Prepared in cooperation with the National Park Service

Mountain Goat Abundance and Population Trends in the Olympic Mountains, Northwestern Washington, 2016

Open-File Report 2016–1185

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph showing three mountain goats observed during aerial surveys in Olympic National Park, Washington, July 2016. Photograph by Patricia J. Happe, National Park Service.

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SALLY JEWELL, Secretary

U.S. Geological Survey
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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Flight speed	
mile per hour (mi/h)	1.609	kilometer per hour (km/h)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	2.471	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Flight speed	
kilometer per hour (km/h)	0.6214	mile per hour (mi/h)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32.

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Mountain Goat Abundance and Population Trends in the Olympic Mountains, Northwestern Washington, 2016

By Kurt J. Jenkins[1], Patricia J. Happe[2], Katherine F. Beirne[2], and William T. Baccus[2]

Executive Summary

We estimated abundance and trends of non-native mountain goats (*Oreamnos americanus*) in the Olympic Mountains of northwestern Washington, based on aerial surveys conducted during July 13–24, 2016. The surveys produced the seventh population estimate since the first formal aerial surveys were conducted in 1983. This was the second population estimate since we adjusted survey area boundaries and adopted new estimation procedures in 2011. Before 2011, surveys encompassed all areas free of glacial ice at elevations above 1,520 meters (m), but in 2011 we expanded survey unit boundaries to include suitable mountain goat habitats at elevations between 1,425 and 1,520 m. In 2011, we also began applying a sightability correction model allowing us to estimate undercounting bias associated with aerial surveys and to adjust survey results accordingly. The 2016 surveys were carried out by National Park Service (NPS) personnel in Olympic National Park and by Washington Department of Fish and Wildlife (WDFW) biologists in Olympic National Forest and in the southeastern part of Olympic National Park. We surveyed a total of 59 survey units, comprising 55 percent of the 60,218-hectare survey area. We estimated a mountain goat population of 623 ±43 (standard error, SE). Based on this level of estimation uncertainty, the 95-percent confidence interval ranged from 561 to 741 mountain goats at the time of the survey.

We examined the rate of increase of the mountain goat population by comparing the current population estimate to previous estimates from 2004 and 2011. Because aerial survey boundaries changed between 2004 and 2016, we recomputed population estimates for 2011 and 2016 surveys based on the revised survey boundaries as well as the previously defined boundaries so that estimates were directly comparable across years. Additionally, because the Mount Washington survey unit was not surveyed in 2011, we used results from an independent survey of the Mount Washington unit conducted by WDFW biologists in 2012 and combined it with the 2011 survey results to produce a complete survey conducted over 2 years. The revised estimates of mountain goat abundance occurring at elevations above 1,520 m were 230 ±19 (SE) in 2004, 350 ±41 (SE) in 2011, and 584 ±39 (SE) in 2016. The difference between the overall 2016 population estimate (623 ±43 [SE]) and the smaller estimate (584 ±39 [SE]) reflected the number of mountain goats counted in the expanded survey areas added in 2011. Based on comparisons within the standardized survey boundary, the mountain goat population

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[2]National Park Service.

in the Olympic Mountains increased at an average finite rate of 6 percent annually from 2004 to 2011, 11 percent annually from 2011 to 2016, and 8 percent annually over the combined period. We caution that the population may have been underestimated in 2011 because of record heavy snows persisting into the survey season. Therefore, the rate of population increase from 2011 and 2016 may be overestimated. The rate of increase measured over the combined period (2004–16) may be more representative of the recent population growth. We conclude that the abundance of mountain goats has increased for more than a decade, and if the recent average rate of population growth were sustained, the population would increase by 45 percent over the next 5 years.

Introduction

Mountain goats were introduced in the Olympic Mountains of Washington during the 1920s prior to the establishment of Olympic National Park (Houston, Schreiner, and others, 1994). Over the next several decades, the mountain goat population grew and expanded throughout the Olympic Mountains, leading to management concerns by the mid-1970s about the potential effects of overabundant mountain goats on soil erosion and endemic plants in high-elevation plant communities (National Park Service, 1995). In 1983, the National Park Service (NPS) conducted the first aerial survey to estimate mountain goat population size throughout the Olympic Mountains, generating an estimate of 1,175 ±171 (standard error [SE]) mountain goats (Houston and others, 1986). Other localized ground and aerial surveys conducted prior to 1983 did not result in complete population estimates (Houston, Schreiner, and others, 1994).

During the early 1980s, the NPS translocated mountain goats from Olympic National Park to other ranges throughout several Western States to reduce the population (Houston, Schreiner, and others, 1991). During 1981–89, 407 goats were captured by the NPS and translocated (Houston, Hoffman, and others, 1994, p. 195). An additional 119 mountain goats were legally harvested during sport hunting seasons outside the park and 3 known mountain goats were illegally harvested in the park during 1983–97. The aerial capture and translocation program was halted in 1990 because of human safety concerns associated with aerial capture operations (Houston, Hoffman, and others, 1994). No mountain goats have been translocated from the Olympic Mountains since 1990. Outside the park, mountain goats were not legally harvested between 1997 and 2013. State and Tribal hunting resumed in 2014; three goats were legally harvested between 2014 and July 2016 (R. Harris, Washington Department of Fish and Wildlife, written commun., 2016).

Beginning with the first comprehensive survey conducted in 1983, the mountain goat population has been estimated in the Olympic Mountains every 3–7 years to assess population status and responses to past management actions. The second survey, conducted in July 1990 following the cessation of the NPS capture and translocation program, produced an estimate of 389 ±106 (SE) goats (Houston, Moorhead, and others, 1991). Subsequent surveys were conducted in 1994, 1997, 2004, and 2011 during a period in which no goats were translocated by NPS managers. In this report, we present results from a 2016 survey, which was the seventh survey conducted since 1983, and estimate patterns of population growth since 2004.

Study Area and Methods

The survey encompassed high-elevation mountain goat habitat throughout the Olympic Mountains, of which about 87 percent is in Olympic National Park, and 13 percent is in the adjoining Olympic National Forest (fig. 1). The Olympic Mountains rise abruptly from the coastal plains and foothills of the Olympic Peninsula, culminating in Mount Olympus, the highest peak at an elevation of 2,430 m, and 37 other major peaks at elevations exceeding 2,130 m, all within about 50 km of the Pacific Ocean, Strait of Juan de Fuca or Puget Sound. The Olympic Mountains are noted for steep gradients in elevation, vegetation, and precipitation within a context of highly convoluted topography and landforms (Tabor, 1987; Henderson and others, 1989).

