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ROTA WHITE-EYE (*Zosterops rotensis*)

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INTRODUCTION

The little-studied Rota White-eye (*Zosterops rotensis*), or Nosa Luta in the Chamorro language, is historically known only from the tropical Pacific Mariana Island of Rota in the Marianas group. Rota is just north of the southernmost island of Guam and 2500 km southeast of Tokyo. All extant Mariana *Zosterops* populations were once thought to comprise a single species, although DNA studies have revealed that the Rota population is specifically distinct and may be derived from a separate *Zosterops* colonization event. Paleontological evidence indicates that Rota birds may once have had a wider distribution, as bones of at least two white-eye species have been found on two southern Mariana islands where only one species is extant.

Much as with a number of *Zosterops* species, the Rota White-eye is a social, flocking species that occupies a home range. Also as with other *Zosterops*, it is a versatile forager that feeds on insects, fruits and nectar. It forages principally in the forest canopy and uses both native and introduced vegetation as foraging substrates.

Several authors have described the Rota White-eye as a habitat specialist of the cloud forest-like conditions found on the high elevation Sabana plateau—the only location where the species is found regularly. However, multiple historical accounts as well as paleontological evidence demonstrate that it also was once widespread in the island's drier lowlands. Hence, its present distribution and apparent habitat affiliation is artifactual, much as the present high elevation habitat restriction of Hawaiian honeycreepers is also artifactual. The low population of the Rota White-eye has led to its designation as U.S. Endangered, although the most recent surveys indicate some population growth. Habitat degradation, typhoons and predation by the introduced Black Drongo (*Dicrurus macrocercus*) and other predators have been implicated in bringing about the present small population and restricted range.

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IDENTIFICATION

Field Identification

A small, active flocking species of the forest canopy, the sexually monomorphic Rota White-eye indeed has a bright white eye ring. It has yellowish green plumage above and bright yellowish plumage below, and is particularly notable for its orange bill and legs. No other white-eye species or even superficially similar species is present on Rota.

Similar Species

The similarly sized, active flocking forest canopy species of Saipan, Tinian and Aguiguan, the Bridled White-eye (*Z. conspicillatus*), also has a white eye ring but has whitish lores and is grayer green above and pale yellow to whitish below. Its bill and legs are largely black. The behaviorally similar Caroline Islands White-eye (*Z. semperi*) of Palau and the Caroline Islands is also green and yellowish, although less yellow than the Rota White-eye. Its bill and legs are primarily black.

PLUMAGES, MOLTS AND STRUCTURE

Plumages

The Rota White-eye has 9 full-length primaries (numbered distally, from innermost p1 to outermost p9), 9 secondaries (numbered proximally from outermost s1 to innermost s9 and including 3 tertials, s7–s9 in passerines), and 12 rectrices (numbered distally, from innermost r1 to outermost r6 on each side of the tail). There is no geographic variation in appearance. The following is based primarily on plumage descriptions of Baker (1951) and Pratt et al. (1987), along with examination of Macaulay Library images; see Pyle et al. (2008), Radley et al. (2011), and Craig (2021) for information on ageing and sexing the closely related and formerly conspecific Bridled White-eye (*Zosterops conspicillatus*). See Molts for molt and plumage terminology. The appearance of sexes is similar in all plumages; definitive-like plumage is assumed at the Formative Plumage and is assumed at the Second Basic Plumage in some individuals. Seasonal variation in plumages (e.g., fresh vs. worn) is based on timing of molts, which are unknown but may occur year-round based on year-round breeding (see Breeding: Phenology) and extend periods of molt observed in the Bridled White-eye.

Natal down. Undescribed in the Rota White-eye. Chicks appear to hatch naked in the closely related Bridled White-eye.

Juvenile (first basic) plumage. As with the Bridled White-eye (Craig 2021), juveniles appear to be grayer above and paler below than in later plum-

ages, as supported by the observations of a juvenile with a yellow throat but white belly (RJC unpublished data) and a Macaulay image. As in the great majority of passerines, juvenile primaries and rectrices are likely thinner and more tapered or pointed at the tips than basic feathers, and juvenile body feathers are likely weaker and more filamentous (barb density sparser) than in later plumages, especially the undertail coverts. Bare-part colors of juveniles also may be duller.

Formative plumage. This plumage is undescribed in the Rota White-eye and may be distinguishable only in a proportion of birds if the Preformative Molt is largely complete, as is the case with Bridled White-eye (Pyle et al. 2008, Radley et al. 2011). In that species, a small proportion of birds can retain contrastingly worn and narrow juvenile outer primaries, secondaries among s4–s6, and/or outer rectrices following this molt and can be aged as first-year birds. One Macaulay image possibly indicates a partial Preformative Molt in the Rota White-eye (see below). Study is needed.

