Population size estimation of breeding Red-faced and Grace's Warblers in pine woodlands of New Mexico: 2016 Report

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Introduction

The Red-faced Warbler (*Cardellina rubrifrons*) and the Grace's Warbler (*Setophaga graciae*) are New Mexico Department of Game and Fish (NMDGF) Species of Greatest Conservation Need (NMDGF 2016), and they are current priority nongame bird species. However, much of the information necessary for effective conservation and management is lacking. Population estimates are limited for Grace's Warblers and speculative for Red-faced Warblers. Information about breeding biology for these two species is also limited, and for the Red-faced Warbler, no specific information exists for New Mexico (Martin and Barber 1995, Stacier and Guzy 2002). Nevertheless, both warbler species face high risk as they breed in pine habitats that have experienced loss and degradation over time. This project was conducted to establish baseline population size estimates of breeding Red-faced and Grace's Warblers in mountain ranges of New Mexico. This will allow for future identification and documentation of status and trends and aid NMDGF with management decisions regarding these species.

The breeding distributions for both the Red-faced and Grace's Warbler are primarily limited to New Mexico, Arizona, and the Sierra Madre Occidental mountains of Mexico; thus New Mexico serves an important role and has a high stewardship responsibility for these limited range species. The ranges of these two species overlap in parts of New Mexico, including in the San Mateo, Magdalena, Sacramento, and Gila mountain ranges. Grace's Warblers are additionally present in most mountain ranges of central and northern New Mexico. Both species occupy pine-oak woodlands at elevations from 1,800 – 2,800 m (5,900 – 9,190 ft). Red-faced Warblers additionally utilize habitats including Douglas fir (*Pseudotsuga menziesii*), spruce (*Picea*), or aspen (*Populus*) trees while the Grace's Warbler is considered a pine specialist, most commonly occurring in ponderosa pine (*Pinus ponderosa*) woodlands in New Mexico.

Size of the New Mexico population for both of these species is unknown (NMPIF 2007). Grace's Warblers are more common, with a larger range, and are encountered more frequently on surveys such as the North American Breeding Bird Survey (BBS) than Red-faced Warblers (Sauer *et al*. 2014). Red-faced Warblers are detected on very few BBS routes, and their low detection rates prevent population size estimates using this method. Both Red-faced and Grace's Warbler are listed as a national and Southwest Region Bird of Conservation Concern by the U.S. Fish and Wildlife Service (USFWS 2008). New Mexico Partners in Flight ranks both species as high conservation priority with high vulnerability as Level 1 Species of Conservation Concern (NMPIF 2007). Grace's Warblers' vulnerability is due to sharp population declines in New Mexico and Red-faced Warblers' ranking stems from having a small distribution and small population size (NMPIF 2007). It is suggested these species are relatively intolerant of disturbance and habitat degradation (Martin and Barber 1995, Stacier and Guzy 2002). Potential factors influencing Red-faced and Grace's Warbler populations in New Mexico include habitat loss and alteration due to timber harvest and grazing, as well as recent loss from fire and current risk of catastrophic fire (NMDGF 2016). Therefore, it is important to establish baseline information on breeding density, abundance, distribution, and population sizes in order to understand how these species are affected by potentially harmful activities and stressors.

In order to document population sizes of these species over the vast state of New Mexico, surveys were spread geographically over three years, and were designed to encompass the state-wide breeding ranges and significant mountain ranges of New Mexico. Surveys in 2016 were conducted in the San Juan, Jemez, Sangre de Cristo, and Sacramento mountain ranges. Previous surveys were conducted in 2015 in the Sandia, Manzano, Magdalena, San Mateo, Jemez, and

Zuni mountain ranges. Future surveys will take place during the 2017 breeding season in the Gila mountain region of southwestern New Mexico. Together, these surveys will build towards estimating state-wide population sizes for these two species.

Methods

Site Selection

The 2016 surveys were conducted in five project areas located in mountain ranges in north central and south central New Mexico (Maps 1–2). These project areas included: the Sacramento Mountains (Map 3) in the Lincoln National Forest, the Sangre de Cristo (Map 4) and Jemez (Map 5) mountains in the Santa Fe National Forest, and the San Juan (Map 6) and Sangre de Cristo (Map 7) mountains in the Carson National Forest. All surveys were conducted on public lands and required no infrastructure or ground disturbance. Project areas were determined based on identification of suitable habitat for breeding Red-faced and Grace's Warblers using range maps, habitat maps, GIS layers, published literature, BBS sightings, eBird sightings, and general knowledge of the species. Within project areas, survey sites were selected in areas where approximately 2 miles of surveyable habitat was present, where land-ownership was public, and where ponderosa pine habitats, especially with oak associations, were present along part of or the entire survey route. Survey routes were placed most frequently along drainages, but also on trails or lightly used roads. Survey routes were conducted at elevations between 2,209 – 2,791 m (7,247 – 9,156 ft). Four survey routes were selected in each project area. A total of 20 survey routes were sampled.

Survey Methodology

Point count surveys were conducted between May 1 and June 30 and followed survey guidelines outlined in Ralph et al. (1993, 1995). Two surveys were conducted at each survey route, and the two sampling periods at each route were spaced at least 10 days apart. Surveys were not conducted during inclement weather, including periods with winds > 10 mph or prolonged rain. Surveys began at sunrise and concluded at 10 AM. Survey routes varied in length according to access, terrain, and habitat, but were approximately 2.5 miles long and typically contained 18-20 points. Point count locations were recorded using GPS receivers (UTM zone 13 in meters, NAD 1983 datum). Points were spaced 200 m apart along each transect, and all avian species either seen or heard within a 100 m radius of each point were recorded; detections outside this radius were excluded. Each point was surveyed for 10 minutes, and the 10 minute survey period was divided into three sequential time intervals (3 min, 2 min, and final 5 min) in order to determine detection probability (Farnsworth et al. 2002). Birds were recorded separately during each time interval, along with detection type (auditory, visual, or both). Location information was recorded for the two focal species and all other Species of Greatest Conservation Need detected during surveys. A habitat description was also recorded at each point location.

Analysis

Detection probability ($\hat{p}$) for Grace's and Red-faced Warblers was determined according to time removal model methods described in Farnsworth et al. (2002) and was calculated using Program SURVIV (White 1992) and R (R Core Team 2013). Density was calculated using $\hat{p}$ and total survey area. Detection probabilities and densities were calculated separately for each project area, and were made only for singing birds; visual detections were not included in these analyses. Differences in detection probabilities between survey bouts were tested using student's two-sample t-tests. Population estimates were extrapolated across each focal mountain range project area from the density of the target species, calculated for each project area, and the total estimated area of suitable habitat within that project area. Because density was calculated from singing males only, density was doubled for the population estimate to reflect the assumption that the males were paired.

Suitable habitat was estimated within each mountain range using the best, large-scale habitat information available for the area. GIS layers were acquired from the U.S. Forest Service for the Santa Fe (http://www.fs.usda.gov/detail/r3/landmanagement/gis/?cid=stelprdb5203736), Carson (https://www.fs.usda.gov/detail/r3/landmanagement/gis/?cid=stelprdb5202766), and Lincoln (https://www.fs.usda.gov/detail/r3/landmanagement/gis/?cid=stelprdb5203236) National Forests. We quantified vegetation and landscape characteristics using mid-scale, extant vegetation dominance type and canopy cover, and 30-m National Elevation Dataset digital elevation models. Remote sensing data (National Land Cover Data; NLCD) available from the U.S. Geological Survey was also considered, but NLCD data only defines very broad categories of forest vegetation types, including evergreen, deciduous, and mixed forest types. Forest Service GIS layers provided the best resolution for smaller-scale habitat features. Because we estimated $\hat{p}$ separately for each mountain range, we also estimated total suitable habitat area separately for each range. We estimated total suitable habitat for each ranger district, or for each separate unit when ranger districts were made up of distinct units. For example, the Espanola Ranger District in the Santa Fe National Forest contains four discrete units, one containing the portion of the Jemez Mountains where our surveys were conducted, and the other units encompassing the surrounding area where no surveys were conducted. Therefore, suitable habitat estimates represent the area of suitable habitat within the surveyed ranger district or within the discrete unit that we surveyed.

To estimate total suitable habitat for each range, we included mid-scale vegetation dominance types defined in the Santa Fe and Carson National Forest as: ponderosa pine mix, upper deciduous-evergreen forest tree mix, and spruce-fir (*Picea, Abies*); and in the Lincoln National Forest as: ponderosa pine mix, deciduous-evergreen tree mix, shade intolerant evergreen tree mix, and upper evergreen forest tree mix. Because the two warbler species occupy mature ponderosa habitat, we only included suitable habitat types with $\geq 30\%$ canopy cover. Finally, because Grace's Warblers breed between 1,800 – 2,700 m (Stacier and Guzy 2002), and Red-faced Warbler breed between 2,000 – 2,800 m (Martin and Barber 1995), we also excluded any habitat above 2,820 m. All mapping analysis was completed using ESRI ArcMap 10.4.

To examine avian community structure, abundance and diversity of all recorded species was quantified by calculating species richness (S; total number of species detected), total number of individuals of all species, and total abundance of all species (individuals/area). Shannon's diversity index (H) was derived from: $H = -\sum [(p_i)(\ln p_i)]$, where p_i is the proportion of individuals of the *i*th species. A measure of evenness (E) of species distribution was calculated

from Shannon's index and species richness using the equation: E = H/lnS. Relative abundance ($p_i = n_i$/N, where n_i is the number of individuals of the ith species and N is total number of individuals of all species) was calculated to describe the proportion of total individuals comprised of any single species, and was used to describe species relatively common or rare within the study area. Differences in abundance and diversity among study sites were tested using one-way ANOVA. Statistical analyses were performed in R version 3.0.1 (R Core Team 2013) and were evaluated at an α-level of 0.05.

Results

Suitable Habitat

We estimated that 325,024 ha of suitable habitat are present in the five project areas that we surveyed (Table 1).

