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Natural Resource Stewardship and Science

Elk Monitoring in Mount Rainier and Olympic National Parks

2008 – 2011 Synthesis Report

Natural Resource Report NPS/NCCN/NRR—2015/904





ON THIS PAGE
Elk, *Cervus elaphus*, in Mount Rainier National Park, WA.
Photograph by: Muckleshoot Indian Tribe.

ON THE COVER
Elk in Olympic National Park, August 2012. Inset, view of observer counting same group from inside the helicopter.
NPS I&M program.

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Executive Summary

Maintaining naturally abundant elk (*Cervus elaphus*) populations is central to the primary purpose of preserving natural ecosystems and processes in both Mount Rainier National Park (NP) and Olympic NP. Elk are key components of ecosystems, affecting the structure, composition, and successional patterns in plant communities, altering nutrient cycling and other natural processes, and serving as food for top-level predators and a diverse community of scavengers. Elk are also exceptionally important components of Native American cultures and are harvested by both Tribal and State hunters. Each year thousands of visitors come to both parks with the hope of viewing and photographing elk in their natural habitats.

There is a long history of monitoring elk in both parks, dating back to the 1970s in Mount Rainier NP and the 1980s in Olympic NP. In Mount Rainier NP, migratory herds that enter the park during summer have been surveyed on the summer ranges as a partnership of the National Park Service (NPS), the Washington Department of Fish and Wildlife (WDFW), and more recently, the neighboring Native American Tribes that co-manage those herds. In Olympic NP, park biologists have surveyed elk opportunistically (as funding was available) on low-elevation winter ranges during early spring in three of the primary elk ranges in the Western rainforest valleys of the park.

Beginning in 2008, the U.S. Geological Survey (USGS) began collaborating with the NPS, the Muckleshoot Indian Tribe (MIT), Puyallup Tribe of Indians (PTOI), and WDFW to develop a standard protocol for monitoring long-term changes in abundance, population composition, and spatial distribution of elk on key summer ranges within both Mount Rainier and Olympic NPs and key winter ranges in Olympic NP (Griffin et al. 2012). In both parks, we attempted to minimize disruption of the established survey methods while also establishing more repeatable procedures and improving data management, analysis, and reporting methods.

The ‘new’ survey methods differed from the historical methods primarily in the way field data were collected, which enabled us to estimate aerial detection probabilities of elk groups and adjust raw counts to account for elk that were likely present but missed by the aerial survey crews. Specifically, we developed a suite of double-observer sightability (DO-S) models that allowed us to adjust the raw counts of elk seen as functions of various factors that influence detection probabilities from the air; for example, vegetation conditions, group sizes of the elk seen, lighting conditions, activity of the elk, and pilot experience (Griffin et al. 2012, 2013). The models were developed based on independent sighting records of both the front-seat and back-seat observer pairs in a helicopter, as well as the probability that either or both observer pairs saw known groups of elk that contained at least one radiocollared elk. Initially we had planned to develop a DO-S model that accommodated the correction of detection biases in both Mount Rainier and Olympic NP summer ranges, but due to extensive failure of radiotelemetry collars in Olympic NP, at the time of this analysis we did not yet have sufficient data to model detection probabilities in Olympic NP. Models for application in Olympic NP will be completed in time for the next review of elk population trends.

Here we analyze the results of the first 4 years of elk monitoring conducted under the new protocols from 2008-2011. Objectives of this first synthetic analysis are to:

(1) update the DO-S model used to adjust aerial survey results in Mount Rainier NP,

(2) examine trends in the abundance, composition, and distribution of elk using key subalpine summer ranges within Mount Rainier NP,

(3) establish a baseline of counts, population composition (sex and age classes), and distribution of elk using key subalpine summer ranges in Olympic NP,

(4) examine trends in the counts and distribution of elk in low-elevation winter ranges during early spring in Olympic NP,

(5) determine environmental factors influencing abundance and composition of elk in selected summer ranges of Mount Rainier NP and unadjusted counts of elk on selected winter ranges in Olympic NP,

(6) review progress in developing a DO-S model for application to elk surveys in Olympic NP, and

(7) examine aerial survey operations and provide suggestions for future surveys.

Because this is the first synthesis of elk survey results based on the new protocol (i.e., detection biases estimated using DO-S model), results are based on only 4 years of data, and all results from summer surveys in Olympic NP are preliminary. We are continuing work to develop and improve the DO-S model for application to summer surveys conducted in Olympic NP and to collect additional survey data each summer. We will update all our findings with additional data following the 2015 field season, using the present report as a template for future more complete analyses. That forthcoming report, based on 8 rather than 4 years of survey results, will permit a more complete analysis than is possible currently of population trends of elk and environmental influences on population estimation and trends.

We successfully completed seven surveys in both the North Rainier Trend Count Area (TCA) and the South Rainier TCA from 2008-2011. After applying the DO-S model to account for detection biases, we estimated an average across all surveys of 358 (SE=30) elk present per survey in the North Rainier TCA and 503 (SE=44) elk present per survey in the South Rainier TCA. We estimated an average of 39 calves (SE=2.0) per 100 adult cows in the North Rainier TCA and 34 calves (SE=2.0) per 100 cows in the South Rainier TCA. There were an estimated 39-40 (SE=4.6-4.8) bulls per 100 adult cows in both TCAs from 2008-2011.

We estimated preliminary trends of elk in Mount Rainier TCAs using two methods: 1) based on weighted linear regression through all the replicated estimates derived each year, and 2) based on linear regression through the maximum estimate each year. Based on all counts, there was no trend in numbers of elk in the North Rainier TCA from 2008-2011; that trend in the South Rainier TCA was not statistically significant but was trending upward at a rate of 3.3% annually (95%CI=-4–11%). The wide confidence interval suggests these results were highly variable. Maximum counts, by contrast , increased in the North Rainier TCA at about 6% annually, although this rate was not significantly different from 0 (P=0.31). Maximum counts in the South Rainier TCA increased significantly (P=0.05) at an estimated rate of 17% annually. We concluded that these preliminary

trends may signify a renewal of herd growth, particularly in the South Rainier TCA, but we cautioned that additional surveys are needed to verify the observed patterns. Power analyses indicated that annual surveys, as proposed between 2012 and 2015 should be sufficient to verify whether these preliminary results signify a sustained trend in numbers of elk using the Mount Rainier NP summer ranges.

The ratio of calves per 100 adult cows did not increase in either of the TCAs in Mount Rainier NP from 2008-2011. The ratio of bulls per 100 cows did not increase based on the regression line fit through all the individual surveys, but did increase in both TCAs based on regression line fit through the maximum survey count each year. These mixed results indicate the need to continue monitoring to verify if these preliminary trends exist and if they persist.

We found only weak support for *a priori* hypotheses that environmental variables associated with temperature, soil moisture or an index of heat (growing-degree days measured from the date of snowmelt to the survey date) affected estimated numbers of elk on the Mount Rainier TCAs within the range of environmental conditions surveyed from 2008-11. There was a slight trend towards higher counts of elk in the South Rainier TCA the later a survey was completed within the interval from15 August-15 September.

Of the five TCAs in Olympic NP on summer range, we only completed surveys in two TCAs, the Core (twice) and the Northwest (once). Completion of summer surveys were impacted by problems associated with failed radiocollars, conflicts with the need to capture additional elk after the collars failed, and the reallocation of efforts needed to conduct specific surveys needed for DO-S model development. We also faced other issues associated with weather, pilot inexperience, and the need to redraw some of the survey unit boundaries after the initial surveys. Consequently, no trend data are available yet for the Olympic TCAs, but in 2 completed surveys of the Core TCA we observed 237-263 elk, including 29-38 calves per 100 adult cows and 56-63 bulls per 100 cows, indicating some of the higher calf:cow and bull:cow ratios ever reported in Olympic NP (Olympic NP, unpublished data). The DO-S model for Olympic NP is currently under development and we have funding to complete four more surveys of the Core TCA and one survey each in the alternate TCA areas in Olympic by 2015. Therefore, we expect to conduct our first estimate of trend on population abundance in the Core TCA in a forthcoming report.

On the Olympic winter ranges, we completed surveys of the Hoh TCA during early spring annually from 2008-10, and of the South Fork Hoh and Queets in 2008 and 2010, building upon the legacy of data collected from 1985-2004 using the same survey protocols. We suspended further surveys of the early-spring counts in 2011 because of high snowfall in 2011, and because of funding limitations in 2012. Additionally, early-spring surveys in Olympic were very difficult to complete due to federal restrictions in the use of helicopters over the nesting habitats of the federally threatened Marbled Murrelet (*Brachyramphus marmoratus*) after 31 March.

The legacy of early-spring surveys conducted in Olympic NP by the NPS since 1985 allowed us to assess trends in counts made on each of the early-spring TCAs from 1985-2010, and to assess the effects on survey results of winter temperatures and growing conditions during February and March,

temperature on the day of the survey, and Julian date. Counts of elk made during early spring have declined in each of the early-spring TCAs surveyed, in total about 63% decline in the South Fork Hoh, 18% in the Hoh, and 22% in the Queets Valley from 1985-2010. The finite annual rate of decline was about 4% in the South Fork of the Hoh and approximately 1% annually for the Hoh and Queets Valleys, respectively. Declining counts of elk were most apparent in the most upriver segment of the Hoh Valley and the area nearest the park boundary in the South Fork Hoh.

We concluded the report with a detailed analysis of survey operations in both parks and considerations for improving the implementation of this monitoring program. No changes to the elk protocol are recommended. Considering several significant NPS cuts already made to elk monitoring in the NCCN (i.e., early-spring surveys cut in Olympic NP, number of replicated counts reduced in Mount Rainier NP), we see no further efficiencies that can be achieved in monitoring elk trends in either park. We believe, however, that because of the management, ecological, and public importance of elk resources in both parks, emerging patterns of increased elk use of the subalpine zone in Mount Rainier NP, observed declines in numbers of elk on selected Olympic NP elk winter ranges, emerging disease issues in southwestern Washington, and the benefits to a broad coalition of both State and Tribal partners, the continuation of long-term monitoring support by the NPS and its partners is warranted.

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List of Terms

Detection Bias: a negative bias in population estimates (i.e., underestimation) resulting from the failure of observers to detect all animals present during an aerial survey

Sightability Model: a statistical model using logistic regression to estimate the probability of aerial survey crews sighting groups of animals as functions of covariates that affect detection probability. Sightability models are generally developed from sightability trials in which aerial survey crews attempt to detect known groups of animals under varying environmental, habitat, or survey-specific conditions that are recorded as model covariates for developing the logistic regression models.

Double-observer Sightability (DO-S) Model: a special class of sightability models applied to data sets in which two observers (or observer pairs) individually record their observations during an aerial survey. DO-S models are structured to include the effects of specified covariates on the unconditional probability a given observer (or observer pair) detects a known animal group. DO-S models include a heterogeneity parameter that accounts for the unconditional probability that an observer pair detects an animal group. The heterogeneity parameter is determined based on DO-S trials, in which there are animals known to be present from radiotelemetry.

DO-S trials: These trials are attempts by front and back seat observer pairs to observe animal groups that were present within the survey area and that contained at least one radiocollared animal. DO-S trials allow the DO-S model to make unconditional estimates of detection probability, because the inclusion of DO-S trials in the data set is not contingent on any circumstance other than that the group was present in the surveyed area. DO-S trials of groups containing collared animals are assumed to be a random sample of all groups, with respect to the recorded covariates.

Double-observer (DO) observations: Double-observer observations were attempts made by front- and back-seat observers to detect animal groups that did not contain any radiocollared animals. Because there were no radiocollars present in groups detected during DO observations, these groups were in the data set only if they were detected by either the front or back seat observers.

Introduction

In 2007, the NPS-NCCN began developing and implementing a program to monitor long-term trends in the status of elk populations within Mount Rainier and Olympic NPs. Elk populations were selected as one of 12 'vital signs' within the NCCN—each sign intended to represent the overall condition of park resources, effects of environmental stressors, or specific natural resources of important human value (NPS, http://science.nature.nps.gov/im/units/romn/monitor/vital_signs.cfm, Accessed 9 April 2014). Because elk populations have such extraordinary value to several agencies and sovereign Native American Tribes, the monitoring protocols were developed collaboratively with the NPS, MIT, PTOI, and WDFW. This is the only monitoring program within the NCCN that was developed collaboratively with several agencies and that is supported by funding and personnel involvement from each of the collaborating agencies and Tribes. We completed and published the peer reviewed protocol based on our consensus views in 2012 (Griffin et al. 2012). Because surveys were conducted according to protocol since 2008 in Mount Rainier NP and Olympic NP, this report synthesizes results of the first 4 years of elk monitoring in both parks, as stipulated in the protocol. Another 4-year synthesis report will be prepared following the completion of another 4 years of surveys.

Elk as a Vital Sign

As key components of lowland and mountain ecosystems in the Pacific Northwest, elk are tightly woven into the ecological, historical, and cultural fabrics of both parks. Primevally, Roosevelt elk (*Cervus elaphus roosevelti*), the Pacific coastal subspecies of elk, were abundant in floodplains and riparian forests along the major river systems in western Washington (Raedeke and Taber 1982). During summer, many herds migrated to subalpine meadows in adjoining mountains (Schwartz and Mitchell 1945, Starkey et al. 1982). Although the ethnographic record clearly indicates that elk were hunted by Native Americans and are indigenous to both the Olympic and Cascades Ranges, elk had become rare or absent around Mount Rainier prior to its settlement in the mid-1800s (Gustafson 1983, Schullery 1983). By the start of the 20th century, unregulated elk hunting for meat, antlers, and trophy 'ivory' teeth had widely decimated elk populations throughout many other accessible and settled areas of Oregon and Washington (Harper and colleagues 1985, Murie 1951). A notable exception was on the Olympic Peninsula where a largely inaccessible wilderness helped protect a remnant stronghold of native Roosevelt elk (Schwartz and Mitchell 1945).

Mount Rainier NP was created in 1899 to preserve the sights and ecosystems associated with Mount Rainier, including its fish, wildlife and renowned subalpine meadows. The area that would become Olympic NP was set aside first as Mount Olympus National Monument in 1909 when elk populations in the Pacific Northwest may have been at their nadir. The monument was established explicitly to protect the last stronghold of the Roosevelt elk and its native forested habitat. Concurrently, elk were protected from hunting throughout Washington in the early 1900s and an active campaign was waged to eradicate wolves and reduce other predator populations in an effort to restore elk populations throughout Washington. Rocky Mountain elk (*Cervus elaphus nelsoni*) were reestablished in the Cascades Range in and around Mount Rainier NP through several translocations of elk from Yellowstone NP and Grand Teton NP from 1912-15 and 1932-33 (Bradley 1982).

Elk populations increased in both parks during the early 20th century in response to these coordinated restoration measures. In Mount Olympus National Monument, 'over-browsing' was reported in the western rainforest valleys as early as 1915, and large numbers of elk were reported dying during severe winters beginning in 1918 (Schwartz 1939). During the 1930s, in preparation for the creation of Olympic NP in 1938, several U.S. Forest Service and NPS biologists examined elk ranges throughout the proposed park and reported concerns about overgrazing in low-elevation winter ranges in the temperate rainforests (Murie 1935a, Murie 1935b, Sumner 1938, Schwartz 1939).

Elk were observed within Mount Rainier NP in 1915, and by the 1930s elk inhabited the primary summer ranges used by elk today (Bradley 1982). During the 1950s to 1970s, intensive logging of elk winter and spring ranges adjoining Mount Rainier NP improved winter and spring foraging conditions for elk and stimulated population growth of migratory elk herds that wintered adjacent to the park and summered within (Raedeke and Lehmkuhl 1985, Jenkins and Starkey 1996). As elk populations continued to grow during the 1970s, signs of trailing, trampling, and grazing impacts led to questions of whether elk herds summering within the parks were threatening unique values of the park (Bradley 1982, Ripple et al. 1988).

Elk were chosen as a vital sign in both Mount Rainier NP and Olympic NP, in large measure because of their strong ecological interactions with vegetation communities and the history of concerns over adverse effects of elk on signature resources of each park. There has been nearly a century of concern and debate over potential impacts of naturally regulated elk populations and resulting levels of herbivory in low-elevation temperate rainforests within Olympic NP. Recent research has demonstrated the ongoing significant ecological role of elk and deer herbivory in shaping both the structure and composition of the park's renowned rainforest communities (Happe 1993, Woodward et al. 1994, Schreiner et al. 1996). The century-long debate over negative impacts of elk on ecosystem properties in Olympic NP was rekindled recently by a study concluding that an overabundance of elk, wrought by the extirpation of wolves, has cascading trophic ecological effects throughout the ecosystem including changes in riparian forest composition, river channel characteristics, and overall impairment of riverine ecosystems (Beschta and Ripple 2008). Concerns over the ecological effects of elk on subalpine communities in Mount Rainier NP have abated during the last two decades, but renewed population growth would reignite concerns over the effects of elk on subalpine ecosystems in either park.

There are complex processes and interactions having the potential to influence future elk population levels and elk use at both Mount Rainier NP and Olympic NP. Changing land uses, hunting, and predator management programs on lands adjacent to these parks all have the potential to influence elk population trends and ecosystem dynamics within the parks. There have been recent proposals to reintroduce wolves to Olympic NP (Ratti et al. 2004), and natural wolf recolonization in Washington is occurring, with wolves from Canada and Idaho now reproducing in Washington (Wiles et al. 2011). There are currently wolf packs established north and east of Mount Rainier NP that have the potential to expand and affect migratory elk herds within Mount Rainier NP. As climates continue to change in the Pacific Northwest, elk populations may be influenced by shifts in temperature,

precipitation and snowpack (Salathé et al. 2009); forest disturbance regime (Dale et al. 2001, Westerling et al. 2006); and vegetation (Zolbrod and Peterson 1999). Nationally, the increased prevalence and proliferation of diseases (e.g., chronic wasting disease, paratuberculosis, and brucellosis) is a growing concern for wildlife managers (Daszak et al. 2000, Angers et al. 2006). In Washington State, the recent emergence and spread of bacterial hoof disease among elk in southwestern Washington presents a very real concern for managers of elk populations throughout western Washington (http://wdfw.wa.gov/conservation/health/hoof_disease/, Accessed 24 June 2014).

Sound scientific information on elk populations and trends is a critical first step in discussing and addressing solutions to complex management issues across management jurisdictions. None of these issues is simple, and all may have implications for policy and management, including relations with sovereign Tribes and other state and federal agencies. Over time, elk monitoring results may be used to help the parks evaluate the effects of climate change, external impacts, and other stressors that may influence elk within and across park boundaries. These same results are useful to Tribes and Agencies in the Mount Rainier area in meeting their population management objectives. Further, understanding of elk population trends is needed to interpret the effects of NPS policies on natural regulation of ungulate populations and associated ecosystem effects and to communicate these trends to diverse and interested public segments.

History of Elk Monitoring in Mount Rainier NP and Olympic NP

For over 20 years, the MIT, PTOI, NPS, and WDFW have cooperated in monitoring trends in elk abundance and composition in Mount Rainier NP. In addition to informing the NPS on the status of elk populations that use the park during summer, the interagency monitoring program provides information that is used by State and Tribal wildlife managers to manage elk herds that summer within Mount Rainier NP and migrate seasonally to winter and spring ranges outside the park (Spencer 2002, Huang et al. 2002).

Historically, the MIT, PTOI, NPS, and WDFW surveyed elk nearly annually in subalpine summer ranges within Mount Rainier NP from either fixed wing airplanes or helicopters during evenings in late summer and early fall. Survey crews recorded the number of elk seen within spatial units defined by Bradley (1982). Bradley (1982) recommended an index of abundance, “E4,” multiplied by two, as a standard metric for comparison of elk abundance over time. The multiplier was intended to account for detection biases (i.e., elk present but not seen by aerial survey crews), and was based on comparisons of counts and densities of elk computed from pellet group surveys in the Cedar River Watershed (Schoen 1977).

Both these Tribes and WDFW also have a history of monitoring elk population trends on the low-elevation winter ranges used by migratory elk that summer within Mount Rainier NP. The PTOI developed a sightability model for improving accuracy of winter helicopter surveys conducted annually in the Cowlitz Valley near Randle and Packwood (Gilbert and Moeller 2008). The WDFW conducted mark-resighting surveys for estimating elk abundance on winter range in the White River until 2000. The MIT cooperated with WDFW in surveys from 1997 through 2000. Cow elk were radio-marked in the White River starting in March 1998 and the MIT began conducting its own

surveys and estimating elk numbers in a portion of the White River in April 1998. The area surveyed by the MIT included the area the WDFW had previously surveyed and some additional area that covered most of the wintering area of elk that use the northern portion of Mount Rainier NP.

Olympic NP does not have the same history of surveying elk on summer ranges as Mount Rainier. Rather, the early focus for elk monitoring in Olympic NP was on the winter and spring ranges in the west-side valleys of the park in response to concerns over potential effects of hunting on or near the park boundaries and local interest to hunt in the Park. In Olympic NP, elk have been surveyed in early spring by helicopter since the mid-1980s in three TCAs in the park's west-side rainforest valleys (Houston et al. 1987), although the frequency of conducting these surveys has been sporadic due to lack of consistent funding. Early-spring surveys in Olympic NP have been timed to coincide with the early period of green-up in river valleys, when elk are visible on floodplain terraces before deciduous trees have leafed out. These early-spring counts occur when calves are nearly the size of adults, and when bull elk are largely without antlers. As a result, the early-spring surveys do not provide information about sex and age composition. Aerial composition surveys of elk populations were conducted for a three-year period in the mid-1980s on summer ranges in Olympic, but were not sustained, most likely due to funding constraints (NPS, unpublished data). Unlike in Mount Rainier, there were no established TCAs or survey unit boundaries delineated on summer ranges in Olympic NP.

Monitoring and Reporting Objectives

The goal for elk monitoring is to detect changes in abundance, spatial distribution, and herd composition in selected TCAs of Mount Rainier and Olympic NPs where elk are seasonally concentrated and highly visible. In both parks we monitor trends in abundance, distribution and composition (sex and age classes) of elk populations within TCAs that correspond with the major summer ranges of migratory elk herds. In Olympic NP, we also monitor trends in elk abundance and distribution of elk populations that concentrate during late winter and early spring on the primary elk winter ranges on floodplains of the major river drainages on the west side of the Park.

A secondary goal of elk monitoring in both Mount Rainier and Olympic NP is to estimate abundances and composition of elk herds on the summer ranges in a manner that estimates and accounts for observational biases inherent in aerial surveys (Pollack and Kendall 1987). With the recent completion of a DO-S model for Mount Rainier NP (Griffin et al. 2013), we estimate elk abundance—adjusted for detection biases—in the Mount Rainier study area based on data from 2008-2011. In Appendix A we compare estimates derived from the DO-S model to indices that were used before 2008 (E4*2, Bradley 1982).

We report progress made in developing a DO-S model for application in Olympic NP. Without a model to adjust for detection biases, we present raw counts of elk for Olympic NP. These raw counts can be updated after the DO-S model is completed to more accurately reflect elk abundances in selected areas of Olympic NP.

Specific objectives of this 4-year reporting interval are to:

1. update the DO-S model used to adjust aerial survey results in Mount Rainier NP,

2. examine trends in the abundance, composition, and distribution of elk using key subalpine summer ranges within Mount Rainier NP,
3. establish a baseline of counts, composition, and distribution of elk using key subalpine summer ranges in Olympic NP,
4. examine trends in the counts and distribution of elk in low-elevation winter ranges during early spring in Olympic NP,
5. determine environmental factors influencing abundance and composition of elk in selected summer ranges of Mount Rainier NP and unadjusted counts of elk on selected winter ranges in Olympic NP,
6. review progress in developing a DO-S model for application to elk surveys in Olympic NP, and
7. examine aerial survey operations and provide suggestions for future surveys.

Elk Populations and Study Areas

Mount Rainier NP

We monitored trends in two migratory elk herds that summer within Mount Rainier NP. In this document we refer to the North and South Rainier herds as those elk using summer ranges in Mount Rainier NP and migrating to winter ranges mostly outside the park to the north and south, respectively (Figure 1). Our definitions are distinctly different from the definition of North and South Rainier herds managed by WDFW and Native American Tribes in Washington State (Spencer 2002, Huang et al. 2002).

Their more broadly defined North Rainier and South Rainier herds are among the ten major elk herds managed by WDFW and Native American Tribes in Washington. The ‘greater’ North Rainier herd inhabits primarily the Snoqualmie, Green, and White River Valleys in Pierce and King Counties (Spencer 2002), whereas the ‘greater’ South Rainier herd inhabits primarily the Cowlitz Valley in Thurston and Lewis counties. (Huang et al. 2002, Moeller 2010). The portion of North herd that summers within Mount Rainier NP, the focus of this study, is also recognized by WDFW and MIT as the White River subherd (Spencer 2002). Approximately 50% of the White River subherd migrates annually into Mount Rainier National Park during summer and comprises the segment of the population reported on here (MIT, unpublished data). This segment of the population migrates to lower elevations in the White River valley for winter (Figure 1). They winter with elk from other migratory subpopulations as well as a resident component of the population that stays the year-round at low elevations.

The portion of the South Rainier herd that we monitored inhabits the southeast portion of Mount Rainier NP during summer and migrates to winter range in the vicinity of the city of Packwood where it mixes with elk from other migratory herds and elk that reside year-round at low elevations (Moeller 2010). The exact proportion of the Packwood subherd that migrates to Mount Rainier NP is not known but approximately 46% of this subherd migrates north of Packwood onto summer ranges

within and near the Park boundary (Moeller 2010). A small number of the adjacent Yakima Herd have also been identified using summer ranges within and adjacent to Mount Rainier during summer (Moeller 2010).