Definitive basic plumage. Crown, upperparts, upper-wing coverts, and sides of head yellowish olive. Lores brighter yellow, this color extending in a point to the postocular area and as a thin line across the forehead above the bill. A full and broad, prominent white eye ring is a conspicuous plumage feature. Rectrices and remiges are grayish with olive edging. Underparts are variably dull to bright yellow, brighter yellow on the throat and often washed olive on the sides and sometimes across the breast. Definitive Basic Plumage is perhaps separated from some birds in Formative Plumage by having all upper-wing coverts and remiges uniform in wear and quality, without molt limits; basic outer primaries and rectrices are broad, more truncate (less pointed), and relatively fresh compared with retained juvenile feathers.

Molts

Molt and plumage terminology follows Humphrey and Parkes (Humphrey and Parkes 1959) as modified by Howell et al. (Howell et al. 2003). Under this nomenclature, terminology is based on evolution of molts along ancestral lineages of birds from ecdysis (molts) of reptiles (cf. Pyle et al. 2024), rather than on molts relative to breeding season, location, or time of the year, the latter generally referred to as “life-cycle” molt terminology (Jenni and Winkler 2020). Rota White-eyes very likely undergo a Complex Basic Strategy (cf. Howell et al. 2003, Howell 2010), including complete prebasic molts and a partial to complete preformative molt in the first cycle, but no prealternate molts, as is found in other white-eyes including the similar Bridled White-eye (Pyle et al. 2008, Radley et al. 2011).

Molt strategies have not been studied in the Rota White-eye. For the Bridled White-eye, examination

of 53 specimens found 15 collected in active molt all occurred January–April i.e., the dry season, and the remainder were not in active molt but banding data indicated a peak of Preformative Molt in April–July. Some birds were also undergoing Definitive Prebasic Molt at this time (Pyle et al. 2008). Of 114 banded individuals, 31 showed evidence of molt of which 24 were captured during the wet season (Craig 2021). Similarly, four specimens collected during the wet season in October were all in molt (Baker 1948). These observations suggest a tendency to segregate the energetically expensive activities of molt to the wet season and breeding to the dry season.

During complete molts, as in most other passerines including white-eyes, primaries (and corresponding primary coverts) are likely replaced distally (p1 to p10), secondaries are replaced proximally from s1 and proximally and distally from the central or innermost tertial (s8 or s9), and rectrices are generally replaced distally (r1 to r6) on each side of the tail, though variation in sequence of rectrix molt may occur. This should be confirmed in the Rota White-eye due to odd sequences of retained remiges in the Bridled White-eye, where old and new primaries in various positions were observed that were not always symmetrical (Pyle et al. 2008).

The Preformative Molt in Bridled White-eye appears to be partial to complete, with all or some secondaries, rectrices, and primaries retained in some but not all birds. Often 1–3 secondaries among s4–s6 could be the only juvenile feathers retained following this molt (Pyle et al. 2008, Radley et al. 2011). One Macaulay Library image may indicate a partial Preformative Molt. Further study is needed on the extent of the Preformative Molt as well as other aspects of the molting strategy of the Rota White-eye.

Bare Parts

The following is based on descriptions in the literature (Baker 1951, van Balen 2008) along with examination of Macaulay Library images.

Bill. The bill of adults varies from pale brown to orange on the maxilla and light yellowish-brown to orange on the mandible, to entirely bright orange-yellow. It may be possible that color can change seasonally, becoming brighter during pre-breeding periods. In juveniles the bill appears to be a duller dusky yellow based on an apparent juvenile in a Macaulay Library image.

Iris. The iris appears to be dark brown at all ages.

Tarsi and Toes. In adults, the legs and feet are brownish-yellow to dull yellow-orange. In juveniles, they may be a duller dusky yellow based on an apparent juvenile in a Macaulay Library image.

Measurements

Linear measurements. Measurements of three study skins demonstrated a flattened wing length of 51–54 mm, tail length of 42–43 mm, culmen of 13–13.5 mm and tarsus of 18–19 mm (Baker 1951). Mean measurements on 21 live birds were 56 mm for wing length, 38 mm for tail length and 26 mm for tarsus length (USFWS 2007). Additional measurements on males were wing: 54–56 mm and exposed culmen: 11–12 ($n = 11$) and on females were wing: 53–56 and exposed culmen: 10.5–11.5 mm ($n = 9$) (Takatsukasa and Yamashina 1931). As with *Z. conspicillatus*, males likely average slightly larger than females, particularly in wing chord (Craig 2021a), as is typical for many passerines.

Mass. Mean mass was 9.7 g for males and 9.2 g for females, although no sample sizes were given (USFWS 2007).