Table 1. Total size of survey areas, and extent and breakdown of suitable habitat within these areas. All sizes are reported in hectares.

Survey area (mountain range)	Total size	Suitable habitat	Ponderosa pine mix	Spruce-fir	Deciduous - evergreen tree mix	Evergreen tree mix
Sacramento	222,069	65,579	6,320	*	4,961	54,298
S. Sangre de Cristo	210,367	86,280	57,898	19	28,363	*
Jemez	147,923	62,628	43,584	458	18,586	*
San Juan	270,407	66,743	48,006	332	18,406	*
N. Sangre de Cristo	137,328	43,793	22,569	71	21,153	*

* Each forest uses slightly different habitat designations in their GIS mapping products. Spruce-fir designation is not used on Lincoln National Forest and evergreen tree mix is not used on Santa Fe or Carson National Forest.

Target Species Density and Population Estimate

Grace's Warblers were detected in all of the sampled mountain ranges, along every survey route, and across the entire range of elevations surveyed (2,209–2,791 m [7,247–9,156 ft]). Red-faced Warblers were detected only in the Sacramento Mountains, and only on two of the four routes in this project area at elevations ranging from 2,255 – 2,494 m (7,397–8,181 ft). Of the 533 Grace's Warbler detections, 521 were auditory, 3 were visual, and 9 were both auditory and visual. 64% of Grace's Warbler detections occurred within the first 3 minute time interval. Of the 17 detections of Red-faced Warblers, 15 were auditory, 0 were visual, and 2 were both auditory and visual. 59% of Red-faced Warbler detections occurred within the first 3 minute time interval.

Detection probabilities were estimated separately for each project area. Detection probabilities were generally high for both warbler species, ranging overall from 0.91-0.99 for Grace's Warbler and 0.87 for Red-faced Warbler (Table 2). Detection probability ($\hat{p}$) did not vary between survey bouts for Grace's Warblers ($t_{4.3} = 1.355$, $P = 0.243$) or for Red-faced

Warblers ($t_{2,0}$ = 1.897, P = 0.197). Therefore, we used the combined detection probability from both survey bouts to estimate density for both species.

Density of target species varied among mountain ranges (Table 2). The highest Grace's Warbler density was recorded in the San Juan Mountains (0.31 ± 0.03 singing birds ha^{-1}) and the lowest density was recorded in the Sacramento Mountains (0.14 ± 0.01 singing birds ha^{-1}). Red-faced Warblers were recorded at a density of 0.08 ± 0.03 singing birds ha^{-1} in the Sacramento Mountains. Across all five project areas that we surveyed, we estimate the population size of Grace's Warblers to be between 135,199 and 165,503 individuals, and Red-faced Warblers to be between 3,521 and 17,685 individuals.

Table 2. Detection probability ($\hat{p}$), density (D), total suitable habitat, and population estimates with upper and lower limits based on 95% confidence intervals for Grace's (GRWA) and Red-faced Warblers (RFWA) in the five project areas surveyed in New Mexico in 2016. Densities were estimated for singing males, therefore population estimates reflect 2(D)*suitable habitat (see Table 1 for habitat estimates).

Project area	Species	$\hat{p}$ ± SE	D ± SE (singing birds ha^{-1})	Total suitable habitat (ha)	Population estimate	Population estimate (95% CI)
Sacramento	GRWA	0.93 ± 0.06	0.14 ± 0.01	65,579	18,165	15,500 – 20,831
S. Sangre de Cristo	GRWA	0.96 ± 0.04	0.20 ± 0.01	86,280	34,770	31,553 – 37,988
Jemez	GRWA	0.99 ± 0.01	0.25 ± 0.004	62,628	31,662	30,695 – 32,630
San Juan	GRWA	0.91 ± 0.07	0.31 ± 0.03	66,743	41,278	34,481 – 48,076
N. Sangre de Cristo	GRWA	0.97 ± 0.03	0.28 ± 0.009	43,793	24,474	22,971 – 25,978
Total	**GRWA**				**150,351**	**135,199 – 165,503**
Sacramento	RFWA	0.87 ± 0.26	0.08 ± 0.03	65,579	10,603	3,521 – 17,685
S. Sangre de Cristo	RFWA	-	0	86,280	-	-
Jemez	RFWA	-	0	62,628	-	-
San Juan	RFWA	-	0	66,743	-	-
N. Sangre de Cristo	RFWA	-	0	43,793	-	-
Total	**RFWA**				**10,603**	**3,521 – 17,685**

Species Diversity and Abundance

Ninety-two species were recorded during surveys (Appendix A). Species richness was highest in the Jemez Mountains (n = 65 species) and was lowest in the southern Sangre de Cristo Mountains (n = 53 species). Examining diversity metrics, there was no significant difference in species richness ($F_{4,15}$ = 2.150, P = 0.125), Shannon's index ($F_{4,15}$ = 1.752, P = 0.191), or evenness ($F_{4,15}$ = 0.692, P = 0.609) among the five project areas.

Including all bird species, 9,314 bird records were obtained during the surveys (Appendix B). Avian abundance was highest in the northern Sangre de Cristo Mountains (4.5 birds ha^{-1}) and lowest in the southern Sangre de Cristo Mountains (3.4 birds ha^{-1}). Examining measures of abundance, there was no significant difference in the total number of individuals ($F_{4,15}$ = 2.109, P = 0.130) or total abundance ($F_{4,15}$ = 1.213, P = 0.346) among the five project areas.

In the Sacramento Mountains, the American Robin, Dark-eyed Junco, and Steller's Jay were the most abundant birds. Approximately half (53%) of the total individuals were comprised

of American Robin, Dark-eyed Junco, Steller's Jay, Mountain Chickadee, Common Raven, Black-headed Grosbeak, Western Tanager, and Northern Flicker (ordered from most to least abundant).

In the southern Sangre de Cristo Mountains, the Mountain Chickadee, Pine Siskin, and Red-breasted Nuthatch were the most abundant birds. 50% of the total individuals were comprised of Mountain Chickadee, Pine Siskin, Red-breasted Nuthatch, Western Tanager, Grace's Warbler, Hermit Thrush, Northern Flicker, and Yellow-rumped Warbler.

In the Jemez Mountains, the Spotted Towhee, Grace's Warbler, and Black-headed Grosbeak were the most abundant birds. 50% of the total individuals were comprised of Spotted Towhee, Grace's Warbler, Black-headed Grosbeak, Northern Flicker, Green-tailed Towhee, American Robin, Western Tanager, Dark-eyed Junco, and Steller's Jay.

In the San Juan Mountains, the American Robin, Grace's Warbler, and Western Tanager were the most abundant birds. 51% of the total individuals were comprised of American Robin, Grace's Warbler, Western Tanager, Dark-eyed Junco, Pine Siskin, Northern Flicker, Chipping Sparrow, Ruby-crowned Kinglet, Black-headed Grosbeak, and Mountain Chickadee.

In the northern Sangre de Cristo Mountains, the Pine Siskin, Western Tanager, and Grace's Warbler were the most abundant birds. 51% of the total individuals were comprised of Pine Siskin, Western Tanager, Grace's Warbler, American Robin, Dark-eyed Junco, Common Raven, Yellow-rumped Warbler, Western Wood-Pewee, and Hermit Thrush.

Species of Greatest Conservation Need

Sixteen Species of Greatest Conservation Need were recorded during surveys (Table 3, Appendix A). The number of species was highest in the San Juan Mountains (n = 12 species) and was lowest in the Sacramento and Jemez mountains (n = 9 species).

Table 3. Number and location of Species of Greatest Conservation Need recorded during 2016 surveys.

	Number of individuals				
Common Name	**Sacramento**	**S. Sangre de Cristo**	**Jemez**	**San Juan**	**N. Sangre de Cristo**
Black-throated Gray Warbler			2	1	
Cassin's Finch		1		3	1
Clark's Nutcracker		2	2	8	14
Common Nighthawk		2	3	5	14
Evening Grosbeak		24		10	1
Flammulated Owl	1				
Grace's Warbler	63	84	113	137	136
Mexican Spotted Owl	3				
Mountain Bluebird	7	3	4	3	
Olive-sided Flycatcher			9	12	4
Peregrine Falcon					1
Pygmy Nuthatch	9	29	23	60	75
Red-faced Warbler	17				
Virginia's Warbler	2	5	9	7	4
Western Bluebird	7	14	35	36	46
Williamson's Sapsucker	2	2		14	4
Total individuals of all SGCN	111	166	200	296	300
Total abundance of all SGCN (individuals/ha)	0.226	0.386	0.442	0.608	0.604
SGCN species richness	9	10	9	12	11

Breeding Behavior Observations

Breeding behaviors were occasionally observed during point count surveys. While not the primary goal of this study, incidental information was recorded and is summarized in Table 4.

Table 4. Incidental observations of breeding behavior recorded during 2016 point count surveys.