The western slopes of the Olympic Mountains, which bear the brunt of the prevailing Pacific storms, have the wettest climate in the conterminous United States, generating highly variable snow conditions from year to year. During 2016, snow water equivalent (SWE) measured on April 1 was 108 percent of the 30-year normal (1981–2010). A much warmer than normal spring resulted in a rapid warming and decreasing snowpack. By May 1, the snowpack at measurement sites ranged from 15 to 94 percent of normal depending on aspect. The snow melt-out date at a snowpack reference site (Waterhole SNOTEL, Hurricane Ridge) was 21 days earlier than average. The result was that most steep terrain was largely free of snow in July when the survey was conducted. These conditions contrasted sharply with snow conditions during the previous mountain goat survey (2011), when SWE was about 167 percent of the 30-year normal (1971–2000) on April 1, 225 percent of normal on May 1, and the documented melt-out date was 30 days later than average.

Sampling

The sampling frame encompassed 60,218 ha comprising all lands free of glacial ice at elevations above 1,520 m (5,000 ft) as well as areas of suitable mountain goat habitat at elevations between 1,425 and 1,520 m (fig. 2). We defined suitable habitat as areas where escape terrain comprised at least 50 percent of the elevational band between 1,425 and 1,520 m. We defined escape terrain as any area less than 111 m from any 25×25-m (0.0625 ha) raster cell classified as rock and with slope greater than 33 percent (Olympic National Park Geographic Information System; Pacific Meridian Resources, 1996). We selected the 111-m threshold because 90 percent of all locations of 11 Global Positioning System (GPS)-collared mountain goats that we tracked during 2005–08 (Jenkins and others, 2011) were within 111 m from escape cover when they were at elevations below 1,520 during the July sampling window. The 50-percent classification was subjectively selected based on cost and logistical considerations to minimize survey effort over relatively large areas of low-quality habitats. With two exceptions, the 2016 sampling frame was the same frame as that used in 2011 (Jenkins and others, 2012). The exceptions were a minor adjustment to the Klahhane survey unit and the inclusion of the Mount Washington survey unit in 2016, which was excluded in 2011 for logistical reasons.

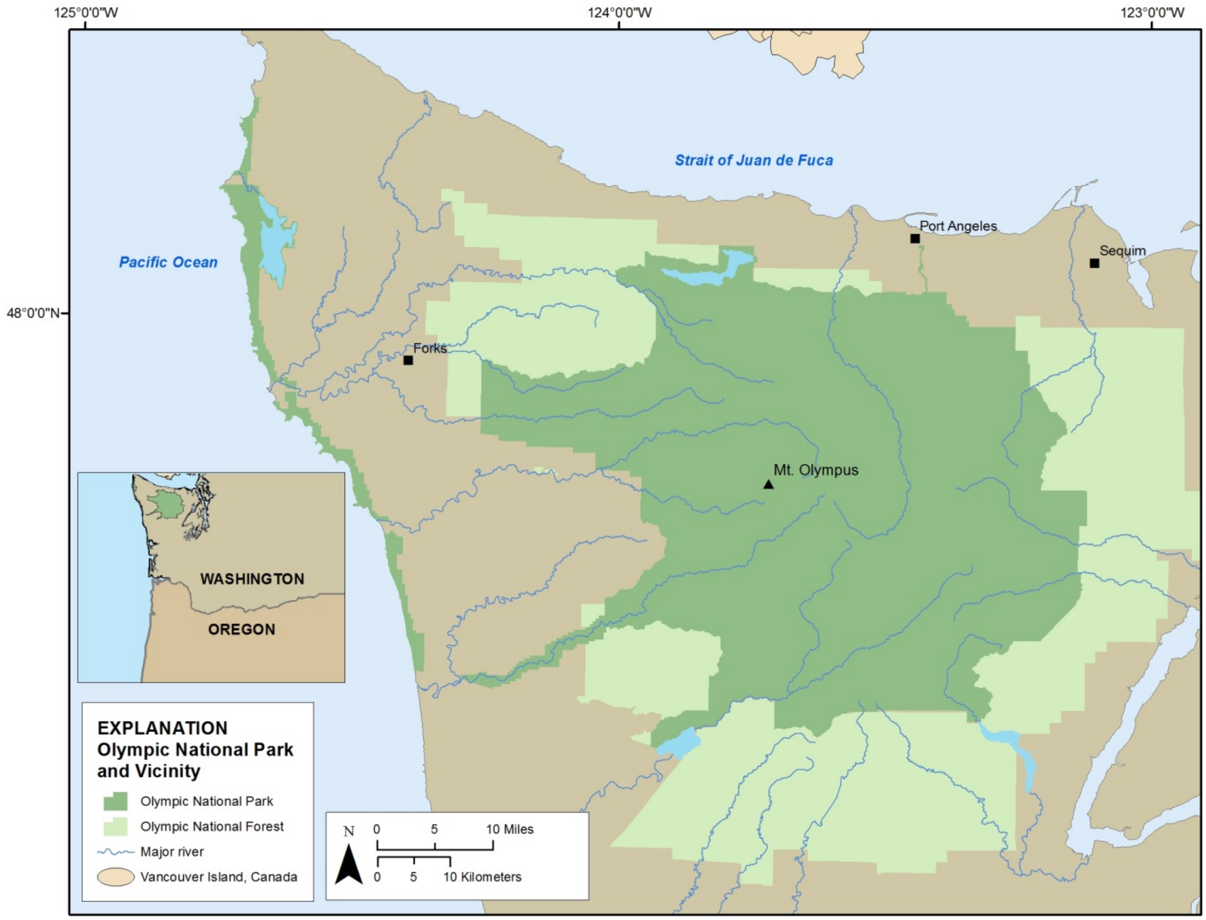

Figure 1. Map showing location of study area in Olympic National Park and Olympic National Forest, northwestern Washington.