SYSTEMATICS

Systematics History

The holotype, an adult male collected by Nobusuke Takatsukasa (1889–1959) and Yamashina Yoshimaro (1900–1989) on 9 March 1931, is not known to be still extant; the collections of Takatsukasa perished almost entirely during World War II (Dickenson et al. 2001). In describing their new taxon, Takatsukasa and Yamashina (1931) had 11 males and nine females available to them; all of these additional specimens can be considered paratypes, of which eight (five males, three females) all taken in March 1931 are held in the Yamashina Institute for Ornithology, Abiko (YIO-45565 to YIO-45572 inclusive).

The first specimens of the Rota White-eye were initially considered indistinguishable from the previously described Caroline Islands White-eye (*Zosterops semperi*) (Oustalet 1895, 1896), which for many years was considered to range widely through Micronesia, although *semperi* was later divided into three species—*conspicillatus*, *semperi* and *hypolaris* (Pratt et al. 1987, Slikas et al. 2000). The species was subsequently assigned to the endemic subspecies *semperi* (Momiya 1922) but later reassigned to the endemic subspecies *rotensis* (Takatsukasa and Yamashina 1931) although its species affiliation was debated to be either Bridled White-eye or Caroline Islands White-eye (Ornithological Society of Japan 1942).

More recently, The Rota White-eye's taxonomic status has been questioned, with its differing appearance and voice compared with other Marianas white-eyes suggesting species-level distinctness (Pratt et al. 1987, Craig 1999). Mitochondrial DNA studies have since demonstrated that the Rota population is genetically distinct from *Z. conspicillatus* of Saipan,

Tinian, Aguiguan and, formerly, Guam and it has been recommended for elevation to species status (Slikas et al. 2000).

Slikas et al. (2000) discovered that some Micronesian islands, e.g., Saipan, are (or were) occupied by white-eye species resulting from separate colonization events. In a few cases the oldest endemics became more strongly or exclusively associated with habitats in the interior of islands, surviving effectively as relict populations, much as the Rota White-eye does now.

Related Species

This species belongs to a very large clade of ca. 40 Indo-Pacific *Zosterops* species (Fjeldsa et al. 2020). Slikas et al. (2000) sampled mitochondrial sequence data pertaining to Bridled White-eye, Caroline Islands White-eye, Plain White-eye (*Zosterops hypolais*), Yap White-eye (*Zosterops oleagineus*) (previously *Rukia oleaginea*) and Golden White-eye (*Cleptornis marchei*), finding substantial genetic divergence (5.7–7.3%) among the first three-named taxa, which formerly were treated as a single species, as well $6.5 \pm 1.7\%$ between *rotensis* and the previously conspecific populations on Guam, Tinian, and Saipan.

Fossil History

Sub-fossils of *Zosterops* bones have been uncovered on Rota (Steadman 1999).

DISTRIBUTION

Confined to Rota Island, in the northern Mariana Islands, which are ca. 2500 km southeast of Tokyo in the western tropical Pacific.

Historical Changes to the Distribution

In 1990–1992, birds were found in isolated flocks occurring solely on the Sabana plateau at ca. 400–490 m elevation (Craig and Taisacan 1994), the latter of which is the highest point on Rota. At present, the distribution is largely restricted to above 150 m on the Sabana plateau (Camp et al. 2015), although birds have been detected at lower elevations when converging on abundant flower food sources (Amidon 2000) much as *Z. conspicillatus* converges on non-forest flowers on Aguiguan (Craig et al. 1993). Most of the population was by 1996 reported to be confined to four forest patches covering 259 ha (Fancy and Snetsinger 2001). However, more recent surveys indicate a population expansion (Camp et al. 2015), which may have led to some range expansion, as significant areas of apparently suitable native forest had previously been found unoccupied (Craig 1999, Fancy and Snetsinger 2001).

A hypothesis raised is that the Rota White-eye has always been largely confined to high elevations and only occasionally moves into lowlands to exploit ephemeral food resources (Fancy and Snetsinger 2001). However, into the 1950s, island residents reported it to be widespread and common at low elevations (Engbring et al. 1986, Craig and Taisacan 1994, USFWS 2007). In 1945, when much of the lowland was cultivated, the species was still described as numerous (Baker 1951), and of four birds collected, all were from lowland locations (Baker 1948). Moreover, paleontological studies at two coastal cave sites have yielded bones of *Zosterops* (Steadman 1999). By the 1970s, birds appeared to have become essentially restricted to the Sabana plateau (Pratt et al. 1979), although even during 1982 surveys an individual was detected at a low elevation (Engbring et al. 1986).

The Rota White-eye also may once have had a wider distribution within the Mariana Islands. Bones of the Golden White-eye (*Cleptornis marchei*) have been found on two of the southern Marianas where they no longer occur, and bones of other bird species have been found on islands where they are no longer present (Steadman 1999). Perhaps only a third of the Marianas pre-human avifauna survives today.