Date	Location	Waypoint	Species	Observation
5/12	S. Sangre de Cristo	SC-Ca4	Evening Grosbeak	2 males and 3 females interacting / courtship
5/26	Sacramento	L-Karr	Mexican Spotted Owl	2 owls calling early evening
6/3	Jemez	J-Ca19	American Kestrel	Male courtship flight and vocalization display
6/3	Jemez	J-Pi5	Western Bluebird	Cavity nest located in aspen snag, both adults observed feeding young
6/5	San Juan	SJ-Ja8	Plumbeous Vireo	Collecting and carrying nesting material
6/5	San Juan	SJ-Ma2	Western Bluebird	Cavity nest located in ponderosa pine, both adults observed feeding young
6/5	San Juan	SJ-Ma18	Warbling Vireo	Cup nest located in aspen, adult observed bringing food or nesting material to nest
6/5	San Juan	SJ-Ma19	Warbling Vireo	Cup nest located in aspen, adult observed at nest
6/6	San Juan	SJ-Ki16	Sharp-shinned Hawk	Display flight
6/7	N. Sangre de Cristo	SC-Amole	Golden Eagle	Pair of GOEA had territorial interaction with PEFA on cliff side
6/7	N. Sangre de Cristo	SC-Amole	Peregrine Falcon	Pair of PEFA had territorial interaction with GOEA on cliff side
6/7	N. Sangre de Cristo	SC-Os18	Common Nighthawk	2 individuals display courtship flight
6/8	N. Sangre de Cristo	SC-Tr16	Western Wood-Pewee	Collecting and carrying nesting material
6/12	Sacramento	L-Ru9	Red-tailed Hawk	2 juveniles calling from trees
6/12	Sacramento	L-Ka17	Cordilleran Flycatcher	Mossy cup nest located on ledge in ponderosa pine snag, adult observed bringing food or nesting material to nest
6/12	Sacramento	L-Ru17	American Robin	Nesting on evergreen tree
6/13	Sacramento	L-Sc16	Red-faced Warbler	Carrying prey
6/13	Sacramento	L-Pe10	Red-tailed Hawk	Juvenile food-begging
6/16	S. Sangre de Cristo	SC-La7	Hairy Woodpecker	3 individuals observed, possibly 2 males courtshipping after one female
6/16	S. Sangre de Cristo	SC-La13	Williamson's Sapsucker	Cavity nest located, both adults observed at nest
6/16	S. Sangre de Cristo	SC-La16	Northern Flicker	Cavity nest located, adult and two nestlings observed at the nest
6/19	Jemez	J-Ca9	Mountain Bluebird	Male and female observed together
6/19	Jemez	J-Pi3	House Wren	Nesting on tree
6/20	Jemez	J-Sa6	Cooper's Hawk	Juvenile food-begging
6/21	San Juan	SJ-Ja18	American Crow	Two fledglings calling at the top of a tree
6/21	San Juan	SJ-Ma10	Northern Goshawk	Carrying food - calling
6/22	San Juan	SJ-Cl6	Williamson's Sapsucker	Cavity nest located in aspen, both adults observed feeding young
6/22	San Juan	SJ-Cl8	Williamson's Sapsucker	Male and female observed on same tree
6/22	San Juan	SJ-Cl11	Williamson's Sapsucker	Male and female observed on same tree
6/22	San Juan	SJ-Cl16	Red-tailed Hawk	Juvenile observed
6/22	San Juan	SJ-Ki16	Dusky Grouse	2 adults and 4 hatchlings observed
6/23	N. Sangre de Cristo	SC-Os16	Sharp-shinned Hawk	Juvenile observed chasing a Northern Flicker
6/24	N. Sangre de Cristo	SC-Tr6	Grace's Warbler	2 warblers chasing each other at the top of a pine tree
6/24	N. Sangre de Cristo	SC-Tr11	Downy Woodpecker	Cavity nest located, both adults observed at nest
6/24	N. Sangre de Cristo	SC-Tr19	Downy Woodpecker	Cavity nest located, both adults observed at nest

Discussion

Habitat and Microhabitat

Grace's Warblers and Red-faced Warblers use largely similar habitats, occupying mature ponderosa pine forests in New Mexico. However, they specialize in ponderosa habitats to different degrees and vary in their specific habitat preferences. These differences should be considered when examining the results of this study. Grace's Warblers are characteristic of ponderosa habitats, and are 2-3 times more abundant in ponderosa habitats than in comparison areas (Carothers et al. 1973, *in* Block and Finch 1997). They rely heavily on pines for foraging activities (Szaro and Balda 1979). Grace's Warblers are found in forests with relatively high canopy closure (the average canopy closure was 46% in an Arizona study), and they are more strongly associated with ponderosa pine woodlands with Gambel's oak (*Quercus gambelii*) understories (Stacier and Guzy 2002). Grace's Warblers are often found in dry, park-like habitats and may occupy mesa tops and lower canyon bottoms (Stacier and Guzy 2002).

Red-faced Warblers also utilize ponderosa habitats, but do not use these habitats as exclusively as Grace's Warblers. Red-faced Warblers are associated with fir, spruce, Douglas fir, aspen, and maple (*Acer*) in addition to ponderosa pine. A ground-nesting species, Red-faced Warblers most frequently place nests at the bases of fir or maple trees and only rarely at the base of ponderosa pine, and they are commonly found in drainage bottoms (Martin and Barber 1995).

The two warbler species also show differences in their tolerance of disturbance and in their elevational range. Although both species are relatively intolerant of disturbance and habitat degradation (Martin and Barber 1995, Stacier and Guzy 2002), Red-faced Warblers use mature ponderosa forests in undisturbed or lightly disturbed areas, while Grace's Warblers use lightly to moderately disturbed ponderosa habitats (Szaro and Balda 1982). There is a large degree of overlap in the elevational ranges that these two species occupy, though Red-faced Warblers typically occupy a slightly higher and narrower range of elevations (Grace's Warbler: 1,800 – 2,700 m [Stacier and Guzy 2002], Red-faced Warbler: 2,000 – 2,800 m [Martin and Barber 1995]). In 2016, Grace's Warblers were detected across the entire range of elevations that we surveyed (2,209–2,791 m), while Red-faced Warblers were detected in a narrow range of elevations (2,255 – 2,494 m). However, examining 2015 survey results as the sample size of Red-faced Warbler detections was larger in 2015, both species occupied the wide range of elevations surveyed (Grace's Warbler: 2,065 – 2,779 m, Red-faced Warbler: 2,179 – 2,691 m).

Evaluation of Suitable Habitat

We estimated the extent of mature ponderosa pine and other appropriate habitat types for these two species using GIS map layers. These layers approximate the dominant vegetation type and the canopy cover for the areas that we surveyed. However, as discussed above, these two species utilize different microhabitats that cannot be differentiated using large-scale GIS layers. The basic habitat types used by these two species (ponderosa pine, Douglas fir, fir, spruce, and deciduous tree species) are similar, but each species shows a preference for one habitat, but not to the exclusion of the other habitat (i.e., Grace's Warblers in ponderosa, Red-faced Warbler association with fir and maple). For this reason, estimates of suitable habitat based on broad scale information will likely overestimate actual suitable habitat for both species. In order to more specifically determine total suitable habitat for these species, a large-scale vegetation

survey or large-scale interpretation of high resolution aerial photography would need to occur. To ground-truth GIS layers and differentiate smaller scale habitat features would be a very large undertaking and was beyond the scope of this project.

This study did not take into account certain habitat features that could impact habitat suitability, such as location on a slope, steepness of a slope, recent wildfire activity, or tree density. Survey routes were often located along canyons, with drainages varying in steepness from broad, park-like forests with shallow slopes to more incised, narrow drainages with steep slopes, and with point locations at the bottom, mid-slope, and along ridges or mesa tops. It is not known whether density of our target species varied according to location on a slope or steepness, and these two factors could be confounding. Location on a slope may play a role in determining presence for Red-faced Warblers, who may preferentially use steeper-walled canyon bottoms, where mesic tree species, such as maple or fir, are more likely to occur (Martin and Barber 1995). Grace's Warblers may use more park-like habitats or mesa tops, both of which are relatively flat habitats, and these habitats may occur both in drainage bottoms and on the uppermost slopes. There is no quantitative information that defines habitat use by location on a slope or steepness for these species. The presence or density of Grace's and Red-faced Warblers may be defined more by the microhabitat conditions that are created by steepness or location on a slope than by these factors intrinsically. Future studies may aim to determine whether density of Grace's and Red-faced Warblers are similar along drainage bottoms, mid-slope, and upper slopes, and whether steepness plays a differential role in defining occurrence or density.

Recent wildfires could also affect the availability of suitable habitat for these two species. Historically, wildfire has played an important ecological role in southwestern ponderosa pine forests. Frequent, low-intensity fires burned every 2-47 years (Fitzgerald 2005), clearing ground fuels, saplings, and shrub layers, but leaving mature trees intact. After decades of fire suppression, fuels accumulated, and present-day fires now burn at greater sizes and intensities and often result in catastrophic, stand-replacing fires (Fitzgerald 2005). The impact of fires on these two warbler species is not clear and should vary based on fire intensity. Two Arizona studies showed conflicting results: in one study, Grace's Warblers were more abundant in unburned areas (Overturf 1979, *in* Block and Finch 1997); in another study, they were more abundant in burned areas (Blake 1982, *in* Block and Finch 1997); fire intensity was not discussed.

The occurrence of wildfire in ponderosa pine forests in New Mexico does not necessarily result in loss of suitable habitat for the two warblers, but severe fires that destroy ground cover and small trees as well as mature trees will result in habitat loss. In calculating total suitable habitat for this study, we attempted to eliminate some habitat that had recently burned, but found the available GIS layers inadequate for determining whether suitable habitat had actually been lost. For example, in 2014, the Pino fire on the Jemez Ranger District burned approximately 4,300 acres. The boundary of this fire lies along one of our 2015 survey routes in Paliza Canyon, which was a route where we observed mature ponderosa pine and detected Grace's Warbler at nearly every point. However, the 2004 Trigo fire, which burned 14,000 acres in the Manzano Mountains, was a severe, stand-replacing fire within much of the burn area. This burn scar is mostly devoid of mature live trees and does not provide suitable ponderosa pine habitat for these species. However, in available GIS layers, only the fire boundaries, not the severity of fires, are displayed. This information does not accurately describe whether the habitat within fire boundaries is suitable for these species. Therefore, we did not attempt to exclude suitable habitat

from areas recently impacted by wildfire, though severe wildfire will certainly limit available habitat for these species.