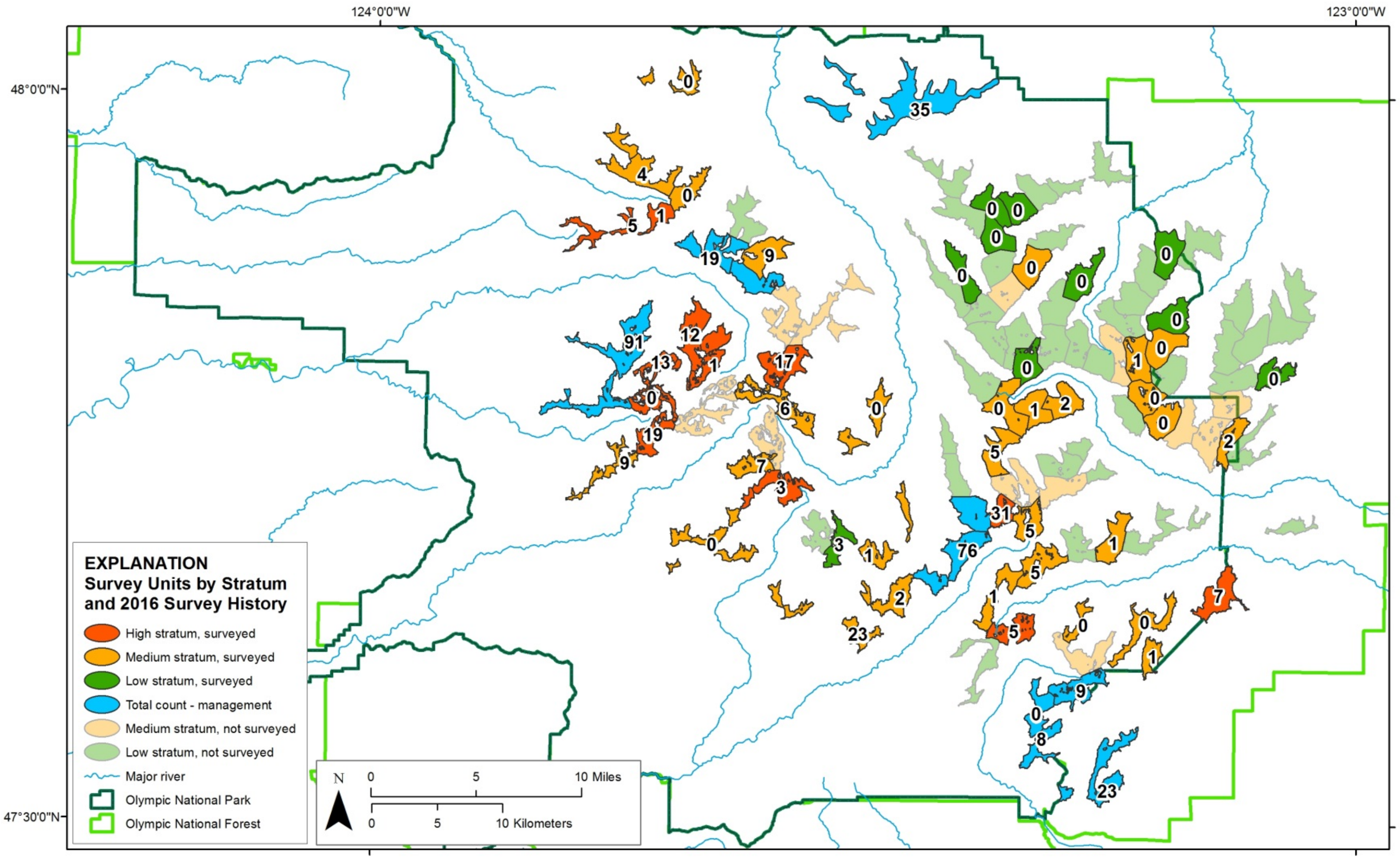

Figure 2. Map showing sampling strata, units surveyed, and number of mountain goats counted during mountain goat surveys in the Olympic Mountains, northwestern Washington, July 13–24, 2016. Total counts and number of kids (young of the year) are presented in appendix 3.

The sampling frame comprised a total of 109 individual sampling units (fig. 2). Sampling units were selected for the survey based on special management considerations and stratified random sampling methods (Cochran, 1977). As in years past, we assigned each of the survey units to one of four survey strata prior to the surveys. These strata included total count areas (TCAs), and low-density, medium-density, and high-density strata. Total count areas were areas of special management interest, all of which were surveyed. Survey units other than TCAs were assigned to mountain goat density strata based on results of past mountain goat surveys, recent observations of park staff, and visitor reports. With the exception of the TCAs, which were more variable in size, high-, medium- and low-density units ranged in size from 220 to 712 ha. After allotting survey time for all TCA units, we allocated the remaining survey effort among high-, medium-, and low-density strata using standard optimal allocation methods (Cochran, 1977) based on sampling variances reported within each stratum in 2011 (Jenkins and others, 2012). The strata were defined as follows:

I. **Total Count Areas (TCAs)**: We identified eight TCAs that were surveyed in their entirety. Four TCAs were of particular interest to the NPS because they have been included in every survey since 1990. These include survey units on Klahhane Ridge, Mount Olympus, Mount Carrie, and Chimney/Chrystal Peaks (fig. 2). Four additional TCAs were in the Olympic National Forest where hunting seasons are managed by WDFW. Collectively, these eight survey units comprised a total of 8,232 ha or about 14 percent of the sampling frame.

II. **Known or suspected high-density areas:** Units were assigned to this stratum if we expected to find 10 or more mountain goats per unit based on previous surveys and field observations. We assigned 12 survey units in the high-density stratum, encompassing 5,534 ha and about 9 percent of the sampling frame (fig. 2). We surveyed all units in the high-density stratum.

III. **Known or suspected medium-density areas:** Units were assigned to this stratum if we expected 1–9 mountain goats inhabiting the survey unit. The medium-density stratum consisted of 42 survey units comprising 21,966 ha (about 36 percent of the sampling frame) (fig. 2). We randomly selected 29 survey units for survey in this stratum.

IV. **Known or suspected low-density areas:** Units were assigned to this stratum if we expected no mountain goats. The low-density stratum consisted of 47 survey units comprising 24,486 ha or about 41 percent of the sampling frame (fig. 2). We randomly selected 10 survey units for survey in this stratum.

Aerial Surveys

Aerial survey procedures were similar to those used in previous surveys (Houston and others, 1986; Houston, Moorhead, and others, 1991; Happe and others, 2005; Rice and others, 2009). We surveyed during mid- to late July, targeting the seasonal window after mountain goats have moved to higher elevations for summer (Rice, 2008; Jenkins and others, 2011), but before hot mid-summer temperatures present operational difficulties for flying at high elevations. Most surveys were conducted between dawn and about 10:30 a.m. PDT by a pilot and three-person crew aboard a Bell 206 B3 helicopter. The pilot's primary responsibility was to safely fly the aircraft, but the pilot also reported observations. We counted mountain goats in the selected survey units by flying multiple contours about 100 m from the terrain (that is, above flat terrain or horizontally away from vertical terrain) at elevations vertically spaced 90–150 m apart. Flight speed was maintained between 56 and 72 km/h (35 and 45 mi/h). Low elevations of each unit were flown first and then the helicopter progressively worked upslope until the entire unit was searched. The implicit assumption is that whereas some mountain goats may have been missed because of non-detection, 100 percent of each survey unit was effectively searched. We used a GPS unit aboard the helicopter during all surveys to assist with navigation, to map flight paths, and to record the approximate locations of mountain goats and other wildlife seen during the surveys.

We recorded conditions related to each helicopter flight, survey unit, and group of mountain goats observed. For each flight, we recorded the names of crew members and various flight descriptors (times and locations of takeoffs and landings). We recorded times at the start and end of each unit surveyed and several environmental conditions, including cloud cover, wind strength, precipitation level, and temperature. Upon observing a group of mountain goats, observers recorded the total number of mountain goats, number of young of the year (kids), and the following covariates: (1) the percentage of vegetation cover capable of obscuring a mountain goat within a 10-m buffer around the group (0, 1–25, 26–50, 51–75, or 76–100 percent), and (2) whether terrain obstruction was present within a 10-m buffer around the group at the moment it was first observed. We defined terrain obstruction as any landform capable of obscuring a mountain goat from the air. The group size, vegetation cover, and terrain obstruction covariates were used to estimate group-specific detection probabilities for bias correction (Rice and others, 2009).

