Elevation Ranges of Birds at Mount Rainier National Park, North Cascades National Park Complex, and Olympic National Park, Washington

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ELEVATION RANGES OF BIRDS AT MOUNT RAINIER NATIONAL PARK, NORTH CASCADES NATIONAL PARK COMPLEX, AND OLYMPIC NATIONAL PARK, WASHINGTON

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ABSTRACT—We used avian point-count data collected from 4030 survey stations at Mount Rainier National Park, North Cascades National Park Complex, and Olympic National Park between 2001 and 2004 to describe observed elevation ranges of 74 bird species in the parks. Detailed elevation range information based on systematic sampling is essential for monitoring the effects of climate change on taxa whose ranges are likely to shift. Existing characterizations of the elevation ranges of Pacific Northwest birds are based primarily on anecdotal observations and professional opinion rather than systematic surveys. Here we analyze a systematically collected data set to describe the elevation ranges of common bird species in 3 large wilderness parks in Washington. These descriptions will facilitate future assessments of shifts in elevation ranges. More immediately, they will provide managers of more intensively managed lands outside the parks with reference information about elevational distributions of bird species from more-pristine park ecosystems.

Key words: bird distributions, elevation, Mount Rainier National Park, North Cascades National Park Complex, Olympic National Park

Ranges of many high-elevation species worldwide have contracted severely, and mountaintop populations and species have been the first taxa to be extirpated because of anthropogenic climate change (Parmesan 2006). Mountain-dwelling birds elsewhere in the western United States have already responded to climate change by shifting their ranges to track preferred temperature or precipitation conditions (Tingley and others 2009), and many montane species throughout the world have shifted their ranges upslope (Pounds and others 1999; Root and others 2003, 2005).

Recent projections suggest that, relative to conditions between 1970 and 1999, average annual temperature in the Pacific Northwest may increase by 3.2°F (1.8°C) by the 2040s and by 5.3°F (3°C) by the 2080s (Littell and others 2009). Temperature changes alone may alter elevation ranges of some bird species, as the boundaries of many bird ranges are correlated with climatic factors (Bohning-Gaese and Lemoine 2004), particularly at the upper latitudinal and elevational boundaries where cold temperatures may impose physiological constraints (Root 1988; Root and Schneider 1993; Newton 2003). At lower latitudinal and elevational limits, biotic factors such as competition and predation may be more important than abiotic factors, but physiological constraints associated with heat stress or water limitation may also limit distribution (Bohning-Gaese and Lemoine 2004).

Other climate-induced changes may have even more effect on the elevational distribution of birds in the region. Spring snowpack is projected to decrease, with a reduction of 40% by the 2040s and 59% by the 2080s, compared with the 1916 to 2006 historical average (Littell and others 2009). Changing temperature and

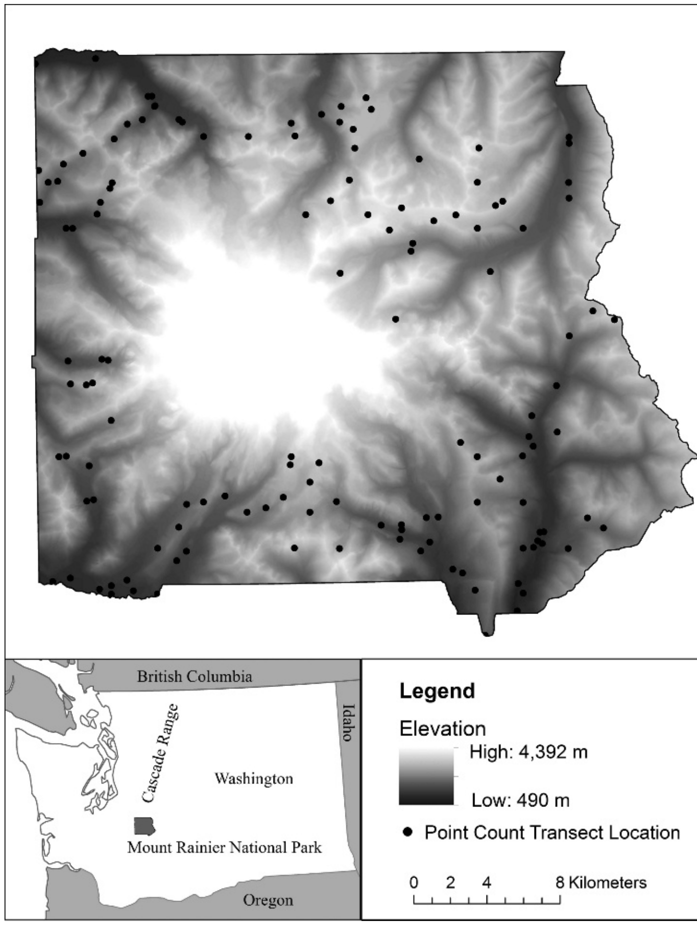

FIGURE 1. Locations of 134 transects of point counts surveyed at Mount Rainier National Park in 2003 or 2004. Each transect comprised 4 to 12 point counts spaced 250 m apart.

precipitation patterns in the region are expected to lead to an increase in the annual area burned by wildfire, increased frequency of Mountain Pine Beetle (*Dendroctonus ponderosae*) outbreaks (and outbreaks occurring at higher elevations) that cause substantial tree mortality, and substantial increases in the area of severely water-limited forests (Littell and others 2009). All of these climatic and biotic factors have the potential to alter distributions, particularly elevational distributions, of Pacific Northwest birds in the coming decades, and may even result in local extirpations of particularly sensitive species.

Occurrence data can yield important insights into historical changes in bird distributions (Tingley and Beissinger 2009), and provide important benchmarks for evaluating future changes (Siegel and others 2011). Benchmark descriptions of the elevation ranges of birds are badly needed throughout the world (Sekercioglu and others 2008). A systematic description of the current occurrence patterns and elevational distributions of birds in Pacific Northwest national parks will facilitate understanding how birds respond to current and future climate change in the parks and in the larger Pacific Northwest region. Existing characterizations of the elevation ranges of Pacific Northwest birds (for example, Campbell 1990-2001) are based primarily on anecdotal observations and professional opinion rather than systematic surveys. Here we analyze a systematically collected data set to describe the elevation ranges of common bird species in 3 large wilderness parks in Washington. These descriptions will facilitate future assessments of shifts in elevation ranges and, more immediately, will provide managers of more intensively managed lands outside the parks with reference information about elevational distribution of bird species from more-pristine park ecosystems. Serving as ''reference sites'' for assessing the effects of regional land-use and land-cover changes is a major role of the national park system (Silsbee and Peterson 1991; Simons and others 1999).