Target Species Detection and Density

The variation in density of Grace's and Red-faced Warblers among the mountain ranges we surveyed may reflect the distributional limits of these two species, the availability of suitable microhabitat, and the quality of habitat. Grace's Warblers were detected on every survey route, although they occurred in varying densities. Density ranged from 0.14 ± 0.01 singing birds ha^{-1} in the Sacramento Mountains to 0.31 ± 0.03 singing birds ha^{-1} in the San Juan Mountains (Table 2). Grace's Warbler density was considerably lower in the Sacramento Mountains than in the other mountain ranges. Interestingly, this mountain range was also the only one where Red-faced Warblers were detected. The combined density of Grace's and Red-faced Warblers in the Sacramento Mountains was 0.22 singing birds ha^{-1}; a density much more similar to those recorded for Grace's Warblers alone in the four other project areas.

Though these species co-occur in pine-oak woodlands, they differ in microhabitat preferences, breeding sites, and foraging behaviors. These differences are likely to alleviate direct competition for resources. However, the similarities in habitat use for these two species could potentially be a limiting factor in ranges where both species occur and could in part explain lower Grace's Warbler densities in areas where Grace's and Red-faced Warblers co-occur. Alternatively, the Sacramento Mountains are on average drier and hotter than the other, northern ranges we surveyed. The drier nature of this mountain range could also limit total bird density, although we found no significant difference in total avian abundance and diversity among the mountain ranges that we surveyed.

We detected Red-faced Warblers in areas where they were previously known to breed, but did not detect this species outside of expected areas. Red-faced Warblers were recorded at a low density of 0.08 singing birds ha^{-1} in the Sacramento Mountains. This lower density may be due to the location of the mountains relative to the warbler's entire distribution; the Sacramento Mountains are at the eastern edge of this species' breeding range (NMPIF 2007). The northern limit of the Red-faced Warbler's breeding range extends into central NM. According to eBird, Red-faced Warblers have been sighted as far north as locations in the Sandia Mountains, at the Rio Grande Nature Center (RGNC) in Albuquerque, and in Galisteo, NM (eBird 2012). However, these detections occurred in April and May and are likely representative of migrant or vagrant individuals. Further, the RGNC and Galisteo do not offer suitable breeding habitat for this species. Regardless, Red-faced Warblers were not recorded during this project in the southern Sangre de Cristo Mountains, which is the project area site closest to Galisteo.

Study Limitations

This study estimated the population sizes of two forest-dwelling warblers based on density determined through survey data and estimation of suitable habitat area. There are, of course, limitations associated with a study of this nature. First, there are assumptions inherent in establishing detection probabilities and therefore densities. These assumptions are fully discussed in Farnsworth et al. (2002), but in summary are: the population of birds within the detection radius does not change during the point count (i.e., closed population), individuals are not double-counted, detection probability is constant throughout the point count, and birds are

correctly assigned to a distance category. Though these assumptions are likely to be violated to some degree, time-removal modeling is still one of the most robust methods available (Farnsworth et al. 2002). This method is appropriate for closed forest habitats, for surveys where most of the detections are by sound, and for focal species that have high singing frequencies (Farnsworth et al. 2002, Reidy et al. 2011, Golding et al. 2016). This method can produce robust estimates of population size and density when detection probabilities are high, when using fixed-radius counts, and when models incorporate heterogeneity (Farnsworth et al. 2005, Efford and Dawson 2009). In this study, focal species detections were almost exclusively auditory, focal species sang frequently, detection probabilities were high overall, fixed-radius counts were utilized, and models accounted for heterogeneity.

We estimated detection probability and density for Grace's and Red-faced Warblers within the areas that we surveyed. In extrapolating these estimates to larger areas that were not all surveyed, we make the following assumptions: our survey areas are indicative of habitat as a whole within each mountain range; the true density of these species is constant over the entire range of suitable habitat. We selected survey routes randomly, as long as they met certain criteria of general habitat type and overall length; therefore, routes should be fairly representative of habitat within a mountain range. However, having only four sampling sites per project area is unlikely to capture all of the habitat characteristics or variability present within each mountain range.

We have attempted to conservatively estimate suitable habitat for these species using the best information available. However, limitations are also inherent in estimating total suitable habitat for a large area. As discussed above, large-scale GIS mapping is incapable of differentiating microhabitat features that may affect the presence or density of these two species. Thus, our methods may overestimate the suitable habitat, and therefore population sizes, for these species.

Though there are limitations to making population estimates as described here, this study provides baseline information about density and population size of Grace's and Red-faced Warblers in New Mexico. We used the best available methods to cost-effectively cover a large portion of suitable habitat across many of the geographically disparate mountain ranges of New Mexico, where these species were likely to occur, in a single breeding season. As discussed previously, there is currently only limited information about the population sizes of these two species in New Mexico. This extant information is based on methods not specifically designed to estimate population size (discussed below). Here, we selected methodology targeted to making robust density estimates for forest-dwelling species and providing stronger information about population sizes.

Population Trends and Estimates

Partners in Flight (PIF), using data from the North American Breeding Bird Surveys (BBS), estimates the population of Grace's Warblers at around 414,825 individuals in New Mexico (Partners in Flight Science Committee 2013). We estimated between 135,199 and 165, 503 Grace's Warblers in the five project areas that we surveyed, and our estimates account for 33-40% of the total population as estimated by PIF. Following future surveys in the Gila Mountains and the integration of results from 2015 through 2017, it is reasonable to assume that our estimate of the Grace's Warbler population in New Mexico will exceed the estimate provided by PIF.

Partners in Flight estimate the population of Red-faced Warblers at around 106,399 individuals in New Mexico (Partners in Flight Science Committee 2013). We estimated between 3,521 and 17,685 Red-faced Warblers in the Sacramento Mountains, accounting for 3-17% of the total population in New Mexico as estimated by PIF. As the Gila mountain region is likely to house much large numbers of Red-faced Warblers, it is unclear at this point how our population estimate for this species will compare to PIF population estimates.

Breeding Bird Surveys, which were used by PIF to make population estimates, were not designed to estimate population sizes, but rather to provide information on relative abundance and to evaluate trends in species abundance over time (Sauer et al. 2014). Neither of our target species receive "good" data quality ratings, as determined by PIF, for New Mexico. Average annual BBS counts and survey route detections of Grace's Warblers and Red-faced Warblers show high degrees of variance, and the sample size for Red-faced Warblers on BBS routes is quite small. Indeed, not enough data is collected during BBS routes on Red-faced Warblers to estimate population trends, much less population size. The BBS trend estimate for Grace's Warbler shows a slight downward trend of -2.73% (95% credible interval: -0.43 to -5.17) per year between 1968 and 2013 in New Mexico (Sauer et al. 2014). BBS routes are placed along roads and only detect Grace's Warblers on 18 of 66 routes, and Red-faced Warblers on 4 of 66 routes. Because these species inhabit mature forests, and prefer moderate degrees of disturbance at most, roadside habitats are unlikely to be highly representative of habitats most often used by these species. Grace's Warblers were one of the most commonly detected species during our surveys in each mountain range. Red-faced Warblers were fairly common where they occurred. Thus, due to the nature of BBS routes, populations of these forest-dwelling birds are unlikely to be accurately described via the BBS method.

Our study provides a targeted approach to estimating the populations of these two warbler species in New Mexico. These methods can easily be applied in the future to evaluate additional population centers for these birds, and to resurvey the 2016 survey areas in order to determine changes in population size and trends. This information will be useful in making management decisions regarding these species and their preferred habitats.

Future Work

To complete state-wide surveys of suitable habitat, Grace's and Red-faced Warbler surveys will be conducted in mountain ranges in the Gila region of southwestern New Mexico in 2017. The Gila National Forest and surrounding areas are important for both of these species. Due to the numerous reports of large numbers of Red-faced and Grace's Warblers in this region, the third year of surveys will be utilized to estimate population sizes for these species in mountain ranges in this large region. Locations for 2017 surveys will include the Black Range, Pinos Altos Range, San Francisco Mountains, and the Mogollon Mountains. Standardized surveys will follow the same methodology established for the 2015 and 2016 surveys.

After the third and final year of surveys, a comprehensive, state-wide analysis of the results will be conducted. At the conclusion of this project, NMDGF will have breeding density and population size estimates of Red-faced and Grace's Warblers in pine woodlands of northern, central, southeastern, and southwestern New Mexico, and state-wide population estimates for these two warbler species.