HABITAT

During observations from 1990–1992, the character of native forest habitat was described as varying from stunted, open forest on the plateau summit to closed, mature forest on the upper Sabana slopes (Fig. 1). Dominant native trees within the range of the Rota White-eye included *Elaeocarpus joga*, *Ficus prolixa*, *Intsia bijuga*, *Guettarda speciosa*, *Pisonia umbellifera*, *Claoxylon marianum*, *Pandanus* spp. and *Hernandia labryinthica* (Craig and Taisacan 1994). More recently, the highest densities of white-eyes have been reported from areas of mature wet forest on the Sabana plateau. Three forest types were used frequently: 1) mixed native forest of *Hernandia labyrinthica* and *Elaeocarpus joga*, 2) native forest dominated by *Merrilliodendron megacarpum* and 3) introduced *Acacia confusa*-dominated forest. Critical habitat for the species has been defined as forest above 150 m with a midstory and canopy layer, high epiphytic plant volume, *Elatostema* and *Procris* on the forest floor and *Elaeocarpus joga*, *Hernandia labyrinthica*, *Merrilliodendron megacarpum*, *Pandanus tectorius*, and *Premna obtusifolia*, *Aglaia mariannensis*, *Artocarpus atilis*, *Ficus prolixa*, *Ficus tinctoria*, *Guettarda speciosa*, *Macaranga thompsonii* and *Pisonia umbellifera* as regular forest components. Trees used for nesting were 3–15 m tall and 2–60 cm dbh (USFWS 2007).

Attempts to find general statistical relationships between populations and vegetation have been unsuccessful (Camp et al. 2015). Similarly, during



FIG. 1. Prime mature forest habitat occupied by Rota White-eyes on the Sabana plateau..

1982 surveys, no relationship between vegetation and populations was found (Engbring et al. 1986). However, more detailed studies performed within the species' present range have determined that high population density plots had more stems with 20–50 cm dbh, more foliage intercepts at 3–9 m, more epiphytes, greater total canopy cover and fewer overall plant species (Zarones et al. 2013). In contrast, attempts to find a link between invertebrate abundance and high vs. low elevation locations (Amidon 2000) and areas of high vs. low white-eye density (Zarones et al. 2013) have been largely unsuccessful.

The Rota White-eye is largely restricted to the above types of forest, it has been asserted to specialize in them (Fancy and Snetsinger 2001) and it appears that these habitats are the most suitable ones present within its existing range (Zarones et al. 2013). However, the species' present distribution is artifactual. Indeed, it is even absent from some areas of mature Sabana forest, suggesting that populations are well below saturation densities. Moreover, birds are reported to occupy alien vegetation, including *Bambusa*, *Cocos nucifera*, *Delonix regia*, *Acacia confusa* and *Leucaena leucocephala* stands. They also once frequented towns (Engbring et al. 1986, Amidon 2000, Fancy and Snetsinger 2001, USFWS 2007). These observations instead provide evidence of ecological versatility, as is also found in *Z. conspicillatus*—an expectation of species inhabiting periodically typhoon-ravaged landscapes (Craig and Beal 2002). The species' original ecological amplitude is as yet unknown and how reproductive success might differ among habitat types is also unknown.

MOVEMENTS AND MIGRATION

Movement

The Rota White-eye is unreported from islands other than Rota. Although it is essentially confined to the Sabana plateau, it has on occasion been observed in lowlands where it was exploiting abundant food resources (Amidon 2000). However, incidental observations and flocks detected at adjacent points on different censuses suggest that flocks are relatively sedentary and occupy areas at least 150 m in diameter (Craig and Taisacan 1994).

DIET AND FORAGING

Feeding

Microhabitat for foraging. Based on 24 observations from 1990–1992, the Rota White-eye foraged mostly in the tree crown where it gleaned insects from leaves. It predominantly chose perches <1.0 cm diameter for foraging, i.e., those branchlets making up the majority of outer tree crowns (Craig and Taisacan 1994). In both the dry and wet seasons, leaves and buds were the primary foraging substrate followed by flowers and branches. Foraging microhabitat was also similar between wet and dry seasons, with >60% of foraging occurring on canopy perches <1.0 cm, followed by branches 2–4 cm. Most foraging occurred at >6 m, followed by 3–6 m and <3 m (Amidon 2000). Of 97 observations of foraging in trees, 34% were in *Elaeocarpus joga*,



FIG. 2. This view of a Rota White-eye illustrates that the species tends to occupy the forest canopy in locations where it is vulnerable to predation by the Black Drongo.

13% in *Hernandia labyrinthica*, 10% in *Macaranga thompsonii*, 9% in *Merrilliodendron megacarpum* and 9% in *Premna obtusifolia* (9%), although how this relates to tree availability is unreported. Feeding has also been observed in *Pipturus argenteus*, *Persea americana*, *Guettarda speciosa*, *Ficus tinctoria*, *Acacia confusa*, *Aglaiia mariannensis*, *Eugenia thompsonii*, *Ficus prolixa*, *Tarennia sambucina* and *Tristiropsis obtusangula* (USFWS 2007).