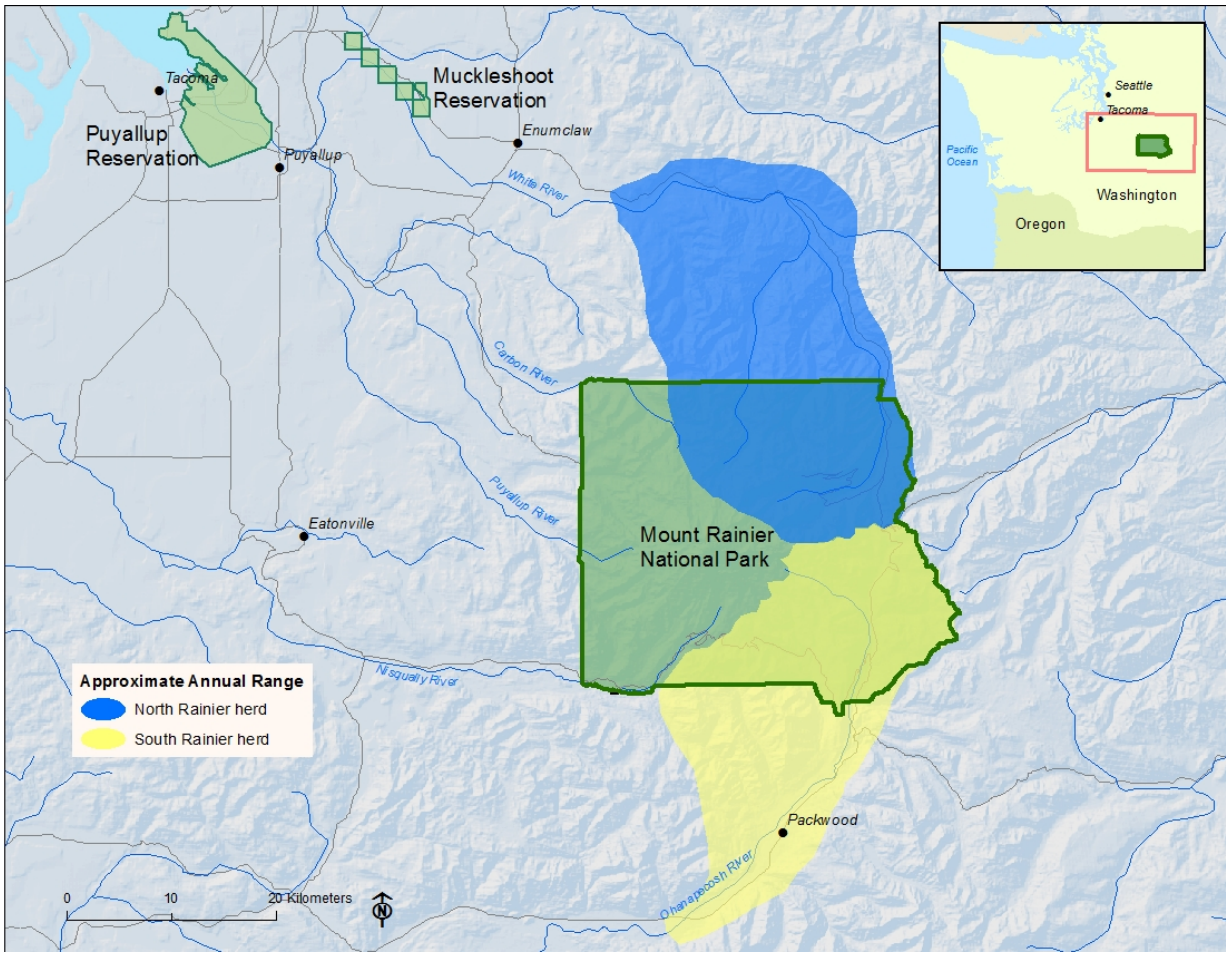


Figure 1. Approximate annual ranges of migratory components of the North Rainier herd (blue) and South Rainier herd (yellow) that use Mount Rainier NP during summer. These elk migrate from Mount Rainier NP to lower elevations outside the park during winter. Winter ranges may also be used by non-migratory elk and elk that use different high elevation summer ranges.

We monitored elk within two TCAs corresponding with the summer ranges of the North and South herds in Mount Rainier NP (Figure 2). The TCAs corresponded closely with herd units first defined by Bradley (1982) and used historically as the framework for all subsequent surveys (Figure 2). The North Rainier TCA (103 km^2) is between 1,500 and 2,100 m elevation. The South Rainier TCA (89 km^2) is between 1,350 and 2,100 m elevation, except on some southwest-facing slopes where past landslides and wildfires maintained open parklands down to 1,200 m. Within these defined survey areas, we referred to satellite-derived estimates of vegetation cover and type (Pacific Meridian Resources 1996) and excluded areas of continuously dense forest canopy cover, rock, or permanent snow from the study area (Griffin et al. 2012). The TCAs encompassed primarily subalpine woodlands and meadows consisting of mosaics of subalpine parkland forests, dominated by subalpine fir (*Abies lasiocarpa*) and mountain hemlock (*Tsuga heterophylla*), subalpine meadows,

and low shrublands (Figure 2; Franklin et al. 1988). The tallest trees in the subalpine parklands were generally <20 m. Canopy closure was highly variable, but tended not to be dense near tree line. Although these TCAs abut on their south and north boundaries, respectively (Figure 2), sightings of marked or radiocollared elk show that there has been very little movement of elk between these two herds for several decades (Bradley 1982:62, Cooper 1988, MIT, unpublished data). Of about 80 radiocollared elk in the North Rainier Herd that use Mount Rainier NP during summer, we have only observed one elk enter the South Rainier Herd summer range over 16 years of monitoring (MIT, unpublished data).

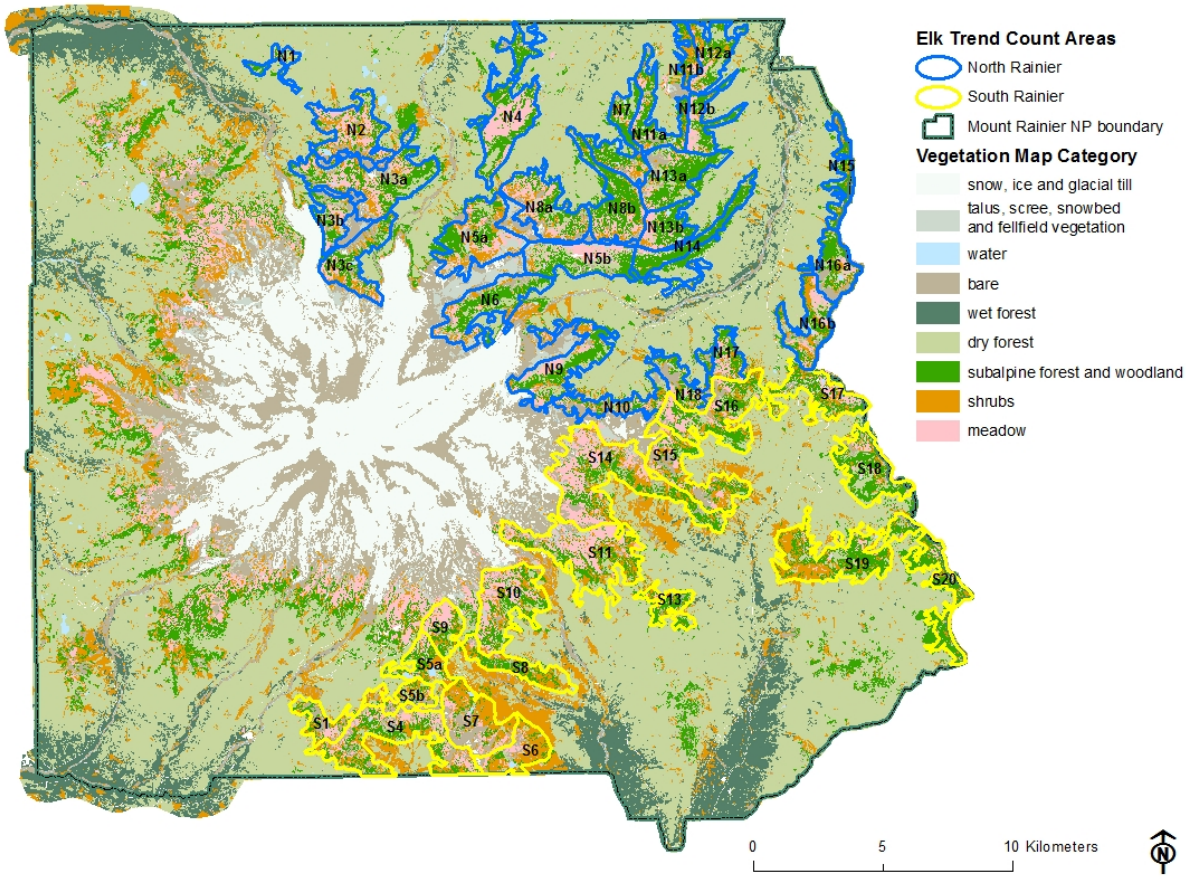


Figure 2. Summer trend count areas (TCA) within Mount Rainier NP, including the North Rainier TCA (103 km^2; survey units in blue) and South Rainier TCA (89 km^2; survey units in yellow).

Olympic NP

Spanning elevations from sea-level to over 2,400m, Olympic NP encompasses summer range and many of the winter ranges used by migratory elk herds on the Olympic Peninsula, particularly in the western drainages. Additionally, there are low-elevation resident herds in the western and northern valleys that remain at low to middle elevations throughout the year (Figure 3).

Trend count areas in Olympic NP consist of five summer TCAs and three early-spring TCAs. Summer TCAs include the majority of summer ranges used by migratory elk herds. The early-spring

TCAs comprise approximately 50% of the primary winter ranges used by both non-migratory and migratory herds in the western rainforest valleys (Jenkins and Manly 2008; Figure 4). The early-spring TCAs are used by both non-migratory and migratory herds. Subalpine habitats occur on lower elevations in Olympic NP than in Mount Rainier NP; consequently we defined summer TCAs differently in Olympic NP as ranging between 1200 m and 1650 m elevation. This elevation range was confirmed by data collected from elk that carried GPS radiocollars in the park (Olympic NP, unpublished data). As in Mount Rainier NP, summer TCAs in Olympic comprised a mosaic of subalpine fir and mountain hemlock forests, and a diversity of high elevation meadow and shrub communities (Fonda and Bliss 1969; Kuromoto and Bliss 1970).

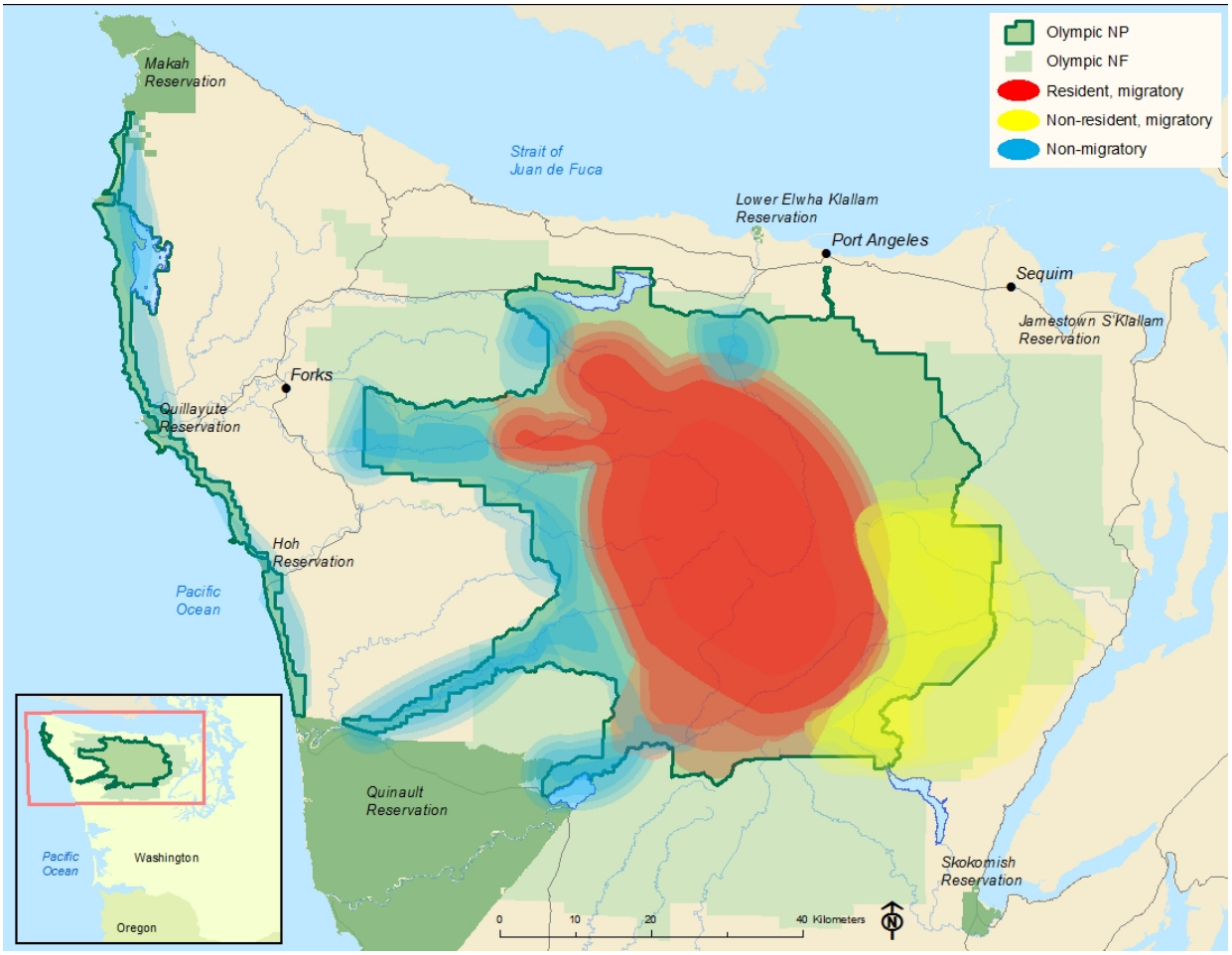


Figure 3. Map of Olympic NP and surrounding areas of the Olympic Peninsula, showing the approximate distributions of elk that use Olympic NP during all or part of the year. Red shading indicates the approximate area occupied by migratory elk herds that that reside in the park throughout the year and migrate seasonally between distinctive summer and winter/spring ranges within the park. Yellow indicates approximate areas used by migratory herds that summer in the park and winter outside the park (non-resident migratory). Blue indicates the area occupied by non-migratory elk herds. The shaded tones of red, blue and yellow on the periphery of each distribution indicate they are approximations lacking identifiable boundaries. Non-migratory herds in the park interior reside in the park year-round. The annual ranges of many herds overlap; this map does not show the ranges of all elk herds on the Olympic Peninsula.

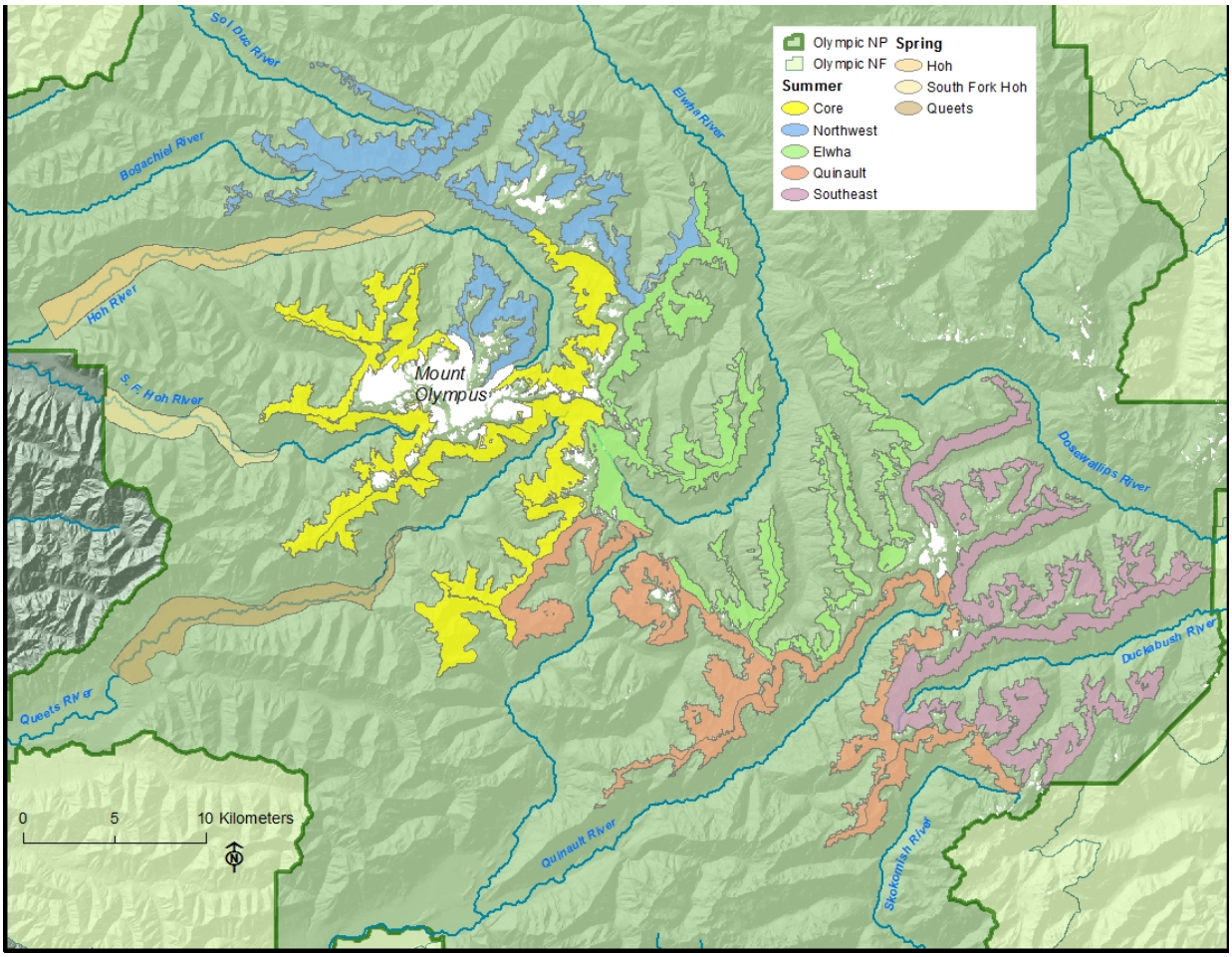


Figure 4. Summer and early-spring TCAs within Olympic NP. Summer TCAs include the annually-surveyed Core TCA (yellow) and four alternate TCAs surveyed once every four years. The Core, Northwest, Elwha, Quinault, and Southeast TCAs are approximately 100, 81, 73, 79, and 86 km^2, respectively. Early-spring TCAs include the Hoh, South Fork Hoh, and Queets TCA (approximately 27, 11, and 24 km^2, respectively).

Early-spring TCAs corresponded with floodplains and alluvial and glacial terraces found on the valley floors of the Hoh, South Fork Hoh and Queets Valleys (Houston et al. 1987). Surveys were truncated at the upstream extent of the floodplain and terraces in each watershed even though each of these valleys extends further upstream beyond the boundaries of the TCAs. Floodplains in each of the valleys are generally 1-3 km wide, and contain series of river terraces of successively greater age (Fonda 1974, McKee et al. 1982). Elevations range from 135-335 m. Forests on the alluvial terraces have been described as a sere from pioneer red alder (*Alnus rubra*) on active floodplains, through black cottonwood (*Populus trichocarpa*)-Sitka spruce (*Picea sitchensis*) on younger river terraces to climax stands of the Sitka Spruce-Western Hemlock forest association on the oldest river terraces (Franklin and Dyrness 1973). Groves of bigleaf maple (*Acer macrophyllum*) occur throughout on shallow rocky soils. The coniferous forests are characterized by massive trees up to 90 m tall at densities of about 670-271 trees/ha (Fonda 1974, McKee et al., 1982). Overall, compared to forests on the valley walls, floodplain forests have relatively open overstories (Fonda 1974), and open understories mediated by high levels of herbivory (Schreiner et al. 1996).

Methods

Survey Design

We designed different annual survey schedules for Mount Rainier and Olympic NP summer surveys and for summer and early-spring surveys in Olympic NP to accommodate differences in the area of important seasonal ranges used by elk in each park. In Mount Rainier NP, initially our goal was to complete two replicate aerial surveys of elk in each of two TCAs annually. Due to funding and logistical constraints, however, we did not always complete both replicate surveys of both TCAs. As a cost saving measure in 2011, we adopted a reduced sampling goal of completing two replicate surveys of each TCA on alternating years and one survey in the intervening years (Griffin et al. 2012).

We devised a different sampling schedule in Olympic NP to ensure complete coverage of important summer ranges over several survey years. Each survey year, we attempted to survey the core area once and one of the four non-core TCAs. Thus, four years are needed to complete surveys in all the TCAs. The sampling design at Olympic NP summer TCAs accomplishes widespread sampling over the Olympic NP summer range, but also documents changes in abundance in the Core TCA in each year of survey.

On the winter and early-spring ranges of Olympic NP, our initial goal was to complete one replicate survey of elk within each of the early-spring TCAs annually. Due to funding, weather, and logistical concerns, described below, however, we discontinued regularly scheduled early-spring surveys in 2011 (Griffin et al. 2012).

Survey Methods

Summer Range Surveys

We surveyed elk in each TCA by helicopter (Bell 206BIII, Bell Helicopter, Hurst, TX; or Hughes 500D, MacDonnell-Douglas Helicopters, Inc., Mesa, AZ) from 15 August–15 September 2008–2011. The goal was to complete an elk survey within a TCA on a single evening in Mount Rainier National Park and in two successive mornings or evenings in Olympic NP. In Mount Rainier NP, all survey flights were conducted during evenings, beginning as early as 4 hours before local sunset and ending as late as 30 minutes after sunset, when elk are most visible (MIT, unpublished data). In Mount Rainier NP, we preferred to survey a single TCA using 2 helicopters and survey crews operating simultaneously in complementary halves of a TCA, but logistical issues sometimes required surveying over two evenings. In Olympic NP, due to the larger areas covered and the use of a single helicopter, surveys were conducted during both evenings (same prescriptions as in Mount Rainier NP) and mornings (30 minutes before to 4 hours after local sunrise), when elk are most visible (NPS, unpublished data). In both parks, helicopter flights were approximately 100–150m above ground level with flight lines approximately 250–500 m apart. Flight speed was approximately 85 km/hr with a search intensity of approximately 0.35km^2/min. To facilitate communication between two helicopters operating simultaneously, to ensure complete survey coverage, and to allow examination of spatial patterns of elk distribution within TCAs, each of the TCAs were subdivided

into smaller survey units and all observed elk were recorded within individual survey units (Figures 2 and 4).

Observers searched intensively for elk within each of the prescribed survey units. Survey crews consisted of a pilot and three experienced observers, one seated beside the pilot in a front seat, and two in the rear seats. The pilot and front-seat observer had views to the front, sides, and below the flight path. Each back seat observer had a view to one side of the flight path. Although pilots' attention was primarily on flying safely, pilots also detected elk groups. While searching for elk within the survey units, observers also recorded elk groups that were detected up to 300 m outside the boundary of a survey unit. This allowed for more careful determination based on GPS coordinates of whether groups close to the boundary were included in the abundance estimates or not. Although the trend counts in abundance were limited to elk observed within the survey boundaries, we included groups of elk recorded near the boundary of the count units in the composition estimates.

Developing the DO-S model required maintaining a sample of radiocollared elk in the population (Griffin et al. 2013). In Mount Rainier NP, prior to the onset of protocol development, a sample of elk in both the North and South herds were equipped with radiocollars by Tribal partners. In Olympic NP there were no pre-existing radiocollars on elk that used the summer range. From 2008-2011 our priorities in Olympic NP were equipping elk with radiocollars, defining and refining survey units, and collecting data for development of the DO-S models.

The DO-S model also required maintaining records of independent observations of elk groups made by two sets of observers in the helicopter (Griffin et al. 2013). For elk groups containing at least one radiocollared animal, we also recorded detections made using a radio-telemetry receiver after completing the visual observations. For the detection modeling exercise, the pair of front-seat observers was considered one independent set of observers , the pair of back-seat observers was considered a second independent set, and for those elk groups with at least one collared elk, the radio receiver was considered a third 'observer'.

The in-flight procedures required each observer to maintain independence while searching for elk. During the surveys, no observer announced any sightings of elk until all observers had a chance to detect the elk group. After determining the total number and sex-age classification of all elk in the observed group, we used a radiotelemetry receiver to determine if there were any collared elk present in the group. We noted which observer pairs detected each group, and the presence of any radiocollars. We noted the rare occasions when either observer pair was inadvertently alerted about the presence of an elk group by the other pair before having a chance to record an observation independently. We omitted those non-independent observations from the data set used for model fitting, but included the observations in calculations of abundance.

We classified each elk present in the group as an adult female (cow), young of the year (calf), yearling male (spike), subadult male (subadult bull), or adult male (mature bull) based on antler characteristics and body size. Spike bulls are yearlings with single-tine antlers. Subadult bulls are bulls with generally 3-4 tines on each side, or 5 tines of small stature. Mature bulls are large bulls

with ≥5 tines on a side. If a motion-stabilizing camera was available, we photographed groups with ≥20 individuals to reduce bias in group size estimation (Cogan and Diefenbach 1998, Schoenecker et al. 2006).

We recorded the following sighting covariates associated with each group (i.e., covariates are variables associated with the elk groups or environment that may influence sighting probabilities): group size, percent concealing vegetation ≤10 m from the group (*V*; within 5 percentage classes: 0, 1–25, 26–26, 51–75, or 76–100), whether the group was standing on herbaceous vegetation (*H*; yes or no), whether the group was in forest vegetation (*F*; yes or no), lighting conditions (*L*; flat or high contrast), and the activity of the group when first detected (*M*; moving or not). We noted whether each elk group was detected to the left, right, or both sides of the helicopter's flight path. We noted when an elk group was directly below the helicopter's flight path and not visible to the back-seat observers (*B:C;* centerline yes or no). A separate covariate denoted whether the elk group was on the same side of the helicopter's flight line as an inexperienced pilot-observer (*F:IXP*; yes if group on same side as a pilot-observer with little experience conducting aerial wildlife surveys, no if pilot was experienced in conducting aerial wildlife surveys or elk group was on other side). For our purposes, we considered any pilot with fewer than 10 ungulate survey flights in mountainous terrain as inexperienced.

After completing the count within a survey unit, we used radio-telemetry to identify and locate any radiocollared elk that were missed during the surveys. We recorded the same covariates for those missed groups as for all groups detected during the survey.

Early-spring Surveys

We conducted all early-spring surveys following survey procedures originally described by Houston et al. (1987), so that survey data from the current reporting interval were comparable to legacy data collected from 1985-2004 (Olympic NP, unpublished data). Timing of the early-spring surveys in Olympic NP corresponded with time of year and time of day when elk were most visible feeding on the new spring growth of herbaceous vegetation (i.e., green-up) in deciduous forest communities or open-canopied spruce forests, but before deciduous trees leaf out (Jenkins and Starkey 1984, Houston et al. 1987). Prior to 1998, 1-3 replicate surveys were conducted during each year of surveys, generally between early to mid-March and mid-April. Beginning in 1998, however, low-level aerial flights were restricted over low-elevation mature conifer forests after March 31 each year as a means of protecting the federally threatened Marbled Murrelet from disturbance during the nesting season. As a consequence, all surveys conducted from 1998 to the present were conducted from March 1–31, typically after March 15. Due to funding limitations and the curtailed survey season, we surveyed elk in each TCA only once each spring from 2008-10. As described below, we modeled the influence of survey date on elk counts as a means of accounting for any potential effects of survey dates on survey results.

These early-spring elk surveys provided aerial coverage of the valley floor and river floodplains. Parallel flight lines crossed the axis of the river valley 150-300 m (0.08 – 0.16 nautical miles) apart with turns being made at the break in slope between the relatively flat valley floor and the steeper valley walls. The targeted flight ground speed was ~55 km/hr but was faster over open gravel bars

where elk were plainly visible. This ground speed and flight pattern yielded a search intensity of ~0.25 km2/minute or less.

In-flight methods and crew responsibilities were the same for early-spring surveys as for summer surveys, except that the cover types inhabited by elk were recorded as River, GravelBar, AlderFlat, Maple, OpenOldGrowth, OldGrowth, or UplandShrub, reflecting the range of cover types present in the early-spring TCAs.

Data Management

Following each aerial survey, data were entered in the project database and were reviewed and verified by the Project Lead before being used for analysis and reporting. Database records were verified for complete and accurate transcription by retrieving and visually comparing the entered data associated with each sampling event against the original forms. Aerial photographs of elk groups were examined carefully, and if necessary, composition classifications of the groups were amended. Once data for the season were entered and verified, a rigorous quality review was conducted on the data set by running a set of pre-built validation queries to check for completeness, missing or out-of-range values, logical consistency, and structural integrity. Errors identified during this review were corrected where possible, and annotations related to specific issues raised by each query were stored within the project database as needed and appropriate.

Replicate Numbering

Because we surveyed a TCA more than once annually in Mount Rainier NP, we assigned each completed survey a replicate number— a unique survey number within each year. If a completed survey was conducted over multiple days, we assigned each of the components of the complete survey the same replicate number. Occasionally, we conducted additional surveys of selected portions of a TCA specifically to increase the sample size of DO-S trials (described below). We assigned replicate number zero to observations in such flights, or to any other portions of a survey that were not part of a replicate survey.