Acknowledgements

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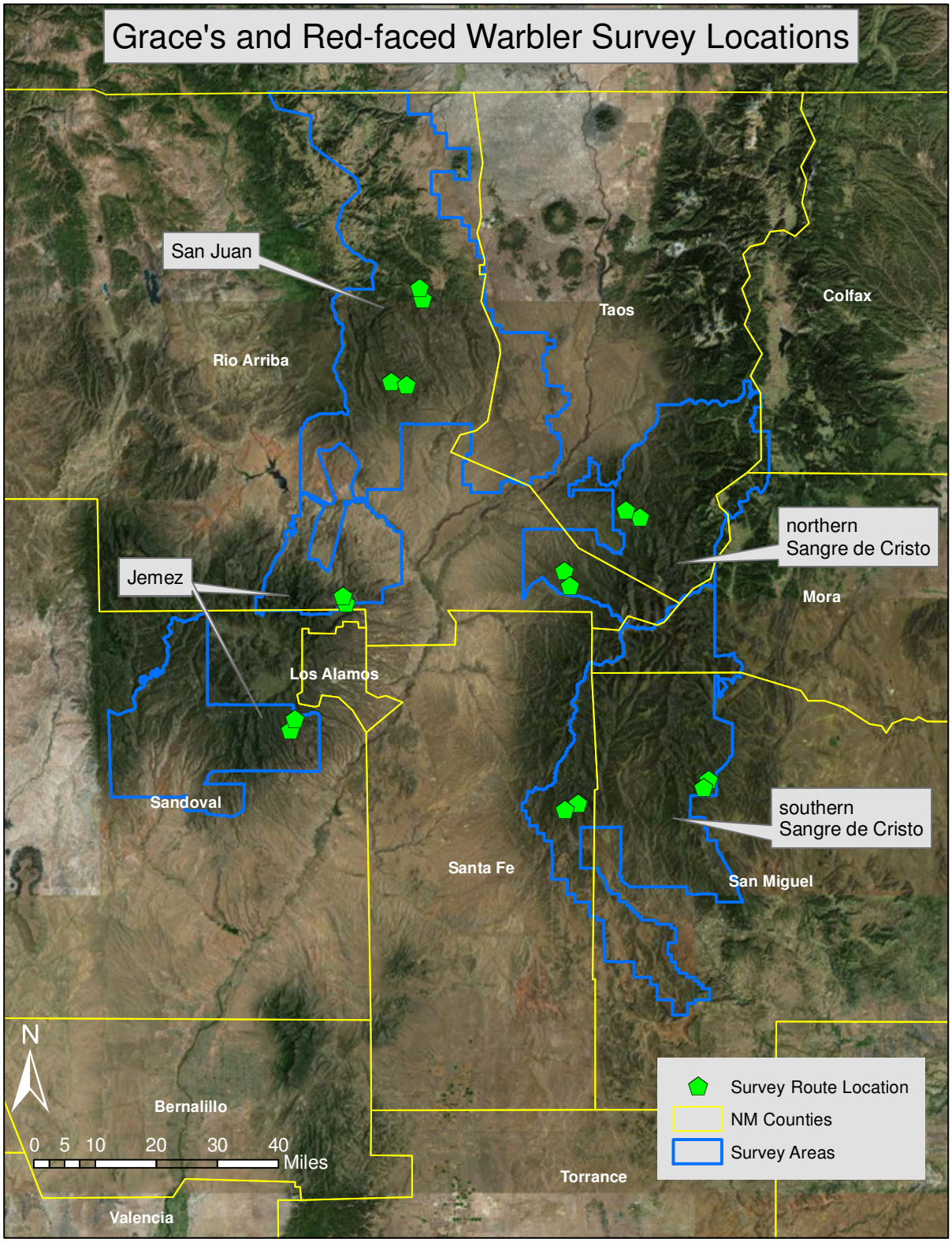
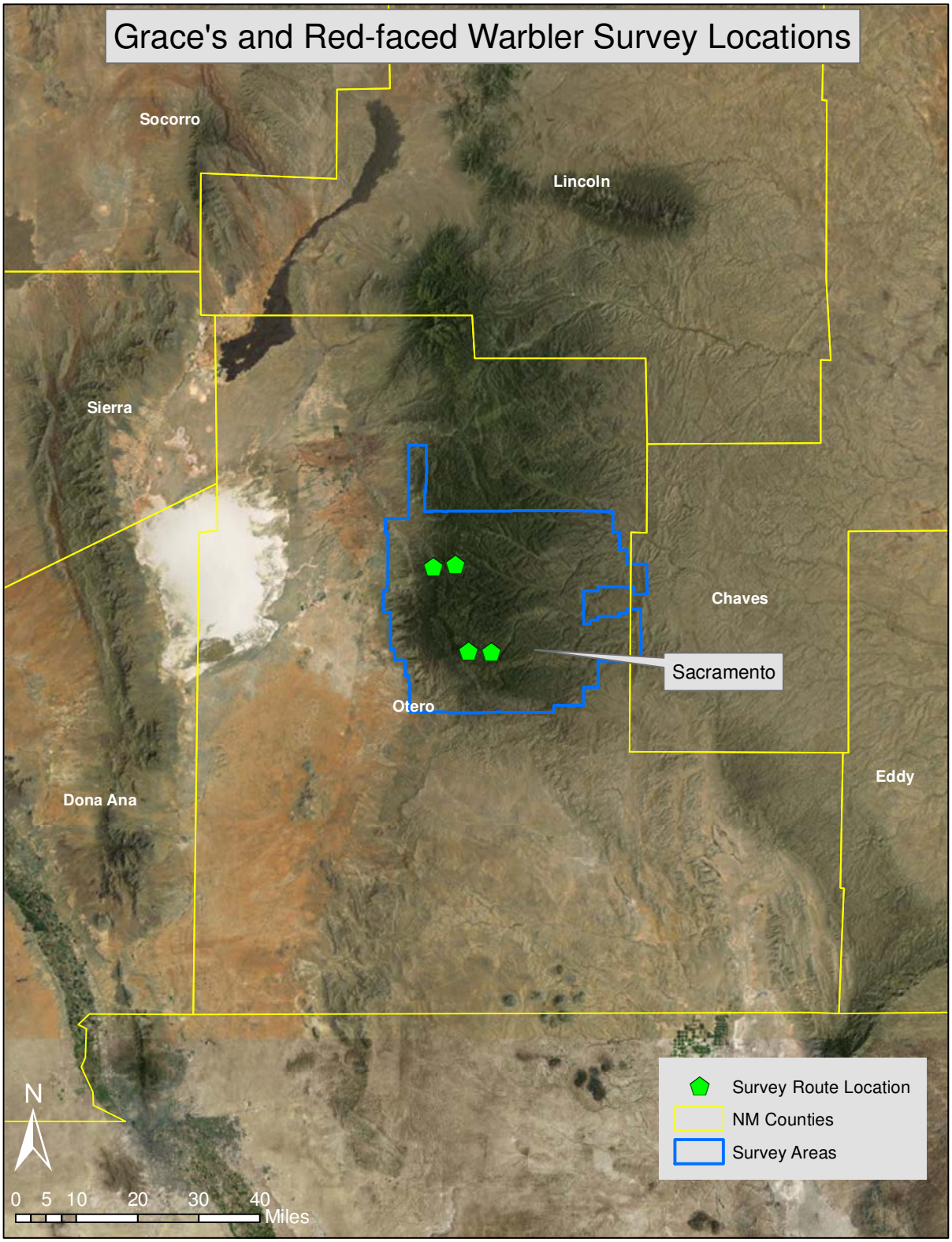
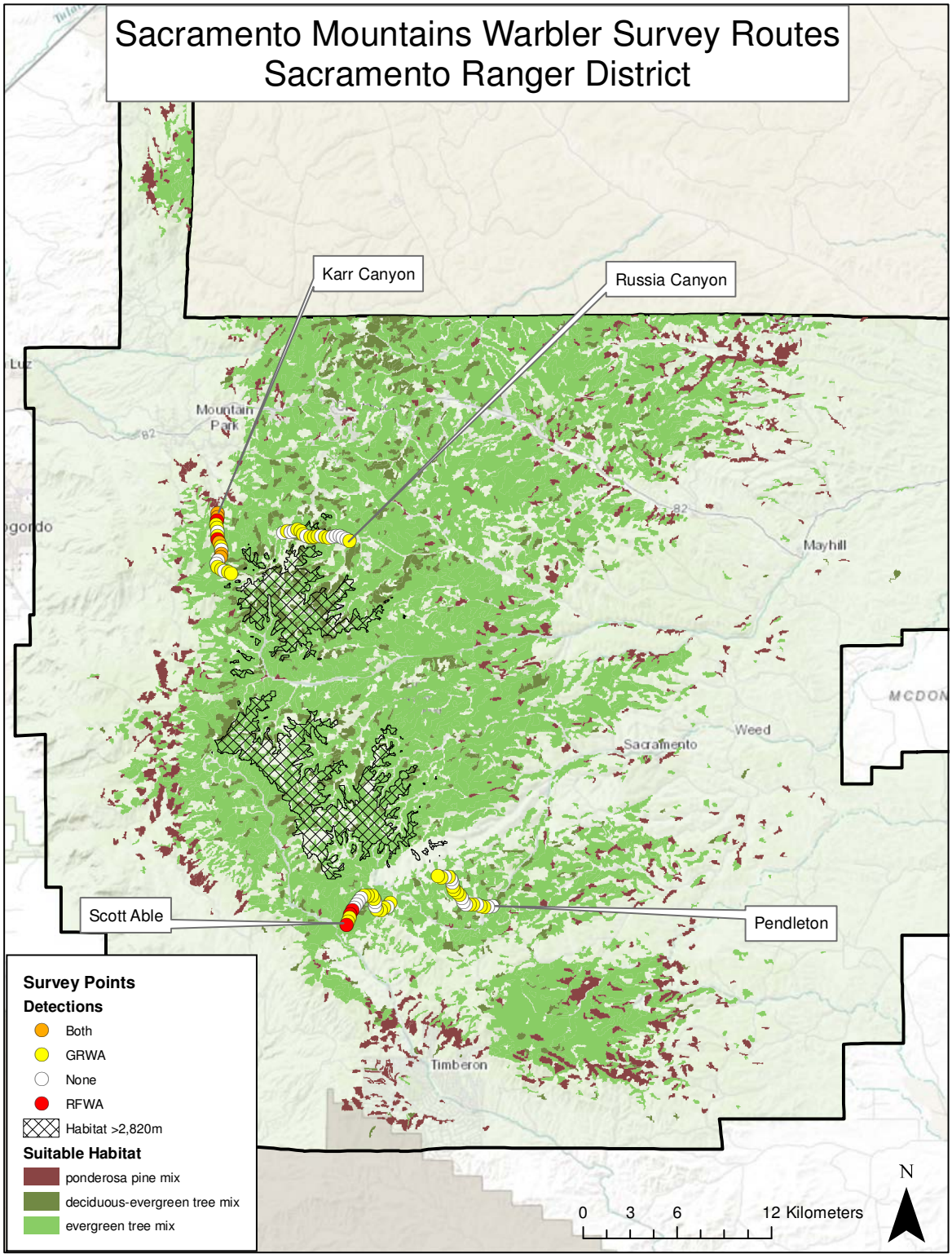
Map 1. Overview of Grace's and Red-faced Warbler survey route locations in the Jemez, San Juan, and Sangre de Cristo Mountains of New Mexico.