METHODS

Study Area

We studied the distribution of birds in Mount Rainier National Park, North Cascades National Park Complex (includes North Cascades National Park, Lake Chelan National Recreation Area, and Ross Lake National Recreation Area, which are contiguous and managed jointly by the National Park Service), and Olympic National Park. The 3 parks contain large tracts of mid- and high-elevation forest and subalpine woodland, as well as alpine and riparian habitats. Olympic National Park differs from the other 2 parks in that its lower boundary, at sea level, encompasses extensive lowland forest. Bird assemblages at the 3 parks are generally quite similar, except that North Cascades National Park Complex includes substantial acreage east of the Cascade Range crest, where several bird species that are characteristic of the eastern Cascades but rare or absent on the western slopes are fairly common (Siegel and others 2009a). The 3 parks span large elevation gradients, with Mount Rainier ranging from 490 to 4392 m above sea level, North Cascades ranging from 106 to 2807 m, and Olympic ranging from sea level to 2432 m.

Sample Design

As part of the National Park Service's Inventory and Monitoring Program, we counted birds at mostly off-trail point-count stations in North Cascades National Park Complex in 2001 and 2002, Olympic National Park in 2002 and 2003, and Mount Rainier National Park in 2003 and 2004. Sample design varied slightly among the 3 parks; detailed sampling procedures for each park are provided in Siegel and others (2009a, 2009b) and Wilkerson and others (2009). In brief, we established point-count stations in a geographic information system (GIS) by randomly selecting starting points for transects of point counts. We constrained the starting points to within 1 km of a trail or road. We inspected maps to discard transect starting points with slope >35% or that were in locations that could not be safely accessed due to cliffs, uncrossable rivers, or other physiographic barriers. Observers hiked to starting points, where they conducted a point count, then randomly selected a cardinal or semi-cardinal direction of travel. The observer conducted up to 11 additional point counts (as many as he or she could complete within 3.5 h of local sunrise), spaced 250 m apart along the direction of travel, unless the route was blocked by a physiographic barrier. When observers encountered such an obstacle, they returned to the previous point count location and then changed the direction of travel clockwise to the next cardinal or semi-cardinal direction that would permit continued travel. Occasionally, when physiographic barriers made off-trail travel toward a starting point impossible, transects were placed along the most proximal section of trail. Additionally, at each of the parks we supplemented the off-trail sample with varying numbers of transect starting points constrained to lie directly on trails; observers then randomly chose a direction on the trail and conducted up to 11 additional point counts spaced 250 m apart directly on the trail.

Data Collection

Prior to the start of the field season each year, all observers participated in a rigorous 2-week training program in bird identification and point-count methods and were required to pass a certification exam that tested their ability to identify by sight and sound all bird species expected to occur in the parks. All surveys took place between 22 May and 31 July. Within each park, we surveyed lower-elevation transects first, moving to higher-elevation transects as the season progressed and most snow melted, making higher areas accessible by foot. Point counts lasted 5 min, during which observers recorded all birds detected by sight or sound at any distance. Distances to each bird were

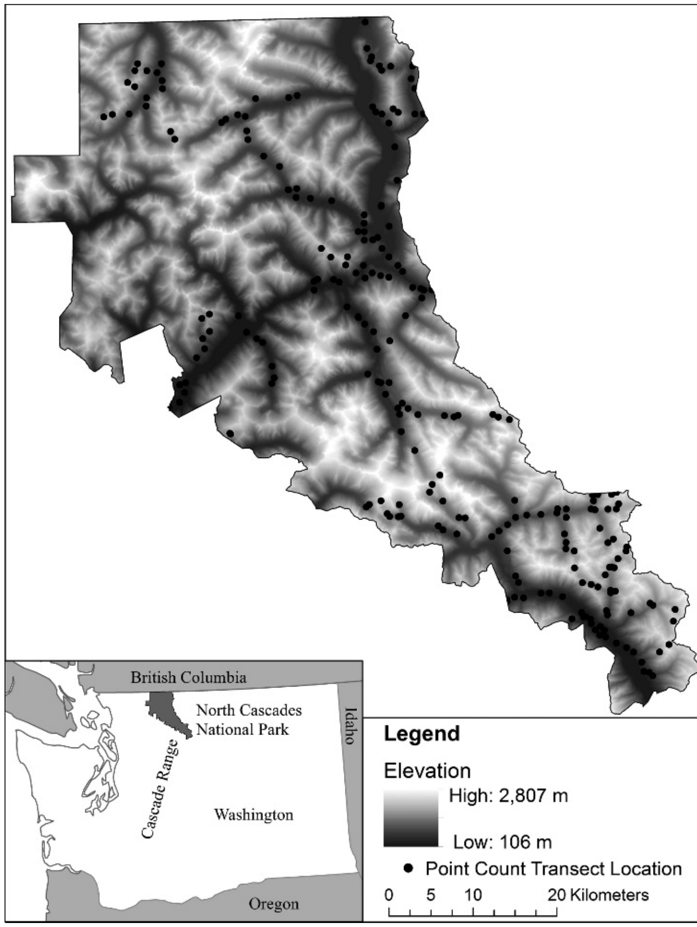

FIGURE 2. Locations of 229 transects of point counts surveyed at North Cascades National Park Complex in 2001 or 2002. Each transect comprised 4 to 12 point counts spaced 250 m apart.

estimated and recorded but were not used in the analysis we report here.

Observers used hand-held Global Positioning System units and topographic maps to determine the coordinates of each point-count station. Later, using GIS, we extracted elevations of point-count locations from digital elevation models of the parks (resolution 10 m). Coordinates described the locations of stations rather than the locations of actual birds, likely introducing a small amount of random error into our results as individual birds could have been upslope or downslope from the station.

Data Analysis

We used data from 969 point counts (including 518 off-trail and 451 on-trail count stations) along 134 transects at Mount Rainier National Park (Fig. 1); 1551 point counts (including 858 off-trail and 693 on-trail count stations) along 229 transects at North Cascades National Park Complex (Fig. 2); and 1510 point counts (including 944 off-trail and 566 on-trail count stations) along 209 transects at Olympic National Park (Fig. 3). Point count stations were distributed widely across the area and elevation range at each park (Figs. 1, 2, 3), excluding only areas $>$ 1 km from trails or roads, and the highest elevation zones which are sparsely vegetated and frequently covered in snow and ice during the breeding season. Point count stations ranged from 544 to 2248 m ($\bar{x}$ = 1250 m) at Mount Rainier, from 107 to 2111 m ($\bar{x}$ = 948 m) at North Cascades, and from 2 to 2037 m ($\bar{x}$ = 675 m) at Olympic.