Covariate Imputation

Occasionally a covariate value was not recorded during the survey or it was not possible to determine all the covariates associated with an elk group observation (for example if the group was in dense forest and group size could not be determined). We used a structured procedure to impute missing covariate values based on the most common or median values recorded for that covariate, given the other covariates that were recorded for the group. For observations with missing data for group size (n=9) or activity (n=18), we substituted the median group size computed from all groups that contained ≥1 cow and were detected in the same category of percent concealing vegetation. For five observations with no percent concealing vegetation recorded, we used the median group size and vegetation cover score based on all observed groups with ≥1 cow. For six observations missing a value for light level, we used the same light level as recorded in the preceding and subsequent observations. We used audio recordings of the cockpit conversation and global positioning system (GPS) records of the survey flight path to determine on which side of the helicopter an elk group was located when that information was not recorded on paper in flight. For seven observations for which we could not determine side-of-helicopter from the recorded flight line, we assumed that the elk

group was available to be seen by crew members on both the right and left sides of the helicopter. We did not use observations with imputed values in DO-S model creation, unless those observed groups contained at least one radiocollared elk (n=9).

Geodatabase and Relational Database

Project spatial data are stored in a geodatabase (ESRI, Redlands, California) that contains several feature datasets, each of which contains sets of point, polygon, or line, feature classes. The main feature datasets are for navigation, survey area boundaries, records of survey flight paths, records of animal observations, and spatial analyses. Spatial features in the geodatabase are linked with related relational database elements via primary key relationships with records maintained in the relational database.

Spatial data collected in the field are processed and attributed as soon as possible after a survey. At the end of a field season, final coordinate data for group observations are derived from flight line paths GPS derived flight line time stamps recorded in the field, and photographs if available. These final coordinates are then stored in the relational database. The relational database is the long-term repository for observation coordinates where additional processing and quality assurance procedures are documented.

Data Analysis

Double-observer Sightability Models

We developed and published a suite of DO-S models for estimating detection biases associated with aerial helicopter surveys of elk in Mount Rainier NP (Griffin et al. 2012, 2013). The DO-S models were developed from surveys conducted in both the North and South Rainier TCAs, so one suite of models was applied to surveys conducted in both areas. For this report, we updated the original models using additional data acquired in 2011, since the original model formulation (Griffin et al. 2013). Here, we present only an abbreviated summary of the DO-S modeling methods. We refer readers to those previous publications for a more complete description of the conceptual underpinnings and analytical methods related to the DO-S modeling approach.

The DO-S model for Mount Rainer NP was a suite of 15 separate parameterized models that we model-averaged to account for their varying levels of support given the survey data. Each model contained several components designed to that constrain sightability parameters and evaluate potential effects of various covariates on sightability of elk groups from the air (Table 1). Additional details on model structures are provided in Griffin et al. (2012, 2013).

Table 1. Model components used to model detection probabilities of aerial elk surveys in Mount Rainier NP, 2008-2010.

Model Component	Description of Model Component
F=B	A constraint forcing front (F) and back (B) observers to have a single parameter for the intercept of detection probability.
F/B	A constraint forcing the estimation of separate intercept parameters for front (F) and back (B) observer detection probabilities.
+Hetero	A constraint forcing front and back observers to have the same single parameter for the heterogeneity effect.
*Hetero	A constraint forcing the estimation of two separate parameters for the front (F) and back (B) observer heterogeneity effect.
+ln(N)	An effect of the continuous variable, natural logarithm of elk group size, on detection probabilities for front and back observers.
+F:IXP	An effect of inexperienced pilots on detection probabilities for front observers when an elk group is on the same side of the helicopter as the pilot. Pilot was considered inexperienced if he had flown less than 10 times with radio-telemetry, or in surveying ungulates in mountainous topography.
+B:C	An effect of an elk group being directly under the helicopter (i.e., on the flight path's Centerline) on detection probabilities for back observers.
+V	An effect of the continuous variable[1], percent concealing vegetation, on detection probabilities for front and back observers.
+L	An effect of flat Light level, on detection probabilities for front and back observers.
+M	An effect of animal activity, on detection probabilities for front and back observers, specifically, the effect of animals 'Moving' at the time of detection.
+H	An effect of the elk group being in the Herbaceous cover type on detection probabilities for front and back observers.
+F	An effect of the elk group being in the Forest cover type on detection probabilities for front and back observers.

[1] Percent concealing vegetation is modeled as a continuous covariate, using the midpoint of the recorded range.

We defined sighting probabilities, $\hat{p}_{g,h,j,k}$, where g indicates the group type (U = unconditional, C = conditional), explained below, h is the observer (F=front, B=back, or R=radio), j indexes the elk group (1, 2, . . ., n, where n is the number of groups detected), and k indexes one of the 15 hypothesized alternative model structures.

The 15 model structures were fit to data from observation trials, corresponding to records of which observers aboard a helicopter detected each elk group known to be present during a survey. For the purposes of model development, each elk group known to be present belonged to either of 2 categories of observation trials:

1. DO-S trials: These trials corresponded with attempts by front and back seat observer pairs to observe elk groups that were present within the survey area and that contained at least one radiocollared elk. Detection probabilities estimated from DO-S trials, $\hat{p}_{U,h,j,k}$, are unconditional estimates(indexed by $g = U$) because marked elk groups are all detected by telemetry, and their inclusion in the data set is not contingent on any circumstance other than that the group was present in the surveyed area. Double-observer sightability trials of elk groups containing collared elk are assumed to be a random sample of all elk groups with respect to the recorded covariates.

2. Double-observer (DO) trials: Double-observer trials were attempts made by front-and back-seat observers to detect elk groups that did not contain any radiocollared animals. Because there were no radiocollars present in groups detected during DO trials, these groups were in the data set only if they were detected by either the front or back seat observers. Consequently, detection probabilities estimated from DO trials, $\hat{p}_{C,h,j,k}$, are conditional estimates that are likely to be biased because there are likely to be unmarked groups of elk missed by both pairs of observers.

The inherent difference between $\hat{p}_{U,h,j,k}$ and $\hat{p}_{C,h,j,k}$is the result of un-modeled heterogeneity that is not adequately explained by other model covariates. This is the degree of heterogeneity bias that would result from using DO trials only. We quantified this degree of bias by including an additive heterogeneity bias parameter in the model structures in the functions for estimating $\hat{p}_{U,F,j,k}$ and $\hat{p}_{U,B,j,k}$. These are the estimated probabilities for an aerial observer pair seeing a radiocollared group, which is, on average, less likely than seeing a group without radiocollars and seen by the other aerial observer pair. Thus, the heterogeneity parameter is a negative coefficient that accounts for the difference in detection probabilities related to conditional (nonrandom) DO sampling versus the unconditional (random) sampling of radio-marked groups. Because the data represent 2 categories of elk groups and 3 observers, any candidate M_H model has 6 detection probabilities. The radio-telemetry observer has perfect detection of unconditional groups ($\hat{p}_{U,R,j,k}$= 1) and no chance of detecting conditional groups ($\hat{p}_{C,R,j,k}$=0). The 4 remaining sighting probabilities are estimated for category *g*, observer *h*, elk group *j*, according to model structure *k* by the logistic function (Huggins 1989, 1991):

$$\hat{p}_{g,h,j,k} = \frac{e^{(\sum_i \hat{\beta}_{k,i} \cdot D_{g,h,k,i} \cdot x_{j,i})}}{1 + e^{(\sum_i \hat{\beta}_{k,i} \cdot D_{g,h,k,i} \cdot x_{j,i})}} \qquad \text{(Equation 1)}$$

for {*g*:*U*, *C*}; {*h*: *F*, *B*}; {j: 1, 2. . . *n*}; {*k*: 1, 2 . . . *m*}

Where:

$\hat{\beta}_{k,i}$= is a fitted coefficient for model *k*, where *i* = 1, 2, . . . *p* indexes the list of all *p* candidate coefficients in all models.

$D_{g,h,k,i}$= is an indicator for model *k* specific to elk groups in category *g*, observer *h.* The value is set to 1 if parameter *i* is included in model *k*, and 0 otherwise.

$x_{j,i}$ = is the observed value of sighting covariate *i* for elk group *j*.

We parameterized the models so that β coefficients corresponding to the effects of sighting covariates on front and backseat detection probabilities applied to both elk group categories (i.e., with and without collared elk). We estimated sightability coefficients for front and backseat observer pairs based on sightability data from all elk groups irrespective of whether or not collared elk were present. The heterogeneity bias parameters, though, could only be estimated with reference to

detection patterns of elk groups with ≥1 radiocollar. We structured models that contained separate estimates of intercept parameters for front and backseat observers as well as models that contained a common intercept for front and backseat observer pairs (Table 2). Similarly, we structured some models with separate heterogeneity bias parameters for front and backseat observers, and other models with a single heterogeneity parameter for both pairs of observers combined (Table 2).

Table 2. Descriptions of models fit to abundance estimates from North Rainier and South Rainier TCAs, where K is the number of model parameters (including model intercept, covariate coefficients, and error sum of squares). Time refers to the year of survey. Residual GDD5 is the difference between the cumulative number of growing degree-days (above 5°C) assessed from the time snow melts out to the survey date and the predicted average for that date. Maximum temperature is from the Cayuse Pass weather station measured on the day of survey. Soil moisture is the sum of measures from 0-20 cm and 20-40 cm depths.

Model	Description	K
M0.	Intercept only	2
M1.	Time	3
M2.	Time + Julian Date	4
M3.	Time + Residual GDD5	4
M4.	Time + Maximum Temperature	4
M5.	Time + Soil Moisture	4
M6.	Time + Residual GDD5 + Soil Moisture	5
M7.	Julian Date	3
M8.	Residual GDD5	3
M9.	Maximum Temperature	3
M10.	Soil Moisture	3
M11.	Residual GDD5 + Soil Moisture	4

We developed the relational database query **qs_z102_Model_building_X** (Figure 5) to generate the list of observations made inside a survey unit or within the 300 m buffer zone. For each group, the query listed which observers independently saw the group, what the sighting covariate values were, and whether or not the group should be used for model fitting, for abundance estimation, or for composition estimation. We did not use observations with missing values for which observer pair saw the group independently, or for which there was a loss of independence between front- and back-seat observers in model fitting.

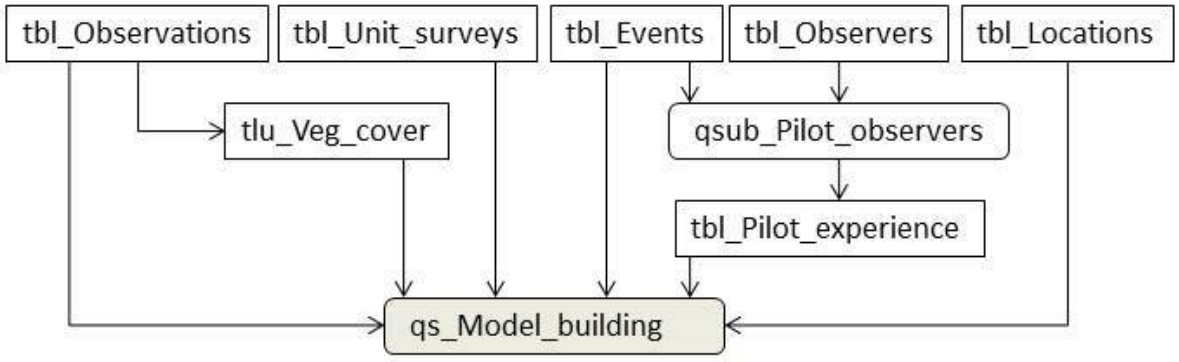


Figure 5. Structure of tables and subquery that contribute to the qs_z102_Model_building_X query.

We used program MARK (Cooch and White 2013) to fit the same 15 candidate DO-S models that were highly ranked during protocol development (Griffin et al. 2012, models 1-15 in Table C3). We applied the new estimates of β parameters for each of the candidate models to find the estimated overall unconditional detection probability, $\hat{p}^{*}_{U,*,j,k}$ (the subscripted asterisk indicates a combined probability for both front- and back-seat observers), for each observed elk group according to each *k* of the candidate models. Model structural components are listed in Table 1.

We used Akaike's information criterion for small sample size, AIC_c, to evaluate model support among the 15 models considered (Burnham and Anderson 2002). Because there was no strong support for any one prevailing model, we used all 15 models in model averaging to determine effects of sightability biases on population estimates (described below).

Abundance Estimation

We estimated abundance of elk in the Mount Rainier TCAs by weighting the raw counts of elk within each of the observed groups by the inverse of the group-specific unconditional detection probabilities estimated from the suite of DO-S models. For each of the *k* DO-S models, we computed specific correction factors, $\hat{\theta}_{j,k}$, for each group, *j*, as $1/\ \hat{p}^{*}_{U,.,j,k}$ (Griffin et al. 2013). The application of such Horvitz-Thompson correction factors for estimating detection biases in aerial surveys is well established (Steinhorst and Samuel 1989, Borchers et al. 1998). Group-specific correction factors derived from $\hat{p}^{*}_{U,.,j,k}$ can be thought of as the per-observed-elk contribution to the overall estimate of abundance, according to model *k*. We computed a model-averaged estimate of abundance, $\bar{\hat{N}}_{a,t}$, for TCA *a* and survey *t* (Equation 2):

$$\bar{\hat{N}}_{a,t} = \sum_{j \in a} \sum_{k}\ n_{t,j} \cdot \hat{\theta}_{j,k} \cdot \hat{w}_{k}. \qquad \text{(Equation 2)}$$

Where *k*=15 models, $n_{t,j}$ is the raw count of elk in the j^{th} group in survey *t*, and $\hat{w}_k$ is the model weighting for model *k*.

Accounting for missed survey units

We did not always manage to complete a replicate survey due to advancing darkness, deteriorating weather, or other logistical complications. In most cases after 2008, the area of non-surveyed units

comprised ≤4% of the total TCA. In cases where one or more survey units were not surveyed, we imputed missing estimates of elk abundance within individual survey units as a way to minimize potential underestimation. We estimated the missing data values for individual survey units as the mean of elk abundance estimated within these same units during other surveys completed from 2008-2011. Relational database query **qs_Abundance_stats_by_unit** provided an estimate of elk abundance for each survey unit during each replicate survey. Subsequently, we computed the mean and standard error of estimated abundance for each survey unit. We added the imputed abundance estimates from un-surveyed units to the total $\widehat{\overline{N}}_{a,t}$ estimated from the surveyed units. The imputed total abundance for such survey, $\widehat{N}_{Imputed\ a,t}$, was $\widehat{\overline{N}}_{a,t}$ plus the abundance in non-surveyed units, $\widehat{N}_{Non-surveyed}$ (Equation 3).

$$\widehat{N}_{Imputed\ a,t} = \widehat{\overline{N}}_{a,t} + \widehat{N}_{Non-surveyed} \qquad \text{(Equation 3)}$$

For survey replicates in which one or more units was not surveyed, we used the imputed abundance value as the point estimate for trend estimation.

Composition Estimation

We estimated herd composition within each of the TCAs as the ratios of calves, spike bulls, subadult bulls, mature bulls, and total bulls relative to 100 cows.

We computed composition ratios from the estimated numbers of cows, calves and bulls (by size/age class) within each observed group of elk. To estimate abundances by sex and age class in each group, we multiplied the observed numbers of cows, calves, and bulls in each group, *j*, by the group-specific, model-specific correction factor $\hat{\theta}_{j,k}$ and by the model weight $\widehat{w}_k$(Equation 4):

$$\widehat{\overline{N}}_{c,a,t} = \sum_k \sum_j n_{j,c,a,t} \cdot \hat{\theta}_{j,k} \cdot \widehat{w}_k, \qquad \text{(Equation 4)}$$

where, $\widehat{\overline{N}}_{c,a,t}$ is the estimated total number of elk in age-sex class *c* (*c* = cow, calf or bull) and $n_{j,c,a,t}$ is the number of elk of age-sex class *c* seen in group *j* in TCA *a* and survey *t*.

We estimated composition ratios of elk within the surveyed units and within 300 m of survey unit boundaries. We did not impute composition of elk in the survey units that were not surveyed. This reflects our assumption that composition ratios are representative of the TCA, even if one or more survey units were not surveyed.

Variance of Abundance and Composition

We estimated variance of abundance, Var($\widehat{\overline{N}}_{a,t}$), and composition ratio estimates using a data bootstrapping method (Wong 1996, Griffin et al. 2012 [see Appendix C of that report], Griffin et al. 2013 [Supplemental Material]) to account for variance due to: 1) random detection of animal groups within surveyed areas, 2) variation in DO-S model estimation (Steinhorst and Samuel 1989, Fieberg and Giudice 2008), and 3) model selection uncertainty. Because we searched survey areas entirely, there was no variation due to subunit sampling.

For surveys in which one or more units was not surveyed, we estimated the variance for each non-surveyed unit, Var($\widehat{N}_{Non-surveyed}$) as the variance of the mean elk abundance computed from other surveys of the same unit. To find the total imputed variance of abundance for surveys with one or more non-surveyed units, Var($\widehat{N}_{Imputed\ a,t}$), we added Var($\widehat{N}_{Non-surveyed}$) for each of the missing units to the variance of $\overline{\widehat{N}}_{a,t}$ estimated from bootstrapping.

If a non-surveyed unit has high Var($\widehat{N}_{Non-surveyed}$), the resulting total abundance estimate for the TCA could have low precision. Because we based Var($\widehat{N}_{Non-surveyed}$) on unit-specific estimated abundance values from other replicate surveys, we assumed that Var($\widehat{N}_{Non-surveyed}$) and Var($\overline{\widehat{N}}_{a,t}$) were independent.

In Mount Rainier NP, there were two estimates of abundance for TCAs that were surveyed twice in a year. In those cases, we included both estimated values of $\overline{\widehat{N}}_{North,t}$ or $\overline{\widehat{N}}_{South,t}$, and their associated variance estimates in the analysis of trend. Although we did not use the mean in trend analyses, we report the arithmetic mean of two replicate surveys, $\overline{\widehat{N}}_{North,t,mean}$ or $\overline{\widehat{N}}_{South,t,mean}$. For these averaged values, which are the mean of two surveys conducted in a single year, the *t* subscript refers to the year of those surveys. For years when there was more than one complete survey of a Mount Rainier NP TCA, total variance for average (arithmetic mean) abundance in year *t*, $Var(\overline{\widehat{N}}_{a,t,mean})$was the variance of the mean due to sampling *s* values of $\overline{\widehat{N}}_{a,t}$ in a single year (Equation 5). For years with two surveys in the same TCA, *s*=2.

$$Var\left(\overline{\widehat{N}}_{a,t,mean}\right) = \frac{\sum_{i=0}^{s}(\overline{\widehat{N}}_{a,t,s} - \overline{\widehat{N}}_{a,t,mean})^2}{s} \qquad \text{(Equation 5)}$$

For replicate surveys where one or more units were not surveyed, we used $\widehat{N}_{Imputed\ a,t}$ and the associated variance estimate in the place of any given $\overline{\widehat{N}}_{a,t}$ and associated variance.

Trends in Abundance

We estimated trends in the abundance of elk within the Mount Rainier TCAs using a weighted linear regression of the natural-log transformed estimates of abundance against time. The natural-log transformation of abundance is standard practice for analyzing population change because the slope of the resulting regression line is a measure of the instantaneous per-capita rate of population increase or decrease under the exponential growth model (i.e., r_o, *sensu* Caughley 1977; see also Ryding et al. 2007). For this analysis, we weighted the log-transformed abundance estimates by the inverse of their variance following Gerrodette (1991) to ensure that imprecise estimates of abundance carried less weight in the trend analysis than precise estimates.

Because the abundance estimates were natural-log transformed, we also transformed the variance. The transform of the point estimate, $\widehat{N}_{i,t}$, was $Y = ln(\widehat{N}_{i,t})$. The variance of each point estimate of abundance was the square of the standard deviation of the mean (i.e., the square of the standard error), taken from the bootstrap iterations. Equation 6, showing the transformation for the variance of

the log-transformed abundance value, is based on the delta method for variance estimation (Seber 1982),

$$Var(Y) = Var[ln(\bar{\bar{N}}_{a,t})] = ln'\left(\bar{\bar{N}}_{a,t}\right) \cdot Var\left(\bar{\bar{N}}_{a,t}\right) = \frac{Var(\bar{\bar{N}}_{a,t})}{\bar{\bar{N}}_{a,t}} \qquad \text{(Equation 6)}$$

We used year, starting in 2008, as the time measure against which we regressed abundance to evaluate temporal trends. For replicate surveys where one or more unit was not surveyed, we used $\hat{N}_{Imputed\ a,t}$ and the associated variance estimate in the place of $\bar{\bar{N}}_{a,t}$ and associated variance.

Although our primary interest was trends in abundance (i.e., the effect of time), we also fit a suite of related models that included Julian date and environmental covariates that we postulated may influence survey results and confound the interpretation of temporal trend (Table 2). The complete model set included a null model, reflecting the hypothesis of no population change over time (nor effect of covariates), as well as models that included potential effects of Julian date, maximum ambient temperature on the day of survey, a relative summer heat index (Residual GDD5, elaborated below), and a relative soil moisture index. Our model set was balanced in the sense that for each model that included a given effect we also had a similarly structured model without that effect. Our model set included models both with and without the time effect, and up to one of the other possible covariates. We limited the models to include just one potential covariate due to the relatively small sample size (i.e., 7 surveys). We structured models around the following *a priori* hypotheses (Table 2): (1) that Julian date may influence the number of elk using TCAs through its effect on forage phenology and its relationship to behavioral changes in elk distribution associated with the rutting season during late summer, (2) that numbers of elk within the TCA might be lower on hot days, as we expected elk to seek shade at lower elevations during hot conditions, and (3) high relative temperatures through the preceding season (Residual GDD5) and low soil moisture may also influence altitudinal distributions of elk through their effects on forage phenology and quality. This last hypothesis is based on our assumption that forage is likely to be more desiccated and of lower nutrient quality in the subalpine zone than in shaded mid-elevation forests, wet meadows, and avalanche chutes during relatively hot, dry summers.

We obtained climate data from the Cayuse Pass SNOTEL site (Natural Resources Conservation Service 2013), situated at 1597 m (5240 feet) elevation above sea level near the boundary separating the North and South Rainier TCAs. That site has been operational since 2007. We determined maximum temperatures during the survey days directly from the SNOTEL data. We assessed Residual GDD5, the summer heat index, from the time when the Cayuse Pass SNOTEL site became snow-free each summer and the date of the survey. We computed Residual GDD5 for each survey date as the deviation between the cumulative number of growing degree-days above 5°C (GDD5) and the average GDD5 for that date derived over the period of record (2007-2013). The average GDD5 for any date was derived from the simple linear regression of GDD5 against Julian date using all available years of record (2007-2013). This relationship was based on Julian dates between August 15-Sept15 (i.e., y intercept corresponds with August 15). The linear relationship between average GDD5 and Julian date, based on these data, was:

$GDD5_{average}$ = Intercept + coefficient*Julian date = -2024.76 + 10.861*Julian date (Equation 7)

As an index to soil moisture available for plant growth, we used soil moisture data collected at the Sunrise weather station, situated at an altitude of 6401 feet (951 m, NPS, NCCN, unpublished data). For the day of survey, we summed the available moisture content (%) in the 0-20 cm depth, and the 20-40 cm depth. Soil moisture in the 20-40 cm depth changes slowly after snow has completely melted, decreasing due to evapotranspiration. Moisture in the 0-20 cm depth decreases more rapidly, but can increase quickly after heavy rains.

We assessed the potential effect of Residual GDD5 on elk abundance only for the time since snow melted because temperature has little effect on plant growth until after snow melt. For surveys that were conducted over multiple days, we assessed relative heat and soil moisture indices for the first day of the survey and measured maximum temperature for the hottest day of the survey.

We used Akaike's Information Criterion adjusted for small sample size (AIC_c) and model weights to compare support among the competing models. We judged the relative support for temporal trend and effects of environmental covariates based on evidence ratios. These are ratios of model weights summed among models that include a particular covariate compared to models without that same covariate. Ratios >1 indicate the relative weight of evidence that the variable should be included in the model, whereas ratios <1 suggest little evidence of an effect. In addition, we computed the estimated rate of population growth (r), as the weighted average estimate of the time coefficient (i.e., the slope of the change in abundance over time), based on model weights of each of the models in the candidate set (Table 2). We also model-averaged the estimated variance and standard error (SE) of each coefficient. To assess whether the effect of time (i.e., trend) was statistically significantly different from zero, we used a z-test where the z-score was the coefficient estimate divided by its SE. We assessed the finite annual growth rate, λ, by exponentiating the coefficient of slope with respect to time. We computed the expected (predicted) values of elk abundance for each of the surveys by estimating abundance from each of the competing models in the candidate set (based on median values of all applicable covariates for the survey), and averaging those results based on model weights.

Some Washington State and tribal management decisions may be informed better by assessing trends with respect to the surveys with the maximum estimated abundance in any given year. To accommodate this approach, we also tested for temporal trends in abundance in each TCA, using an unweighted linear model with the effect of year, fit only through the highest ln-transformed estimate of abundance in any year.

Trends in Herd Composition

We estimated trends in the composition of elk groups observed in Mount Rainier NP using a weighted linear regression of the composition ratios against time. Similar to the analysis of abundance, we weighted composition estimates by the inverse of their variance to allow for a proportionally greater influence of precise estimates (Gerrodette 1991). However, because there were several near-zero values for ratios of spike-bulls: 100 cows, we felt that extraordinarily low variances

associated with these estimates would place excessive weights on these values. Therefore, in the case of spike bulls: 100 cow ratios, we fit unweighted regression models for the analyses of trend.

We examined trends in the ratios of calves, spike bulls, subadult bulls, mature bulls and all bulls per 100 cows. We examined several potential models of change in composition ratios: the null model in which ratios remained invariant over time and models that incorporated the effects of time (i.e., year), Julian date of the survey, Residual GDD5, and maximum temperature during the survey (Table 3). We hypothesized that the ratio of bulls observed with the cow herds may vary as the peak breeding season approached in middle and end of September. Further, we hypothesized the summer heat index or temperatures during the surveys may affect composition ratios due to potential gender difference in nutritional requirements or heat tolerance in male and female elk. As with trends in abundance, we used AIC_c and model weights to examine support among competing models of trends in population composition. We averaged results from the competing models on the basis of model weights.

Table 3. Descriptions of models fit to composition ratios from North Rainier and South Rainier TCAs, where K is the number of model parameters (including model intercept, covariate coefficients, and error sum of squares). Time refers to the year of the survey. Residual GDD5 is the difference between the cumulative number of growing degree-days (above 5°C) assessed from the time snow melts out to the survey date and the predicted average for that date.

Model	Description	K
M0.	Intercept only	2
M1.	Time	3
M2.	Julian Date	3
M3.	Time + Julian Date	4
M4.	Residual GDD5	3
M5.	Time + Residual GDD5	4
M6.	Maximum Temperature	3
M7.	Time + Maximum Temperature	4

In addition to the above analysis of composition based on all available survey results, as with trends in abundance, we also tested for temporal trends in calves per 100 cows and total bulls per 100 cows in each TCA using an unweighted linear model with the effect of year fit only through the composition values from the surveys that had the highest estimated abundance values in any year.

Trends in Raw Counts of Elk Seen at Olympic NP

Because we did not develop a sightability model for early-spring surveys, we report raw counts (i.e., not adjusted for sightability bias) of elk for the years when surveys were conducted on summer TCAs and the composition ratios computed from those raw counts. There were insufficient years in the time series to permit a meaningful evaluation of trend.