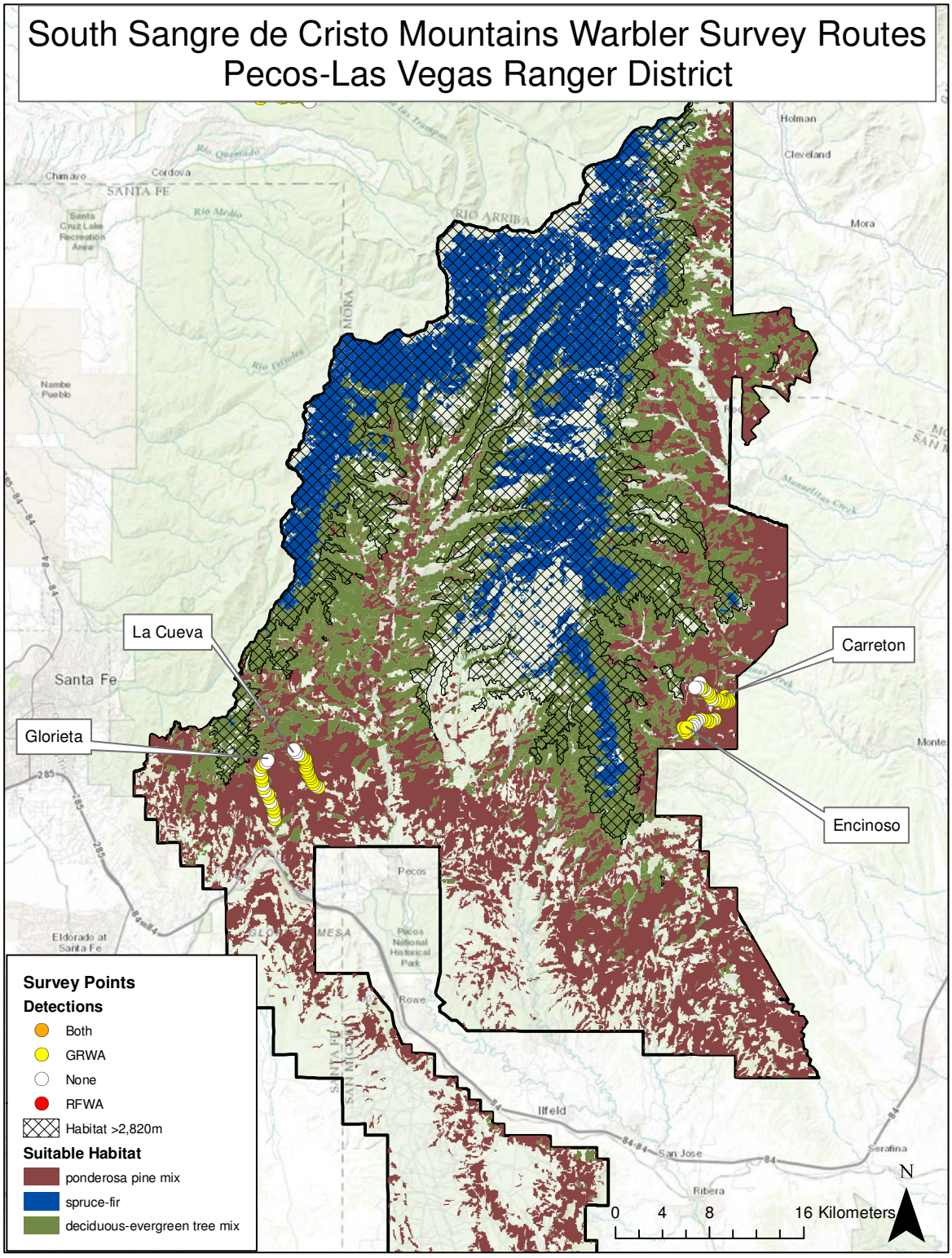
Map 2. Overview of Grace's and Red-faced Warbler survey route locations in the Sacramento Mountains of New Mexico.



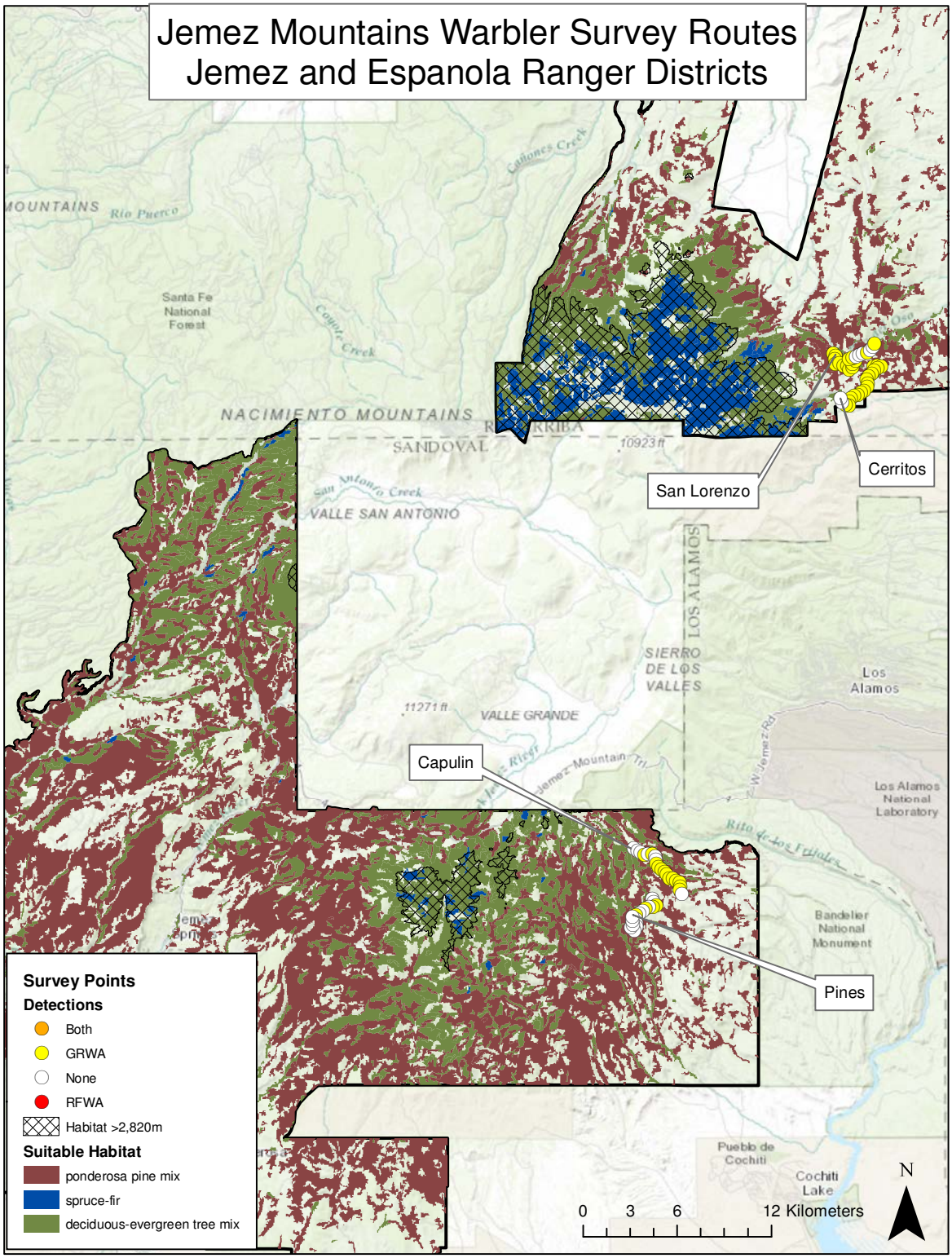
Map 3. Location and name of Grace's and Red-faced Warbler survey routes and type and extent of suitable habitat in the Sacramento Mountains, Sacramento Ranger District, Lincoln National Forest, New Mexico.



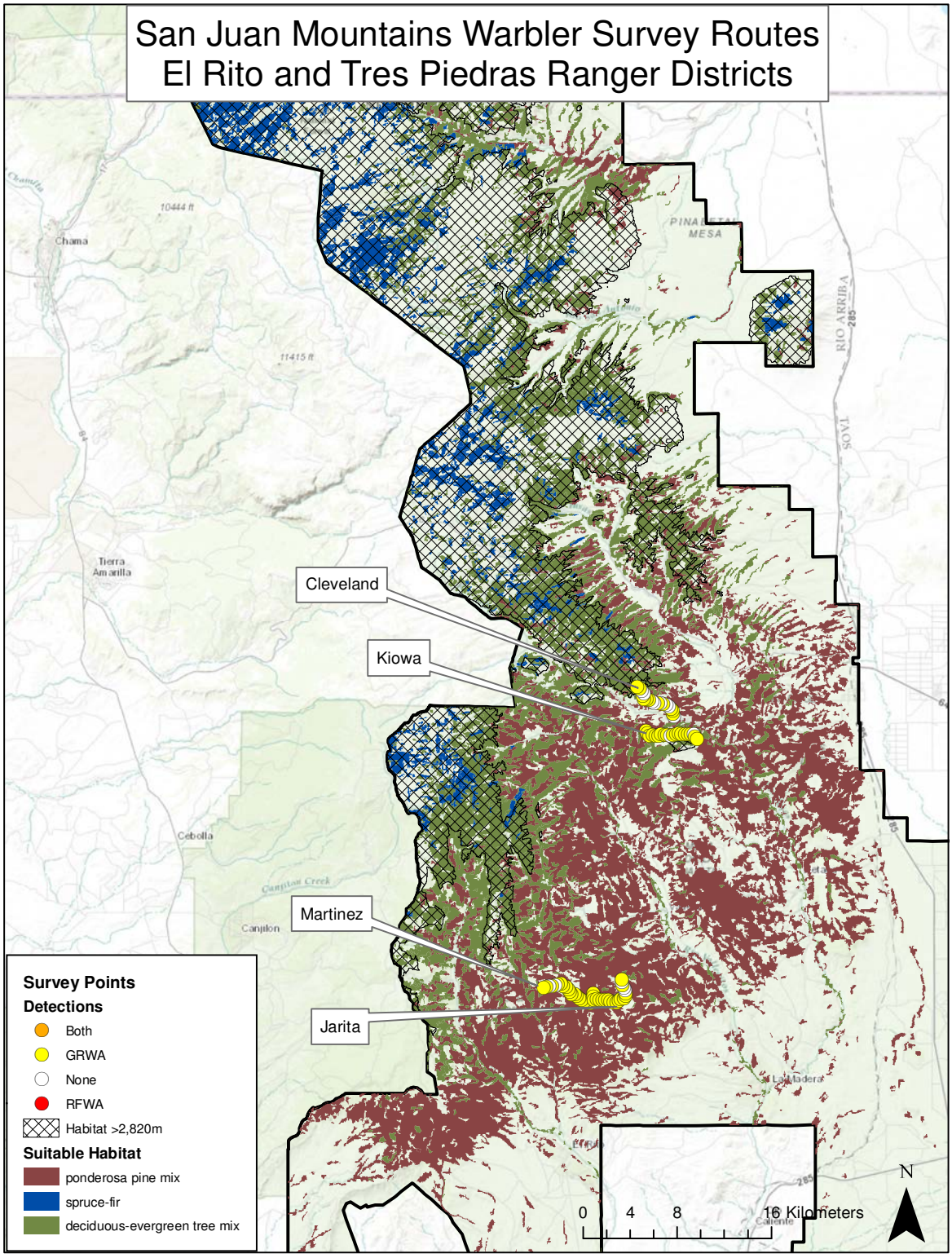
Map 4. Location and name of Grace's and Red-faced Warbler survey routes and type and extent of suitable habitat in the southern Sangre de Cristo Mountains, Pecos-Las Vegas Ranger District, Santa Fe National Forest, New Mexico.