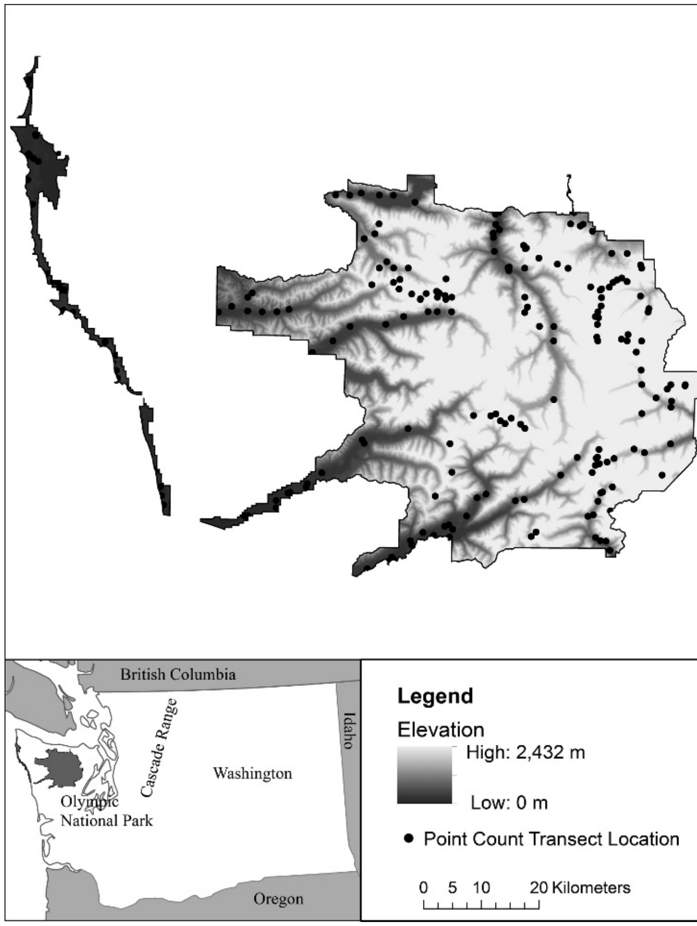

FIGURE 3. Locations of 209 transects of point counts surveyed at Olympic National Park in 2002 or 2003. Each transect comprised 4 to 12 point counts spaced 250 m apart.

We compiled a list of all bird species that we detected at 8 or more point-count stations in any of the 3 parks, a total of 74 species. For every point-count station, we characterized each of these species as detected or not detected. We then calculated summary statistics to describe the range of elevations at which a particular species was detected in each park. Although information on range boundaries can be informative for assessing distributional responses to climate change (for example, Hill and others 2002), other researchers have argued that mean elevation of occurrence may be a better indicator, as it is less prone to bias resulting from different sampling effort between sampling events (Archaux 2004; Shoo and others 2006); we therefore calculated the mean elevation of detection and its standard deviation, as well as the upper and lower quantiles encompassing 95% of detections. We estimated quantiles by interpolation with method 7 (the default method) of the quantile function in R (see Hyndman and Fan 1996 for details).

Additionally, because climate change may alter patterns of species abundance across elevational gradients in nuanced or unpredictable ways (Shoo and others 2005), we graphically described the full complexity of the elevational distribution of our detection data. Following methods in Siegel and others (2011), we graphed the distribution of stations with and without detections by means of bean plots, which we generated with the ''beanplot'' package (Kampstra 2008) in R version 2.9.2 (R Development Core Team 2009). We produced these graphs only for species detected at least 20

TABLE 1. Summary statistics of data on the elevational distribution of the 74 species most frequently detected during point count surveys at Mount Rainier National Park (2003–2004), North Cascades National Park Complex (2001–2002), and Olympic National Park (2002–2003). The sample size, *n*, is the number of point count stations at which a species was detected in each park. 'Range' is the modeled elevation range that contains 95% of the detections.

	Elevation (m) of point count stations with detections								
	Mount Rainier			North Cascades			Olympic		
Species	*n*	Mean *(SD)*	Range	*n*	Mean *(SD)*	Range	*n*	Mean *(SD)*	Range
Canada Goose (*Branta canadensis*)	5	824 *(193)*	604–1091	10	372 *(98)*	245–517	1	96	
Ruffed Grouse (*Bonasa umbellus*)	0			11	448 *(158)*	177–650	3	503 *(462)*	230–996
Sooty Grouse (*Dendragapus fuliginosus*)	16	1532 *(272)*	1129–1800	136	1025 *(434)*	436–1954	78	846 *(596)*	73–1875
Bald Eagle (*Haliaeetus leucocephalus*)	0			1	638		8	54 *(33)*	7–102
Spotted Sandpiper (*Actitis macularia*)	7	1222 *(441)*	673–1783	11	962 *(652)*	268–1665	8	167 *(165)*	34–471
Band-tailed Pigeon (*Columba fasciata*)	10	1104 *(369)*	616–1561	0			25	349 *(478)*	3–1396
Vaux's Swift (*Chaetura vauxi*)	29	883 *(183)*	657–1202	31	501 *(274)*	165–1148	9	146 *(167)*	7–452
Calliope Hummingbird (*Stellula calliope*)	0			20	761 *(343)*	410–1553	0		
Rufous Hummingbird (*Selasphorus rufus*)	40	1316 *(466)*	679–2142	114	818 *(441)*	252–1894	119	654 *(645)*	9–1694
Belted Kingfisher (*Ceryle alcyon*)	1	840		4	487 *(203)*	339–758	15	102 *(81)*	4–250
Red-naped Sapsucker (*Sphyrapicus nuchalis*)	0			19	870 *(298)*	483–1567	0		
Red-breasted Sapsucker (*Sphyrapicus ruber*)	2	813 *(29)*	793–832	48	727 *(273)*	118–1365	2	121 *(159)*	14–227
Downy Woodpecker (*Picoides pubescens*)	1	1151		9	829 *(433)*	159–1481	5	163 *(107)*	21–294
Hairy Woodpecker (*Picoides villosus*)	34	1195 *(411)*	622–1784	35	902 *(511)*	112–2062	46	301 *(386)*	10–1419
Northern Flicker (*Colaptes auratus*)	33	1402 *(421)*	754–1914	53	1014 *(580)*	335–2005	68	1232 *(639)*	77–1913
Pileated Woodpecker (*Dryocopus pileatus*)	18	997 *(341)*	652–1542	43	687 *(272)*	346–1178	24	202 *(144)*	35–514
Olive-sided Flycatcher (*Contopus borealis*)	16	1450 *(363)*	829–1848	106	1131 *(471)*	513–2018	73	1293 *(470)*	224–1893
Western Wood-Pewee (*Contopus sordidulus*)	1	1226		53	570 *(238)*	346–1109	1	29	
Willow Flycatcher (*Empidonax traillii*)	0			9	472 *(375)*	108–986	0		
Hammond's Flycatcher (*Empidonax hammondii*)	93	831 *(144)*	579–1235	379	629 *(315)*	116–1513	173	442 *(365)*	58–1331
Pacific-slope Flycatcher (*Empidonax difficilis*)	160	873 *(211)*	583–1393	61	664 *(355)*	145–1705	596	336 *(340)*	6–1190
Cassin's Vireo (*Vireo cassinii*)	0			129	613 *(230)*	281–1209	1	74	
Hutton's Vireo (*Vireo huttoni*)	0			0			8	70 *(38)*	19–115
Warbling Vireo (*Vireo gilvus*)	53	924 *(203)*	636–1453	159	795 *(343)*	128–1496	126	293 *(319)*	4–1169
Red-eyed Vireo (*Vireo olivaceus*)	0			23	422 *(236)*	111–895	0		
Gray Jay (*Perisoreus canadensis*)	88	1488 *(288)*	850–1899	60	1323 (377)	608–1852	64	1119 *(502)*	39–1730
Steller's Jay (*Cyanocitta stelleri*)	47	958 *(323)*	629–1698	43	745 (436)	109–1918	90	200 *(279)*	6–1061
Clark's Nutcracker (*Nucifraga columbiana*)	21	1954 *(217)*	1538–2242	30	1800 *(323)*	1185–2094	0		
American Crow (*Corvus brachyrhynchos*)	1	813		6	607 *(371)*	148–1147	33	140 *(220)*	3–880
Common Raven (*Corvus corax*)	36	1117 *(390)*	617–1747	16	691 *(188)*	462–1046	44	248 *(359)*	3–1125
Horned Lark (*Eremophila alpestris*)	0			0			10	1967 *(41)*	1903–2014

