Population and Species Needs
We previously identified the individual needs of the Rota blue damselfly:

- the larval or naiad life stage requires stream water of sufficient duration and an adequate abundance of aquatic prey to complete its development to the adult stage;
- additionally, the stream habitat must be sufficiently cool, and relatively free of pollution, silt, and other particulate matter;
- following its metamorphosis into the adult stage, the damselfly requires sufficiently complex forest understory to support an abundance of prey and provide places to evade predators.

Here, we assess the Rota blue damselfly's needs as a population and a species using the concepts of the 3R's (resiliency, representation, and redundancy, as summarized below in **Table 6**).

The Rota blue damselfly is endemic to Talakhaya region on Rota, which is the historical limit of its range and where it is exists as a single population. We discuss the needs of the Rota blue damselfly at the population- and species-levels together, because we believe the species is comprised of a single population on Rota.

Resiliency of Current Populations: Low to moderate
Resiliency is the capacity of a population to withstand stochastic disturbance events. Quantitative information on Resiliency is often unavailable for evaluating the status of a species. In the most general sense, a species showing good population growth is more likely to be resilient to an environmental perturbation. Additionally, occupying a larger landscape with viable migration corridors among habitats will greatly facilitate resilience, and sustain geographically dispersed populations.

As a species, the Rota blue damselfly is comprised of a single population located within a relatively small region of Rota, and possibly within a single, relatively small stream system, (the only mountain to ocean-stream occurring among the 14 islands comprising the CNMI). Thus, the resiliency, or ability of the species to withstand stochastic events, is primarily tied to the size and distribution of its population within the Talakhaya on the island of Rota. The Rota blue damselfly's population size, distribution, and overall resiliency is tied directly to the availability of stream habitat of sufficient quality, flow, and continuity, as well as the absence of certain invasive insect and fish predators.

Only discovered in 1996 and remaining unstudied since, we possess almost no information regarding Rota blue damselfly population demographics. A few (<10) individuals have been observed on three occasions within Okgok Stream, beginning in 1996, in 2014, and most recently in 2015. According to the available literature, the Rota blue damselfly has not been observed utilizing other freshwater sources on the island including fountains, pools, or other small perennial seeps. Based upon what is known about the species' genus (*Ischnura*), we know that the Rota blue damselfly is most likely a stream breeder as correlates with recorded observations to date. Additionally, based upon what is known about Coenagrionidae and Pacific Islands damselflies in general, we can infer general characteristics about its biology and life history. For example, breeding habitat requirements may be quite specific, which may limit the Rota blue damselfly's range, abundance, and ability to respond to stochastic change.

With its distribution possibly limited to the single perennial stream of Okgok Stream, we believe the Rota blue damselfly's existence is intertwined with consistent and sufficient streamflow in the Okgok Stream. On the other hand, based upon its persistence in a single stream to date, the Rota blue damselfly clearly possesses biological traits for tenacity and an ability to survive periodic stochastic events affecting its stream habitat over time.

Species Representation: Low

Representation is having one or more populations of a species occupying the full range of habitat types used by the species. In general, conserving the biogeographic range occupied by populations of a species should take into account historic latitudinal and longitudinal ranges, elevation gradients, climatic gradients, soil types, habitat types, seasonal condition, etc. Connectivity among populations and habitats is also an important consideration in evaluating representation.

The Rota blue damselfly is represented by (or exists as) a single population with no observable discontinuity among individuals from geographic or other barriers. The potential for stream habitat distribution on Rota is limited by geology to the Talakhaya region, the only portion of the island that contains relatively impermeable volcanic soils. Consequently, the Rota blue damselfly's distribution probably has varied little over time, although it possibly included one or more of the adjacent, seasonal stream channels located to the east of it known habitat. Although we lack specific knowledge of the Rota blue damselfly's genetics, we expect that its capacity to adapt to future environmental change is limited to the adaptive capacity currently within its single population. It is unlikely the species could quickly adapt to different freshwater habitats such as ponds or small pools if streamflow within Okgok Stream ceased or appreciably diminished. We therefore measure the species as low in representation because it is plausibly susceptible to certain stochastic events and exists as a single, presumably small population lacking any apparent potential for growth into other habitats.

Species Redundancy: Low

Redundancy is minimizing the risk of extinction of the species by establishing multiple populations across a landscape so some populations will always survive a catastrophic event. In general, a wider range of habitat types, a greater geographic distribution, and connectivity across the geographic range will increase the redundancy of a species and its ability to survive a catastrophic event.

Species redundancy is measured as a function of the scale of catastrophic events relative to the spatial distribution of multiple populations or spatial extent of a single population. As the Rota blue damselfly exists as a single population with a small distribution, its redundancy as a species is low. Furthermore, because the Rota blue damselfly requires consistent and sufficient streamflow, we consider the possibility of streamflow disruption within Okgok Stream to be a catastrophic event of great concern for the species. To maintain the current Rota blue damselfly population density and sustain the species, streamflow cannot appreciably diminish. The species' limited distribution also leaves the Rota blue damselfly particularly vulnerable to invasion by nonnative insect and fish predators. Its habitat must remain relatively free of high densities of predators in general and entirely devoid of non-native predators such as certain fish species to which the Rota blue damselfly may not be adapted.

Current Species Viability Summary

The Rota blue damselfly has low to moderate resiliency, low representation, and low redundancy compared to likely historic conditions, which would lead one to a conclusion of low viability currently. However, it is necessary to balance this assessment within the context of a species is facing a moderate to high degree of threat from multiple stressors including ongoing water extraction and degradation of necessary forest habitat. Without increased and improved forest habitat management and conservation as well as stream habitat protection, the damselfly's viability may further decrease if the species remains restricted to its current narrow range of limited stream habitat.

Table 6. The 3Rs analysis for examining Rota blue damselfly viability.

3Rs	Brief Definition	Application to the Rota Blue Damselfly
Resiliency	Large, robust or growing populations able to withstand periodic and localized disturbance from stochastic events	The Rota blue damselfly has low to moderate resiliency because it exists as a single, presumably small population with no apparent habitat growth potential. Despite obvious persistence to date, the species is at risk from stochastic events.
Representation	Interconnected populations exhibiting genetic diversity and occupying ecological diversity to maintain adaptive potential	The Rota blue damselfly does not exhibit representation. We are unaware of any biological or geographic barriers precluding Rota blue damselfly gene flow on Rota, and the species is apparently comprised of one interbreeding population lacking any appreciable variation in adaptive capacity. Additionally, it is reasonable to assume that the species is not adaptable to breeding within different freshwater habitats such as ponds or small pools based upon the known biology of coenagrionid damselflies.
Redundancy	Multiple and widely distributed populations capable of surviving extirpation due to catastrophic events	The Rota blue damselfly has low redundancy because it exists as a single population within one relatively small region on Rota and is therefore vulnerable to streamflow loss due to catastrophic events including climate change.

Even with documented habitat declines in recorded history, surveys freshwater aquatic insects on Rota have been woefully insufficient to date to allow a thorough and complete understanding of the Rota blue damselfly's status. It is possible that additional and rigorous surveys of the Talakhaya's streams will reveal the extent of damselfly's range to be greater than our present understanding. Despite a narrow distribution, small amount of remaining habitat, and substantial threats to both streams and forest habitat on Rota, continued observations of the species are hopeful and highlight the Rota blue damselfly's capacity to survive to date under adverse conditions.

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