We also recorded whether each observed group was in the survey area at elevations below 1,520 m and whether the group was below, level with, or above the helicopter flight line. These last two pieces of information were recorded so that we could estimate population abundance for sampling frames defined for the 2011 and 2016 surveys (that is, including suitable habitat at elevations between 1,425 and 1,520 m) and for the more restricted sampling frame used prior to 2011 (that is, lands at elevations above 1,520 m).

Population Abundance

We estimated mountain goat abundance using the sightability modeling approach developed by Samuel and others (1987) and Steinhorst and Samuel (1989). This approach combines counts of animals, or groups of animals, in a set of randomly sampled survey units with a model for their probability of detection. For a stratified random sample of survey units, the estimate of population size ($\hat{\tau}$) is given by:

$$\hat{\tau} = \sum\sum\sum\left(\frac{N_h}{n_h}\hat{\theta}_{h,i,j}Y_{h,i,j}\right) \qquad (1)$$

where the sums are over strata (*h*), sampled survey units (*i*), and observed groups (*j*); n_h and N_h are, respectively, the number of stratum h plots in the sample and in the population; the $\hat{\theta}$'s are estimated sightability correction factors associated with each observed group (that is, the inverse of each group's detection probability); and $Y_{h,i,j}$ gives the number of animals in the j^{th} observed group (in the i^{th} survey unit in stratum h).

We estimated sightability correction factors for each observed group using model-averaged regression coefficients and their unconditional variance covariance matrix from Rice and others (2009), along with formulas from Steinhorst and Samuel (1989). Specifically, Rice and others (2009) used sighting data from 205 sightability trials to model the probability of detection for each mountain goat group (*j*), $P_{detect,j}$, as a function of group size ($GroupSize,_j$), percent vegetative cover (*%Veg,j*), and terrain obstruction (Terrain).

$$P_{detect,j} = \frac{e^{(\beta_1+\beta_2*GroupSize,j+\beta_3*Terrain,j+\beta_4\%Veg,j)}}{1+e^{(\beta_1+\beta_2*GroupSize,j+\beta_3*Terrain,j+\beta_4*\%Veg,j)}} = \frac{e^{(x_j'\beta)}}{1+e^{(x_j'\beta)}} \qquad (2)$$

The estimated regression coefficients ($\hat{\beta}$; Rice and others, 2009, p. 474) and their estimated unconditional variance/covariance matrix, $\hat{\Sigma}$ (Rice and others, 2009, p. 474), were then used to estimate the sightability correction factors using the following equation from Steinhorst and Samuel (1989):

$$\hat{\theta}_{h,i,j} = 1 + e^{\left(-x_j'\hat{\boldsymbol{\beta}} - \frac{x_j\hat{\boldsymbol{\Sigma}}x_j'}{2}\right)} \qquad (3)$$

Three random processes create uncertainty in the estimated abundance ($\hat{\tau}$): (1) the random sampling of survey units; (2) random detection (and failed detection) of independent groups in surveyed units; and (3) variation in estimation of parameters used to model sightability. Wong (1996) developed consistent (asymptotically unbiased) estimators of each of these variance components. We estimated $\hat{\tau}$ based on the Steinhorst and Samuel (1989) estimator (eq. 1), and Var($\hat{\tau}$) using equations from Wong (1996) as applied in R SightabilityModel package (R Development Core Team, 2011; Fieberg, 2012).

To place the 2004 to 2016 population estimates in historical context, we computed minimum population indices from all surveys conducted from 1983 to 2016. Minimum population indices were based on raw counts of mountain goats without any adjustment for aerial detection biases. To maintain consistency among years, we computed population indices based on survey area boundaries used prior to 2011. We computed population indices based on stratified random sampling computational methods described by Norton-Griffiths (1978) and used by Houston and others (1986) and Houston, Moorhead, and others, 1991). Standard errors of the minimum population indices account for sampling variability only, in contrast to standard errors of the population estimates, which account for sampling variation, random detection, and sightability model estimation. Because indices do not explicitly account for animals present but not seen during surveys, any comparison of indices implicitly assumes that sightability of mountain goats remained constant between surveys.

Population Trends

We computed population trends and rates of population increase from surveys conducted in 2004, 2011, and 2016. The 2004 estimate was derived retroactively by applying the detection bias model developed in subsequent years (Rice and others, 2009). Because we adjusted survey boundaries between the 2004 and 2011 surveys, we estimated population growth based on consistent survey boundaries used prior to 2011. That is, all observations of mountain goats from the new survey areas added in 2011 (elevations between 1,425 and 1,520 m) were omitted from the 2011 and 2016 datasets. Because we did not conduct surveys in the Mount Washington survey unit in 2011, we also substituted survey results for that unit from a survey conducted by WDFW partners in 2012. We recognize that there may have been some population growth in the Mount Washington unit between 2011 and 2012 or movement in or out of the unit in the intervening period, but we concluded that adding these data provided a more representative estimate for 2011 and a more valid comparison of population trend across years. We estimated the instantaneous rate of exponential population growth (r) and the average finite rate of growth ($\lambda = e^r$) necessary to cause the observed changes in estimated abundance from 2004 to 2016, based on the difference of the log-transformed abundance estimates (Caughley, 1977, p. 51). Because we used the same sightability model to estimate abundance of mountain goats in 2004, 2011, and 2016, we accounted for covariance between years by estimating variance of the population growth rate using the R SightabilityModel package (Fieberg, 2012). We used a two-tailed z-test to determine whether or not two estimates of abundance differed statistically from a null hypothesis of zero change (Thompson and others, 1998).

Results

Aerial Surveys

Mountain goats were surveyed during six mornings from July 13 to July 24, 2016, in 59 survey units totaling 33,391 ha (table 1). This sampling effort was roughly 40 percent greater than the area surveyed in either 2004 or 2011 (39–41 survey units comprising 23,458–24,524 ha were surveyed in the previous two surveys; Happe and others, 2005; Jenkins and others, 2012). A total of 13 flights were conducted by NPS and 2 flights were conducted by WDFW personnel (appendix 1). Total flight time was about 31 hours and 47 minutes. NPS flights, including travel between survey units and fueling locations, totaled about 26 hours and 17 minutes , and WDFW flights totaled another 5 hours and 30 minutes. On several days, cloud cover interfered with survey efforts. We discontinued surveys in five survey units because of deteriorating weather. All five count units were resurveyed at a later date (appendix 2). A total of 23 hours and 17 minutes were spent actually surveying (that is, disregarding transit times). Two hours were spent on surveys that were omitted because of bad weather, leaving a total of about 21 hours and 17 minutes spent on usable surveys. Survey intensity averaged 3.9 min/km^2 across all surveyed units, ranging from 2.35 to 5.28 min/km^2 in the low and high-density strata, respectively (table 2). Differences in survey intensity among survey units and strata indicated variation in habitat complexity and the time required to count mountain goats and record observations, rather than any variation in our flight patterns. Detailed summaries of all individual flights and survey conditions are provided in appendixes 1 and 2, respectively.