Food capture and consumption. Foraging appears to be generally similar to that of the Bridled White-eye (Craig 1989, Craig and Beal 2002) although foraging flock sizes are generally much smaller (Craig and Taisacan 1999). Based on 116 observations in 1998–1999, the most commonly used foraging motion was gleaning, followed by probing and hover/sallying (Amidon 2000).

Diet

Major food items. Although appearing to be primarily insectivorous, birds have been observed feeding on fruits of *Pipturus argenteus* and *Macaranga thompsonii* and probing the flowers of *Elaeocarpus joga*, *Hernandia labyrinthica*, *Macaranga thompsonii*, *Persea americana*, *Premna obtusifolia* and *Eugenia thompsonii* (USFWS 2007). Flower probing by white-eyes can indicate nectarivory or gleaning of insects from the interior of flowers (RJC personal observation).

SOUNDS AND VOCAL BEHAVIORS

Vocal Array

Songs. There has been little study of the vocal behavior of the Rota White-eye. Songs are a discontinuous series of calls produced in an abrupt manner. Rota birds' calls are buzzy than the calls of *Z. conspicillatus* (Amidon 2000).

Calls. Calls are described as a harsh, rolling low-pitched *tsheip*, a buzzy *zee-zee-zeee-e-e* and a less buzzy *see-tseep* (Pratt et al. 1987). The *tsheip* call is most commonly heard. Scolding alarm calls, which are series of the *tsheip* calls, are also given particularly in response to the presence of predatory Mariana Kingfishers (*Todiramphus albicilla*).

Social context and presumed function of vocalizations. The frequent calling among foraging flock members indicates that these function primarily as contact calls (RJC personal observation).

BEHAVIOR

Social and Interspecific Behavior

Degree of sociality. Much like *Z. conspicillatus* (Craig 1989, Craig and Beal 2002), the Rota White-eye is a social, flocking, highly vocal species of the forest canopy, which it frequently flies above. From 1988–1991, maximum flock size dropped from 23 to

ca. 10, although small groups of 2–3 birds were frequent (Craig and Taisacan 1994). Decline in flock size has been linked to population decline (Jenkins 1983, Craig 1989). In 1990–1992, based on observation of frequent food begging, flocks appeared to be composed of related individuals. Flock members occurred in the same vicinity and no birds appeared to be present in identical habitat between existing flocks. These observations indicate that the species is relatively sedentary, inhabits a home range, and lives in family groups or extended families (Craig and Taisacan 1994). In 1998–1999, >20% of social behaviors were of mutual preening or allopreening. Much as has been observed for *Z. conspicillatus* (Craig 1996), in 1998–1999 foraging birds were observed associating with 1–2 Micronesian Rufous Fantails (*Rhipidura versicolor*) 5% of the time. Foraging groups of 2–3 birds occurred 53% of the time. Flocks of up to 14 birds were observed twice and 18% of observations were of groups of 4–5 individuals (Amidon 2000).

Predation

Kinds of predators. The native Mariana Kingfisher (Marshall 1949, Craig 1989, 1996) and introduced Black Drongo (Maben 1982, Amidon 2000) have been reported to harass and prey upon white-eyes. Mobbing, scolding and alarm calls are often directed at the Mariana Kingfisher by *Z. conspicillatus* (Craig 1996). Possible additional non-native predators include rats (*Rattus* spp.), feral cats (*Felis catus*) and monitor lizards (*Varanus indicus*).

BREEDING

Phenology

Breeding has been reported in December–January and March–August in both the wet and dry seasons (Amidon et al. 2004, USFWS 2007). It is unclear whether there is a seasonal peak in breeding, although *Z. conspicillatus* shows evidence of having a dry season breeding peak (Craig 2021a).

Nest site

Site characteristics. Located nests were in *Aca-cia confusa* ($n = 3$), *Elaeocarpus joga* ($n = 7$), *Hernandia labyrinthica* ($n = 9$) and *Merrilliodendron megacarpum* ($n = 27$) at 150–460 m elevation. Distance of nests from the ground was 2.5–12.8 m (mean = 7.7 m, $n = 23$), height of nest trees was 3.3–14.6 m (mean = 10.1 m, $n = 18$), the dbh of nest trees was 2.3–60.2 cm (mean = 28.2 cm, $n = 19$) and distance of nests from the tree trunk was 0.8–6.7 m (mean = 3.0 m, $n = 19$) (Amidon et al. 2004, USFWS

2007).

Nest

Dimensions. A June 1993 nest was 50 mm high, 70 mm in total diameter, had an interior diameter of 50 mm and was 30 mm deep (Lusk and Taisacan 1997). Four nests measured in 1999 were 40.0 ± 1.0 mm high, 59 ± 0.7 mm wide and with an internal diameter of 45.9 ± 0.7 mm and depth of 28.0 ± 1.0 mm (Amidon et al. 2004).