TABLE 1. Continued.

Species	Mount Rainier *n*	Mount Rainier Mean (*SD*)	Mount Rainier Range	North Cascades *n*	North Cascades Mean (*SD*)	North Cascades Range	Olympic *n*	Olympic Mean (*SD*)	Olympic Range
Black-capped Chickadee (*Parus atricapillus*)	0			23	635 (*399*)	285–1639	6	638 (*735*)	12–1620
Mountain Chickadee (*Parus gambeli*)	38	1772 (*112*)	1629–2005	62	1531 (*419*)	340–2018	0		
Chestnut-backed Chickadee (*Parus rufescens*)	403	1093 (*312*)	653–1732	477	812 (*326*)	256–1509	437	533 (*491*)	8–1602
Red-breasted Nuthatch (*Sitta canadensis*)	270	1405 (*360*)	696–1928	369	909 (*432*)	336–1791	194	1148 (*562*)	66–1875
Brown Creeper (*Certhia americana*)	80	1049 (*312*)	610–1750	109	851 (*295*)	410–1578	116	475 (*431*)	17–1394
Pacific Wren (*Troglodytes pacificus*)	456	1111 (*344*)	621–1767	588	922 (*420*)	154–1798	818	542 (*531*)	6–1585
American Dipper (*Cinclus mexicanus*)	4	1135 (*527*)	639–1661	4	862 (*517*)	564–1561	8	865 (*633*)	231–1685
Golden-crowned Kinglet (*Regulus satrapa*)	194	1224 (*329*)	631–1753	336	936 (*352*)	337–1646	446	708 (*597*)	9–1702
Ruby-crowned Kinglet (*Regulus calendula*)	6	1380 (*477*)	779–1869	10	1826 (*208*)	1453–2030	30	1480 (*187*)	1101–1785
Mountain Bluebird (*Sialia currucoides*)	12	1978 (*220*)	1715–2244	3	1739 (*233*)	1549–1980	0		
Townsend's Solitaire (*Myadestes townsendi*)	2	1812 (*141*)	1717–1907	35	1021 (*435*)	380–1743	30	1619 (*143*)	1397–1900
Veery (*Catharus fuscescens*)	0			34	410 (*86*)	335–625	0		
Swainson's Thrush (*Catharus ustulatus*)	59	814 (*179*)	617–1268	400	823 (*375*)	127–1609	151	139 (*185*)	3–680
Hermit Thrush (*Catharus guttatus*)	225	1369 (*289*)	767–1824	254	1324 (*403*)	555–1967	167	1352 (*334*)	567–1889
American Robin (*Turdus mitgratorius*)	91	1337 (*496*)	602–2146	276	657 (*467*)	113–1980	351	378 (*536*)	5–1873
Varied Thrush (*Ixoreus naevius*)	425	1212 (*343*)	674–1805	460	902 (*385*)	173–1721	517	749 (*575*)	7–1670
American Pipit (*Anthus rubescens*)	12	1957 (*193*)	1704–2198	8	1907 (*94*)	1780–2032	40	1774 (*226*)	1423–2017
Cedar Waxwing (*Bombycilla cedrorum*)	1	1722	1722–1912	14	555 (*468*)	107–1258	3	38 (*26*)	11–58
Orange-crowned Warbler (*Vermivora celata*)	1	1756	1756	6	1124 (*379*)	648–1468	22	107 (*338*)	12–808
Nashville Warbler (*Vermivora ruficapilla*)	0			62	755 (*322*)	342–1549	0		
Yellow Warbler (*Dendroica petechia*)	7	1108 (*211*)	852–1414	104	763 (*330*)	349–1451	15	437 (*517*)	3–1411
Yellow-rumped Warbler (*Dendroica coronata*)	27	1725 (*196*)	1259–1907	306	862 (*484*)	335–1945	44	1545 (*476*)	141–1897
Black-throated Gray Warbler (*Dendroica nigrescens*)	12	780 (*170*)	647–1159	116	629 (*304*)	119–1256	61	159 (*201*)	4–846
Townsend's Warbler (*Dendroica townsendi*)	192	1030 (*278*)	654–1706	613	798 (*307*)	349–1541	122	457 (*352*)	43–1602
MacGillivray's Warbler (*Oporornis tolmiei*)	9	944 (*223*)	669–1226	145	820 (*366*)	288–1585	10	261 (*186*)	52–567
Common Yellowthroat (*Geothlypis trichas*)	1	839		7	609 (*253*)	369–1066	12	37	3–60
Wilson's Warbler (*Wilsonia pusilla*)	31	1075 (*262*)	710–1499	28	720 (*256*)	342–1159	121	186 (*262*)	3–934
Spotted Towhee (*Pipilo maculatus*)	3	1187 (*35*)	1161–1223	51	623 (*337*)	190–1547	9	130 (*127*)	34–352
Chipping Sparrow (*Spizella passerina*)	31	1742 (*195*)	1379–2029	86	1168 (*608*)	336–2041	6	1516 (*247*)	1161–1776
Fox Sparrow (*Passerella iliaca*)	24	1788 (*208*)	1373–2036	75	1649 (*287*)	1143–2077	0		

Elevation (m) of point count stations with detections

TABLE 1. Continued.