Table 1. Mountain goat survey characteristics and raw counts of mountain goats in eight total count areas, and in high-, medium-, and low-density strata, Olympic Mountains, northwestern Washington, July 13–24, 2016.

[ha, hectare; min, minute; hr, hour; min/km^2, minute per square kilometer. Totals or averages are reported for each column depending on the quantity reported.]

Stratum	Area (ha)	Number of units	Area sampled (ha)	Number of survey units sampled	Percentage of stratum surveyed	Survey time (hr)	Survey intensity (min/km^2)	Number of goats observed
Total count areas	8,232	8	8,232	8	100	6.9	4.23	221
High density	5,534	12	5,534	12	100	4.3	5.28	114
Medium density	21,966	42	14,782	29	67	8.1	3.72	85
Low density	24,486	47	4,843	10	20	1.8	2.35	3
Total	60,218	109	33,391	59		21.2		463
Average					55		3.9	

Table 2. Population estimates of mountain goats, associated components of variance, standard errors, and 95-percent confidence intervals in the Olympic Mountains survey area, northwestern Washington, 2004–2016.

[All numbers in table are number of mountain goats, except as otherwise noted. For comparison among years, estimates in 2016 are computed for two survey unit definitions: (1) the expanded survey unit boundaries, which included suitable habitats at elevations above 1,425 meters (m), and (2) the original survey unit boundaries including lands at elevations above 1,520 m. **Variance component:** Variance components as defined by Steinhorst and Samuel (1989) were computed following Wong (1996). **Standard error:** Computed as square root of total variance. NAVD 88, North American Vertical Datum of 1988]

Year	Survey boundary definition (meters above NAVD 88)	Estimate (Number of goats)	Variance component				Standard error	95-percent confidence interval
			Total	Sampling	Detection	Modeling		
2016	>1,425	623	1,846	771	424	651	43	561–741
2016	>1,520	584	1504	568	381	555	39	528–689
2011	>1,520	350	1,831	1,049	441	341	43	294–479
2004	>1,520	230	387	137	168	82	20	205–293

Population Abundance

A total of 463 mountain goats were counted in the four strata (table 1, fig. 2, additional detail is provided in appendix 3). The estimated population of mountain goats in the Olympic Mountains survey area corrected for detection bias was 623 ±43 (SE) at the time of the survey (table 2). The total variance of the population estimate, $Var(\hat{\tau})$, was 1,846, which accounts for variance associated with random sampling of survey units ($Var_{sampling}$=771 or 42 percent of the total), random detections of independent groups ($Var_{detection}$=424 or 23 percent of total), and uncertainty in model estimation (Var_{model}=651 or 35 percent of total). The 95-percent confidence interval ranged from 561 to 741 mountain goats. Strictly interpreted, the confidence interval of the estimate implies that if the exact same mountain goat survey were replicated many times, 95 percent of the resulting confidence intervals would include the true mean. Informally, the confidence interval often is considered the range in which we would expect to find the true population size if it were known (Mills, 2013, p. 18).

Minimum population indices based on unadjusted counts of mountain goats in the Olympic Mountains ranged from a high of 764 ±116 (SE) in 1983, to a low of 181 ±15 (SE) in 1997 several years following the cessation of experimental removals (fig. 3). The population index increased from about 191 ±10 (SE) in 2004 to about 516 ±27 (SE) in 2011. Differences between the estimated abundance and minimum population index each year represent the estimated undercounting bias associated with using the uncorrected raw counts of mountain goats.

Population Trends

Population estimates corrected for detection biases and adjusted for comparable survey boundaries were 230 ±20 (SE) mountain goats in 2004, 350 ±43 (SE) mountain goats in 2011, and 584 ±39 (SE) mountain goats in 2016 (table 2, fig. 3). Compared with the overall abundance estimate of 623 mountain goats, the estimate of 584 mountain goats reported here corresponds with the more restricted survey boundaries used in previous years. The estimated population in the expanded survey area was about 7 percent greater than in the previous survey area, representing mountain goats observed in the newly added area at elevations between 1,425 and 1,520 m.

Based on population estimates of mountain goats in comparable survey boundaries, mountain goat abundance was significantly greater in 2016 than in 2011 (z=4.63, $P<0.01$). The z-statistic indicated that a difference in population estimates of the observed magnitude (or greater) would occur less than 1 percent of the time if the null hypothesis of equal population size was true. The estimated population of mountain goats increased at an instantaneous rate (r) of 0.06 ±0.02 (SE) between 2004 and 2011, 0.10 ±0.02 (SE) between 2011 and 2016, and at an overall rate of 0.08 ±0.01 (SE) for the combined period of 2004–16. These instantaneous rates convert to average annual finite rates of growth approximating 6 percent annually from 2004 to 2011, 11 percent annually from 2011 to 2016, and 8 percent annually over the combined 12-year period (that is, λ=1.06, 1.11, and 1.08, respectively).