Structure and composition. Four 1999 nests were cup-shaped, composed of *Asplenium* rootlets, woven grass or *Pandanus* fibers, spider webs, light green moss and a yellow cottony material. The inner cup was of woven grass or *Pandanus* fibers, and materials from previous nests had been recycled into new nests (Amidon et al. 2004).

Eggs

Size. Egg ($n = 2$) mean measurements were 17.1 x 13 mm (Yamashina 1932).

Color and surface texture. Eggs are light blue and unmarked (Amidon et al. 2004).

Clutch size. Based on seven nests, clutch size is 1–2 (Amidon et al. 2004).

Incubation

Incubation period. Based on observations of seven active nests, both the incubation and nestling period are 10–12 days (Amidon et al. 2004).

Parental behavior. Adults share in incubation (Amidon et al. 2004).

Parental care. Adults share in brooding and feeding of nestlings and eat fecal sacs. Post-fledging parental care lasted at least 8 days (Amidon et al. 2004).

Fledgling stage. The fledgling period is at least eight days (Amidon et al. 2004).

DEMOGRAPHY AND POPULATIONS

Population Status

In the 1940s, the Rota White-eye was described as numerous (Baker 1948, 1951). Into the 1950s, island residents still reported it to be widespread and common (Engbring et al. 1986, Craig and Taisacan 1994, USFWS 2007, E. Taisacan pers. comm.). The first evidence of a population decline occurred in 1969, when observers found no birds (Eldridge 1969). By 1976, birds appeared to have become essentially restricted to the high elevations of the Sabana plateau (Pratt et al. 1979).

The first quantitative population survey was performed in 1977, when 48 birds were detected along 6.9 km of modified Emlen (Emlen 1977) tran-

sects through primarily forested landscapes. A population density of 224.8 birds/km² was estimated and the species was ranked as rare (Ralph and Sakai 1979), although there was no discussion of the species' island-wide distribution. If this density measure refers to only the island's 59.6 km² of forested landscape, then a total population estimate of 13,398 results. In 1982, the analytically superior variable circular plot (VCP) technique was used to survey Rota birds throughout the island, which yielded a density estimate of 183 birds/km² and total population estimates of 10,763 (Engbring et al. 1986). By 1987, a reduction in detections/station of 26% occurred from 1982, although this decline was attributed to poor survey conditions (Engbring 1987). From 1989 to 1991, VCP counts showed a statistically non-significant trend toward declining counts. By 1991, counts yielded population estimates of <300–1,500 (Craig and Taisacan 1994). In 1996, surveys estimated a population of 1,167 and 1998–1999 surveys estimated a population of 1,092—a 90% decline from the 1982 estimate (USFWS 2007).

Between 1982 and 2012, 12 major population surveys were conducted using VCP, although observers, month of survey and details of methodology have differed enough to make examination of trends to be of uncertain reliability. There can be substantial differences in observer perception and seasonal changes might occur in species detectability, although analysis of *Z. conspicillatus* VCP surveys showed little evidence of seasonal variation in density estimates (Craig 2021b). Based on a reanalysis to help improve comparability among surveys, the 1982 population estimate was 14,963 (95% CI = 8,741–18,487) and, although the population appeared to decline through the 1990s, it increased by 2012 to 14,384 (95% CI = 5,620–20,961), which yielded moderate evidence of a fluctuating but overall stable trend, perhaps since the 1970s. The species has not been detected on counts outside of the Sabana area during these 30 years (Camp et al. 2015).

Disease and Body Parasites

As part of an effort to establish a captive breeding program in 1993 and 1995, 20 birds were screened for avian pox, avian malaria, and other diseases. No evidence of disease was found, although disease has been found in Saipan *Z. conspicillatus*, albeit without obvious effect on populations. A potential threat from West Nile virus also exists, as other *Zosterops* have proven susceptible to this disease, although to date this virus has not been detected in the Mariana Islands (USFWS 2007).

Causes of Mortality

Typhoons are a likely cause of periodic population declines in white-eyes, as such storms have been

reported to reduce populations in Caribbean island birds due to both direct and indirect effects (Askins and Ewert 1991, Wiley and Wunderle 1993). Indeed, on Rota the abundance of the Mariana Crow, Philippine Collared Dove (*Streptopelia dussumieri*), and Micronesian Rufous Fantail have shown significant relationships with cyclonic events (Ha et al. 2012) and Rota White-eye nest failure due to a typhoon has been confirmed (Amidon 2000). Although the species has evolved in landscapes that are periodically typhoon-damaged, when populations are small, all sources of mortality become important (Craig 1999).