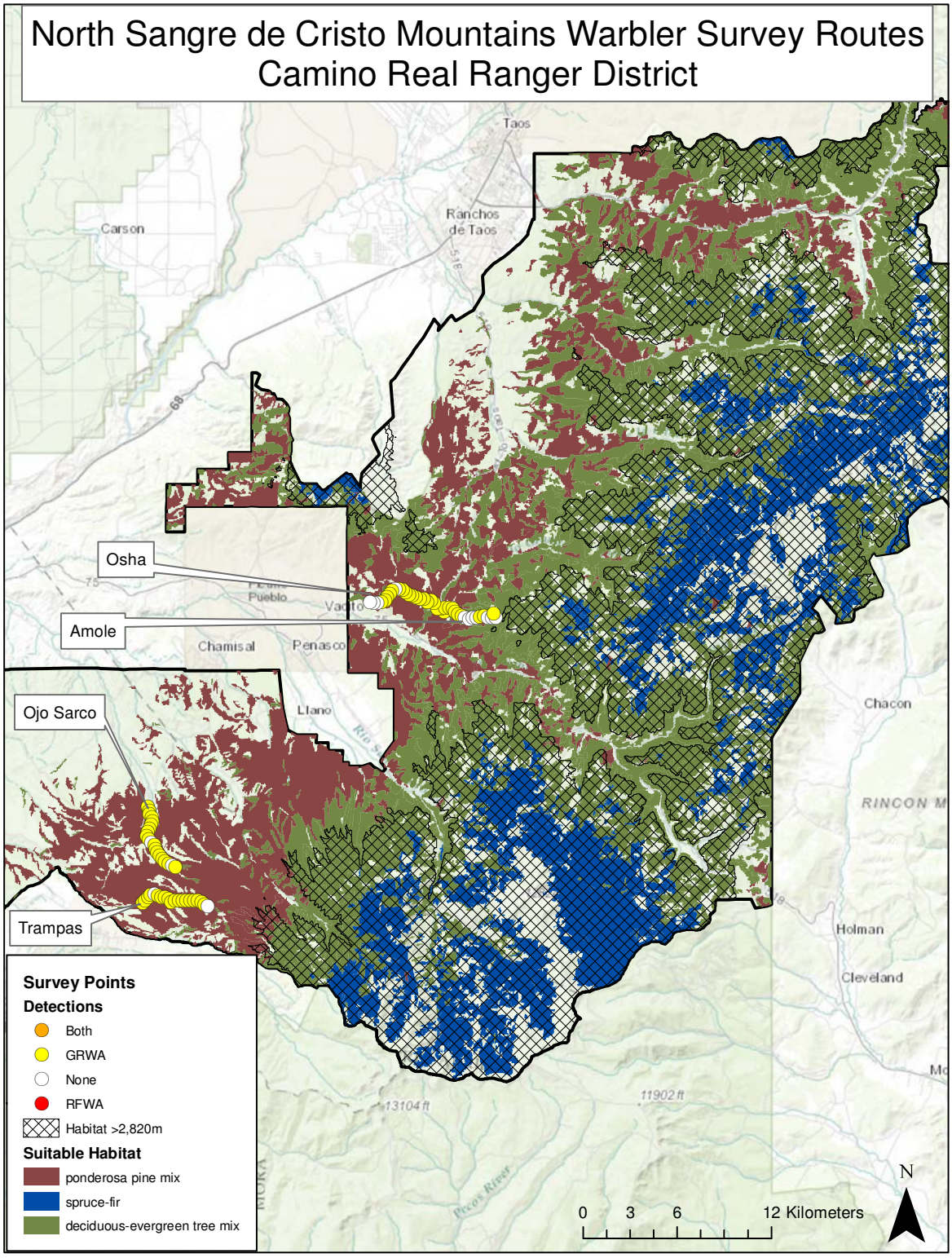
Map 5. Location and name of Grace's and Red-faced Warbler survey routes and type and extent of suitable habitat in the Jemez Mountains, Jemez and Espanola Ranger Districts, Santa Fe National Forest, New Mexico.



Map 6. Location and name of Grace's and Red-faced Warbler survey routes and type and extent of suitable habitat in the San Juan Mountains, El Rito and Tres Piedras Ranger Districts, Carson National Forest, New Mexico.



Map 7. Location and name of Grace's and Red-faced Warbler survey routes and type and extent of suitable habitat in the northern Sangre de Cristo Mountains, Camino Real Ranger District, Carson National Forest, New Mexico.



Appendix A. Avian species inventory from 2016 surveys. Species listed in taxonomic order and with the NMDGF conservation status.

Common Name	Scientific Name	NMDGF status*	Species detected by location				
			Sacramento	S. Sangre de Cristo	Jemez	San Juan	N. Sangre de Cristo
Mallard	*Anas platyrhynchos*					x	
Dusky Grouse	*Dendragapus obscurus*					x	
Wild Turkey	*Meleagris gallopavo*		x	x	x	x	x
Turkey Vulture	*Cathartes aura*		x	x	x	x	x
Sharp-shinned Hawk	*Accipiter striatus*					x	x
Cooper's Hawk	*Accipiter cooperii*		x	x	x	x	
Northern Goshawk	*Accipiter gentilis*		x			x	x
Swainson's Hawk	*Buteo swainsoni*		x				
Zone-tailed Hawk	*Buteo albonotatus*		x				
Red-tailed Hawk	*Buteo jamaicensis*		x		x	x	x
Golden Eagle	*Aquila chrysaetos*						x
Band-tailed Pigeon	*Patagioenas fasciata*		x	x	x	x	x
White-winged Dove	*Zenaida asiatica*				x		
Mourning Dove	*Zenaida macroura*		x	x	x	x	x
Flammulated Owl	*Psiloscops flammeolus*	SGCN	x				
Great Horned Owl	*Bubo virginianus*				x	x	
Northern Pygmy-Owl	*Glaucidium gnoma*		x				
Mexican Spotted Owl	*Strix occidentalis lucida*	SGCN	x				
Common Nighthawk	*Chordeiles minor*	SGCN		x	x	x	x
Common Poorwill	*Phalaenoptilus nuttallii*		x		x	x	
White-throated Swift	*Aeronautes saxatalis*				x		
Black-chinned Hummingbird	*Archilochus alexandri*				x		x
Broad-tailed Hummingbird	*Selasphorus platycercus*		x	x	x	x	x
Rufous Hummingbird	*Selasphorus rufus*		x	x			
Williamson's Sapsucker	*Sphyrapicus thyroideus*	SGCN	x	x		x	x
Red-naped Sapsucker	*Sphyrapicus nuchalis*		x	x	x	x	x
Downy Woodpecker	*Picoides pubescens*		x	x	x	x	x
Hairy Woodpecker	*Picoides villosus*		x	x	x	x	x
American Three-toed Woodpecker	*Picoides dorsalis*			x		x	x

Common Name	Scientific Name	NMDGF status*	Sacramento	S. Sangre de Cristo	Jemez	San Juan	N. Sangre de Cristo
Northern Flicker	*Colaptes auratus*		x	x	x	x	x
American Kestrel	*Falco sparverius*				x		
Peregrine Falcon	*Falco peregrinus*	SGCN					x
Olive-sided Flycatcher	*Contopus cooperi*	SGCN			x	x	x
Western Wood-Pewee	*Contopus sordidulus*		x	x	x	x	x
Hammond's Flycatcher	*Empidonax hammondii*			x	x	x	x
Dusky Flycatcher	*Empidonax oberholseri*			x	x	x	x
Cordilleran Flycatcher	*Empidonax occidentalis*		x	x	x	x	x
Unknown Empidonax Flycatcher	*Empidonax*				x	x	
Say's Phoebe	*Sayornis saya*		x		x		
Ash-throated Flycatcher	*Myiarchus cinerascens*				x		
Cassin's Kingbird	*Tyrannus vociferans*				x		
Plumbeous Vireo	*Vireo plumbeus*		x	x	x	x	x
Warbling Vireo	*Vireo gilvus*		x	x	x	x	x
Steller's Jay	*Cyanocitta stelleri*		x	x	x	x	x
Clark's Nutcracker	*Nucifraga columbiana*	SGCN		x	x	x	x
American Crow	*Corvus brachyrhynchos*		x	x		x	x
Common Raven	*Corvus corax*		x	x	x	x	x
Tree Swallow	*Tachycineta bicolor*		x		x	x	x
Violet-green Swallow	*Tachycineta thalassina*		x		x	x	x
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*		x		x		
Mountain Chickadee	*Poecile gambeli*		x	x	x	x	x
Bushtit	*Psaltriparus minimus*		x				x
Red-breasted Nuthatch	*Sitta canadensis*		x	x	x	x	x
White-breasted Nuthatch	*Sitta carolinensis*		x	x	x	x	x
Pygmy Nuthatch	*Sitta pygmaea*	SGCN	x	x	x	x	x
Brown Creeper	*Certhia americana*		x	x	x	x	x
Rock Wren	*Salpinctes obsoletus*				x		
Canyon Wren	*Catherpes mexicanus*				x		
House Wren	*Troglodytes aedon*		x	x	x	x	x
Bewick's Wren	*Thryomanes bewickii*			x	x	x	
Cactus Wren	*Campylorhynchus brunneicapillus*				x		
Blue-gray Gnatcatcher	*Polioptila caerulea*		x				