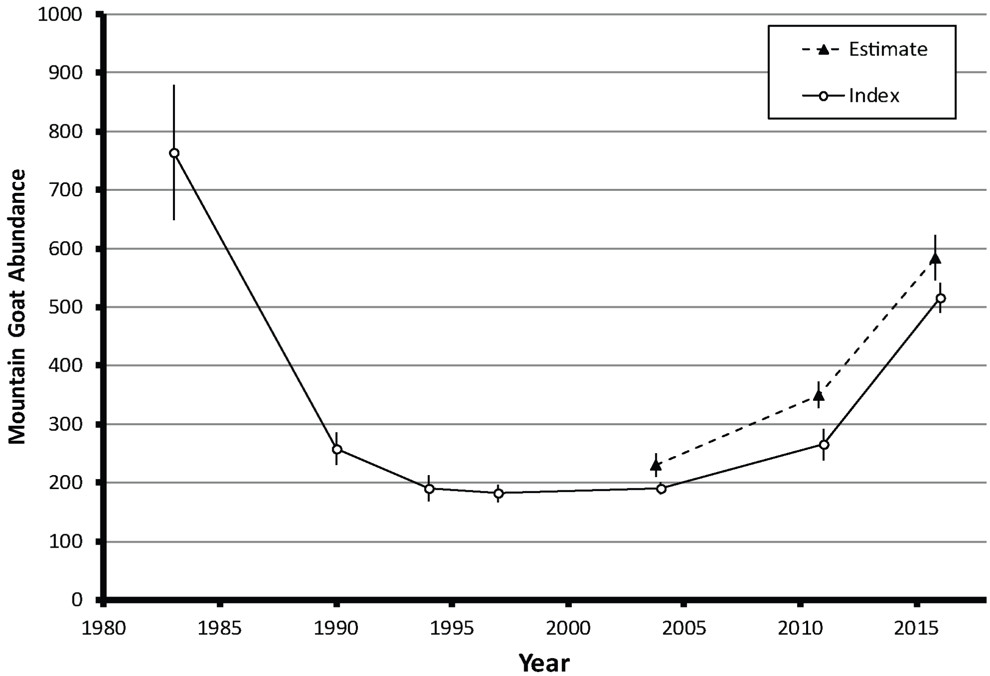

Figure 3. Graph showing trends in the minimum population index and estimated population abundance (±standard error) of mountain goats in the Olympic Mountains, northwestern Washington, 1983–2016. All estimates correspond with survey unit boundaries at elevation contours above 1,520 m and included the Mount Washington survey unit.

Discussion

The mountain goat population in the Olympic Mountains, which remained at relatively low numbers during the 1990s and began increasing after 2004 (Jenkins and others, 2012), continued to increase between 2011 and 2016. The observed exponential rate of increase, *r*, measured between 2004 and 2016 (0.08 ±0.01 [SE]) was less than but comparable (based on the SE) to that measured for the Klahhane Ridge subpopulation during its documented increase in the 1960s and 1970s (about 0.09; Houston and Stevens, 1988).

Comparison of population growth rates from 2011 to 2016 (r=0.10) compared to 2004–11 (r=0.06) suggested that the rate of population increase may have accelerated after 2011. We caution, however, that poor counting conditions may have resulted in a low population estimate in 2011. Such an underestimation would result in an underestimation of actual population growth from 2004 to 2011 and an overestimation of population growth after 2011. The 2011 surveys followed one of the deepest snow years and latest season snow melts on record in the Olympic Mountains (Jenkins and others, 2012). In Jenkins and others (2012), we speculated that deep snow may have hindered the seasonal movement of mountain goats to high-elevation survey areas during 2011, or that the prevailing white background of snow may have resulted in greater than average detection biases. We cannot, however, rule out the alternative possibility that severe winter and spring conditions in early 2011 promoted a high level of over-winter mortality (White and others, 2011) also contributing to the low population estimate.

In contrast to conditions that raised uncertainties in the interpretation of 2011 surveys, optimal survey conditions, funding, and interagency cooperation all contributed to a successful survey in 2016. Snowfall during winter 2015–16 was approximately normal, but early snow melt promoted optimal phenology and forage conditions during the survey period. As evidence that mountain goats were distributed at higher elevations in 2016 than in 2011, we found only 7 percent of observations in the lower elevations of the survey area (between 1,425 and 1,520 m) during 2016, compared to 14 percent of observations in 2011 (Jenkins and others, 2012). Furthermore, because of optimal funding levels, survey logistics, and participation of WDFW biologists, we surveyed the largest proportion of goat habitat in 2016 (55 percent) than in any prior survey, contributing to relatively high survey precision.

Our current estimate of population growth from 2004 to 2011 (r=0.06) was greater than we estimated in a previous report based on a smaller dataset without the Mount Washington unit (r=0.05; Jenkins and others, 2012). The difference in estimated rates of population growth is owing to the inclusion of the Mount Washington unit, where counts increased from 12 to 33 between 2004 and 2012. The number of mountain goats in the Mount Washington unit possibly increased from 2011 and 2012, consistent with the general population trends, which may have contributed to a slight overestimation in the 2004–11 rate of population growth. We suspect that because of this potential bias, the true rate of population growth for the entire population from 2004 to 2011 likely is between the previous and current estimates.

The mountain goat population in the Olympic Mountains has sustained growth for more than a decade. Given uncertainties in the 2011 population estimate, the rate of population growth measured from 2004 to 2011 (r=0.08) likely is the best indication of near future trends. Over the next 5 years, if trends were to remain constant in the absence of density-dependent population responses or management intervention, we would expect the current population of about 623 mountain goats to increase by as much as 45 percent. Any extrapolation past that horizon is clouded by distinct possibilities that density-dependent demographic responses will begin to regulate population growth as was evident during the last population high mark (Houston and Stevens, 1988).

Acknowledgments

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Appendix 1. Survey Flight Characteristics during Aerial Mountain Goat Surveys, Olympic Mountains, Northwestern Washington, 2016

[**Survey duration:** Total time spent on surveys excluding time spent flying to and among survey units. **Navigator/observer:** Operated Global Positioning System during surveys. **Primary observer:** Focused on searching for goats at all times. **Secondary observer:** Data recorder: recorded all observations and covariate data]

Flight No.	Date	Departure time (a.m. PDT)	Departure location	Arrival Time	Arrival location	Flight duration (hours:min)	Survey duration (hours:min)	Personnel/seating position			
								Right front: Pilot	Left back: Navigator/ observer	Left front: Primary observer	Right back: Secondary observer
ONP01[1]	7/13/2016	5:40	Port Angeles	8:10	Sweets Field	2:29	1:57	Olmstead	Beirne	Happe	Baccus
ONP02	7/14/2016	5:20	Port Angeles	7:18	Obstruction	1:58	1:14	Olmstead	Beirne	Happe	Baccus
ONP03	7/14/2016	7:37	Obstruction	9:43	Obstruction	2:06	1:38	Olmstead	Beirne	Happe	Baccus
ONP04	7/14/2016	10:03	Obstruction	11:12	Sweets Field	1:08	0:30	Olmstead	Beirne	Happe	Baccus
ONP05	7/15/2016	5:15	Sweets Field	8:12	Obstruction	2:57	2:22	Olmstead	Beirne	Happe	Baccus
ONP06	7/15/2016	8:41	Obstruction	10:41	Sweets Field	2:00	1:38	Olmstead	Beirne	Happe	Baccus
ONP07	7/16/2016	5:17	Sweets Field	7:46	Obstruction	2:29	1:59	Olmstead	Beirne	Happe	Baccus
ONP08	7/16/2016	8:07	Obstruction	10:24	Sweets Field	2:17	1:58	Olmstead	Beirne	Happe	Baccus
ONP09	7/17/2013	5:14	Sweets Field	7:42	Obstruction	2:28	1:52	Olmstead	Beirne	Happe	Baccus
ONP10[1]	7/17/2013	8:03	Obstruction	9:15	Sweets Field	1:12	0:41	Olmstead	Beirne	Happe	Baccus
ONP11	7/24/2016	5:26	Obstruction	6:59	Obstruction	1:33	1:23	Olmstead	Beirne	Happe	Baccus
ONP12	7/24/2016	7:26	Obstruction	9:29	Obstruction	2:03	1:33	Olmstead	Beirne	Happe	Baccus
ONP13	7/24/2016	9:52	Obstruction	11:29	Shelton Airport	1:37	1:07	Olmstead	Beirne	Happe	Baccus
W01	7/14/2016	6:15	Olympia	.	Bremerton	.	1:53	Hagerman	Rice	Harris	Kindschuh
W02[1]	7/14/2016	.	Bremerton	12:45	Olympia	[2]5:30	1:32	Hagerman	Rice	Harris	Kindschuh
Total hours						31:47	23:17				

[1]Survey curtailed because of deteriorating weather.