Video surveillance of six active Rota White-eye nests in 2003, 2004 and 2005 revealed that abandoned eggs in one were scavenged by a rat (*Rattus* spp.) and another nest was preyed upon by a Mariana Crow (*Corvus kubaryi*) (Berry and Taisacan 2008). Nestling predation by unknown predators also has been documented, and an adult or juvenile was preyed upon by a Black Drongo. Another potential predator, the Brown Treesnake (*Boiga irregularis*) is not known to be established on Rota, but it has decimated bird populations on neighboring Guam (Amidon 2000, USFWS 2007). Rats, monitor lizards (*Varanus indicus*) and cats (*Felis catus*) are not known to be major predators on tree nesting birds in the Marianas, although the native Micronesian Starling (*Aplonis opaca*) and Mariana Kingfisher are documented to be predators on nests of other forest birds (Sachtleben 2005). Even though such native birds may prey upon the nests of Rota White-eyes, these species have co-evolved and coexisted with white-eyes for millennia, so such predation would seem to be unlikely to promote a substantial population decline. However, increases in kingfisher and starling abundance were observed to be concurrent with a decline of white-eyes along four transects on the Sabana from 1982 and 1994 (USFWS 2007), although more recent data demonstrate that kingfishers have undergone a long-term decline (Camp et al. 2015). Still, when populations become low, all sources of mortality can have important effects on a species' survival.

CONSERVATION AND MANAGEMENT

Conservation Status

The Rota White-eye is listed as Critically Endangered by BirdLife International, according to IUCN threat criteria, in which category it has been since 2000 (Stattersfield and Capper 2000, Butchart and Stattersfield 2004). The species was also listed as federally endangered in 2004. It has a recovery priority of 2 on a scale of 1 (highest) to 18 (lowest), reflecting a high degree of threat, strong prospects for recovery, and its taxonomic status as a full species. (Anonymous 2004, USFWS 2007).

Effects of Human Activity

Habitat loss and degradation. In 1946, when the Rota White-eye was common and widespread, only ca. 25% of Rota was covered by well-developed forest that was broken into small parcels or located along steep slopes. Much of the island's forest was of medium stature and degraded by logging and bombing during World War II (Fosberg 1960). By 1984, 62% of the island had regenerated to forest, although much of this was altered. The majority of the mature native forest was found along the steep slopes leading to and at the summit of the Sabana plateau, with the forest on lower elevation, level portions of the island being mostly secondary growth. Low canopy but well-developed more xeric native forest occurred on low terraces and coastal strand near the ocean. Lower canopy native forest also occurred in the interior Sabana (Falanruw et al. 1989). The most recent estimate of forest cover is 67%, with 79% of this being native forest. In level areas planted to sugarcane (*Saccharum officinarum*) prior to World War II, second growth comprised of mixed introduced and native trees constituted 13.0% of forest cover, with many native species aggressive competitors with aliens (Craig 1994). Areas of planted crop-producing trees, termed agroforest, accounted for 5.8% of forest area, and 1.8% was low coastal strand forest that occurred principally along the north-central coast (Donnegan et al. 2011). Hence, the trajectory of forest cover and white-eye populations has been largely opposite, indicating that habitat loss is not the principal factor limiting populations.

One exception to this general pattern is that the forests of the Sabana plateau, in which the entire population of the Rota White-eye survive, have been subjected to repeated typhoon damage. Especially mature native forest in this region—the habitat holding the highest density of birds—has been degraded (Fancy and Snetsinger 2001, USFWS 2007). Although the extent of recent changes has not been documented, it appears that large areas of mature native forest have been converted into perhaps less suitable *Pandanus tectorius* thickets (although Yamashina (1932) found a nest in *Pandanus*). These thickets, along with browsing by introduced Philippine deer (*Cervus mariannus*) and Cuban slugs (*Veronicella cubensis*), may be impacting regeneration of more diverse forest (USFWS 2007).

Effects of invasive species. Although the Rota White-eye co-evolved with the native avian predators the Mariana Kingfisher, Mariana Crow, Micronesian Starling, and possibly other now extinct species, the introduction of the alien avian predator, the Black Drongo, presents a new element within the Rota environment. It was introduced to Rota in 1935 to control agricultural pests. It 1) did not become abundant on Rota until the 1960s—the time when the decline in Rota White-eye populations was first noted, 2) its

distribution shows an inverse relationship with that of the white-eye, with 1982 drongo populations of 29/km² on the Sabana plateau, where white-eyes are still present, and with an average of 76/km² in the lowlands, where white-eyes are absent (Engbring et al. 1986), 3) it is known to be a predator of birds in the Marianas and 4) Rota White-eyes are particularly susceptible to drongo predation because they are within the prey size range of drongos, they feed in the exposed microhabitats of the upper tree canopy (Fig. 2), and they fly in flocks above the forest canopy where drongos might seize them (Craig 1999, Craig and Taisacan 1994), as aerial foraging is the principal strategy used by drongos (Bilal et al. 2020). Moreover, the also small Micronesian Rufous Fantail, known to be preyed upon by drongos, shows much lower densities on Rota compared with those on other Mariana Islands (Engbring et al. 1986, Camp et al. 2009, 2012, 2015). In this case, the Micronesian Rufous Fantail inhabits the forest interior, infrequently entered by drongos, so its lower susceptibility to predation may account for its still widespread distribution (Craig 1999).