We developed linear models that assessed temporal trends in the numbers of elk counted during early-spring surveys from 1985-2010 using both legacy data collected from 1985-2004 and data collected from 2008-2010 following the same procedures. We developed a set of candidate linear regression models to examine temporal trends in counts as well as variation in the raw elk counts as

functions of survey timing (Julian date) and environmental conditions during the surveys (Table 4). We transformed the early-spring counts by the natural logarithm, so that the slope of the regression of counts over time corresponded with the instantaneous exponential rate of growth or decline. This analysis reflects the untested assumption that detection biases remained constant over the years. We formulated several models around hypotheses that the numbers of elk counted within the TCAs may vary over time, or as functions of Julian date of the survey, minimum temperature on the day of the survey and the cumulative number of growing degree-days above 40°F (GDD40) measured between February 1 and the survey date (Table 4).

Table 4. Description of the nine candidate linear regression model structures fit to counts of elk in each of the early-spring TCAs in Olympic NP, 1985 – 2010, where K is the number of model parameters (including model intercept, covariate coefficients, and error sum of squares). Each model potentially includes the effect of Time (temporal trend), Julian date, minimum temperature on the day of survey, and Residual GDD40. Residual GDD40 is the difference between the cumulative number of growing degree-days (above 40°F) assessed from 1 February to the survey date and the predicted average for that date.

Model	Model description	K[1]
M0.	Intercept only	2
M1.	Time	3
M2.	Time + Julian Date	4
M3.	Time + Residual GDD40	4
M4.	Time + Minimum Temperature	4
M5.	Time + Julian Date + Residual GDD40	5
M6.	Time + Julian Date + Minimum Temperature	5
M7.	Time + Julian Date + Residual GDD40 + Minimum Temperature	6
M8.	Time + Residual GDD40 + Minimum Temperature	5
M9.	Julian Date	3
M10.	Residual GDD40	3
M11.	Minimum Temperature	3
M12.	Julian Date + Residual GDD40	4
M13.	Julian Date + Minimum Temperature	4
M14.	Julian Date + Residual GDD40 + Minimum Temperature	5
M15.	Residual GDD40 + Minimum Temperature	4

We speculated that numbers of elk may increase with Julian Date as winter turns to spring and forage conditions improve on the low-elevation riverine floodplains. Further, we hypothesized that fewer elk may be observed within the survey areas on cold mornings when elk tend to select south-facing slopes for thermal advantages (Jenkins and Starkey 1984) or following relatively cold winters when the seasonal phenology of forage production is delayed on the floodplains.

We obtained climate data representing the early-spring TCAs in Olympic NP from the Quillayute weather station (National Weather Service 2013). The station is situated at 59 m elevation above sea level, approximately 28 km WNW from the Hoh TCA. Although the weather station is under a more maritime influence than the survey areas, which are likely colder, the long-term weather records at Quillayute are the best available for lowland sites in the western Olympics and provide a useful index

of regional conditions. We determined minimum temperatures, recorded in degrees Fahrenheit (°F = 32 + 1.8*°C), for each of the survey dates. We assessed relative temperatures during several weeks leading up to each survey as the deviation between the cumulative sum of growing degree-days above 40°F (GDD40) as measured between February 1 and each survey and the average GDD40 for that date. The average GDD40 for any date was derived from the simple linear regression of GDD40 against Julian date using all available records over the last 30 years. This relationship was based on Julian dates between 69 (March 10) to 103 (April 13). For this range of survey dates, the equation predicting GDD40 based on Julian date was:

$$GDD40 = -177.3591 + 4.6526*\text{Julian date} \qquad \text{(Equation 8)}$$

In addition to determining trends in counts of elk within each of these TCAs, we also examined changes in the counts of elk made within 2 or 3 longitudinal segments of each TCA (Figure 6). This finer-scale analysis targeted our supposition that temporal trends in elk counts may vary with distance from the park boundary. The defined survey segments reflected the relative proximity to human disturbances or land use changes near the park boundary in the lower end of the TCA, and conversely, relative isolation from human influences upriver. The three segments also partition the gradient of progressively decreasing temperatures and increasing snow depths upriver during winter. Although the altitudinal migration patterns of elk herds are highly individual and reflect annual weather variations, generally, the downriver segment corresponded with an area inhabited primarily by non-migratory resident elk herds and the upriver segment corresponded more closely with winter ranges used by migratory herds (Schwartz and Mitchell 1945, NPS unpublished data). Consequently, patterns in change related to the river segments may also imply different processes operating on migratory and resident components of the populations in each watershed. To define these segments, we first delimited a reference line at the lower end of each watershed where the park boundary intersects the floodplain. From that point, we partitioned the longitudinal gradient upriver as 0-5, 5-15, and >15 km from the reference line. Because the Queets TCA is buffered from human influences, we identified only two segments upriver in the Queets (5-15, >15 km) (Figure 6). The South Fork Hoh was relatively short so there was no portion of the TCA >15 km from the park boundary (Figure 6).

In each watershed segment, we examined trends as the slope of the natural log of abundance against time and compared this model to the null model of no temporal effects. We examined the relative evidence of trend in each of the survey segments based on evidence ratios of models with and without the temporal trend.

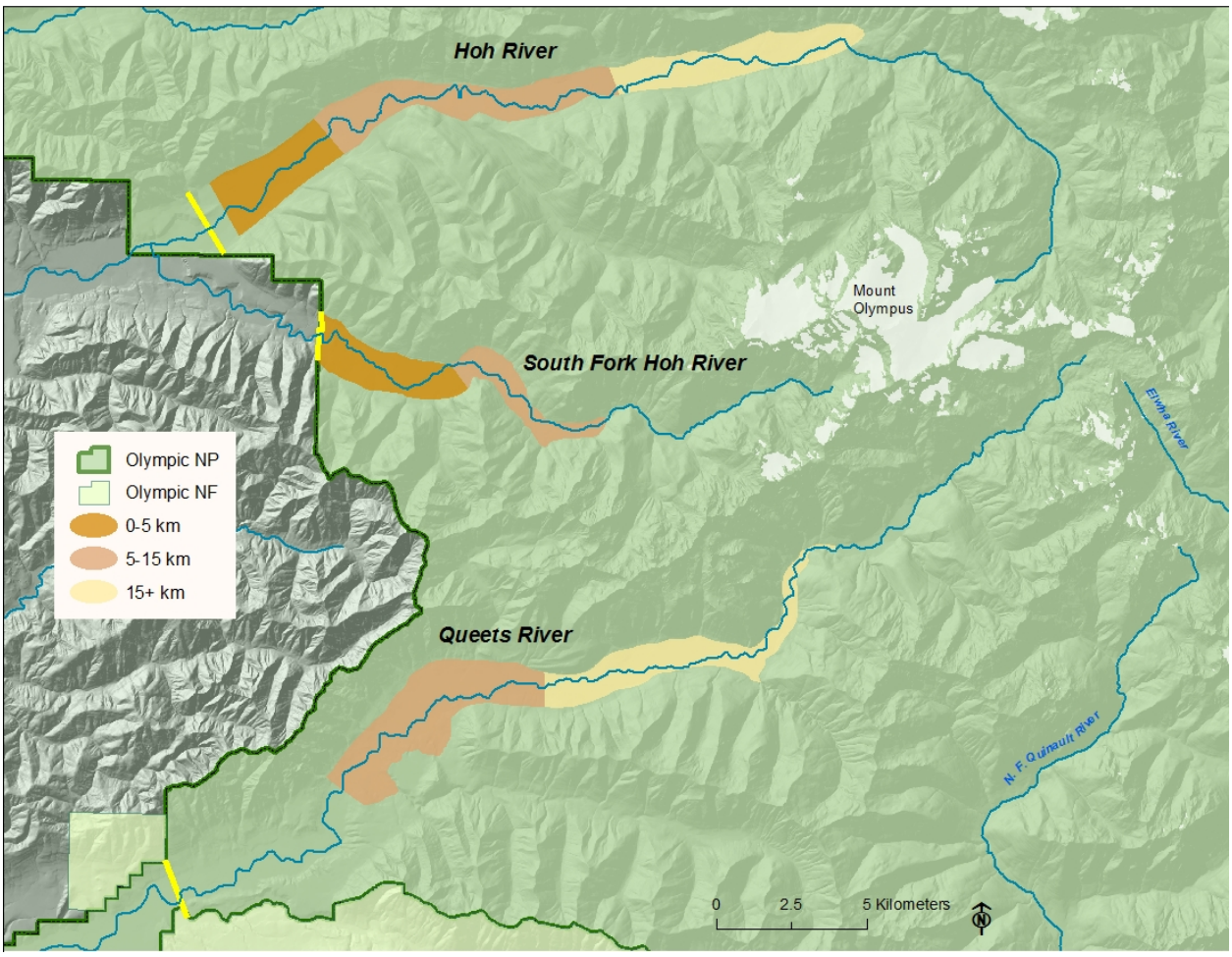


Figure 6. Map of Olympic NP early-spring TCAs showing spatial subunits (segments) used to examine trends in elk counts relative to the river gradient. Segments of the river floodplain reflect increasing distances upstream from the line where the park boundary intersects the valley floor (yellow lines). Segments of each watershed upriver of these spatial subunits were narrow valleys that lacked the floodplain winter ranges of elk. The 0-5 segment was not surveyed in the Queets Valley, and the 0-5 segment began at approximately km 1 in the Hoh Valley, both artifacts of how the surveys were initially set up in 1985.

Prospective Power Analysis

Power to detect a trend increases as a function of sampling replication, frequency and precision (Gerrodette 1987). Preliminary results from the monitoring protocol suggested that statistical power (i.e., one minus the type II error rate, 1-β) would be adequate (i.e., 1- $\beta > 0.8$) over eight years of surveys at Mount Rainer NP and in the Olympic NP Core TCA to detect a halving or doubling of elk abundance (Griffin et al. 2012). These changes correspond to roughly an annual increase or decrease of 10.5%. Trend estimates based on survey data are a reflection of the underlying rate of change and two sources of variation: process variance and enumeration error (Thompson et al. 1998:20). Process variation refers to variation in counts that result from environmental processes that affect elk numbers in the survey area; for example, weather variation. Enumeration error is imprecision in the abundance estimates due to uncertainty in the estimation of the number of elk that were present in the sample frame but not seen.

For this report, we made use of abundance and precision estimates from 2008 – 2011 elk surveys and we revisited the calculations of projected power for Mount Rainier NP. To be conservative in projections we assumed that 2012 – 2015 surveys would take place only once per year in each TCA.

We modeled prospective estimates of the power to detect annual changes for 2011 – 2015 of from +10.5% to -10.5%, and also to detect a statistically significant change if the abundance continued to change at the levels estimated from the 2008-2011 data. We simulated four years of additional survey results with Monte Carlo simulations (Crowley 1992), using values for estimation error from the 14 Mount Rainer NP survey replicates, and values for process variance from the 6 pairs of survey replicates conducted in the same year. Here, estimation error represents variation in the accuracy of estimated abundance in the TCA and process variance represents variation in the changes of the total population that are present in the surveyed TCA. Based on all 14 available survey estimates, we found the CV for the average value of estimation error (CV=0.087), for use as the CV for estimation error variance in simulations.

For each year when there were two replicate surveys in the North Rainier TCA (n=3) and South Rainier TCA (n=3), we found total variance in abundance as the average squared difference between the imputed abundance estimates ($\bar{\hat{N}}_{a,t}$) and the mean estimated abundance for that year ($\bar{\hat{N}}_{a,t,mean}$). We estimated the value for process variance for each survey by subtracting estimation variance ($Var(\bar{\hat{N}}_{a,t})$) from total variance, based on Link et al. (1994, p. 1098; Equation 9).

$$Var_{Process}\left(\bar{\hat{N}}_{a,t}\right) = \frac{\sum_{i=0}^{s}(\bar{\hat{N}}_{a,t,s} - \bar{\hat{N}}_{a,t,mean})^2}{s} - Var\left(\bar{\hat{N}}_{a,t}\right) \qquad \text{(Equation 9)}$$

In the above equation, the first additive term represents total variance for the *s* estimates of abundance in a single TCA in a single year; it is the average of the squared differences between each $\bar{\hat{N}}_{a,t}$ value in a given year and the mean value from that year. The second term is the estimation variance associated with each measurement of abundance, where that estimation variance is the square of the bootstrapped standard error.

In this context, process variance was within-year variation in elk abundance that was not explained by measurement error. We found the CV of process variance for each survey as the $SE_{Process}(\bar{\hat{N}}_{a,t})$ divided by the point estimate of $\bar{\hat{N}}_{a,t}$. We used the average value of the CV of process variance (0.109) in our projection models. When averaging to find this value for process variance, we did not use estimated process variance from North Rainier TCA 2011 abundance estimates because estimation error was greater than total variance; as a result, if anything, the value we used for process variance in simulations was slightly greater than observed in this data set.

For each simulated iteration, we assigned an initial population size as a random variable based on the estimated 2011 abundance, plus or minus a fraction of that value drawn from a normal distribution with mean of zero and standard deviation equal to the CV from the estimation error associated with the most recent estimate of abundance. For the South Rainier TCA, the estimation error CV for the

2011 abundance estimate was 0.085, and for the North Rainier TCA we used the average estimation error value from two estimates in 2011, which was CV=0.177.

We simulated future (2012 -2015) abundance trajectories as a function of the annual rate of change, while also adding process variance in each simulated time step. This additional process variance term was the abundance times a randomly drawn value from a normal distribution with mean of 0.0 and standard deviation equal to 0.109 (the CV of process variance). In this context, we used the value for within-year process variance as a proxy for a comparable level of between-year process variance. We modeled imprecision in each simulated estimate of abundance by adding an estimation error term to the true abundance for the year surveyed. The estimation error term was the product of the true abundance in the year of survey, times a randomly drawn value taken from a normal distribution with mean of 0.0 and standard deviation equal to 0.087, the CV of estimation error.

For each of 1000 iterations of simulated abundance change over time, we fit an unweighted linear regression through estimates of abundance (2008 - 2011) and simulated estimates of abundance (2012 - 2015) and determined whether the slope of the line was significantly different from zero. We considered a given iteration to have a statistically significant non-zero slope if the ratio of the estimated slope divided by the estimated standard error of the slope was greater than the critical value from a t-distribution, with d.f. = n-2 (Gerrodette 1991). We interpreted the proportion of iterations in which a statistically significant trend was detected as the power to detect the simulated trend. We recorded the expected statistical power to detect change, using a range of negative and positive values for the annual rate of change for simulations applied to 2012-2015.

Trends in Spatial Distribution of Elk in Mount Rainier NP

We defined the spatial distribution of elk in terms of the relative density of elk in all the survey units of a TCA. Relative density was computed as the density of elk within a survey unit divided by the mean density of elk within the entire TCA. Relative densities less than 1 indicated density less than the TCA average, whereas relative densities greater than 1 corresponded with greater than average densities. We tested for statistically significant temporal trends in relative density within individual survey units. For each survey unit we fit a linear regression where all the available estimates of relative density for the unit were the response variable (y-axis), predicted as a function of time (x-axis, in years). For this analysis, we only used estimated unit-level densities from survey replicates (i.e., we did not use data from survey flights that were targeted to increase the sample size of DO-S trials). We had no *a priori* hypotheses about effects of covariates other than time on spatial distribution in the summer survey areas, so this analysis did not include multi-model inference. Rather, we concluded that there was a statistically significant trend in relative density over time if the coefficient of time in the linear regression was statistically significant based on a *z*-test (where *z* = point estimate of the coefficient divided by the standard error of the coefficient) and assuming a type-I error of 0.10.

Results

Mount Rainier NP—Summer Range Surveys

Survey Summaries

We conducted 14 aerial surveys of elk within Mount Rainier NP from 2008-2011, seven surveys each in the North Rainier TCA and South Rainier TCA (Table 5) with the intent of completing each survey in a single evening using two helicopters operating simultaneously. For six of the surveys, we encountered scheduling and weather-related problems requiring that we complete the surveys over 2-3 evenings. In eight surveys, we were unable to survey a small portion of the TCA due to approaching darkness. The largest impact was in the North Rainier TCA during 2008 when additional helicopter time was needed to collect data for DO-S model development, specifically radiotracking collared elk that were not seen during the survey to record sightability covariates. In 2009-11 we completed surveys on 90-100% of the TCAs. Survey intensity ranged from 0.31-0.47 km^2/minute (mean=0.36, SD=0.06). Because the estimated survey intensity included times searching for elk groups as well as time counting and classifying all elk groups observed, actual survey duration and intensities were likely overestimated in units with abundant elk. Consequently, the recorded survey intensities were very close to the goal of 0.35 km^2/minute.

Table 5. Flight summary statistics for elk aerial surveys conducted in the North and South Rainier TCAs in Mount Rainier NP, 2008-11. Shown for each replicate survey are TCA name, year, survey dates, replicate number (Rep), omitted survey units, flight duration in minutes, survey duration in minutes, survey intensity in km^2/min, the area surveyed in km^2, and the percentage of the total TCA surveyed (% of TCA).

TCA	Year	Survey Dates	Rep	Survey Units Omitted	Flight Duration (mins)	Survey Duration (mins)[1]	Survey Intensity (km^2/min)[1]	Area Surveyed (km^2)	% of TCA
North	2008	8/22/2008-8/26/2008	1	N6,N15,N16a,N16b, N17,N18	335	251	0.33	83.6	81.0
North	2008	9/3/2008-9/6/2008	2	N5,N9,N10,N14	346	243	0.33	79.4	77.0
South	2008	8/26/2008-9/10/2008	1	S9	390	304	0.29	87.0	97.4
South	2008	9/10/2008-9/11/2008	2	none	321	265	0.34	89.3	100.0
North	2009	8/17/2009	1	none	384	318	0.32	103.2	100.0
South	2009	8/18/2009	1	S20	336	260	0.33	84.6	97.4
South	2009	9/2/2009	2	S11	336	191	0.42	80.7	90.3
North	2010	8/17/2010	1	none	299	218	0.47	103.2	100.0
North	2010	8/25/2010	2	none	411	277	0.37	103.2	100.0
South	2010	8/18/2010	1	none	380	291	0.31	89.3	100.0
South	2010	8/26/2010-9/2/2010	2	S1	318	194	0.45	87.2	97.6
North	2011	8/17/2011	1	N16b	337	285	0.35	99.3	96.2
North	2011	9/12/2011	2	N11b	309	218	0.47	101.9	98.7
South	2011	9/1/2011-9/13/2011	1	S5b,S20	364	250	0.33	82.5	92.3

[1] Survey duration and intensity included time surveying for elk and also time counting and classifying elk in each observed elk group.

Double-Observer Sightability Model

We recorded 635 usable DO observations and 99 DO-S trials from 2008-2011 at Mount Rainier NP for developing a suite of 15 DO_S models (Table 6). Four of 15 models examined received substantial empirical support (i.e., AIC_c <2, Burnham and Anderson 2002:70), but results of all 15 models were averaged in estimating sightability biases and the numbers and composition of elk. In addition to the variables that were included in all the models (ln(N), F:IXP, B:C), we found strong consistent support for including vegetation cover (V) in the model (Griffin et al. 2013). The influence of lighting (L), animal movement (M), herbaceous vegetation (H), and forest vegetation (F) were also included in some models, but the effect of each variable was relatively low based on evidence ratios. Evidence ratios, computed as the ratio AIC_c weights of paired models with and without the variable in question, ranged from 4.8 for L (i.e., the evidence for inclusion of L was 4.8 times stronger than the evidence for excluding it), 1.87 for M, <1.0 for F (0.37), and H (0.70). We found little support for separate sighting probabilities for front and backseat observers (ER = 0.40) or for differences in the residual heterogeneity parameter between front and backseat observers (ER = 0.39). Beta coefficients for all the covariates in each of the 15 models are shown in Appendix B. Parameter estimates for lowly supported models received comparatively low weights relative to those for the top models; consequently they had little effect on population estimation.

Table 6. Ranked list of 15 candidate models from the protocol fit to Mount Rainier NP data from 2008-2011. Model number was assigned in the protocol (Griffin et al, 2012; Table C3); here, models are listed according to level of support, taken as a measure of ΔAIC_c. AIC_c weights are a measure of the strength of evidence in support of each model in the candidate set. K is the number of model parameters. All components of model structure were described previously in Table 1.

Model Number and Structure	ΔAIC_c	AIC_c Weights	K
Model 1 {F=B + Hetero + ln(N) + F:IXP + B:C + V + L}	0.00	0.31	7
Model 5 {F/B + Hetero + ln(N) + F:IXP + B:C + V + L}	1.84	0.12	8
Model 3 {F=B + Hetero + ln(N) + F:IXP + B:C + V + M}	1.90	0.12	7
Model 4 {F/B*Hetero + ln(N) + F:IXP + B:C + V + L}	1.91	0.12	9
Model 2 {F=B + Hetero + ln(N) + F:IXP + B:C + V}	3.16	0.06	6
Model 10 {F/B + Hetero + ln(N) + F:IXP + B:C + V + M}	3.74	0.05	8
Model 8 {F/B*Hetero + ln(N) + F:IXP + B:C + V + M}	3.76	0.05	9
Model 7 {F=B + Hetero + ln(N) + F:IXP + B:C + V + H}	3.86	0.04	7
Model 9 {F/B + Hetero + ln(N) + F:IXP + B:C + V}	4.99	0.03	7
Model 6 {F/B*Hetero + ln(N) + F:IXP + B:C + V}	5.05	0.02	8
Model 12 {F=B + Hetero + ln(N) + F:IXP + B:C + V + F}	5.17	0.02	7
Model 13 {F/B + Hetero + ln(N) + F:IXP + B:C + V + H}	5.70	0.02	8
Model 11 {F/B*Hetero + ln(N) + F:IXP + B:C + V + H}	5.75	0.02	9
Model 15 {F/B + Hetero + ln(N) + F:IXP + B:C + V + F}	7.00	0.01	8
Model 14 {F/B*Hetero + ln(N) + F:IXP + B:C + V + F}	7.07	0.01	9

Differences in model ranking were minimal compared to the model ranks in the protocol (Griffin et al. 2012). Overall, the very slight differences in model ranking and beta parameters can be gauged by the slight differences between the point estimates for each survey replicate under this updated model, compared to the interim values published in annual reports (Griffin et al. 2011, Happe et al. 2013).

Abundance Estimates

Survey crews counted an average of 306 elk per survey (range: 221-375) in the North Rainier TCA, and 391 elk per survey (range: 273-705) in the South Rainier TCA (Table 7). After applying the DO-S model to account for detection biases, and after accounting for non-surveyed units, we estimated an average of 358 elk in the North Rainier TCA and 503 elk in the South Rainier TCA from 2008-2011 during the surveys (Table 7). These averages imply estimated densities of 3.5 elk/km^2 in the North Rainier TCA (103.2 km^2) and 5.6 elk/km^2 in the South Rainier TCA (89.3 km^2) during the surveys. On average, the survey crews detected a greater proportion of the estimated abundance ($\widehat{\overline{N}}_{a,t}$) of elk in the North (87.9%) than in the South (81.3%). In surveys where the non-surveyed units had a relatively high mean abundance from other surveys the imputed total abundance ($\widehat{N}_{Imputed\ a,t}$) and imputed variance increased correspondingly.

Table 7. Raw elk counts, estimated elk abundance in surveyed units ($\widehat{\overline{N}}_{a,t}$ and associated standard error (SE)), imputed elk abundance for surveys with one or more non-surveyed units ($\widehat{N}_{Imputed\ a,t}$) and associated SE in the North Rainier TCA and South Rainier TCA in Mount Rainier NP, 2008-2011. Percent seen was estimated as the raw count divided by $\widehat{\overline{N}}_{a,t}$.

TCA	Year	Replicate	Raw Count	$\widehat{\overline{N}}_{a,t}$	SE($\widehat{\overline{N}}$)	CV($\widehat{\overline{N}}$)	$\widehat{N}_{Imputed\ a,t}$	SE($\widehat{N}_{Imputed\ a,t}$)	CV($\widehat{N}_{Imputed\ a,t}$)	Percent Seen
North	2008	1	221	251	20.2	0.08	283	21.4	0.08	88.2
North	2008	2	248	297	32.1	0.11	332	32.5	0.10	83.5
North	2009	1	365	427	22.8	0.05	427 *	22.8 *	0.05	85.4
North	2010	1	290	312	12.5	0.04	312 *	12.5 *	0.04	92.8
North	2010	2	375	411	22.1	0.05	411 *	22.1 *	0.05	91.3
North	2011	1	373	412	46.3	0.11	414	46.3	0.11	90.6
North	2011	2	268	321	50.1	0.16	325	50.3	0.15	83.5
	$\overline{x}$		***306***	***347***	***29.4***	***0.08***	***358***	***29.7***	***0.08***	***87.9***
South	2008	1	349	443	37.9	0.09	444	37.9	0.09	78.7
South	2008	2	291	363	33.7	0.09	363 *	33.7 *	0.09	80.2
South	2009	1	397	500	65.7	0.13	541	66.9	0.12	79.4
South	2009	2	225	273	25.1	0.09	369	30.4	0.08	82.5
South	2010	1	612	705	40.3	0.06	705 *	40.3 *	0.06	86.8
South	2010	2	327	405	40.4	0.10	405 †	40.4 †	0.10	80.8
South	2011	1	538	658	57.8	0.09	700	59.2	0.08	81.3
	$\overline{x}$		***391***	***478***	***43.0***	***0.09***	***503***	***44.1***	***0.09***	***81.4***

* All units were surveyed.

† The non-surveyed unit had a mean abundance of zero.

Abundance Trends

Based on the analyses of all seven replicated counts in each TCA, there was little evidence for temporal trend in the abundance of elk using either the North Rainier or South Rainier TCAs. In both TCAs, the null model — that is, the model with neither a temporal trend nor effects of survey-specific covariates — was strongly supported by the data (model weights 0.85 in the North Rainier TCA and 0.55 in the South Rainier TCA; Table 8). The weight of evidence in support of the existence of a temporal trend in the North Rainier TCA, expressed as the ratio of model weights for models with and without the temporal component, was only 0.03 (i.e., the evidence for including a temporal trend in the model was only 3% of the relative evidence for excluding it). The evidence ratio in support of the existence of a temporal trend in the South Rainier TCA, 0.20, indicated that evidence of a trend was only 20% relative to the evidence of no trend.

Table 8. Candidate models for the natural log of abundance for elk surveys in the North and South Rainier TCAs. The row for each model includes the model's name (specifying the effects included in the model), the number of parameters (K), ΔAIC_c value, and model weights for the North and South. Residual GDD5 is the difference between the cumulative number of growing degree-days (above 5°C) assessed from the time of snow melt to the survey date and the predicted average for that date.

			North		South	
Model	**Description**	**K**	**ΔAIC_c**	**weight**	**ΔAIC_c**	**weight**
M0.	Intercept only (null model)	2	0.0	0.85	0.0	0.56
M1.	Time	3	6.7	0.03	2.4	0.17
M2.	Time + Julian Date	4	20.7	0.00	13.4	<0.01
M3.	Time + Residual GDD5	4	19.5	0.00	15.7	0.00
M4.	Time + Maximum Temperature	4	20.4	0.00	14.9	0.00
M5.	Time + Soil Moisture	4	20.6	0.00	14.4	0.00
M6.	Time + Residual GDD5 + Soil Moisture	5	56.2	0.00	55.2	0.00
M7.	Julian Date	3	7.0	0.03	2.3	0.18
M8.	Residual GDD5	3	6.0	0.04	6.3	0.02
M9.	Maximum Temperature	3	7.0	0.03	4.8	0.05
M10.	Soil Moisture	3	6.9	0.03	6.6	0.02
M11.	Residual GDD5 + Soil Moisture	4	20.0	0.00	18.2	0.00

The exponential population growth rate (r) for the South Rainier TCA (Figure 7) was positive (r=0.033), but not statistically significantly different from zero (P= 0.37). The exponential growth rate for the South Rainier TCA equates to a finite annual growth rate (λ) of 1.033, an estimated growth of 3.3% annually. Because of the relatively low precision of these estimates, however, the 95% confidence interval of this finite annual rate of growth ranges from -3.9% to +11% annually. For the North Herd TCA, r was 0.001 (SE=0.013). The finite annual rate of growth, λ, 1.001 (0.1% annual growth) was indistinguishable from zero (P=0.94) (Figure 8).