[2]Flight duration calculations include refueling time. Estimated flight hours are 5 hours and 30 minutes for the Washington Department of Fish and Wildlife surveys.

Appendix 2. Survey Characteristics and Environmental Conditions Measured at the Beginning of Each Unit Surveyed in the Olympic Mountains, Northwestern Washington, 2016

[Polygons are subunits that are used for data recording and survey planning. Duration of survey in each surveyed unit. Ppt: Precipitation level. At elevation: Elevation at which air temperature was recorded, in feet above North American Vertical Datum of 1988. Light refers to lighting conditions during the survey. High lighting casts shadows whereas flat lighting does not. oC, degrees Celsius; ft, feet; h, hour; min, minute; sec, second; km^2, square kilometer. No data were recorded during the survey for table cells that are left blank]

Flight No.	Date	Unit ID	Polygon ID(s)	Unit area (km^2)	Survey duration (hh:min:sec)	Survey intensity (min:sec/km^2)	Sky condition	Winds	Ppt	Cloud cover (percent)	Temp (°C)	At elevation (ft)	Light
ONP-01	7/13/2016	143W	143W	2.6	0:15:10	0:05:55	clear	calm	none	0	4	5,500	Flat
ONP-01	7/13/2016	141	141, 142	3.8	0:24:00	0:06:23	clear	calm	none	0			Flat
ONP-01	7/13/2016	129	129	6.7	0:23:28	0:03:31	clear						
ONP-01	7/13/2016	[1]137	139, 137 part	([1])	0:33:18	([1])	mostly clear- fog	calm	none	30			Flat
ONP-01	7/13/2016	145	145, 146, 147	5.3	0:21:25	0:04:05	mostly cloudy	calm	none	50			Flat
ONP-02	7/14/2016	122	122	4.0	0:14:46	0:03:42	clear	light	none	0	7	5,000	Flat
ONP-02	7/14/2016	127S	127S	3.5	0:19:00	0:05:30	clear	calm	none	0			Flat
ONP-02	7/14/2016	125	125, 126	5.5	0:39:59	0:07:15	clear	light	none	0			
ONP-03	7/14/2016	125	128	9.1	0:43:28	0:04:46	clear	calm	none	0	8	5,000	
ONP-03	7/14/2016	127N	127N	2.3	0:20:32	0:08:46							
ONP-03	7/14/2016	130	130	5.8	0:33:44	0:05:46	clear	calm	none	20	7	6,000	High
ONP-04	7/14/2016	35	35	5.6	0:12:21	0:02:13	clear	calm	none	0	9	5,000	High
ONP-04	7/14/2016	27	27	5.5	0:18:09	0:03:17	clear	calm	none	0	9	5,000	High
ONP-05	7/15/2016	119	119, 120, 121	3.8	0:22:43	0:06:01	clear	moderate	none	0	8	5,000	Flat
ONP-05	7/15/2016	110	110, 111, 112, 113, 150	6.6	0:18:54	0:02:52	clear	light	none	0			Flat
ONP-05	7/15/2016	115	115	6.1	0:31:13	0:05:08	clear	light	none	0	9		
ONP-05	7/15/2016	116W	116W	3.8	0:14:52	0:03:52	clear	light	none	0			
ONP-05	7/15/2016	124	124	7.0	0:29:37	0:04:15	clear	light	none	0			
ONP-05	7/15/2016	131	131	6.7	0:24:45	0:03:43	clear	light	none	0	8	6,000	High
ONP-06	7/15/2016	102	102	5.6	0:15:37	0:02:48	clear	light	none	0	8	6,000	
ONP-06	7/15/2016	101	101, 104, 107	4.9	0:29:48	0:06:07							
ONP-06	7/15/2016	109	109	3.6	0:12:42	0:03:30	clear	light	none	0			

Flight No.	Date	Unit ID	Polygon ID(s)	Unit area (km^2)	Survey duration (hh:min:sec)	Survey intensity ($min:sec/km^2$)	Sky condition	Winds	Ppt	Cloud cover (percent)	Temp (°C)	At elevation (ft)	Light
ONP-06	7/15/2016	105	105,106	5.0	0:13:33	0:02:43	clear	light	none	0			
ONP-06	7/15/2016	70	70	5.1	0:14:44	0:02:53	clear	light	none	0			
ONP-06	7/15/2016	49	49	5.1	0:11:37	0:02:17	clear	light	none	0			
ONP-07	7/16/2016	69	69, 78, 103	14.2	1:46:24	0:04:55	mostly clear	calm	none	0	9	5,000	Flat
ONP-07	7/16/2016	73W	73W	3.0	([2])	([2])	mostly cloudy	calm	none	60			Flat
ONP-07	7/16/2016	73E	73E	4.4	([2])	([2])							
ONP-07	7/16/2016	32	32	4.8	0:13:05	0:02:45	mostly clear	calm	none	0	8	7,000	High
ONP-08	7/16/2016	137	139, 137	12.4	1:15:06	([3])	clear	calm	none	0	10	5,000	High
ONP-08	7/16/2016	138	138	5.7	([2])	([2])	clear	calm	none	10	9	6,000	High
ONP-08	7/16/2016	143E	143E	4.0	0:18:56	0:04:41							
ONP-08	7/16/2016	144	144	7.1	0:24:05	0:03:25							
ONP-09	7/17/2013	[1]1	3	([1])	0:11:55	([1])	mostly clear	calm	none	10	9	5,000	Flat
ONP-09	7/17/2013	54	54	5.1	0:23:58	0:02:23	clear	calm	none	0			Flat
ONP-09	7/17/2013	52	52	4.9	([2])	([2])	clear	calm	none	0			Flat
ONP-09	7/17/2013	44	44	5.3	0:32:05	0:02:52	mostly clear	calm	none				High
ONP-09	7/17/2013	45	45	5.9	([2])	([2])	mostly clear	calm	none	15			Flat
ONP-09	7/17/2013	46	46	5.8	0:10:29	0:01:49	mostly clear	calm	none	20			Flat
ONP-09	7/17/2013	42	42	6.1	0:10:56	0:01:48	mostly clear	calm	none	10			High
ONP-09	7/17/2013	17	17	4.4	0:08:27	0:01:55	mostly clear	calm	none	15			Flat
ONP-09	7/17/2013	16	16	4.5	0:05:55	0:01:19	mostly clear	calm	none	15			Flat
ONP-09	7/17/2013	22	22	4.9	0:08:12	0:01:40	mostly clear	calm	none				High
ONP-10	7/17/2013	[1]1	4	([1])	0:21:04	([1])	mostly cloudy				10		Flat
ONP-10	7/17/2013	117	117, 118	5.0	0:20:04	0:03:59	mostly cloudy	light	none	70	11	4,000	Flat
ONP-11	7/24/2016	1	2,3,4	19.3	1:10:10	0:03:38	clear	light	none	0	12	6,000	
ONP-11	7/24/2016	24	24	4.7	0:12:27	0:02:39	clear	light	none	0	12	6,000	High
ONP-12	7/24/2016	64	64	4.1	0:15:50	0:03:50	clear	light	none	0	12	6,000	High
ONP-12	7/24/2016	65W	65W	4.0	0:19:28	0:04:53	clear	light	none	0			High
ONP-12	7/24/2016	85	85	5.4	0:20:57	0:03:53	clear	light	none	0			High
ONP-12	7/24/2016	50	50	5.0	0:17:51	0:03:34	clear	light	none	0			High
ONP-12	7/24/2016	48	48	6.9	0:18:26	0:02:41	clear	light	none	0	12	7,000	High