Species	Mount Rainier			North Cascades			Olympic		
	Elevation (m) of point count stations with detections								
	n	Mean *(SD)*	Range	*n*	Mean *(SD)*	Range	*n*	Mean *(SD)*	Range
Song Sparrow (*Melospiza melodia*)	18	731 *(93)*	648–906	46	513 *(249)*	108–964	66	236 *(446)*	4–1527
White-crowned Sparrow (*Zonotrichia leucophrys*)	2	789 *(8)*	783–795	13	596 *(346)*	366–1351	17	153 *(85)*	58–257
Dark-eyed Junco (*Junco hyemalis*)	341	1417 *(369)*	700–1991	528	1096 *(499)*	335–1978	549	1192 *(564)*	64–1908
Western Tanager (*Piranga ludoviciana*)	15	1010 *(429)*	589–1915	309	726 *(316)*	335–1529	65	227 *(178)*	27–647
Black-headed Grosbeak (*Pheucticus melanocephalus*)	3	1165 *(483)*	881–1681	41	509 *(289)*	109–1111	15	286 *(211)*	31–723
Lazuli Bunting (*Passerina amoena*)	0			8	1070 *(199)*	943–1464	0		
Brown-headed Cowbird (*Molothrus ater*)	1	846		25	380 *(141)*	108–659	3	81 *(39)*	59–123
Gray-crowned Rosy-Finch (*Leucosticte tephrocotis*)	9	2068 *(140)*	1861–2201	4	1438 *(682)*	525–1933	1	1912	
Pine Grosbeak (*Pinicola enucleator*)	3	1568 *(124)*	1436–1653	10	1467 *(283)*	1082–1897	16	1415 *(181)*	1140–1727
Cassin's Finch (*Carpodacus cassinii*)	3	1851 *(98)*	1746–1912	15	1391 *(378)*	606–1923	0		
Red Crossbill (*Loxia curvirostra*)	74	1231 *(350)*	670–1908	43	802 *(372)*	177–1639	149	897 *(649)*	30–1858
Pine Siskin (*Carduelis pinus*)	257	1548 *(290)*	839–1983	309	1193 *(523)*	348–2001	234	1470 *(394)*	100–1923
Evening Grosbeak (*Coccothraustes vespertinus*)	34	1460 *(308)*	753–1861	46	869 *(450)*	367–1848	3	963 *(664)*	279–1514

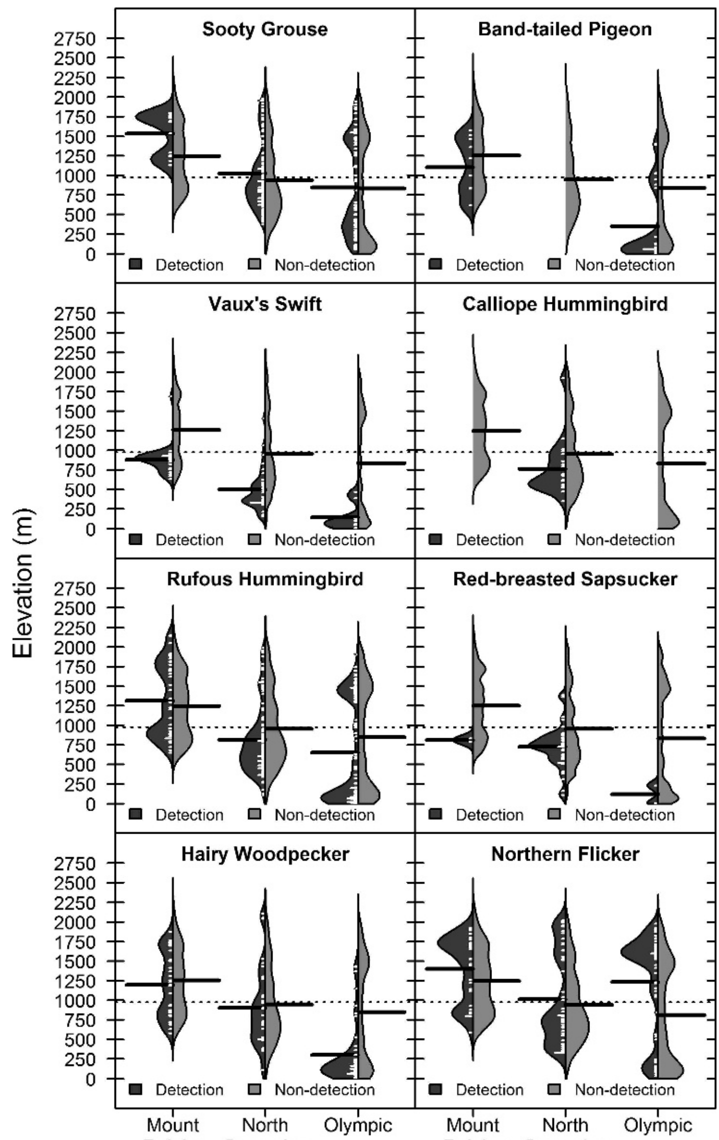

FIGURE 4. Elevational distributions of count stations where birds detected at least 20 times in 1 or more parks were detected and not detected during bird surveys at Mount Rainier, North Cascades, and Olympic National Parks. White tick marks left of the vertical center line represent single point count stations where the indicated species was detected; longer tick marks represent multiple stations at the same elevation. Shaded regions delineate density traces of the data. For each park, sites of detection are shown to the left of vertical center lines and are described by dark gray density traces; density traces of non-detection sites are shown to the right of vertical center lines and are represented by lighter gray density traces. The mean elevations of count points where species were detected (left of center) and not detected (right of center) are represented by black horizontal lines. The dashed line shows the mean elevation of all stations surveyed across the 3 parks.