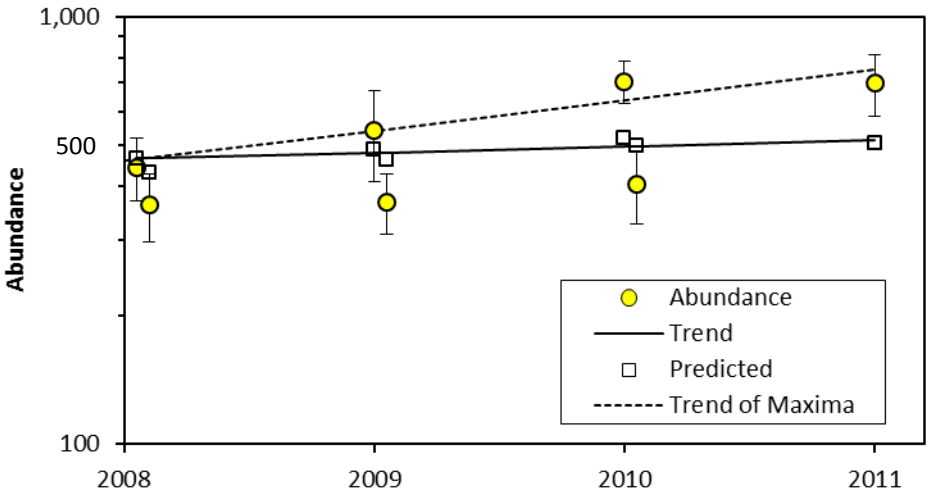


Figure 7. Trends in the estimated abundance of elk (plotted on a logarithmic scale) in the South Rainier TCA, 2008-2011. The solid line represents the model-averaged trend based on median values of all model covariates except time. The empty box symbols represent model-averaged predicted abundances based on observed covariate values specific to each survey. Error bars around estimates for surveys represent 95% confidence intervals of the estimated measurement error truncated on the lower limit at the numbers of elk counted. The dashed line (Trend of Maxima) represents the unweighted linear relationship between year and the maximum abundance estimated each year.

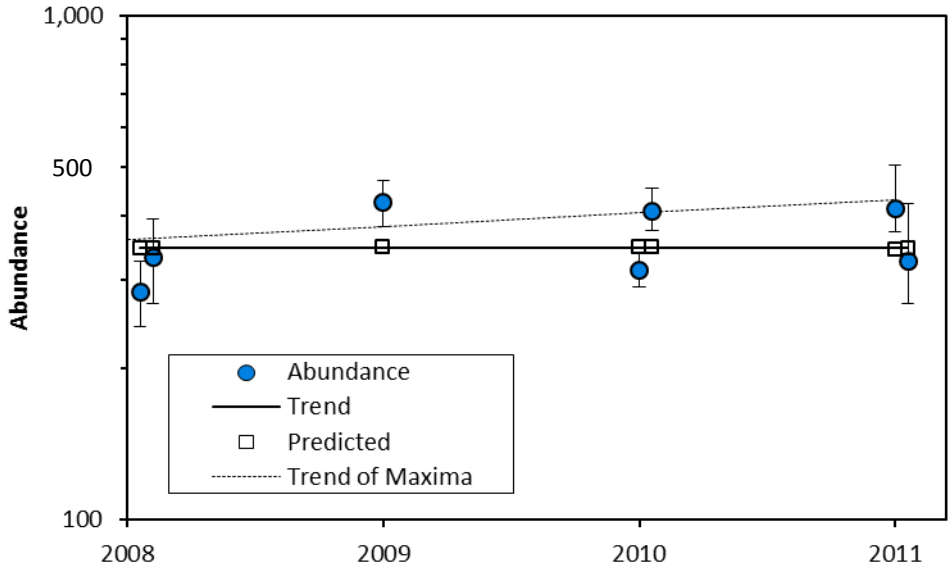


Figure 8. Trends in the estimated abundance of elk (plotted on a logarithmic scale) in the North Rainier TCA, 2008-2011. The solid line represents the model-averaged trend based on median values of all model covariates except time. The empty box symbols represent model-averaged predicted abundances based on observed covariate values specific to each survey. Error bars around estimates for surveys represent 95% confidence intervals truncated on the lower limit at the numbers of elk counted. The dashed line (Trend of Maxima) represents the unweighted linear relationship between year and the maximum abundance estimated each year.

To contrast this analysis of trends through all replicated counts, we also fit unweighted linear regression through only the maximum estimates of abundance each year (Figures 7, 8). For the South

Rainier TCA, the slope of the unweighted trend line fit through each year's highest estimated ln-transformed abundance value (Figure 7 dashed line) was greater than the slope of the line fit to all the replicates, and this relationship was statistically significantly different from zero (slope, r=0.1628, SE=0.040, P=0.05; λ=1.176). For the North Rainier TCA, the slope of the unweighted trend line fit through each year's highest estimated ln-transformed abundance value also was greater than the trend through all replicates, but was not statistically significantly different from zero (slope, r=0.062, SE=0.045, P=0.305; λ=1.064).

Relative to the null model, there was little support for the effect of environmental variables on abundance estimates (Table 8). Only the effect of Julian date measured in association with South Rainier TCA surveys had an appreciable model weight (0.178, Table 8). Based on evidence ratio, there was approximately 32% relative support for including the effect of Julian date. The model averaged coefficient for the effect of Julian date was -0.004 (SE 0.004) suggesting a potential small negative effect of calendar date on estimated abundance (Figure 9). All of the other potentially confounding environmental variables associated with individual surveys had negligible support (Table 8). Despite our a priori hypothesis that high ambient temperatures may influence survey results, we found low support for temperature effects on abundance estimates within the range of temperatures in which we surveyed (Table 5, Figure 10).

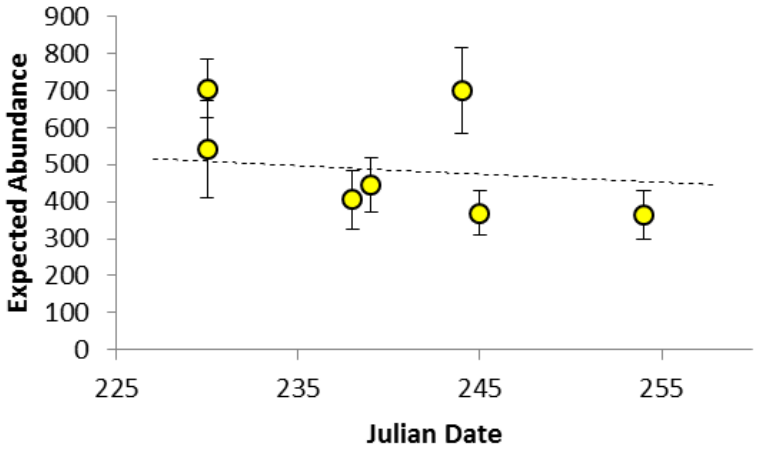


Figure 9. Expected elk abundance, $\widehat{N}$, as a function of Julian date, for the South Rainier TCA. The dashed line represents the model-averaged trend based on median values of all model covariates except Julian date. Error bars around the estimated abundance values are 95% confidence intervals.

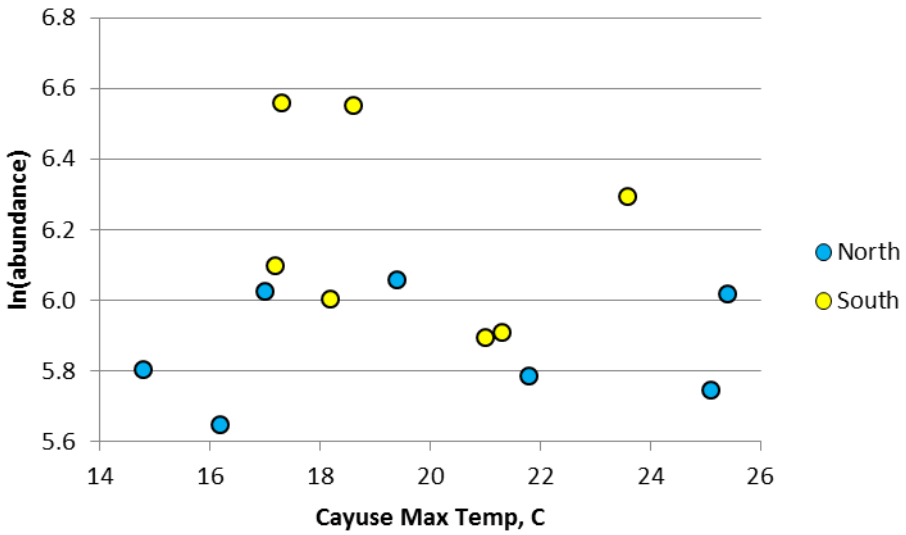


Figure 10. Scatter plot of estimated total abundance, $\hat{N}$, for replicate surveys within North and South Rainier TCAs, 2008-2011, versus maximum temperature at Cayuse Pass Snotel site on the day of surveys.

Composition Ratios and Trends

For all the population ratios examined, the null model was the most highly ranked and strongly supported, suggesting there was minimal influence of temporal trend, Julian date, or temperature variables on composition estimates (Table 9). There were no differences in composition estimates between the North Rainier TCA and South Rainier TCA (t-tests, 6 df, $P>0.15$ for comparisons of all composition ratios), although the point estimates for mean ratios of calves: 100 cows and spike bulls:100 cows tended to be greater in the North Rainier TCA. Calf: cow ratios ranged from 25-50 annually in the North Rainier TCA, and 32-38 in the South Rainier TCA (Table 10). The ratio of all bulls: 100 cows averaged approximately 39-40:100 cows in both TCAs. The pooled ratio of subadult and mature bulls: 100 cows averaged 31:100 cows in the North Rainier TCA and 34:100 cows in the South Rainier TCA.

The model-averaged temporal trends were negligible for ratios of calves:100 cows (Figure 11) and for ratios of any of the bull classes relative to cows (Figure 12) due to the overwhelming support for the null models over models with a temporal trend. Of all the other models examined, there was strong support for the effect of Residual GDD5 on subadult bulls: 100 cow ratios in the South Rainier TCA (w=0.63, Table 10) and moderate support for the effect of Julian date on the estimation of mature bull:100 cow ratios in the North Rainier TCA (ΔAIC_c=2.51, w=0.22; Table 10). The ratio of subadult bulls:100 cows in the South Rainier TCA was negatively associated with Residual GDD5, reflecting the high ratio of subadult bulls observed during one particularly short growing season (Residual GDD5<-300, Figure 13). The ratio of mature bulls: 100 cows in the North Rainier TCA tended to decrease with advancing season (Figure 14).

Table 9. Candidate linear regression models of factors potentially affecting composition ratios of elk in the North Rainier TCA and South Rainier TCA, based on all available estimates from 2008-2011, and associated ΔAICc values and model weights (*Wk*). Residual GDD5 is the difference between the cumulative number of growing degree-days (above 5°C) assessed from the time of snow melt to the survey date and the predicted average for that date.

TCA	Calves: 100 Cows		Spike Bulls: 100 Cows		Subadult Bulls: 100 Cows		Mature Bulls: 100 Cows		Total Bulls: 100 Cows	
North Rainier	ΔAIC_c	w_k	ΔAIC_c	w_k	ΔAIC_c	w_k	ΔAIC_c	w_k	ΔAIC_c	w_k
M0. Intercept only (null model)	0.00	0.85	0.00	0.76	0.00	0.85	0.00	0.67	0.00	0.86
M1. Time	5.81	0.05	5.62	0.05	6.00	0.04	6.62	0.02	6.65	0.03
M2. Julian Date	5.54	0.05	6.20	0.03	5.62	0.05	2.51	0.19	5.89	0.05
M3. Time + Julian Date	18.61	0.00	18.51	0.00	18.80	0.00	15.42	0.00	19.43	0.00
M4. Residual GDD5	6.91	0.03	5.45	0.05	6.86	0.03	6.23	0.03	6.75	0.03
M5. Time + Residual GDD5	19.60	0.00	12.44	0.00	19.94	0.00	18.48	0.00	20.55	0.00
M6. Maximum Temperature	6.91	0.03	4.01	0.10	7.00	0.03	4.21	0.08	6.62	0.03
M7. Time + Maximum Temperature	19.81	0.00	17.82	0.00	18.57	0.00	18.05	0.00	20.55	0.00
South Rainier										
M0. Intercept only (null model)	0.00	0.88	0.00	0.79	1.34	0.32	0.00	0.86	0.00	0.71
M1. Time	6.97	0.03	6.44	0.03	7.17	0.02	6.05	0.04	4.73	0.07
M2. Julian	6.89	0.03	6.98	0.02	8.18	0.01	6.90	0.03	6.52	0.03
M3. Time + Julian	20.89	0.00	20.43	0.00	21.16	0.00	19.77	0.00	15.59	0.00
M4. Residual GDD5	7.00	0.03	3.78	0.12	0.00	0.63	6.89	0.03	2.79	0.18
M5. Time + Residual GDD5	20.97	0.00	14.66	0.00	10.29	0.00	19.28	0.00	14.17	0.00
M6. Maximum Temperature	6.58	0.03	6.57	0.03	7.59	0.01	6.09	0.04	7.00	0.02
M7. Time + Maximum Temperature	20.58	0.00	19.50	0.00	20.69	0.00	18.91	0.00	18.59	0.00

Table 10. Composition ratios of elk in the North and South Rainier TCAs in Mount Rainier NP, 2008-2011. Arithmetic means of estimated values for each TCA are shown as $\bar{x}$. For each ratio, the value in parentheses is the standard error of the mean (SE).

TCA	Year	Rep	Calves: 100 Cows	Total Bulls: 100 Cows	Spike Bulls: 100 Cows	Subadult Bulls: 100 Cows	Mature Bulls: 100 Cows
North	2008	1	47 (2.3)	35 (4.8)	12 (1.5)	5 (2.2)	18 (3.2)
North	2008	2	45 (2.8)	41 (4.5)	19 (2.2)	7 (1.2)	15 (2.8)
North	2009	1	38 (1.2)	31 (4.1)	1 (0.2)	9 (1.8)	20 (3.1)
North	2010	1	34 (0.9)	49 (5.5)	4 (0.8)	8 (1.7)	37 (4.3)
North	2010	2	50 (1.5)	47 (4.0)	10 (0.8)	9 (2.2)	27 (3.9)
North	2011	1	36 (1.4)	54 (5.9)	11 (1.5)	20 (3.2)	23 (3.2)
North	2011	2	25 (3.9)	24 (5.4)	6 (1.7)	6 (2.2)	13 (3.0)
	$\bar{x}$		*39 (2.0)*	*40 (4.8)*	*9 (1.2)*	*9 (2.1)*	*22 (3.4)*
South	2008	1	35 (2.0)	33 (3.0)	10 (1.2)	10 (1.4)	14 (1.6)
South	2008	2	32 (2.2)	37 (4.3)	6 (1.1)	11 (2.1)	20 (2.6)
South	2009	1	35 (1.5)	36 (6.3)	5 (0.6)	11 (2.6)	19 (4.2)
South	2009	2	33 (2.5)	28 (4.9)	1 (0.1)	4 (1.3)	24 (4.6)
South	2010	1	32 (1.1)	34 (2.4)	5 (0.5)	11 (1.2)	18 (2.2)
South	2010	2	38 (2.4)	54 (6.8)	1 (0.3)	8 (1.6)	45 (6.2)
South	2011	1	35 (1.9)	51 (4.1)	7 (0.8)	25 (2.6)	19 (2.1)
	$\bar{x}$		*34 (2.0)*	*39 (4.6)*	*5 (0.7)*	*11 (1.8)*	*23 (3.4)*

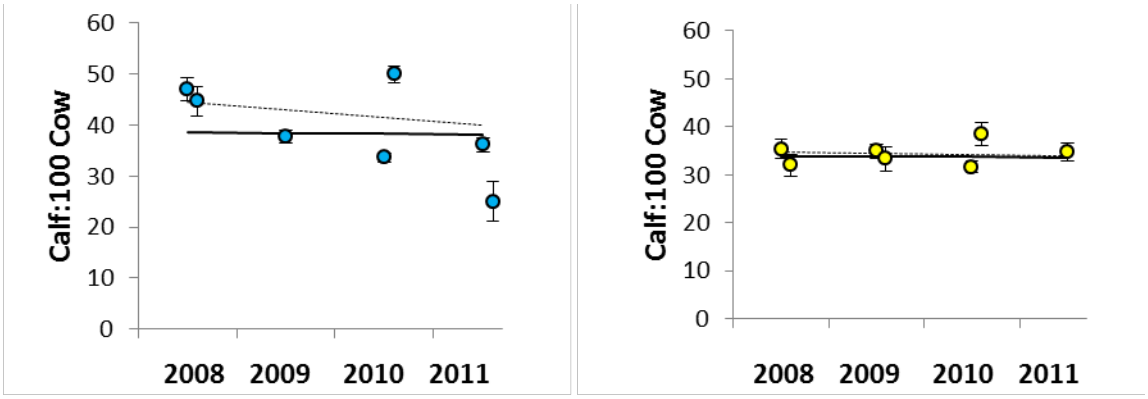


Figure 11. Trends in ratios of calves:100 cows in the North Rainier TCA (at left) and South Rainier TCA (at right), 2008-2011. Point estimates from surveys are shown with error bars representing ± 1 standard error. In each graph, the flat solid line represents the estimated trend, which in all cases has a slope of zero. The dashed line represents the unweighted linear relationship between year and calf:cow ratios estimated from the survey with the greatest number of elk classified each year.

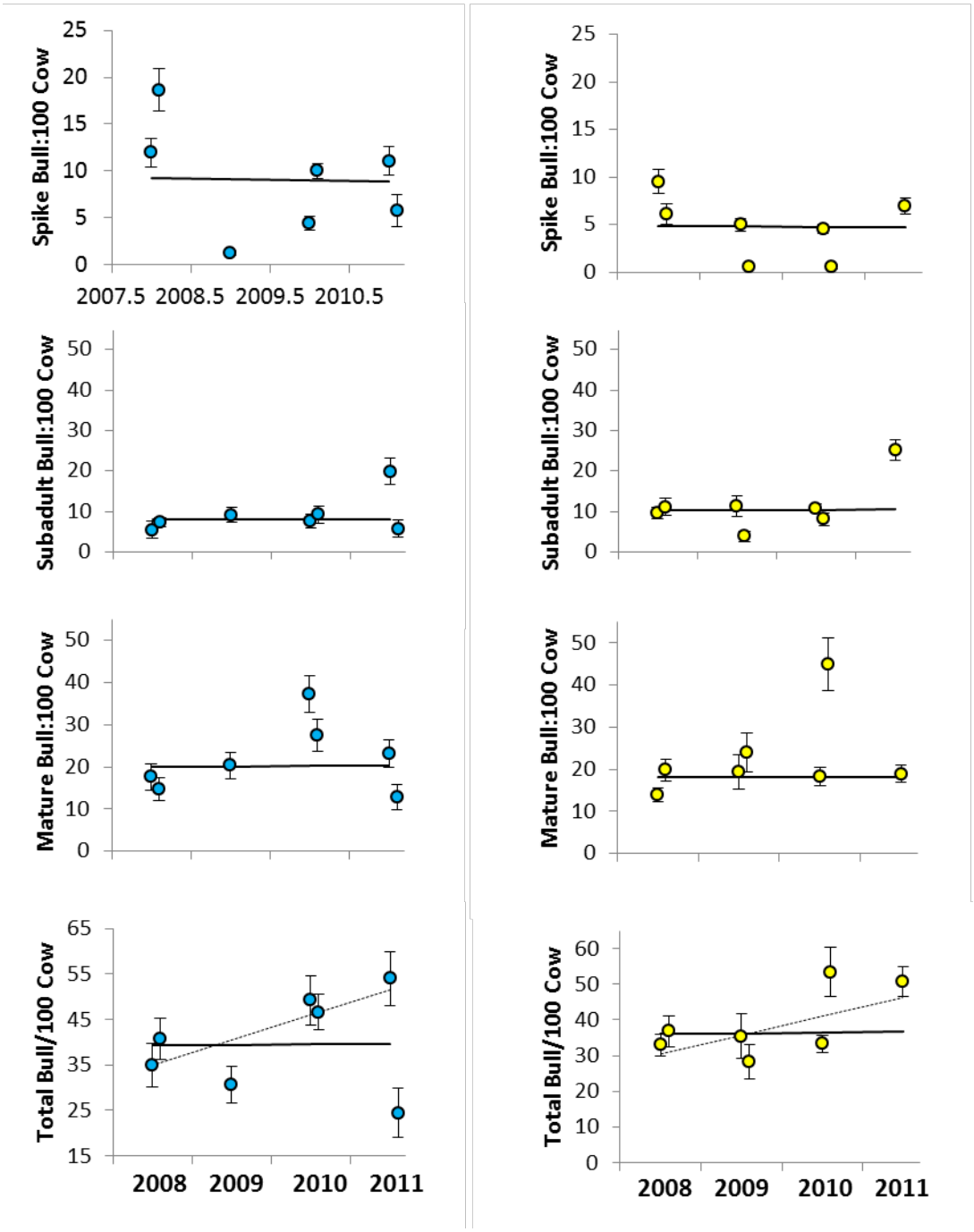


Figure 12. Trends in the ratios of bulls:100 cows in the North Rainier TCA (at left) and South Rainier TCA (at right), 2008-2011. Point estimates from surveys are shown with error bars representing ± 1 standard error. In each graph, the flat solid line represents the estimated trend, which in all cases has a slope of zero. In the graphs for Total Bulls (bottom graph of each panel), the dashed line represents the unweighted linear relationship between year and bull:cow ratios estimated from the survey with the greatest number of elk classified each year.

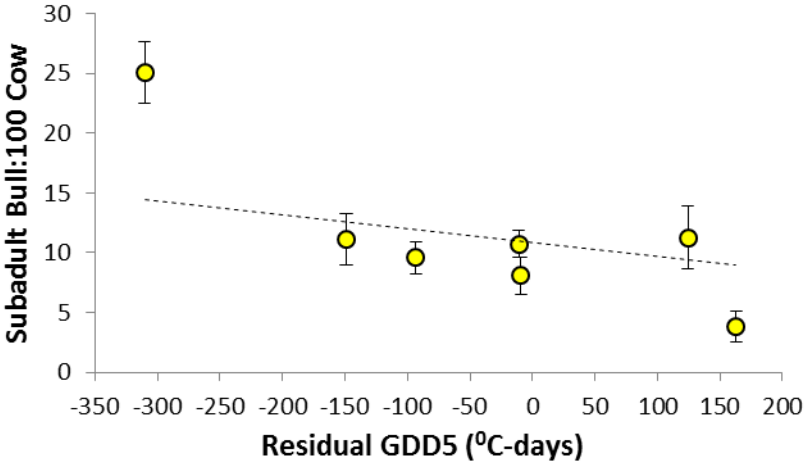


Figure 13. Model-averaged effect of residual growing degree-days (Residual GDD5) on the subadult bull:100 cow ratio for the South Rainier TCA, 2008-2011. Residual GDD5 is the difference between the cumulative number of growing degree-days (above 5°C) assessed from the time of snow melt to the survey date and the predicted average for that date. The dashed line represents the model-averaged trend based on median values of all model covariates except Residual GDD5. Point estimates from surveys are shown with error bars representing ± 1 standard error.

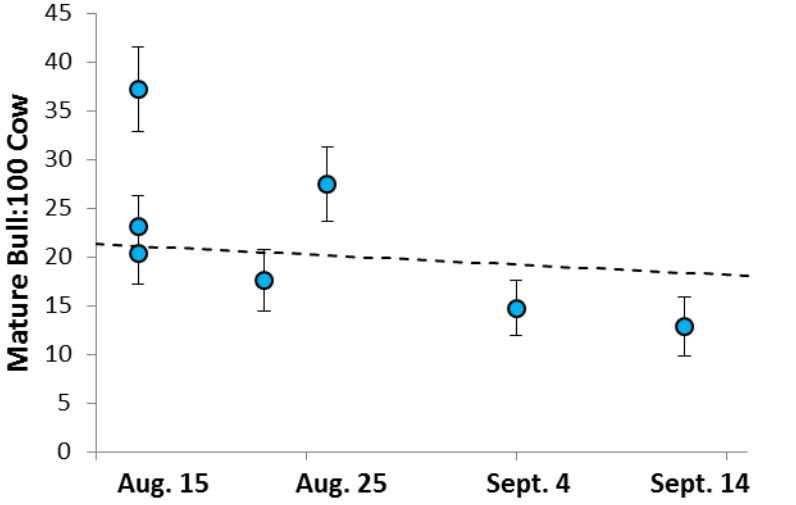


Figure 14. Model-averaged effect of Julian date on the mature bull:100 cow ratio for North Rainier TCA, 2008-2011. Estimated mature bulls: 100 cows ratios are plotted with respect to Julian date (x-axis; August 15=Julian date 227). The dashed line represents the model-averaged trend based on median values of all model covariates except Julian date. Point estimates from surveys are shown with error bars representing ± 1 standard error.

As in the case of examining trends in abundance, we also evaluated possible trends in calf:cow ratios or in total bull:cow ratios derived from the 'best' surveys each year; i.e., those with the highest numbers of elk classified in a given year (Figures 11,12). Slopes of the unweighted trend lines, as fit through calf:100 cow ratios from each year's 'best' survey, were statistically indistinguishable from

zero (Figure 11 dashed lines; North Rainier TCA: slope=-1.5, SE=3.37, *P*=0.70; South Rainier TCA: slope=-0.3, SE=0.794, *P*=0.74). The slopes of the unweighted trend lines fit through total bull:100 cow ratios from each year's best survey were positive (Figure 12 dashed lines), but not statistically significant (North Rainier TCA slope=5.5, SE=3.65, *P*=0.271; South Rainier TCA slope=5.2, SE=2.79, *P*=0.203).

For historical context, we also examined trends in the ratios of calves:100 cows and total bulls:100 cows based on raw counts obtained during the 'best' survey each year (i.e., the survey with the greatest number of elk classified; Figure 15). Unadjusted estimates of bull:100 cow ratios in the North Rainier TCA tended to be greater during 2008-11 (mean=38.2, SE=12.0) than during 1992-2007 (mean=31.2, SE 7.0), although the difference was not significant (*t*=1.55, *P*=0.13). Unadjusted bull:100 cow ratios in the South Rainier TCA, however, tended to be lower during 2008-11 (mean=34.9, SE=7.4) than during 1999-2007 (mean=45.9 (SE=9.8); *t*=1.83, *P*=0.11). Unadjusted calf:100 cow ratios did not differ from 2008-11 and the earlier interval in either the North Rainier or South Rainier TCAs (North TCA: *t*=-0.08, *P*=0.94; South TCA: *t*=0.26, *P*=0.80). In the North Rainier TCA, however, calf:100 cow ratios may have decreased during the 1990s and increased during the 2000s (Figure 15). With the exception of a particularly high count obtained in 2007, calf:100 cow ratios have remained relatively constant since the 2000s. Bull: 100 cow ratios appear to have decreased during the 1990s and have increased since 2000. In the South Rainier TCA, calf:100 cow ratios have been constant for several years, while bull:100 cow ratios have been highly variable (Figure 15). There was no discernable difference between calf:100 cow ratios estimated from the raw counts versus the DO-S models from 2008-2011, but that bull:100 cow ratios were consistently higher for ratios estimated from the DO-S models than for those estimated from raw counts (Figure 15).