Common Name	Scientific Name	NMDGF status*	Sacramento	S. Sangre de Cristo	Jemez	San Juan	N. Sangre de Cristo
Golden-crowned Kinglet	*Regulus satrapa*		x	x			x
Ruby-crowned Kinglet	*Regulus calendula*		x	x	x	x	x
Western Bluebird	*Sialia mexicana*	SGCN	x	x	x	x	x
Mountain Bluebird	*Sialia currucoides*	SGCN	x	x	x	x	
Townsend's Solitaire	*Myadestes townsendi*		x	x	x	x	x
Swainson's Thrush	*Catharus ustulatus*				x		
Hermit Thrush	*Catharus guttatus*		x	x	x	x	x
American Robin	*Turdus migratorius*		x	x	x	x	x
Northern Mockingbird	*Mimus polyglottos*		x				
Orange-crowned Warbler	*Oreothlypis celata*		x	x	x	x	x
Virginia's Warbler	*Oreothlypis virginiae*	SGCN	x	x	x	x	x
MacGillivray's Warbler	*Geothlypis tolmiei*		x	x			x
Yellow-rumped Warbler	*Setophaga coronata*		x	x	x	x	x
Grace's Warbler	*Setophaga graciae*	SGCN	x	x	x	x	x
Black-throated Gray Warbler	*Setophaga nigrescens*	SGCN			x	x	
Red-faced Warbler	*Cardellina rubrifrons*	SGCN	x				
Green-tailed Towhee	*Pipilo chlorurus*		x		x	x	x
Spotted Towhee	*Pipilo maculatus*		x	x	x	x	x
Rufous-crowned Sparrow	*Aimophila ruficeps*				x		
Canyon Towhee	*Melozone fusca*		x		x		
Chipping Sparrow	*Spizella passerina*		x	x	x	x	x
Lark Sparrow	*Chondestes grammacus*					x	
Song Sparrow	*Melospiza melodia*					x	
Dark-eyed Junco	*Junco hyemalis*		x	x	x	x	x
Western Tanager	*Piranga ludoviciana*		x	x	x	x	x
Black-headed Grosbeak	*Pheucticus melanocephalus*		x	x	x	x	x
Brown-headed Cowbird	*Molothrus ater*			x		x	x
Cassin's Finch	*Haemorhous cassinii*	SGCN		x		x	x
Red Crossbill	*Loxia curvirostra*			x		x	x
Pine Siskin	*Spinus pinus*		x	x	x	x	x
Evening Grosbeak	*Coccothraustes vespertinus*	SGCN		x		x	x

*Species of Greatest Conservation Need (SGCN; NMDGF 2016)

Appendix B. Species relative abundance by site, and total abundance and diversity measures for each site including total number of individuals recorded, total abundance (total individuals/area), Shannon's index, evenness, and species richness. Relative abundance values for a given site sum to 100%.

	Relative abundance (%) by location				
Common Name	**Sacramento**	**S. Sangre de Cristo**	**Jemez**	**San Juan**	**N. Sangre de Cristo**
Mallard				0.101	
Dusky Grouse				0.402	
Wild Turkey	0.927	0.407	0.319	0.251	0.537
Turkey Vulture	0.195	0.068	0.830	0.101	0.045
Sharp-shinned Hawk				0.050	0.090
Cooper's Hawk	0.098	0.068	0.064	0.050	
Northern Goshawk	0.049			0.101	0.090
Swainson's Hawk	0.098				
Zone-tailed Hawk	0.049				
Red-tailed Hawk	1.220		0.575	0.201	0.358
Golden Eagle					0.090
Band-tailed Pigeon	1.562	0.203	0.064	0.050	0.358
White-winged Dove			0.128		
Mourning Dove	0.049	1.831	0.830	1.307	2.104
Flammulated Owl	0.049				
Great Horned Owl			0.255	0.050	
Northern Pygmy-Owl	0.098				
Mexican Spotted Owl	0.146				
Common Nighthawk		0.136	0.192	0.251	0.627
Common Poorwill	0.049		0.192	0.050	
White-throated Swift			0.128		
Black-chinned Hummingbird			0.128		0.045
Broad-tailed Hummingbird	3.514	1.831	2.427	1.508	0.895
Rufous Hummingbird	0.146	0.068			
Williamson's Sapsucker	0.098	0.136		0.704	0.179
Red-naped Sapsucker	0.634	0.475	0.064	0.704	0.134
Downy Woodpecker	1.611	1.492	2.299	1.256	1.477
Hairy Woodpecker	1.074	1.831	1.149	0.955	0.403
American Three-toed Woodpecker		0.136		0.101	0.045
Northern Flicker	4.832	4.814	5.619	4.472	3.223
American Kestrel			0.383		
Peregrine Falcon					0.045
Olive-sided Flycatcher			0.575	0.603	0.179
Western Wood-Pewee	0.830	0.475	3.065	3.819	4.521
Hammond's Flycatcher		0.610	0.255	0.151	0.537
Dusky Flycatcher		0.203	0.511	0.352	0.582
Cordilleran Flycatcher	4.783	2.102	2.363	1.307	1.656
Unknown Empidonax Flycatcher			0.128	0.050	
Say's Phoebe	0.146		0.064		
Ash-throated Flycatcher			0.064		

Common Name	Sacramento	S. Sangre de Cristo	Jemez	San Juan	N. Sangre de Cristo
Cassin's Kingbird			0.192		
Plumbeous Vireo	1.074	1.424	2.171	1.809	3.044
Warbling Vireo	3.709	1.492	1.916	2.312	2.014
Steller's Jay	6.979	4.136	3.959	3.769	2.731
Clark's Nutcracker		0.136	0.128	0.402	0.627
American Crow	0.049	0.136		0.201	0.985
Common Raven	6.247	3.864	3.959	3.618	4.790
Tree Swallow	0.878		0.255	0.402	0.090
Violet-green Swallow	1.513		0.447	0.653	1.164
Northern Rough-winged Swallow	0.195		0.575		
Mountain Chickadee	6.686	9.220	1.724	4.121	3.044
Bushtit	0.488				0.134
Red-breasted Nuthatch	0.976	6.237	0.575	0.754	0.627
White-breasted Nuthatch	1.025	1.085	1.405	2.412	3.671
Pygmy Nuthatch	0.439	1.966	1.469	3.015	3.357
Brown Creeper	0.049	0.271	0.064	0.201	0.090
Rock Wren			0.383		
Canyon Wren			0.255		
House Wren	1.611	0.136	2.490	1.508	0.313
Bewick's Wren		0.068	0.128	0.101	
Cactus Wren			0.255		
Blue-gray Gnatcatcher	0.098				
Golden-crowned Kinglet	0.195	0.271			0.045
Ruby-crowned Kinglet	0.586	1.017	0.192	4.221	1.701
Western Bluebird	0.342	0.949	2.235	1.809	2.059
Mountain Bluebird	0.342	0.203	0.255	0.151	
Townsend's Solitaire	0.683	0.881	0.511	0.854	0.895
Swainson's Thrush			0.064		
Hermit Thrush	4.197	5.492	2.171	3.869	4.521
American Robin	10.054	4.746	4.598	7.337	5.909
Northern Mockingbird	0.049				
Orange-crowned Warbler	0.537	1.763	0.319	0.251	0.448
Virginia's Warbler	0.098	0.339	0.575	0.352	0.179
MacGillivray's Warbler	0.195	0.271			0.090
Yellow-rumped Warbler	3.123	4.746	3.448	2.663	4.611
Grace's Warbler	3.075	5.695	7.216	6.884	6.088
Black-throated Gray Warbler			0.128	0.050	
Red-faced Warbler	0.830				
Green-tailed Towhee	0.195		4.662	0.452	0.582
Spotted Towhee	0.488	0.542	9.387	0.101	0.492
Rufous-crowned Sparrow			0.128		
Canyon Towhee	0.049		0.447		
Chipping Sparrow	0.732	1.017	2.235	4.472	3.402
Lark Sparrow				0.101	
Song Sparrow				0.050	
Dark-eyed Junco	7.418	4.542	4.470	4.824	4.879

Common Name	Sacramento	S. Sangre de Cristo	Jemez	San Juan	N. Sangre de Cristo
Western Tanager	5.027	6.034	4.470	5.729	7.028
Brown-headed Cowbird		0.068		0.050	0.358
Cassin's Finch		0.068		0.151	0.045
Red Crossbill		0.746		1.960	0.492
Pine Siskin	2.196	7.797	1.405	4.774	8.326
Evening Grosbeak		1.627		0.503	0.045
Total individuals of all species	2049	1475	1566	1990	2234
Total abundance of all species (# birds/ha)	4.181	3.427	3.462	4.087	4.501
Shannon's index	3.342	3.339	3.507	3.504	3.444
Evenness	0.813	0.841	0.840	0.843	0.841
Species richness	61	53	65	64	60