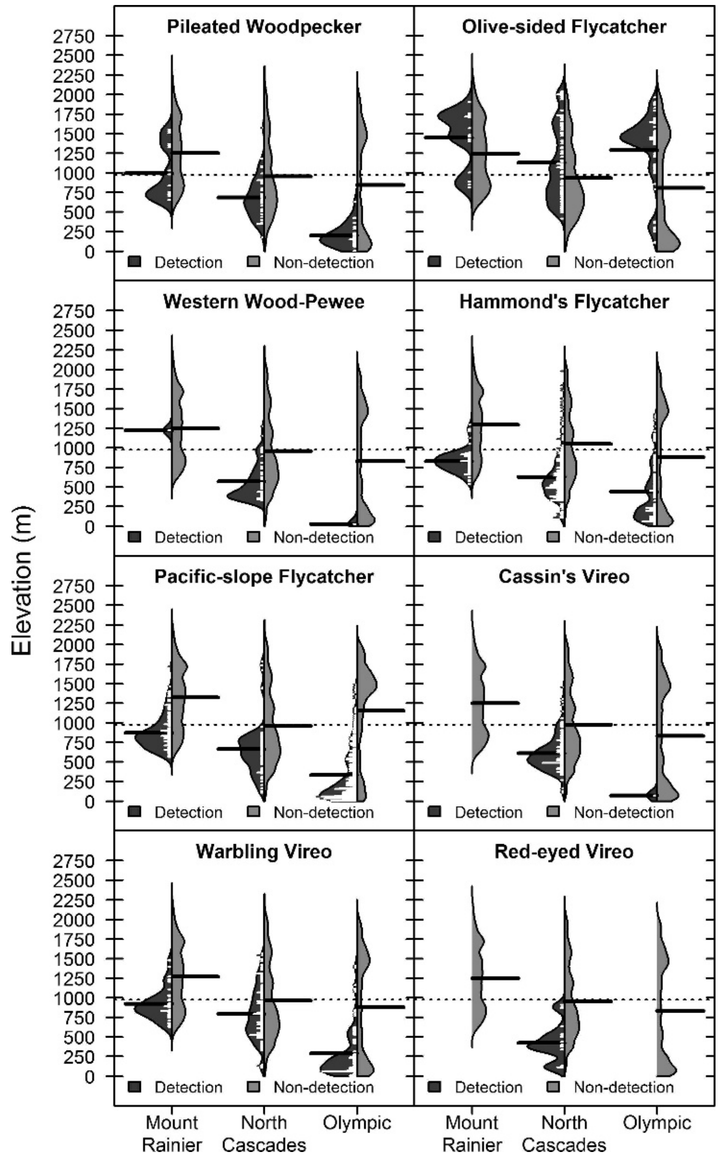

FIGURE 4. (Continued).

times in 1 or more parks, as density traces of less-frequently detected species often indicated dramatic variation in abundance with elevation that was likely just an artifact of small sample size. Bean plots facilitate comparison of distributions of data points by displaying the data simultaneously with density traces of the data. We used asymmetrical bean plots to show elevational distributions of points with detections for individual species alongside the distributions of points without detections at each park. Individual data points (point-count stations) in the bean plots were represented by short line segments displayed as a one-dimensional scatterplot, or strip chart. Elevations represented by multiple points were displayed as longer lines representing the summed lengths of the line segments for the various count stations. The sizes and shapes of density traces for detection count stations (or non-detection count stations) in the bean plots reflect the distributions of data along the elevation

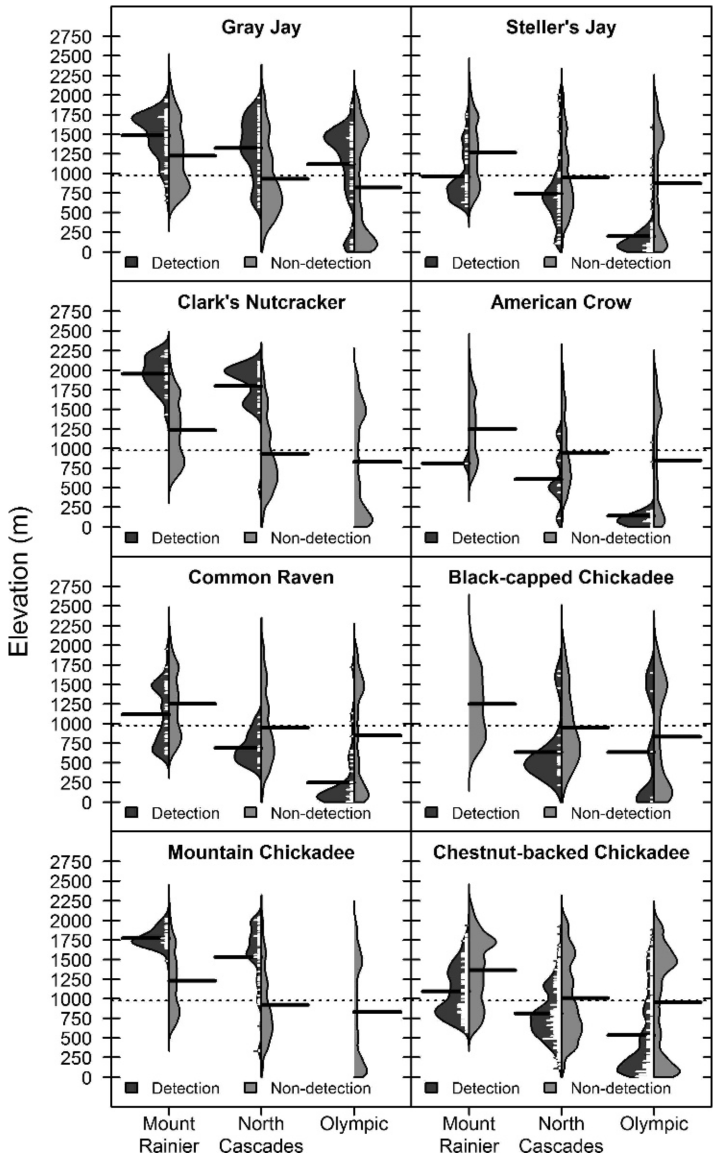

FIGURE 4. (Continued).

gradients and a bandwidth (smoothing) parameter whose value we determined by the Shaether–Jones method (Shaether and Jones 1991). The width of the density trace (along the x axis) is selected by an algorithm that incorporates the sample size and the distribution of values to generate a shape that illustrates relative differences within a species in density of detections or non-detections at various elevations. Venables and Ripley (2002:126–129) provide additional detail on density traces and their implementation in R.