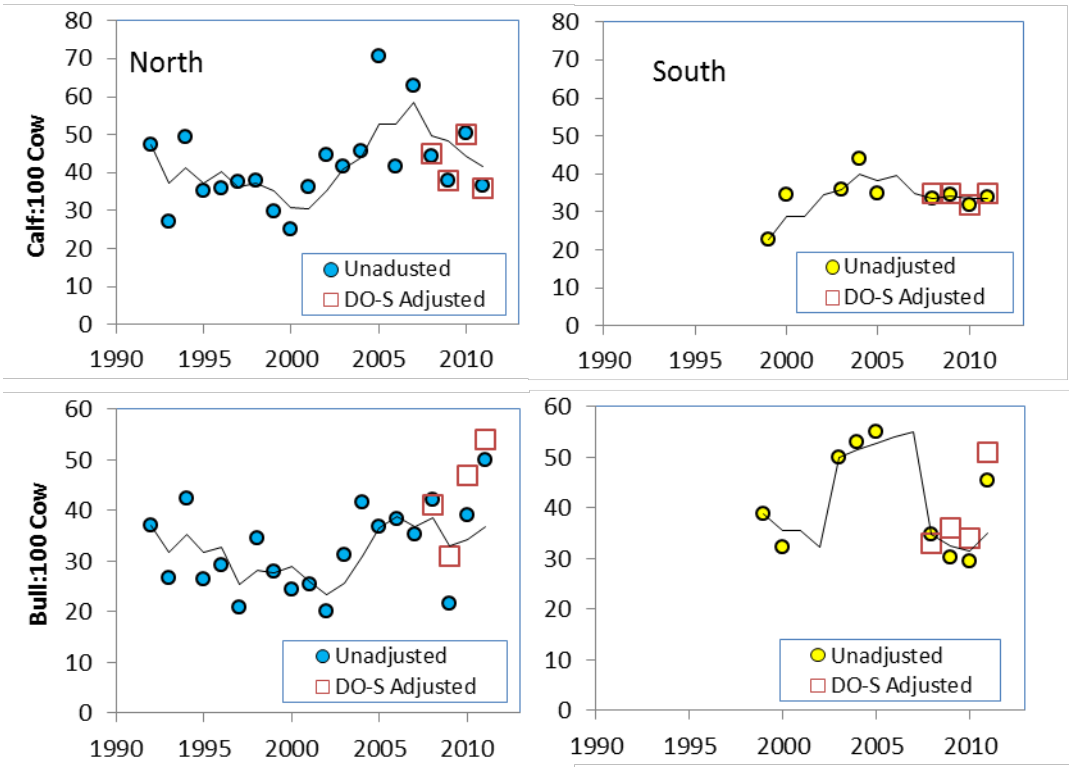


Figure 15. Trends in calf:100 cow and bull:100 cow ratios for the North and South Rainier TCAs, 1992-2011. The lines are 3-year averages of unadjusted ratios fit through the unadjusted composition ratios derived from raw numbers of elk counted (closed circles). Ratios estimated based on application of the DO-S models (open red boxes) are shown for comparison.

Statistical Power of Future Mount Rainier NP Surveys

Based on the abundance of elk and associated variances estimated for 2008-2011 and the simulated values for 2012 – 2015, statistical power of the existing survey schedule is adequate (>0.80) to detect positive growth in the South Rainier TCA as low as +1% per year, sustained over the 4-year period from 2012 -2015 (Figure 16). Growth less than ~1% annually would be detected with less certainty because such low annual growth differs from the observed positive annual growth reported for South Rainier TCA from 2008-11, and would tend to reduce the rate of growth measured over 8 years.

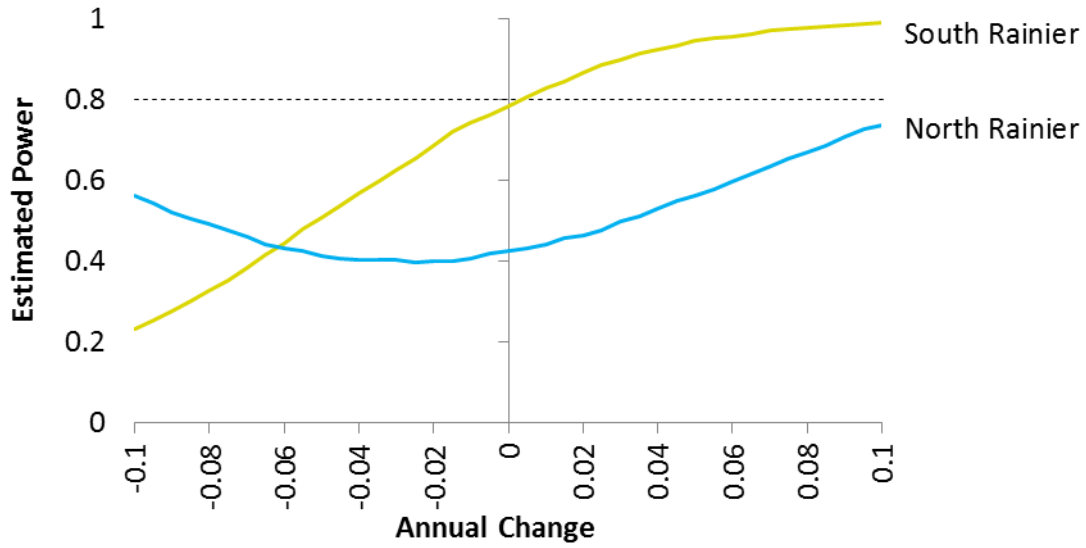


Figure 16. Estimated power to detect a statistically significant, non-zero trend from four more years of aerial surveys (2012 – 2015) in the North Rainier (yellow line) and South Rainier (green line) TCAs, given the abundance values estimated from 2008-2011 surveys, and stochastic simulations of future abundance and survey results. Power is a function of the annual proportional change in elk abundance (x-axis); the annual change shown here is percent change divided by 100.

Spatial Distribution of Elk on Summer Ranges

There was sizable variation in estimated elk densities among survey units in the North Rainier TCA (Figure 17) and South Rainier TCA (Figure 18). No elk were recorded in units N2, N3b, N5b, N16a, or S1 during any survey. Conversely, average elk densities were >10 elk / km^2 in units N12a, N17, and S11. Average elk density at the survey unit level is a function of both the estimated number of elk and the area of the survey unit. The estimated density maps provide some indication of the relative concentration of elk in both TCAs.

During 2008-2011, the average estimated density in the North Rainier TCA was 3.5 elk/ km^2, and in the South Rainier TCA it was 5.6 elk/ km^2. We also computed mean relative density in each survey unit as the mean density of a survey unit divided by the mean density of the TCA. If a survey unit's relative density was >1, that result signified that the unit's estimated density was greater than the elk density in the TCA as a whole. Very few survey units exhibited a statistically significant change in relative elk density over the 2008-2011 time period (Table 11). Units N4, N16b, and S10 all appeared to have declining proportions of elk over this time period. Unit N4 had relative density values of 1.5 and 2.2 in the 2008 replicate surveys, but values of 0 and 0.7 in 2011. Unit N16b had a relative density value of 0.4 in 2008, which subsequently declined. Unit S10 had high relative density values of 2.1 in 2008, but had relative density of 1.0 in 2011.

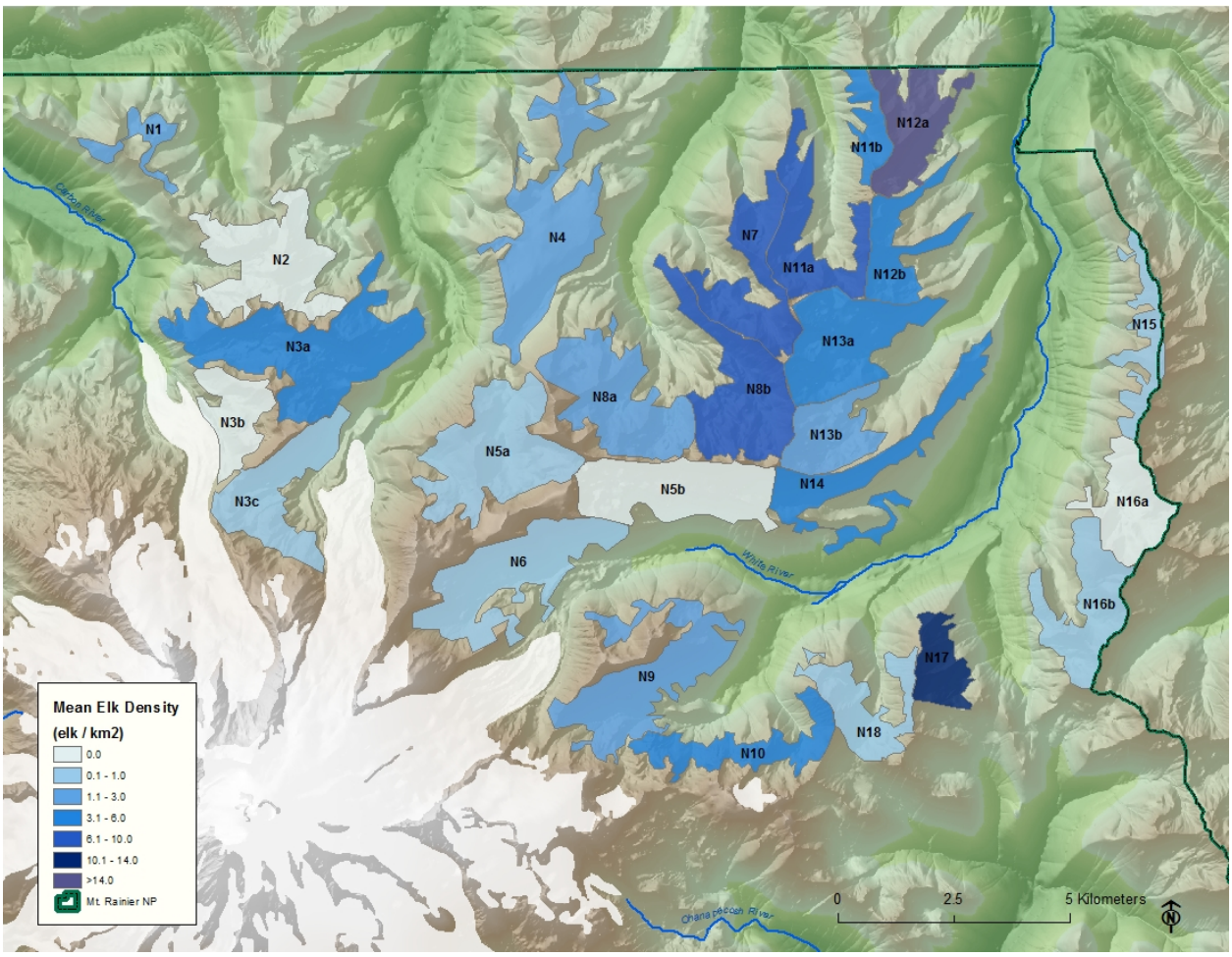


Figure 17. Mean estimated elk density (elk / km^2) in each survey unit of the North Rainier TCA based on seven surveys from 2008-2011.

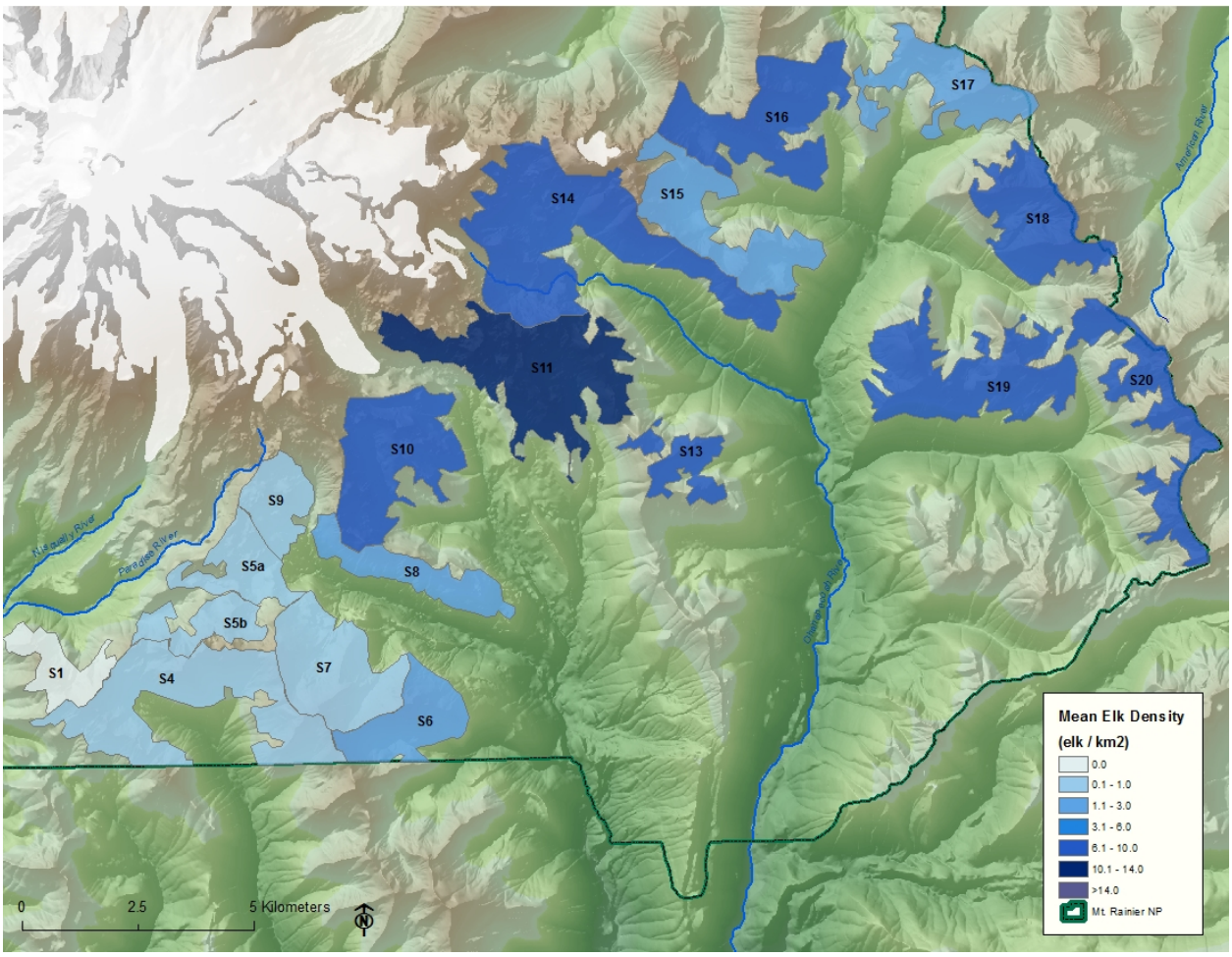


Figure 18. Mean estimated elk density (elk / km^2) in each survey unit of the South Rainier TCA based on seven surveys from 2008-2011.

Table 11. Trends in the relative density of elk in Mount Rainier NP survey units in the North Rainier TCA (unit name preceded by 'N') and South Rainier TCA (unit name preceded by 'S'), 2008-2011. For each survey unit, the area, number of surveys completed, and the mean abundance, $\widehat{N}$, mean density (in elk per km^2), and mean relative density are also listed for each survey unit. Units with relative density below 1 have less than the average density, and units with relative density above 1 have greater than average density. The slope in relative density (and SE) describes the linear relationship between relative densities over time (2008-11). Bold font signifies that trends in mean relative density were significant (P<0.10).

Survey unit	Area (km^2)	No. Surveys	Mean $\widehat{N}$	Var($\widehat{N}$)	Mean Density (elk/km^2)	Mean Relative Density[1]	Slope, Relative Density	SE (Slope)	P (Slope)
N1	1.04	7	2.76	6.18	2.65	0.72	-0.82	0.47	0.19
N2	5.08	7	0.00	0.00	0.00	0.00	0.00	0.00	--
N3a	7.83	7	24.20	59.78	3.09	0.89	-0.25	0.23	0.33
N3b	2.30	7	0.00	0.00	0.00	0.00	0.00	0.00	--
N3c	4.03	7	0.65	0.11	0.16	0.05	0.03	0.02	0.18
N4	6.68	7	14.88	65.66	2.23	0.65	**-0.50**	**0.22**	**0.07**
N5a	6.21	6	0.65	0.43	0.11	0.03	-0.02	0.02	0.50
N5b	5.11	6	0.00	0.00	0.00	0.00	0.00	0.00	--
N6	5.67	6	4.17	2.35	0.74	0.19	-0.08	0.06	0.25
N7	3.93	7	31.27	110.24	7.96	2.18	0.25	0.68	0.73
N8a	5.44	7	15.80	68.84	2.90	0.77	0.03	0.36	0.93
N8b	5.12	7	42.03	338.11	8.21	2.38	0.68	1.02	0.54
N9	5.71	6	11.97	7.51	2.10	0.59	-0.02	0.13	0.90
N10	2.90	6	9.57	9.50	3.30	0.94	0.22	0.32	0.54
N11a	3.64	7	26.09	119.01	7.17	2.02	1.26	0.65	0.11
N11b	1.35	6	4.33	18.73	3.21	1.07	-1.17	0.91	0.27
N12a	3.30	7	86.86	443.79	26.30	6.96	-0.38	1.43	0.80
N12b	2.54	7	9.88	44.77	3.89	0.96	0.53	0.54	0.37
N13a	4.90	7	25.71	46.55	5.25	1.54	0.28	0.39	0.51
N13b	2.68	7	5.65	7.96	2.11	0.59	-0.27	0.24	0.30
N14	3.84	6	12.71	7.29	3.31	0.94	-0.15	0.17	0.44
N15	2.19	6	0.26	0.07	0.12	0.04	0.04	0.04	0.32
N16a	3.13	6	0.00	0.00	0.00	0.00	0.00	0.00	--

[1] Mean relative density was computed as elk density in the survey unit divided by average elk density in the TCA.

Table 11. Trends in the relative density of elk in Mount Rainier NP survey units in the North Rainier TCA (unit name preceded by 'N') and South Rainier TCA (unit name preceded by 'S'), 2008-2011. For each survey unit, the area, number of surveys completed, and the mean abundance, $\widehat{N}$, mean density (in elk per km^2), and mean relative density are also listed for each survey unit. Units with relative density below 1 have less than the average density, and units with relative density above 1 have greater than average density. The slope in relative density (and SE) describes the linear relationship between relative densities over time (2008-11). Bold font signifies that trends in mean relative density were significant (P<0.10) (continued).

Survey unit	Area (km^2)	No. Surveys	Mean $\widehat{N}$	Var($\widehat{N}$)	Mean Density (elk/km^2)	Mean Relative Density[1]	Slope, Relative Density	SE (Slope)	P (Slope)
N16b	3.89	5	2.16	1.40	0.55	0.14	**-0.15**	**0.04**	**0.02**
N17	1.86	6	24.02	45.13	12.91	3.48	1.01	0.83	0.29
N18	2.83	6	2.31	1.68	0.81	0.21	0.12	0.10	0.28
S1	2.10	6	0.00	0.00	0.00	0.00	0.00	0.00	--
S4	8.48	7	0.86	0.31	0.10	0.02	0.02	0.01	0.14
S5a	2.44	7	0.80	0.64	0.33	0.06	-0.08	0.06	0.24
S5b	2.15	6	0.74	0.55	0.34	0.07	0.11	0.08	0.26
S6	3.35	7	8.69	7.59	2.59	0.51	0.18	0.16	0.31
S7	5.36	7	2.02	1.03	0.38	0.09	-0.01	0.05	0.86
S8	3.00	7	8.28	12.24	2.76	0.54	-0.28	0.18	0.20
S9	2.29	6	1.00	0.52	0.44	0.08	0.06	0.07	0.43
S10	6.11	7	54.48	11.05	8.92	1.75	**-0.36**	**0.11**	**0.02**
S11	8.65	7	95.87	293.60	11.08	2.03	-0.21	0.27	0.48
S13	1.87	7	13.01	29.00	6.96	1.21	-0.29	0.47	0.57
S14	11.33	7	102.95	207.63	9.09	1.69	0.11	0.17	0.55
S15	5.30	7	14.69	19.78	2.77	0.51	>0.01	0.14	0.98
S16	6.36	7	42.07	53.89	6.61	1.16	-0.13	0.15	0.44
S17	4.08	7	12.39	32.78	3.03	0.48	0.06	0.19	0.78
S18	4.76	7	34.56	179.79	7.26	1.11	0.39	0.33	0.30
S19	6.98	7	55.92	118.70	8.01	1.45	0.30	0.17	0.14
S20	4.70	5	41.02	163.39	8.73	1.66	0.12	0.29	0.70

[1] Mean relative density was computed as elk density in the survey unit divided by average elk density in the TCA.

Olympic NP—Summer Range Surveys

Survey Summaries

Survey objectives were to fly the Core TCA and one of the alternate TCAs each summer from 2008-2011. During 2008, we completed a survey of the Core TCA, and a partial survey of the Northwest TCA (Table 12). It became clear during the 2008 surveys that additional reconnaissance of the Elwha TCA and Quinault TCA was needed to finalize the survey boundaries so we also flew these additional surveillance flights. Because these surveys resulted in incomplete counts, they are not reported here. During 2009, surveys were curtailed due to a combination of poor weather and conflict with aerial capture operations. During 2010, survey flights were cancelled as there was no helicopter available due to a serious helicopter accident elsewhere. In 2011 we completed a survey of the Core TCA, and then focused all additional flights in subunits where we had functional radiocollars for DO-S trials. Because many collared elk were in the Northwest TCA, we repeated a survey of that TCA to acquire DO-S trials. Additionally, we completed a partial survey of the Quinault TCA to obtain additional DO-S trials (Table 12).

Double-Observer Sightability Model

We placed 10 GPS collars on elk in 2008, 10 GPS and 10 VHF collars on elk in 2009, and 18 GPS collars on elk in 2010. We recorded 14 DO-S trials and 99 DO trials in Olympic NP from 2008-11. This was less than projected due to manufacturing defects in two batches of GPS radiocollars that caused mass telemetry failures. Because of this we did not complete the development of a DO-S model for Olympic NP and were unable to complete counts of two TCAs per year (core and non-core until 2012. Further, we continued to collect DO and DO-S data for two additional summer survey years in 2012 and 2013. At the conclusion of the 2013 surveys, we completed gathering data associated with the DO-S and DO trials, with a total of 45 usable DO-S and 213 DO trials.

Table 12. Flight summary statistics for complete surveys conducted in Olympic NP, 2008-2011. We list only surveys in which the entire TCA or identifiable TCA units were surveyed. Partial reconnaissance surveys completed in 2008 are not reported. Shown for each replicate survey are TCA name, year, survey dates, replicate number (Rep), omitted survey units, flight duration in minutes, survey duration in minutes, survey intensity in km^2/min, the area surveyed in km^2, and the percentage of the total TCA surveyed (% of TCA).

TCA	Year	Survey Dates	Rep	Survey Units Omitted	Flight Duration (min)[1]	Survey Duration (min)[2]	Survey Intensity (km^2/min)[2]	Area surveyed, (km^2)	% of TCA
Core	2008	9/2/2008 to 9/4/2008	1	none		295	0.34	100.2	100.0
Northwest	2008	9/3/2008 to 9/4/2008	1	NW1, NW2		142	0.29	41.7	57.4
Core	2011	9/7/2011 to 9/8/2011	1	none	492	247	0.41	100.2	100.0
Northwest	2011	9/6/2011	1	none	236	156	0.47	72.7	100.0
Quinault	2011	9/9/2011	1	Q1a,b, Q2a,b,c	233	80	0.44	35.5	44.7

[1] Total flight time associated with surveys of the Core and Northwest TCA could not be determined in 2008.

[2] Survey duration and intensity included time surveying for elk and also time required to count and classify elk in each observed elk group. Consequently, the estimated survey intensity included both search time and time required to count and classify.

Raw Counts and Composition of Elk Seen

During two surveys in the Core TCA, survey crews recorded 237-263 elk. Ratios of calves:100 cows ranged from about 29-38 and ratios of all bulls:100 cows ranged from 56-63 (Table 13). In the Quinault TCA we recorded 29 calves:100 cows and 44 bulls:100 cows.

Averaged among two survey years, the greatest proportional concentration of elk was observed in the Core TCA, particularly in the Kimta Peak Unit (C7) and the western flank of Mount Olympus (Units C2-C5; Figure 19). With only two years of data, density appeared to be lower in the Northwest than in the Core TCA overall, although density was comparable on the south side of High Divide in Northwest Unit 5a and in the Kimta Peak area in Core Unit C7 (Figures 19-20).

Table 13. Olympic NP counts by TCA: Year, number of units surveyed (units), percent of the total TCA area surveyed (% Survey), the total number of elk counted (Count), number of cows counted, calves per 100 cows (Calf:cow), spike bulls per 100 cows (Spike Bull:cow), subadult bulls per 100 cows (Subadult Bull:Cow), mature bulls:100 cows (Mature Bull:cow), and total bulls:100 cows (Total Bull:cow).