Flight No.	Date	Unit ID	Polygon ID(s)	Unit area (km^2)	Survey duration (hh:min:sec)	Survey intensity (min:sec/km^2)	Sky condition	Winds	Ppt	Cloud cover (percent)	Temp (°C)	At elevation (ft)	Light
ONP-13	7/24/2016	98	98	6.3	0:31:23	0:05:01	clear	light	none	0	12	5,000	High
ONP-13	7/24/2016	96	96	5.8	0:21:30	0:03:42	clear	light	none	0			High
ONP-13	7/24/2016	97	97	2.7	0:14:04	0:05:08	clear	light	none	0	13	5,000	High
W-01	7/14/2016	99	100	7.2	0:34:00	0:04:43	clear				9	4,000	
W-01	7/14/2016	90	99	0.8	0:04:00	0:04:50	clear				6	5,000	
W-01	7/14/2016	90	90	3.6	0:14:00	0:03:51	clear				4	5,500	
W-01	7/14/2016	91	91	1.7	0:05:00	0:02:55	clear				4	6,000	
W-01	7/14/2016	91	92	2.6	0:06:00	0:02:19	clear				5	5,500	
W-01	7/14/2016	93	93	5.8	0:18:00	0:03:07	clear						
W-01	7/14/2016	[1]96	96	([1])	0:19:00	([1])	clear - fog				5	5,500	
W-01	7/14/2016	[1]97	97	([1])	0:13:00	([1])	clear - fog				4	5,500	
W-02	7/14/2016	[1]98	98	([1])	0:26:00	([1])	clear - fog				6	5,000	
W-02	7/14/2016	95	95	2.2	0:08:00	0:03:38	clear				6	5,500	
W-02	7/14/2016	83	83	6.0	0:18:00	0:03:00							
W-02	7/14/2016	82	82	4.7	0:18:00	0:03:51							
W-02	7/14/2016	81E	81E	4.7	0:22:00	0:04:40					7	5,500	

[1]Survey was curtailed because of deteriorating weather. Not all unit was surveyed. Unit was counted later on another flight.

[2]Unit(s) were surveyed with preceding units. Time and intensity values are for the group of units surveyed together.

[3]Unit was surveyed on multiple flights. Survey effort calculations are not valid.

Appendix 3. Raw Counts of Mountain Goats by Survey Unit, Olympic Mountains, Northwestern Washington, 2016

[For each unit, the number of mountain goats observed in the part of the survey unit at elevations below 1,520 meters above North American Vertical Datum of 1988 is noted in parentheses. **Stratum:** TCA, Total Count Area; H, high density; M, medium density; L, low density]

Stratum	Unit ID	Unit name	Number of groups	Total	Adults	Kids
TCA	1	Klahhane Total Count	12	35	28	7
TCA	69	Chimney Total Count	44	76	63	13
TCA	90	Sawtooths	3	8	6	2
TCA	91	Gladys/Henderson	0			
TCA	93	Mount Skokomish	4	9	8	1
TCA	99	Mount Washington	3	23	18	5
TCA	125	Olympus Total Count	41	91 (5)	75	16
TCA	137	Carrie Total Count	8	19	17	2
H	73W	Mount Anderson West	13	31	25	6
H	81E	Steel East	3	5	5	0
H	98	The Brothers	6	7 (1)	7	0
H	115	Seattle	3	3	3	0
H	122	Paull Creek	10	19 (5)	15	4
H	127N	Olympus Summit North	4	13 (6)	8	5
H	127S	Olympus Summit South	0			
H	129	Glacier Meadows	7	12 (3)	9	3
H	130	Mount Mathias	1	1	1	0
H	131	Mount Childs	6	17	15	2
H	141	High Divide/Bogaciel	4	5	4	1
H	143W	High Divide West	1	1	1	0
M	27	Moose Lake	0			
M	44	Mount Deception	1	1	1	0
M	45	Royal Lake	0			
M	48	Mount Fromme	0			
M	49	Thousand Acre Meadow	1	1	1	0
M	50	Wellesley Peak	1	2	2	0
M	52	Mount Mystery	0			
M	54	Sunnybrook Meadows	0			
M	65	Constance West	1	2	2	0
M	70	Sentinel	1	5	3	2
M	73E	Mount Anderson East	5	5	5	0
M	82	Hart Lake	1	1	1	0
M	83	LaCrosse	1	5	4	1
M	85	Mount Elk Lick	1	1	1	0

Stratum	Unit ID	Unit name	Number of groups	Total	Adults	Kids
M	95	Mount Hopper	0			
M	96	Lena Lake	0			
M	97	Mount Bretherton	1	1	1	0
M	101	Muncaster	5	23 (4)	18	5
M	102	Rustler	2	2	2	0
M	105	Delabarre	1	1	1	0
M	110	Muncaster	0			
M	117	Mount Dana.	0			
M	116W	Mount Queets West	2	7	5	2
M	119	Valhallas	8	9(1)	9	0
M	124	Mount Barnes	3	6(2)	5	1
M	138	Long Creek	4	9	7	2
M	143E	High Divide East	0			
M	144	Appleton	2	4	4	0
M	145	Boulder Peak	0			
L	16	Elk Mountain	0			
L	17	Elk Mountain East	0			
L	22	Badger	0			
L	24	Lillian River	0			
L	32	Mount Cameron	0			
L	35	Cameron Creek	0			
L	42	Baldy	0			
L	46	Royal Creek	0			
L	64	The Gargoyles	0			
L	109	Christie	2	3	2	1

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