RESULTS

We detected 74 species at 8 or more point-count stations in at least 1 park, and provide species names and summary statistics describing their observed elevation distribution at each park in Table 1. Forty-five of these species were detected at least 20 times at 1 or more parks; for

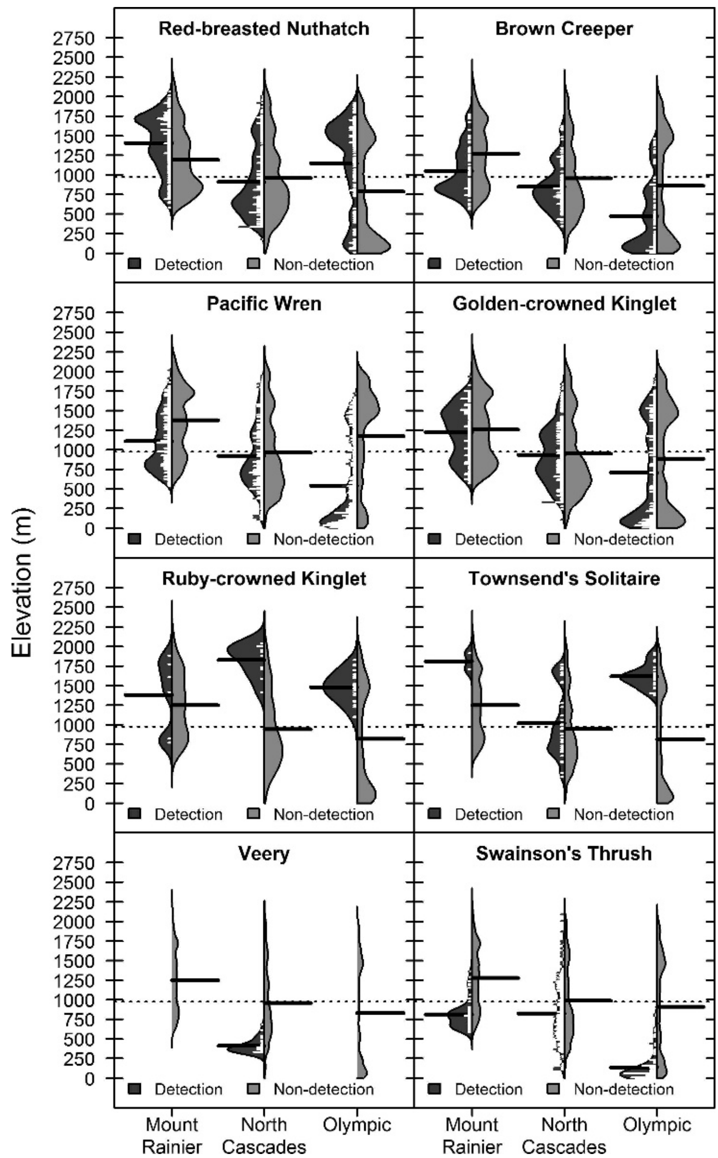

FIGURE 4. (Continued).

these species, Figure 4 provides bean plots indicating actual detections and density traces of distributions of each species at each park. Note that the lower and upper tails of the density traces extend slightly beyond the actual range of data and consequently extend below the park's lower boundaries, except for the Olympic National Park density traces which we truncated at sea level. For most species, average detection elevation was highest at Mount Rainier, intermediate at North Cascades, and lowest at Olympic (Fig. 4), but this may largely reflect differences in the lower elevation boundary of the 3 parks, rather than bird preferences. Species that did not exhibit this pattern tended to be those that are associated with high-elevation habitats and were detected primarily at higher point count stations, such as Ruby-crowned Kinglet, Hermit Thrush, and American Pipit (Fig. 4).

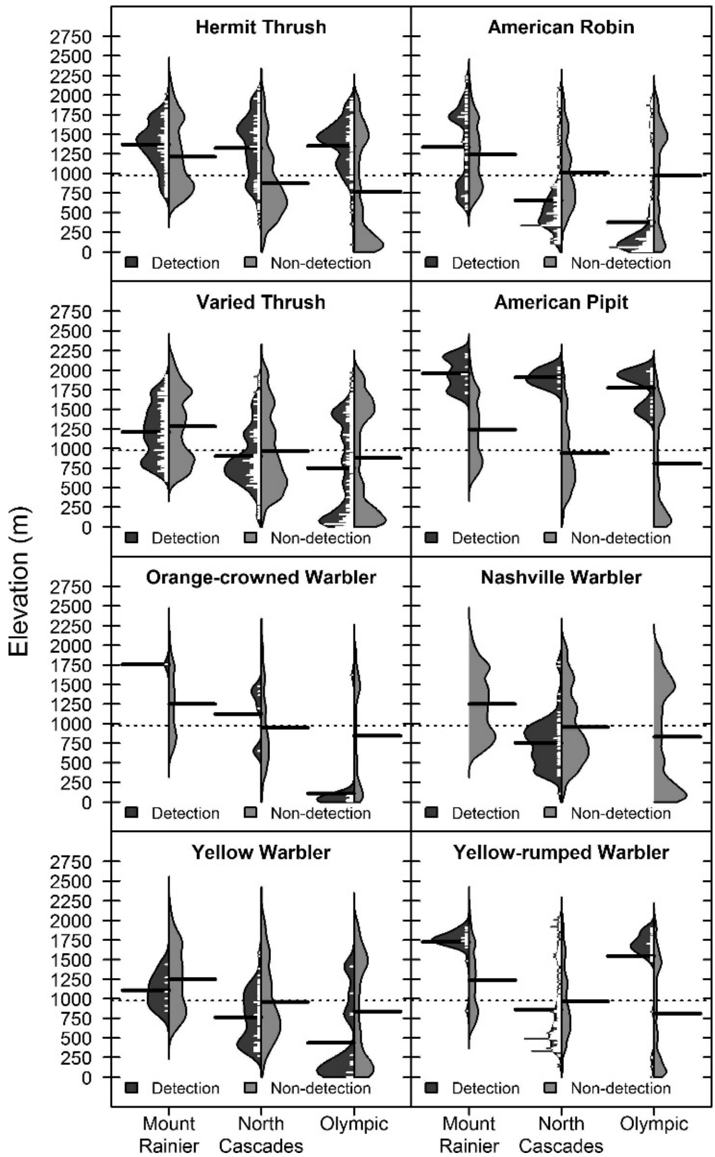

FIGURE 4. (Continued).

DISCUSSION

We report here the first quantitative data on elevation distributions of Pacific Northwest birds, based on a systematic sampling design involving extensive point counts in 3 protected areas that collectively span an elevation gradient from sea level to the alpine zone. These data will serve as a benchmark for evaluating future climate-induced changes in bird distributions and assemblages in the Pacific Northwest, and may also provide useful comparative information for assessing how land management regimes have affected avian distributions and species assemblages on more heavily managed lands at comparable elevations throughout the region.