Year	TCA	Units	Survey Area %	Count	Cows	Calf: Cow	Spike: Cow	Subadult Bull: Cow	Mature Bull: Cow	Total Bull: Cow
2008	Core	10	100.0	263	138	37.7	5.1	5.1	52.9	63.0
2008	Northwest	6	57.4	83	52	34.7	5.8	1.9	19.2	26.9
2011	Core	10	100.0	237	133	29.3	6.0	9.0	41.4	56.4
2011	Northwest	8	100.0	18	8	12.5	12.5	0.0	87.5	100.0
2011	Quinault	3	44.7	169	98	28.6	0.0	12.2	31.6	43.9

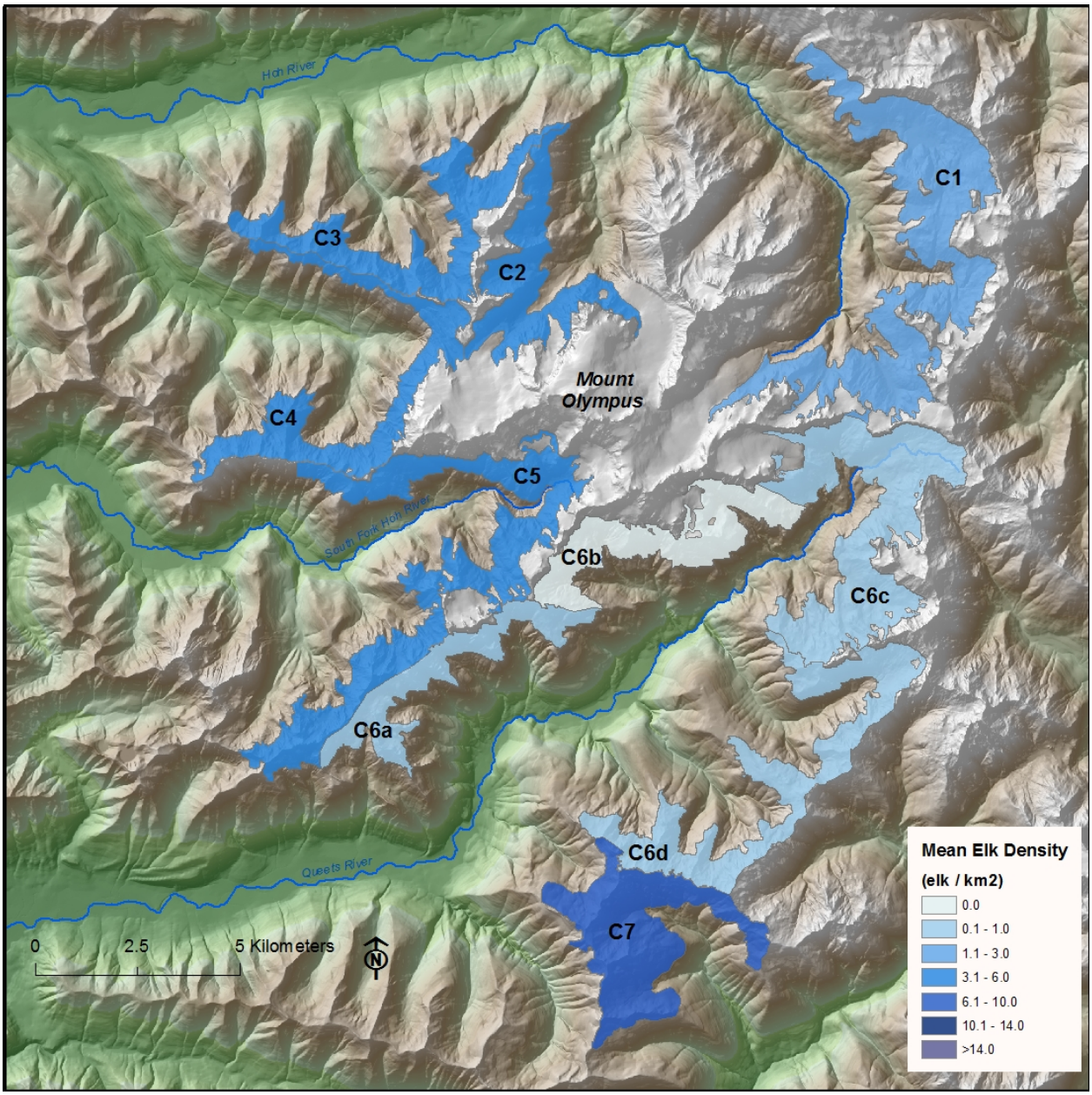


Figure 19. Mean estimated elk density (elk / km^2) in each survey unit of the Core TCA in Olympic NP based on two surveys from 2008-2011.

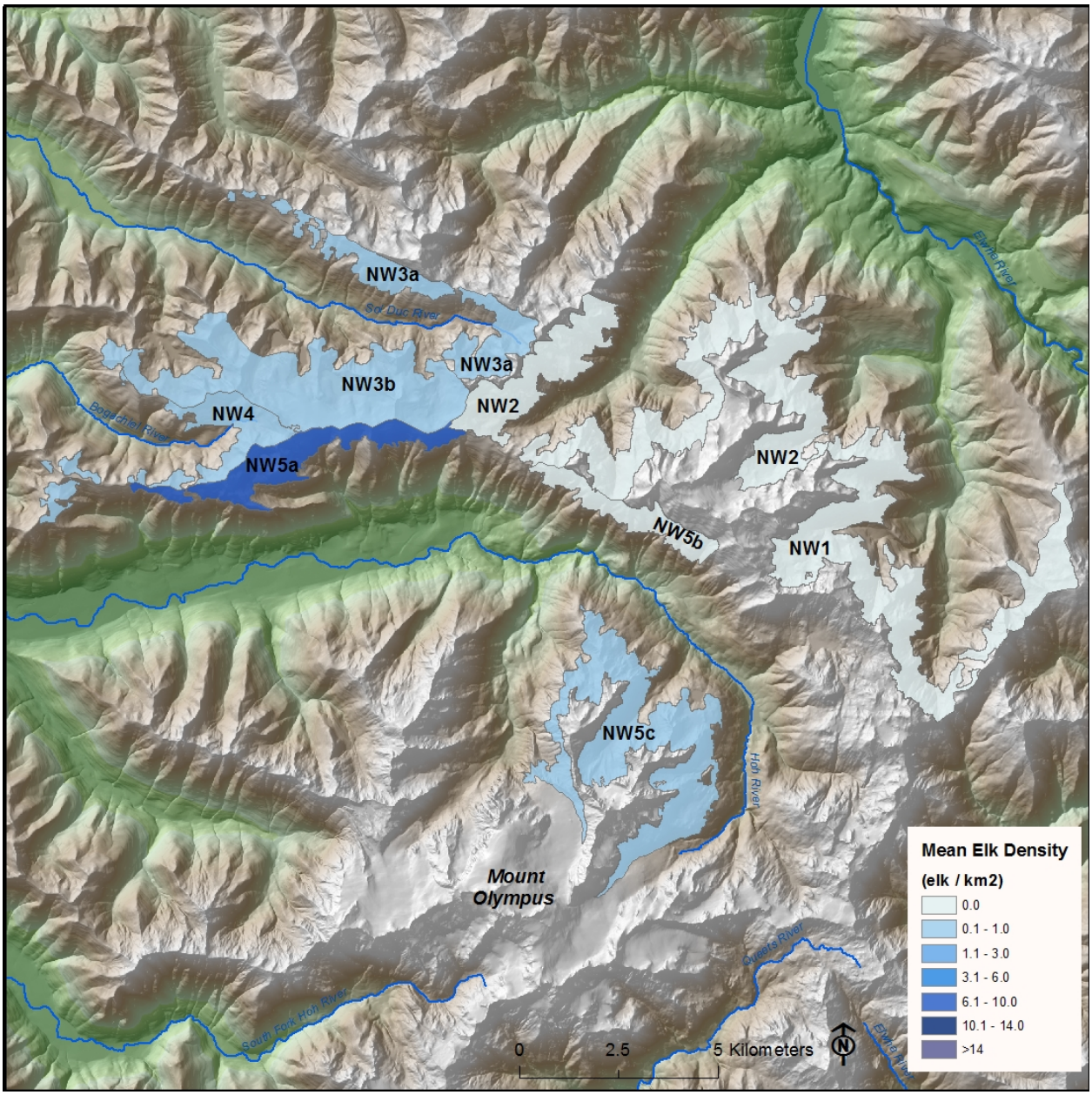


Figure 20. Mean estimated elk density (elk / km^2) in each survey unit of the Northwest TCA in Olympic NP based on two surveys from 2008-2011 (except units NW1 and NW2, which were sampled only once).

Olympic NP—Early-spring Surveys

Survey Summaries

From 1985 -2010, 16 replicate surveys were completed in the Hoh TCA, 17 replicate surveys in the South Fork Hoh TCA, and 15 replicate surveys in the Queets TCA (Table 14). The number of elk counted ranged from 124-242, 24-130 and 134-333 in the Hoh, South Fork Hoh and Queets TCAs, respectively.

Table 14. Summary of early-spring elk surveys in Olympic NP, 1985-2010 in the Hoh, South Fork Hoh, and Queets TCAs. Each survey is listed by date, replicate number (Rep), the time when the survey crew first arrived at the trend count area (Start), and the number of elk counted in the TCA (Count).

Hoh				South Fork Hoh				Queets			
Date	Rep	Start	Count	Date	Rep	Start	Count	Date	Rep	Start	Count
3/19/1985	1	6:55	174	3/21/1985	1	6:50	90	3/20/1985	1	6:50	261
3/25/1985	2	6:58	144	4/1/1985	2	6:49	123	3/29/1985	2	6:47	163
4/4/1985	3	6:45	186	4/12/1985	3	6:20	130	4/13/1985	3	6:17	250
3/17/1986	1	6:55	211	3/20/1986	1	6:41	104	3/22/1986	1	6:44	262
3/25/1986	2	6:54	222	3/23/1986	2	6:46	45	3/29/1986	2	6:33	215
4/2/1986	3	6:46	185	3/31/1986	3	6:41	87	4/3/1986	3	6:47	224
3/30/1988	1	6:34	214	3/19/1987	1	6:44	72	3/25/1987	1	6:25	339
4/8/1991	1	7:30	209	3/28/1988	1	6:41	101	3/31/1988	1	6:32	298
3/11/1998	1	7:04	156	3/22/1991	1	6:35	88	3/16/1998	1	7:03	229
3/18/1998	2	6:44	179	3/14/1998	1	6:41	69	3/21/1998	2	6:38	257
3/24/1998	3	6:41	242	3/19/1998	2	6:44	47	3/30/1998	3	6:24	333
3/28/2004	1	6:55	144	3/23/1998	3	6:32	53	3/29/2007	1	7:19	204
3/31/2004	2	6:27	167	3/21/2006	1	6:34	54	3/30/2007	2	7:17	199
3/30/2008	1	7:16	124	3/27/2006	2	6:29	75	3/22/2008	1	7:37	134
3/26/2009	1	7:21	188	3/29/2006	3	6:15	35	3/24/2010	1	6:13	153
3/20/2010	1	6:25	137	3/21/2008	1	9:14	24				
				3/19/2010	1	6:28	27				

Trends in Elk Counts

There was strong support for models that included a temporal trend in the numbers of elk counted in early-spring surveys in Olympic NP (Table 15). Models with a Time effect had a total of 74% of the model weight in the Hoh TCA, >99% in the South Fork Hoh TCA, and 69% in the Queets TCA.

In all three TCAs, there were statistically significant negative trends in the counts of elk seen during early-spring surveys from 1985-2010 (Figures 21-23). As a function of Time, the slopes of the trends in the natural-log transformed number of elk counted were -0.0079 in the Hoh TCA (SE = 0.004; P = 0.036), -0.0395 in the South Fork Hoh TCA (SE = 0.009, P <0.001), and -0.0102 in the Queets TCA

(SE = 0.005, $P = 0.045$). Counts in the South Fork Hoh diminished by about 63% from 1985-2010, whereas counts in the Hoh and Queets valleys diminished by about 18 and 22%, respectively.

Table 15. Candidate linear regression models of factors affecting counts of elk seen in the Hoh, South Fork Hoh, and Queets TCAs during early-spring surveys, 1985-2010, and associated ΔAIC_c and model weights (wk). The models with the greatest support are shown in bold font. Residual GDD40 is the difference between the cumulative number of growing degree-days (above 40°F) assessed from 1 February to the survey date and the predicted average for the survey date.

		Hoh		SF Hoh		Queets	
	Description	**ΔAIC_c**	**w_k**	**ΔAIC_c**	**w_k**	**ΔAIC_c**	**w_k**
M0.	Intercept only (Null Model)	2.55	0.10	12.93	0.00	2.74	0.06
M1.	Time	1.11	0.20	**0.00**	**0.35**	1.44	0.12
M2.	Time + Julian	4.65	0.03	1.64	0.15	5.23	0.02
M3.	Time + Residual GDD40	**0.00**	**0.35**	1.21	0.19	**0.00**	**0.25**
M4.	Time + Minimum Temperature	3.88	0.05	1.59	0.16	0.50	0.20
M5.	Time + Julian Date + Residual GDD40	3.87	0.05	4.83	0.03	4.64	0.03
M6.	Time + Julian Date + Minimum Temperature	7.18	0.01	3.68	0.06	4.82	0.02
M7.	Time + Julian Date + Residual GDD40 + Minimum Temperature	9.20	<0.01	7.89	0.01	9.11	<0.01
M8.	Time + Residual GDD40 + Minimum Temperature	4.15	0.04	3.61	0.06	3.32	0.05
M9.	Julian Date	5.44	0.02	12.22	<0.01	5.76	0.01
M10.	Residual GDD40	3.52	0.06	15.15	<0.01	4.15	0.03
M11.	Minimum Temperature	4.43	0.04	12.59	<0.01	1.14	0.14
M12.	Julian Date + Residual GDD40	6.67	0.01	15.71	<0.01	7.47	0.01
M13.	Julian Date + Minimum Temperature	6.45	0.01	12.41	<0.01	4.96	0.02
M14.	Julian Date + Residual GDD40 + Minimum Temperature	10.19	<0.01	16.51	<0.01	9.53	<0.01
M15.	Residual GDD40 + Minimum Temperature	7.03	0.01	15.46	<0.01	4.88	0.02

The slopes of the regression for the three early-spring TCAs are the expected exponential rate of growth (or decline) of the unadjusted counts (i.e., no correction for detection biases).After exponentiating from base e, the expected finite annual growth rates for the counts (λ, lambda), were 0.992 (about 1% annual decline) in the Hoh TCA (Figure 21), 0.961 (about 4% annual decline) in the South Fork Hoh TCA (Figure 22), and 0.990 (1% annual decline) in the Queets TCA (Figure 23). The model-averaged equations for the predicted value of the natural-log transformed counts were as follows:

Hoh ln(elk counted) = 5.170 –(0.0079*Time) + (0.0006*Julian) + (0.0005*Residual GDD40) + (0.0012*Minimum Temperature) (Equation 9)

South Fork Hoh ln(elk counted) = 4.0288 – (0.0395*Time) + (0.0037*Julian) – (0.0004*Residual GDD40) + (0.0057*Minimum Temperature) (Equation 10)

Queets ln(elk counted) = 5.095 – (0.0102*Time) – (4.96E-06*Julian) + (0.0005*Residual GDD40) + (0.0111*Minimum Temperature). (Equation 11)

The coefficients for covariates in the model-averaged equations indicate the effects of those covariates on elk counts (log scale). In addition to the negative effect of time, all three models predicted a positive effect of either Julian date or residual GDD40 on the observed counts and all three models predicted a small positive effect of minimum temperature. The evidence ratio in support of including residual GDD40 in the model ranged from 40% in the South Fork Hoh (negative effect) to 114% in the Hoh Valley (positive effect). Evidence for including a positive effect of minimum temperature ranged from 0.21-0.65. Evidence for a positive effect of Julian date ranged from 0.12 in the Hoh to 0.27 in the South Fork Hoh.

We also examined the relative evidence for temporal trends within 2 or 3 longitudinal sections of each TCA (Table 16). Compared to the null model, we discovered the greatest evidence for negative trend in elk counts in the upper section of the Hoh TCA, and both sections of the South Fork Hoh TCA. In the upper Hoh Valley (>15 km from the park boundary), evidence of a temporal trend in elk counts was 3.6 times greater than evidence of no temporal effects, as compared to much less evidence of temporal trend in the lower sections closer to the Park boundary (Table 16). In the South Fork Hoh TCA, evidence of temporal trend was greatest near the park boundary (0-5 km from park boundary; evidence ratio=2.5) and was less in upper reaches of the floodplain (5-15 km from the park boundary (evidence ratio=1.74). Despite the overall negative trend in the Queets TCA, evidence for temporal trends within the individual longitudinal sections of the Queets TCA was less than in segments of the South Fork Hoh TCA and Hoh TCA (evidence ratio=0.73-1.11 in the Queets zones).

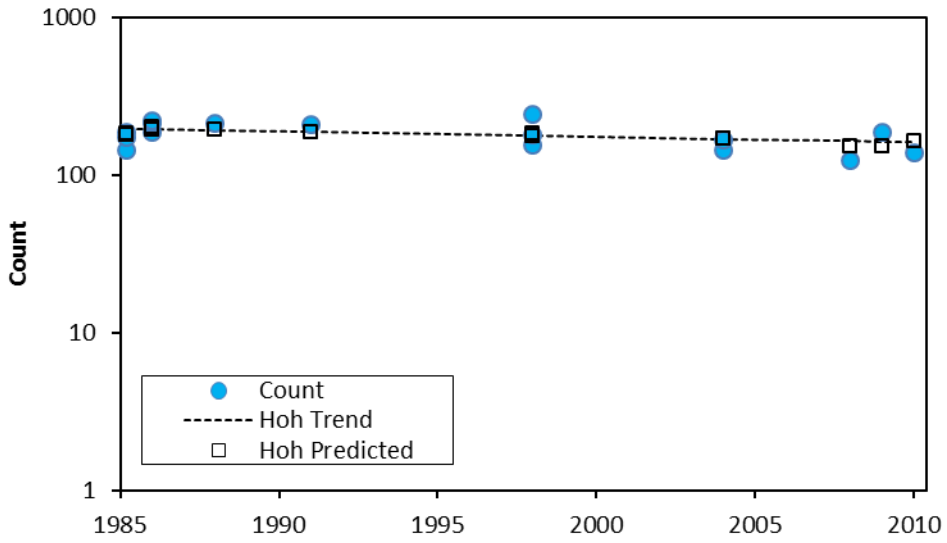


Figure 21. Trends in the number of elk counted during early-spring surveys in the Hoh TCA, 1985-2010 (plotted on a logarithmic scale). The dashed line represents the model-averaged trend based on median values of all model covariates except time. The box symbols represent model-averaged predicted counts based on observed covariate values specific to each survey.

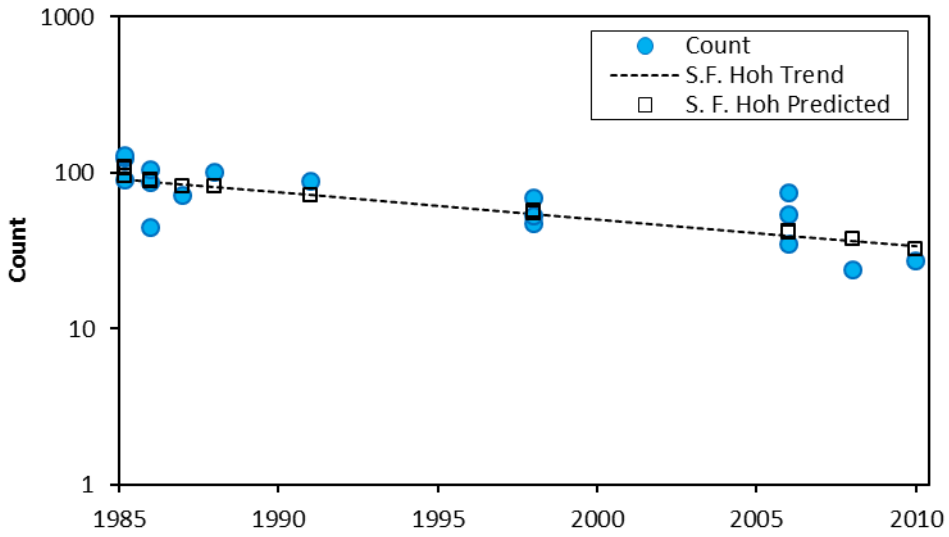


Figure 22. Trends in the number of elk counted during early-spring surveys in the South Fork Hoh TCA, 1985-2010 (plotted on a logarithmic scale). The dashed line represents the model-averaged trend based on median values of all model covariates except time. The box symbols represent model-averaged predicted counts based on observed covariate values specific to each survey.

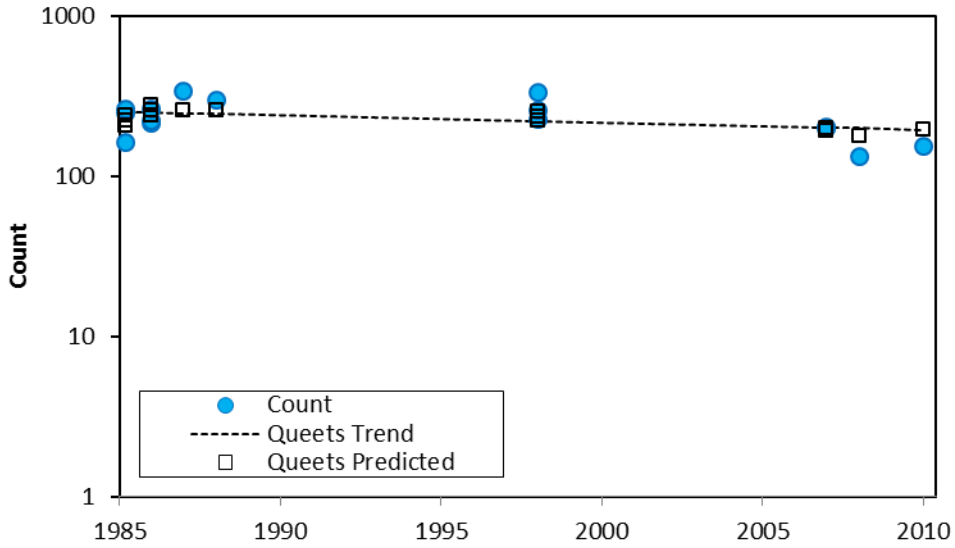


Figure 23. Trends in the number of elk counted during early-spring surveys in the Queets TCA, 1985-2010 (plotted on a logarithmic scale). The dashed line represents the model-averaged trend based on median values of all model covariates except time. The box symbols represent model-averaged predicted counts based on observed covariate values specific to each survey.

Table 16. Evidence ratios (ER) indicating relative support for models including a temporal trend in elk counts within 2-3 longitudinal segments of Hoh, South Fork Hoh (SF Hoh), and Queets TCAs during early-spring surveys, 1985-2010.

TCA	Segment[1]	Model	Description	AIC_C	ΔAIC_c	*w*	Evidence ratio[3]
Hoh	0 - 5 km	M0	Null [2]	3.16	0.00	0.80	
Hoh	0 - 5 km	M1	Time	5.95	2.79	0.20	0.25
Hoh	5 - 15 km	M0	Null [2]	-45.10	0.00	0.82	
Hoh	5 - 15 km	M1	Time	-42.07	3.04	0.18	0.22
Hoh	>15 km	M1	Time	-18.14	0.00	0.78	3.63
Hoh	>15 km	M0	Null [2]	-15.57	2.58	0.22	
Queets	5 - 15 km	M0	Null [2]	-26.08	0.00	0.58	
Queets	5 - 15 km	M1	Time	-25.46	0.62	0.42	0.73
Queets	>15 km	M1	Time	-27.23	0.00	0.53	1.11
Queets	>15 km	M0	Null [2]	-27.01	0.22	0.47	
SF Hoh	0 - 5 km	M1	Time	1.15	0.00	0.72	2.52
SF Hoh	0 - 5 km	MO	Null [2]	2.99	1.84	0.28	
SF Hoh	5 - 15 km	M1	Time	12.21	0.00	0.64	1.74
SF Hoh	5 - 15 km	M0	Null [2]	13.32	1.11	0.36	

[1] Segments displayed in Figure 6

[2] Null model consists of intercept only

[3] Evidence ratio=w_{time}/w_{null}

Discussion

Elk Trends in Mount Rainier NP

Our estimates of trends in elk abundance should be considered preliminary in recognition that four years is a very short time series for trend analyses. The preliminary nature of our findings is supported by the fact that replicated estimates of elk abundance obtained within the same year often varied considerably reflecting random variation associated with estimation, as well as potential effects of local elk movements inside and out of the survey unit boundaries (an effect often referred to as availability bias because not all animals are always available within the survey area (Marsh and Sinclair 1989). Such variation can have a particularly large effect on trend estimation from short time series, particularly if large or small estimates occur in the first or last year of the series. Our power analysis of trends fit through all available survey estimates suggest that an additional four years of data should be sufficient to determine if preliminary trends are sustained and statistically significant.

The preliminary analyses suggested that elk abundance remained stable or increased in both the North and South Rainier TCAs during the 4-year period examined depending on the analysis. Fitting the trend line through all replicated estimates obtained from 2008-11 suggested no trends in abundance of elk summering in either of the TCAs, whereas fitting the trend line to the greatest estimates each year suggested an increase in abundance, particularly in the South Rainier TCA. Even though analysis of trends through the highest estimates produced the strongest evidence of increased numbers of elk on Mount Rainier summer ranges, additional surveys are needed to determine which of the two estimates of trend is most reliable.

Preliminary estimates of elk abundance on the North Rainier TCA and South Rainier TCA were not related strongly to variations in environmental conditions at the time of the surveys. Though we found weak support for the effect of Julian date on estimated abundance in the South Rainier TCA, we found essentially no support for the influence of ambient temperatures during the surveys on the resulting abundance estimates contrary to our *a priori* hypothesis. We suspect that temperature had little effect on survey results because the surveys were conducted over a relatively narrow range of temperatures, but we continue to caution that temperature effects may be important if surveys are conducted during hotter conditions than we examined.

Adjustments made to the raw survey counts by applying the DO-S model increased abundance estimates by an average factor of 1.13 in the North herd and 1.22 in the South herd (Table 7). We believe the DO-S modelling approach, which accounts for the inability of aerial survey crews to see all elk present within the TCAs, is a substantial improvement over the previous method of using a constant multiplier of 2 to account for unseen elk (Bradley 1982). Variability in the proportion of elk migrating each year (33-53%; MIT, unpublished data) suggests that the annual measure of availability bias is not constant and does not justify using the constant multiplier to correct for estimation biases as practiced previously.

Comparisons in trends estimated by MIT and PTOI on corresponding winter ranges of both the North Rainier and South Rainier herds corroborate preliminary trends discerned from the analysis of maximum counts each summer. The abundance of elk during winter on winter ranges of the North

Rainier herd in the White River Valley increased at a rate of approximately 7% annually from 2008-11 (r=0.07, t=0.93, P=0.45; MIT, unpublished data), which is comparable to the 6% annual growth estimated from maximum counts on the summer range of the North Rainier TCA (Figure 8). Similarly, the estimated overwintering elk population of the South Rainier herd in the Cowlitz Valley increased at approximately 22% during the same time interval (WDFW 2013), as compared to 17% on the summer range (based on maximum counts, Figure 7). Although these estimates of growth seem high considering the estimated fall ratios of calves in the population, they both corroborate potential growth in the South Herd TCA. Explanation of these preliminary increases on the winter ranges remain speculative, but may be related to fewer predators on winter range, closed antlerless hunting seasons and improved habitat conditions resulting from logging on private forests (MIT, unpublished data). Corresponding increases in the South herd may also reflect closed antlerless hunting seasons (except by permit) and habitat improvement through thinning of second growth stands on both winter ranges and summer ranges outside Mount Rainier NP (WDFW 2013). Additionally, elk were fed on the winter range of the South herd due to harsh winter conditions in 2009, which may also have contributed to the recent increasing trend (B. Moeller, PTOI, personal communication, 2014).

With the possible exception of the ratio of all age-classes of bulls (pooled) to cows in the population, sex and age composition of elk herds summering in Mount Rainier NP remained constant during this study. The ratio of calves in the populations, which appeared constant in both herds, tended to be higher in the North Rainier than in the South Rainier TCA, but that edge in productivity was not evident in a greater rate of increase in numbers of elk using the North Rainier TCA (Figures 7, 8). Although we detected no net difference in the ratio of calves estimated during this study compared to all years surveyed prior to 2007, calf: cow ratios varied over a longer time period since the early 1990s (Figure 15). We cannot identify the causes of long-term variation in calf production, but temporal variations over the last decades in the North herd may be associated with changes in management practices on the winter and spring range. Calf: cow ratios decreased for a few years after Washington State Initiative 655 was passed in 1997, which curtailed the harvest of cougars (*Puma concolor*). Subsequently, calf:cow ratios increased after MIT liberalized cougar hunts on winter ranges adjoining the park in 2001, and ratios began to decrease following the managed reduction of cougar hunting in 2008 (MIT, unpublished data). Although the ratio of calves to cows was measured on summer ranges within the park where predators are not managed, many cows produced calves on low to mid-elevation spring ranges outside the park (Cooper 1988) where they may have been affected by local predator management practices before moving into the TCA after calving.