Notably, overall drongo populations on Rota declined from 1982 to 2012, during which time white-eye numbers declined and then increased, although Sabana drongo population trends showed weak evidence of a decline (Camp et al. 2015). This may indicate that there has been a lag in the white-eye population response to a drongo decline, as is typical in predator/prey dynamics, particularly in bird species with low clutch size, although more likely it provides evidence that greater than one factor is influencing white-eye populations.

Pesticides and other contaminants/toxics.

There is no clear evidence linking pesticides to Rota White-eye populations, although malathion was sprayed on Rota in 1989 to control the melon fly (USFWS 2007). However, survey data had by 1989 already shown a substantial and consistent decline since 1982 (Craig and Taisacan 1994), so pesticides appear unlikely to have been the cause.

Management

Conservation areas. In 1994, part of the Sabana plateau was designated as a wildlife conservation area. In 1996, a management plan for the area was developed (USFWS 2007).

Conservation measures and habitat management. In 1991, two Commonwealth of the Northern Marianas (CNMI) Division of Fish and Wildlife biologists and four Rota Police Department officers initiated a pilot effort to control the Black Drongo. Using a total of 1,350 rounds of shotgun ammunition, they shot 6.1 birds/man-hour, achieved a kill/shot rate of 81%, and found that they could routinely shoot birds to >50 m. In eight mornings, they eliminated 1,100 drongos, or 20% of the estimated

(Engbring et al. 1986) population. The effort was concentrated on the Sabana plateau, where drongos living near white-eye flocks were preferentially removed. Hunters also took advantage of the drongos' propensity for congregating at sites where large insects are numerous, including the island dump and at the airport during grass mowing. Based on their results and the assumption that removing birds would become more difficult with time, they estimated that 40 mornings of effort over two months would be sufficient to reduce the drongo population by 80–90%, thereby reducing numbers to a level at which they likely posed little threat to white-eyes. Follow-up shooting was planned to prevent population resurgence and, ultimately, to eliminate drongos from the island. Elimination of this alien species from the island ecosystem was in itself deemed to be a valid goal even if it did not result in the recovery of the white-eye population. However, despite the project's early promise, it was never initiated (Craig 1999).

In 1993 and 1994, CNMI biologists conducted another study to determine if firearm removal of drongos would increase white-eye abundance. This effort was abandoned when it was deemed too difficult, however. In 2004, efforts were also undertaken to develop a drongo trap, although the trap was destroyed in a typhoon and it was not rebuilt (USFWS 2007).

A captive breeding program was initiated in 1993, with the initial goal of establishing 10 pairs of birds in captivity. Five female and 15 males mist netted in 1993 and 1995 were transferred to the National Zoological Park. Three birds soon died of capture-related stress and two died of bacterial infections. By 2005, the captive population consisted of six males, with the last female dying in 2005. Eggs were produced by three females, but only two females produced offspring and no parent-reared birds reached maturity. One male was successfully hand-reared. Diet was found to be responsible for the poor success, as mortality was related to abnormal nestling bone development. Efforts to manipulate calcium and vitamin levels and use of ultraviolet light were unsuccessful at correcting this issue (Craig 1999, USFWS 2007).

PRIORITIES FOR FUTURE RESEARCH

1. Researching methods to control or eliminate Black Drongos from Rota is a top priority, as removal of an alien invasive species from an island environment is always desirable regardless of its value for Rota White-eyes. Doing so would also permit a definitive evaluation of the extent to which drongos have affected the range and population of this and other native bird species.
2. Researching methods to expand the extent of mature native forest is also a high priority. On neighboring Saipan and Aguiguan, densities of *Z. conspicillatus* and other forest species were far greater in native forest than in alien habitats, indicating that native forest provides superior habitat for them (Craig 2021b). Because typhoons will periodically damage some forests, increasing their extent will help to improve the probability that sufficient mature forest will persist and thereby provide optimal habitat conditions for this and other forest bird species.
3. Obtaining more extensive wet and dry season life history, population biology and foraging ecology data on the Rota White-eye will assist with evaluating strategies for population recovery. In particular, studies aimed at documenting nest survivorship, survivorship of age classes of individuals and agents of mortality will pinpoint the extent to which individual factors limit populations.
4. Developing protocols and identifying locations for establishing new island populations of Rota White-eyes is recommended, as doing so will offset the risk of local extinction.
5. Establishing a captive population of *Z. conspicillatus* to act as a surrogate for *Z. rotensis* in developing techniques for successfully maintaining individuals in captivity.

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