Breadth of elevation range has been shown to be a major predictor of the risk of local or global

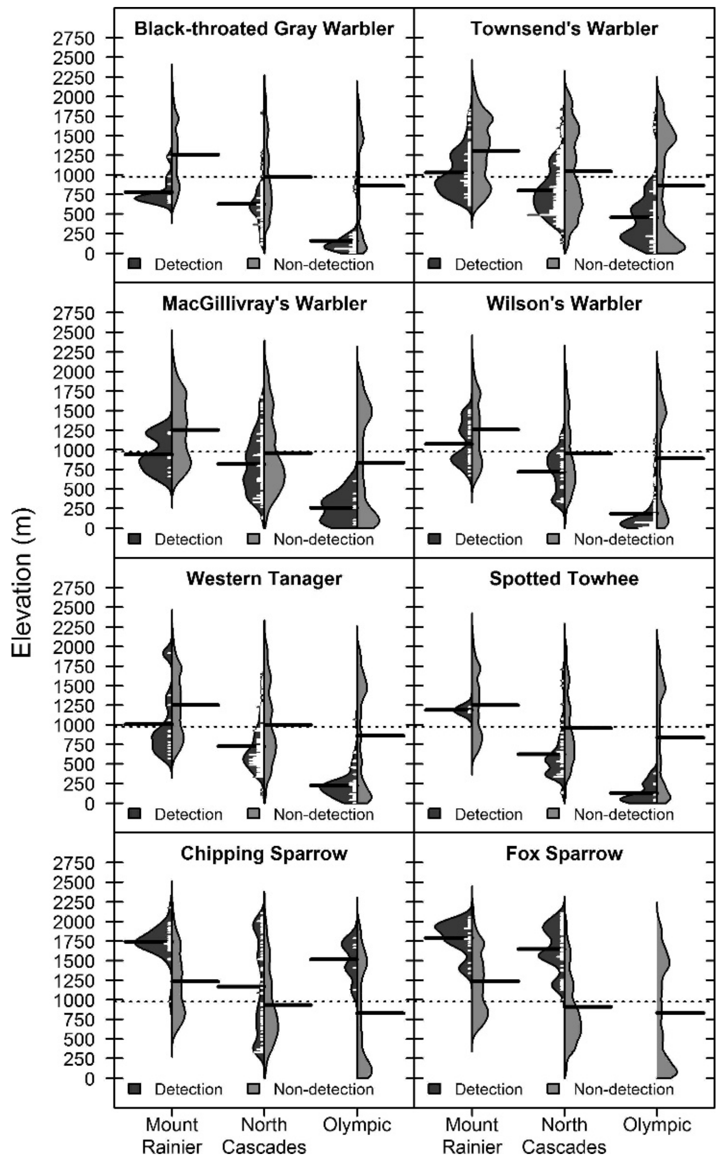

FIGURE 4. (Continued).

extinction of bird species in the context of climate change (Sekercioglu and others 2008), so these data may provide useful information for assessing vulnerability to climate change. The narrowest observed elevational ranges were generally evident in a handful of species that are restricted to relatively low (for example, Belted Kingfisher, Willow Flycatcher, Red-eyed Vireo, Veery, Brown-headed Cowbird) or relatively high (for example, Clark's Nutcracker, Horned Lark, Mountain Bluebird, American Pipit) habitats in the parks. Of these 2 groups, the high-elevation species are probably of much greater concern; lower-elevation species may have opportunities to shift their ranges upslope as conditions change, whereas high-elevation species may have little possibility for upslope range extensions (Pounds and others 1999; Hill

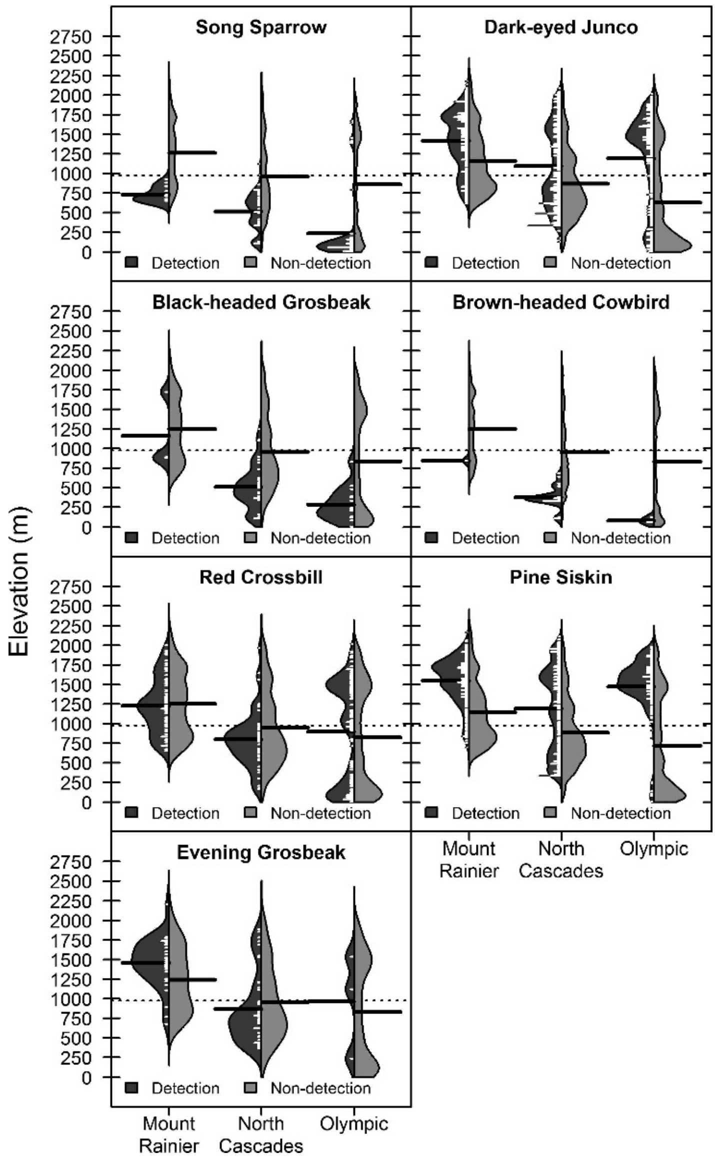

FIGURE 4. (Continued).

and others 2002). Additionally, because mountains narrow with increasing elevation, high-elevation zones generally have a smaller absolute land area than lower-elevation zones, such that high-elevation bird species tend to have relatively smaller areas of occurrence (Sekercioglu and others 2008). Continued monitoring of the elevation distributions of birds in the parks, particularly alpine-associated birds, is therefore warranted.

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