Our preliminary data were insufficient to identify trends in specific components of the bull elk population. Although the ratio of total bulls to cows estimated from the best survey each year (i.e., the greatest number of animals classified) suggests an upward trend in both herds, we emphasize that neither trend is statistically significant due to the high variability in the composition ratios. A high degree of variation seen in the ratios of spikes (yearling bulls) per 100 cows, including some surveys with essentially no spikes classified, suggests that not all spike bulls were classified accurately during all surveys. Pooling all bull age-classes into a single category of total bulls would reduce the effects

of classification errors for spike bulls, and pooling of branched antler bulls (excluding spikes) would further reduce problems associated with classification errors. The average ratios of over 35 bulls (all size classes combined) and about 30 branched-antlered bulls per 100 cows, however, indicates a healthy breeding population of bulls; greater than in many other managed herds in Washington (WDFW 2013) and in the upper range of the State's management guidelines for preseason bull:cow ratios (i.e., 15-35 bulls:100 cows, WDFW 2008). Although male elk are hunted in both the North and South Rainier herds outside the park boundary, the migratory elk herds within Mount Rainier NP generally do not leave the park for lower elevations until driven down by fall storms, often in late October or November (Cooper 1988), during or following the late hunting seasons. Consequently, Mount Rainier NP likely provides a seasonal refugium from hunting.

Elk Trends in Olympic NP

Summer Range

The observed ratio of calves to cows in the Core TCA (about 29-39:100 cows), was higher than previously recorded during helicopter surveys conducted throughout the western Olympic Mountains during 1985-87 (22-28:100 cows) (Olympic NP, unpublished data). Bull:cow ratios in the Core TCA (56-63:100 cows) were higher generally than we have found reported in other unmanaged elk populations (Flook 1970, Houston 1982, also see review by DeSimone et al. 1993), including Roosevelt elk in Olympic NP (Smith 1980, Olympic NP, unpublished data). Our findings provide a useful baseline for comparison to other managed populations in the region and for long-term assessment of trends in Olympic NP. Previous studies indicated that bulls captured in the core of the Olympic Mountains rarely move outside park boundaries where they would be susceptible to legal harvest (NPS, unpublished data). This information on bull elk movements and the high ratio of bulls observed in the Core TCA suggest that natural sex ratios and mating systems of elk are intact in the park's interior. Preliminary information on bull elk movements also suggested that some bulls near the park boundary left the park during the breeding season (NPS unpublished data), presumably as a result of sexual competition for mates. Additional information on the composition of elk herds in more peripheral areas of the park, as represented in the alternating TCAs, are needed to examine any potential boundary effects on sex composition of elk populations within Olympic NP.

Early-spring Range

Even after accounting for variations in growing seasons, survey date, and temperature, counts of elk on the three early-spring TCAs declined significantly since the mid-1980s (Figures 21-23; Hoh, $P = 0.036$; South Fork Hoh, $P < 0.001$; and Queets, $P = 0.045$). Until the mid-1980s elk populations were generally considered to be at ecological carrying capacity and relatively stable in numbers (Jenkins and Starkey 1981, Leslie et al. 1984). The causes of recent declines are poorly understood. Initially we hypothesized the decline may be due to recent changes in the seasonal timing of surveys relative to plant phenology and elk distribution during early spring. Before 1998, surveys were conducted beginning in March and extending into April as needed to capture the time of year when elk are maximally concentrated on the river floodplains (i.e., during peak period of early-spring growth of herbaceous vegetation). Beginning in 1998, however, helicopter use was precluded after 31 March within old-growth forested habitats to protect nesting populations of Marbled Murrelets, which are

federally designated as a threatened species. Previous telemetry studies indicated that elk use of the deciduous forests and open-canopied coniferous forests in the Hoh Valley increased during early to mid-March (Jenkins and Starkey 1984) resulting in favorable counting conditions by middle to late March (Houston et al. 1987). Studies of plant phenology, however, indicated that there was high variability in the initiation of vegetation green-up during early spring, and in many years, peak green-up did not occur until April (USGS, unpublished data). It was also the impression of aerial survey crews that counts of elk may be lower following late, cold winters and on days when temperatures were below freezing, particularly if snow was on the ground. This is likely because, elk tend to use south-facing slopes outside the survey area during cold, snowy periods (Jenkins and Starkey 1985). Since surveys were implemented in 1985, the survey teams avoided flying when snow covered the ground, but some years that was unavoidable, particularly in the upper watersheds where snow persists later in the season. Overall, the influence of growing seasons, temperature, and survey date were poorly understood, but their effect on counts strongly suspected.

Contrary to these expectations, we found only moderate support for an effect of residual GDD40 on counts of elk in the Hoh and Queets, compared to relatively weak support for an effect of Julian date in the South Fork Hoh and for the effect of minimum temperature in all three winter ranges. Residual GDD40 reflected the warmth of the late winter period measured (since 1 February each year) relative to the long-term mean. Presumably this also reflected annual variation in phenology and availability of herbaceous forage during early-spring growth. Although many of these effects were only weakly supported, we left all of them in the models of elk population trends to cumulatively accommodate the small but directional effect of these variables on numbers of elk counted during the early-spring surveys.

A potential limitation of the counts has to do with the fact that they have not been adjusted for differences in detection probability. Therefore, we must consider the possibility that true densities of elk have not changed at all, but that survey crews are now counting a smaller fraction of elk present. There are reasons to believe, however, that there were no systematic changes in detection probability over time. All the surveys since 1985 have been conducted by two experienced survey crews that have remained nearly constant over time. The survey conducted in 1998 was a year of transition with two of three observers replaced. Since 1998, only one observer has retired, <5 different people have conducted surveys, and the same helicopter pilot and 2 of three observers have been consistent since 1998. Numbers of elk counted in both the Hoh and the Queets Valley were constant through the 1998 surveys, and the majority of the decline has occurred since 1998 during which time the same helicopter and survey crew were used. Additionally, variation in the spatial location of the declines also suggests that declines are not due to uniformly reduced efficiency of the survey crews over time.

The most prevalent declines were observed in the South Fork Hoh, where the TCA abuts the park boundary, consistent with the hypothesis that declines are related to changes in land use, legal and illegal elk harvests, and potentially also changes in cougar harvests adjacent to the park boundary. During the 1970s and early 1980s, clearcut logging practices near the park boundary converted large areas of old-growth timber to optimal foraging habitat for elk that regularly crossed the park boundary (Jenkins 1980). Subsequently, forest succession into midseral stages likely reduced habitat

capacity for those boundary herds. Further, although trends in predator populations are not known, more restrictive cougar hunting methods implemented in 2007 may have resulted in increased predation on elk over the last decade. Without a longer time series to examine and reliable data on predator population trends, we cannot decipher the role of predators and their influence on ungulate populations over time. The disappearance of wolves in the 1920s and the potential relationships between wolves and cougar populations further confounds the interpretation of elk population trends relative to predator populations historically.

Declining counts of elk that were much less pronounced in the Hoh and Queets may reflect the greater separation of the TCAs from the park boundary in those watersheds (Figure 6). Previous studies of elk movements in the Hoh Valley indicated that the Hoh TCA largely excluded a boundary herd that lived on the park boundary (extending approximately 3 km into the park), and which would have been most affected by changing land uses and forest characteristics outside the park (Jenkins 1980). Rather, the Hoh TCA encompassed primarily ranges of resident elk herds that lived exclusively in the park. The Queets TCA was buffered from the park's boundary to an even greater extent than in the Hoh Valley, and encompassed winter ranges of elk that were least influenced by effects of adjoining land uses or hunting pressures.

We are unsure why elk counts in the Hoh Valley decreased at the greatest rate at the head of the valley. Recent unpublished data on movements of GPS-collared elk in the Hoh Valley indicate that the proportion of radiocollared elk found at low-elevations depends largely on the presence or absence of snow (NPS, unpublished data). Unpublished data on movements of GPS-collared elk in Olympic NP, confirm earlier observations of Schwartz and Mitchell (1945) that annual variability in snow cover influences both the movements of elk down valley during severe winters, as well as local movements between the floodplain and south-facing side-hill forests (NPS, unpublished data). High variability of local snow cover during early spring and lack of records in the upper watersheds preclude the analysis of local variations of snowpack and its influence on elk distributions in the upper reaches of the valleys.

Operational Considerations

The failure of GPS telemetry collars in Olympic NP was the most significant operational challenge faced during the first four years of this monitoring program. Telemetry failures prevented us from completing a workable DO-S model for application in Olympic NP and completing all scheduled surveys. By 2013 we completed a sufficient number of DO-S trials for model development that will allow future surveys results to be adjusted for observational biases.

In Mount Rainier NP, we benefited from the radiotelemetry collars that were deployed previously and maintained by the MIT and PTOI throughout the study, as well as the participation and funding of both Tribes and WDFW. This cooperation and support made it possible to complete both the development of a DO-S model for Mount Rainier NP and a sufficient number of repeat surveys to assess trends in the abundance and composition of elk in the two Mount Rainier TCAs.

In Mount Rainier NP, it was sometimes difficult to complete surveys of elk within a TCA on a single evening as prescribed in the protocol. It has not always been possible to arrange for both surveys to

be completed concurrently due to scheduling issues, weather, or other contingencies. Failure to complete both halves of a survey during the same evening is unavoidable on occasion and is to be expected in the future. Some elk groups are likely to move between sections of the TCAs counted on different days. Such movement should not cause a systematic bias in the counts, but it would increase variability among counts which would reduce power to detect trends. Whenever possible, surveys should be completed simultaneously as described in the protocol. If that is not possible, the survey teams should attempt to divide the effort among survey units where few elk are generally seen to avoid problems associated with crossover of elk between sequential surveys of a single TCA (Figures 17, 18).

Even with the use of two aircraft operating simultaneously, surveys were not always completed due to bad weather or darkness. Time was more limiting during the early years of protocol development (i.e., 2008-09) when substantial effort was required to radiotrack and locate unseen collared elk following each survey for developing the DO-S model (Griffin et al. 2013). Now that data collection for DO-S model development has been completed in both parks, time limitations should be less of a problem for future surveys. Now that survey duration is better known for each of the TCAs, the effects of darkness can be mitigated by starting the surveys with sufficient time for their completion. Still, the occasional curtailment of a survey for safety reasons associated with weather, darkness, or fuel limitations is unavoidable.

We have demonstrated in this report how missing values for selected survey units may be imputed to minimize the effects of missing data in trend analyses. If the omission of selected survey units can be managed, for example in the case of darkness, it would be advisable to omit survey units that generally have low counts because errors associated with imputing their missing values will be minimal.

We also faced occasional problems associated with high temperatures during the surveys, particularly during the afternoon surveys in Mount Rainier NP. In the protocol we recommended conducting surveys when temperatures are <20°C (measured at 6,000 feet [1829 m] altitude) and to consider cancelling surveys at temperatures above 27°C (Griffin et al. 2012). We found no significant trend in elk counts associated with ambient temperature during the summer surveys in Mount Rainier, which were conducted at temperatures ranging from 2.0- 25.4°C (6,000 ft [1829 m] altitude). We find no reason to modify the temperature prescription of the aerial surveys, but continue to recommend cancelling surveys at higher temperatures if no elk are being seen.

We had considerable discussion in planning these surveys about how best to record environmental covariates associated with elk groups sighted during an aerial survey. Initially we were undecided whether it was better to record the percentage of vegetation cover within 10 m of elk that were first seen in a group, or of all elk identified in a group after searching through nearby cover. Consequently, we estimated both variables so they could be examined objectively. In an ancillary analysis presented in Appendix C we evaluated which of the measures performed better in two sets of DO-S models that were structured in an identical manner except for the variable used to denote vegetation cover. We concluded that identical models generally performed better with cover

measured around the entire group rather than around elk first seen. As a result, it is no longer necessary to record vegetation cover around the elk first seen within a larger group.

In contrast to summer surveys, early-spring surveys were difficult to complete in the western valleys of Olympic NP due to unfavorable weather or growing conditions in March and flying restrictions in April. During the years covered by this synthesis report (2008-2011) we met the challenge of surveying each of the early-spring ranges once before the end of March each year from 2008-10, but only with difficulty. Often several surveys were aborted for every successful survey due to ground fog, rain, or high-contrast lighting conditions that made it difficult to see elk in the forest shadows. Other surveys were flown under less than ideal conditions, for example, early in the season before growing conditions were optimal for spring green-up or snow was still on the ground in the upper valley. Surveys were cancelled during 2011 due to deep snow persisting into April. Growing budget concerns in 2012 led us to suspend future early-spring surveys until further funding is available. Declining counts of elk in the early-spring TCAs, however, provide compelling reasons to continue surveying elk on these early-spring ranges if and when possible.

Funding notwithstanding, we foresee continued difficulties conducting early-spring elk surveys in Olympic NP due to the highly variable environmental conditions during early spring and flight restrictions later in the spring. We need a longer window of survey opportunity in the spring to help ensure elk are concentrated on the early-spring ranges during the surveys, or we need to survey more selectively during years with warmer late-winter weather when elk are expected to concentrate earlier in the season. By either of the above strategies, the goal is survey when elk are maximally concentrated in the TCAs. The tracking of growing-degree days after February 1 may provide a practical guideline for recognizing optimum survey years when elk are likely to be concentrated on the valley floodplains early in the spring. Other possible alternatives might include: (1) focusing survey effort during the predicted warm cycles of the Pacific Decadal Oscillation and El Nino/La Nina cycle (http://cses.washington.edu/cig/pnwc/pnwc.shtml), (2) surveying during April in years with late snow and delayed forage phenology, or (3) developing alternative survey methods that would allow population estimation under variable environmental conditions earlier in the season. Surveying during April would require review and permitting by the U.S. Fish and Wildlife Service because of potential adverse impacts on Marbled Murrelets.

Among the alternative survey methods considered, mark-recapture methods using radio-marked animals has been used successfully on elk winter ranges of the North Rainier herd (MIT, unpublished data) and adjoining elk herds in the North Cascades (McCorquodale et al. 2013). Sightability modeling has proven useful on winter ranges of the South Rainier herd (Gilbert and Moeller 2008), but more recent comparative work suggests that the utility of sightability correction modeling may be limited by the high proportion of groups with very low detectability in densely forested systems (McCorquodale et al. 2013). Lastly, population estimation methods based on microsatellite analyses of DNA to identify individual animals from fecal samples, used in conjunction with mark-recapture estimation techniques, have proven useful for estimating abundance of Sitka black-tailed deer at the watershed scale in southeast Alaska (Brinkman et al. 2011). Although each of these methods has merits, each is expensive and beyond our current financial means. Given current evidence of

population decline on the west-side valleys, however, we suggest continuing to conduct aerial surveys for a pulse of about 3 years every decade if funding permits. The sampling pulse of three years would help mediate the effects of bad survey conditions during one year. That schedule is not too different from what has been possible during that last 30 years when surveys were conducted opportunistically based on available funding. Despite the irregular sampling schedule, it has been possible to detect a low rate of population decline (1% per year) because of the long data series that is available.

Inconsistent funding is likely to be the most pervasive operational constraint on elk monitoring in the NCCN parks into the future for both summer and winter surveys. Since this program was implemented in 2008, NPS funding that initially permitted annual surveys on the Mount Rainier summer ranges, with two replicate counts on both herd ranges, has been scaled back to 1-2 surveys of each herd on alternating years. Early-spring surveys in Olympic NP have been discontinued. To date, we have managed to complete annual surveys in Mount Rainier NP with vital support from PTOI, MIT, and WDFW, as well as ancillary funding from the Washington National Park's fund, base funding at Mount Rainier NP, and the NCCN Science Learning Network. Similar private funding has sustained annual monitoring efforts on Olympic summer ranges and appears to be sufficient to cover survey costs through 2015. This funding will allow us to complete one replicate survey in each of the Olympic summer TCAs and 4-6 additional replicates in the Olympic Core TCA the North and South Rainier TCAs for the next synthesis report. With the costs rising for staff, aviation, and all costs associated with sustaining 12 monitoring programs in the NCCN, funding to sustain elk monitoring into the future is doubtful unless monitoring priorities of the NCCN are amended.

The NCCN has requested that each monitoring team examine potential efficiencies, reductions of effort, or opportunities to reduce monitoring costs in the future. As described previously, elk monitoring has been reduced to the barest of bones by discontinuing early-spring surveys in Olympic NP, scaling back the number of survey replicates in Mount Rainier, and reducing funding to alternate years. The power analyses suggested that annual monitoring in Mount Rainier NP will verify emerging changes in elk abundance, and the partners and elk monitoring team are working hard to sustain annual monitoring through the next synthesis analysis to meet that goal. It has been suggested to us that we may minimize survey costs by eliminating survey units where elk have not been observed in recent surveys. We caution, however, that many of these units are adjacent to units where elk currently are observed (Figures 17, 18). We do not advise restricting surveys to currently occupied survey units because sampling confined to only the best habitats would fail to distinguish changes in elk distribution from changes in numbers of elk using the subalpine summer range overall. Hence, we see no further reduction in funding possible other than further reducing the number of replicated surveys or survey frequency in one or both parks. The high variability in replicated counts in Mount Rainier NP, however, suggests the value of increasing rather than decreasing the number of replicate surveys of elk in each TCA and maintaining at least the current frequency of sampling.

The following considerations may be helpful in making the tough decisions on which monitoring protocols to sustain in the NCCN: (1) overpopulation or over use of key summer or winter ranges has

been a very important recurrent issue in both Mount Rainier and Olympic NPs (Bradley 1982, Ripple et al. 1988, ; Jenkins and Starkey 1981, Beschta and Ripple 2009); (2) There are preliminary indications of increased use of subalpine meadow communities by elk in Mount Rainier NP, but additional monitoring is needed to verify these trends; (3) elk counts on key winter and spring ranges have declined since the 1980s in Olympic NP; (4) interpreting the elk 'story' is of great interest to visitors of both parks; (5) elk are immensely important to neighboring Tribes and other stakeholders outside Mount Rainier NP; (6) collaboration with neighboring Tribes and WDFW has resulted in considerable cost efficiencies; (7) the emergence of a new infectious bacterium in southwestern Washington poses new threats to elk herds in the NCCN (http://wdfw.wa.gov/conservation/health/hoof_disease/); and (8) collaborative monitoring of elk trends in Mount Rainier NP has improved communications among agencies and Tribes, and has enhanced opportunities to collaborate in setting population objectives and managing this important shared resource.

Conclusions

Elk monitoring is unique among the monitoring programs within the NCCN in that it builds upon the legacy of earlier monitoring programs, as well as the collaboration of many managing partners with strong interests in the welfare of a shared resource. The NCCN elk monitoring program is still in its early years, but the long history of monitoring elk trends on summer ranges in Mount Rainier NP and winter ranges in Olympic NP extend the value of this young program. Similarly, this collaborative elk monitoring program has given new importance to the contributions of the earlier monitoring studies.

After a decade of population decline and relatively low levels of elk use on the Mount Rainier NP summer ranges (mid 1990s to 2000s), we detected early indications of potential population growth in the South Rainier TCA. The results based on two methods of analyzing the temporal trends are ambiguous, but additional monitoring that is currently funded through 2015 will help to substantiate or refute those potential trends.

We detected statistically significant negative trends in the counts of elk seen during early-spring surveys in the Hoh, South Fork Hoh, and Queets TCAs, three of the principal winter ranges of elk in Olympic NP. Causes of the decline are uncertain, but were greatest in the upper reaches of the Hoh Valley, where we surmise variation in snow accumulation may influence annual distribution patterns of migratory elk, and the South Fork Hoh, where changing land-use patterns and hunting pressure or predation along the boundary may have influenced elk numbers.

Elk summering in the core of Olympic NP have among the highest ratio of bulls to cows ever reported. The ratio of bulls to cows in Mount Rainier NP, although lower than in Olympic NP, is still higher than most harvested populations throughout Washington. These results indicate a relatively small influence of elk hunting on sex composition in Mount Rainier NP. Elk population composition in Olympic NP provides a useful baseline of natural sex ratios of unhunted elk populations in the Pacific Northwest.

Operationally, we encountered significant setbacks in completing the scheduled surveys of elk on the Olympic NP summer ranges (2009-10) due to radio-telemetry failure, but those problems have been resolved and the program is now ready to resume a steady sampling schedule through 2015. We encountered problems related to a short sampling season for early-spring surveys in Olympic NP, and have discontinued those counts until funding becomes available again in the future. All summer range surveys are now operating according to protocol with no major changes in protocol suggested.

Funding poses the greatest uncertainty for elk monitoring within the NCCN parks. We could find no remaining cost efficiencies for implementing these protocols short of further reducing or discontinuing sampling in either park. Both parks have secured funding to allow surveys to continue until the next synthesis report is prepared. At that time additional information will be available to more reliably interpret preliminary trends observed in elk use of the Mount Rainier NP summer range, and to conduct the first analysis of trend on Olympic NP summer ranges.

This monitoring program was established as a collaborative effort of the NPS, two Tribes and the State of Washington to provide information useful to all participants in meeting their individual goals and objectives for conserving and managing elk populations and unique resource values in both parks. In addition to providing a common information base, the monitoring program has provided additional benefits through fostering communication and collaboration among several parties managing these herds. Moreover, continuation of this long-term monitoring program will provide the basis for assessing long-term changes in elk-vegetation relationships, which has been an important issue in both parks historically, and will provide a foundation for discerning effects of emerging new issues (such as disease) and interpreting these issues to a greatly interested public.

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Appendix A: Comparison of elk abundance computed from the DO-S models to estimates derived from the E4*2 index in Mount Rainier NP

Introduction

Elk have been surveyed from fixed-wing aircraft or helicopters in Mount Rainier NP almost annually since the mid-1970s following protocols first described by Bradley (1982). In 2008 we reviewed the previous elk monitoring practices, enhanced standardization of the surveys, and began developing DO-S models that have allowed for the estimation and correction of observational biases. In developing the new protocols, it was our goal to refine the survey standards and estimation methods while minimizing discrepancies between the former and new aerial survey methods so that trends may be roughly comparable.

Historically, count data were converted to a metric known as the E4*2 index, which has been used as the basis for herd management by the MIT, PTOI and WDFW for several decades. At the request of the MIT, PTOI and WDFW, here we summarize the results of E4*2 indices historically, and extend these by also computing the E4*2 index from surveys completed under the new protocol from 2008-2011. We begin by reviewing and summarizing the E4*2 metric, and then compare current estimates to these indices.

Review of the E4*2 Index

Elk have been surveyed in Mount Rainier NP primarily during evenings in late summer and early autumn from fixed wing airplanes prior to 1989 and from helicopters since then. Survey crews recorded the number of elk seen within spatial units defined by Bradley (1982) at three hierarchical spatial scales (Figure A1).

Bradley defined one North and one South ‘herd’ unit corresponding with the North Rainier and South Rainier TCAs as currently defined. Each herd unit contained lettered ‘management’ units that were further subdivided into numbered ‘range’ units. In each herd unit, there also was one range unit called “Other,” which was not included in a management unit (Figure A1). Our past experience suggested that prior to following this protocol elk group locations were associated with the closest range, management, and herd units, even if the observation fell somewhat outside of the boundaries drawn in Figure 1. Using GIS, we made the herd unit polygons closely follow the delineated herd units in Figure A1, *except* that the North Rainier herd unit polygon was extended to include Glacier Basin, as indicated in Figure A1. Elk observations from Glacier Basin were historically counted as being within the “Other” range unit of the North Rainier herd unit, after radio-marked elk from the White River were seen to use Glacier Basin.

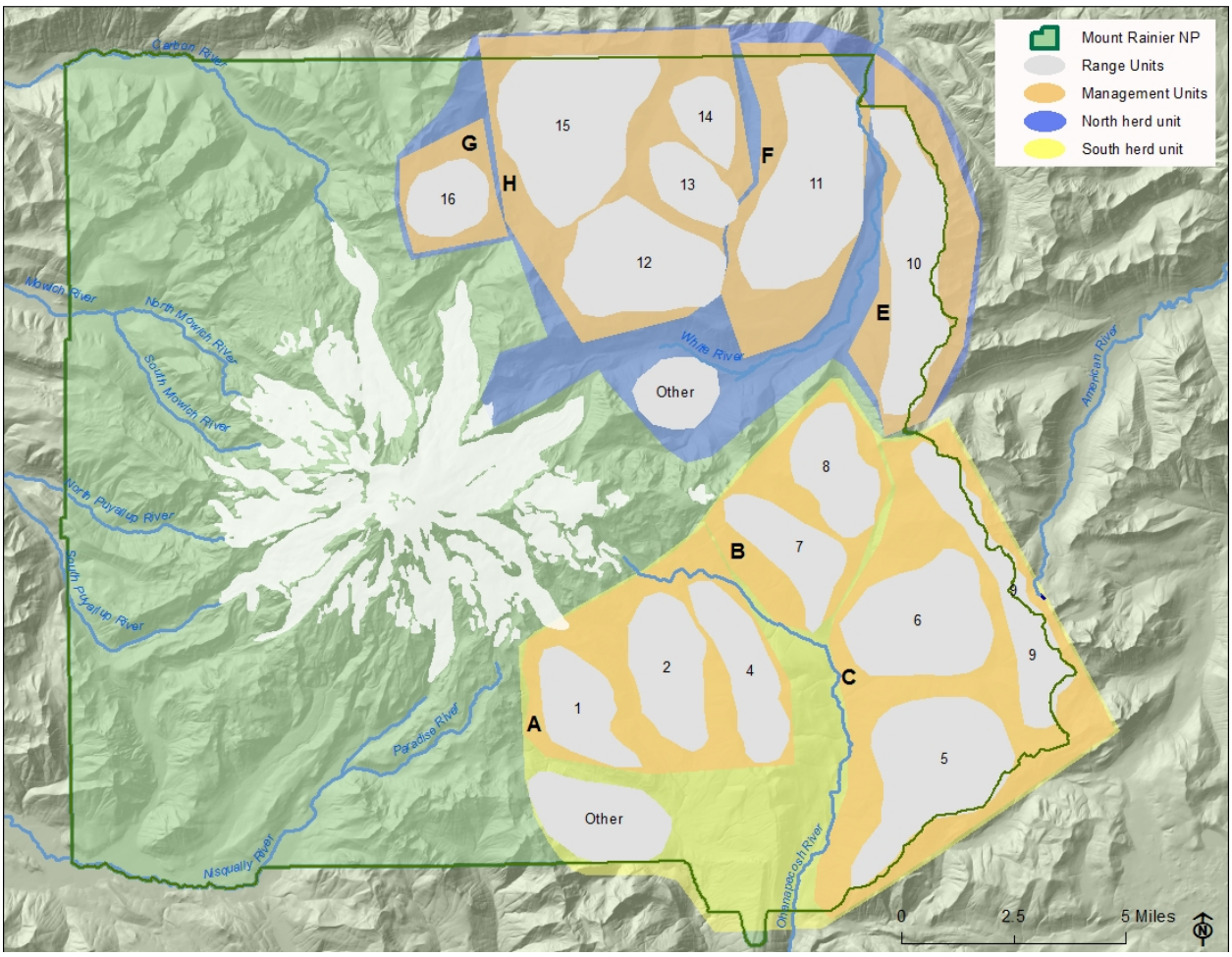


Figure A1. Historical range, management, and herd units in Mount Rainier NP, Washington. Herd units (North or South) enclose several management units (lettered) and some areas outside of any management unit. Management units enclose one or more range units. Range units are numbered, except two that are called 'Other.' In the North, 'Other' includes Glacier Basin, whereas in the south 'Other' includes the Tatoosh Range. In the past, range units were surveyed and survey results were used to make inferences to the larger management and herd units indicated.

When initially designed by Bradley (1982), surveys were planned to be replicated three times annually within all management and range units within each herd unit, although survey efforts often varied among years and between North and South herd units for several logistical reasons. Notably, the shift from using fixed-wing aircraft to helicopters for the surveys beginning in 1989 reduced survey speeds and often led to incomplete replication of some surveys. Because the South Rainier herd unit is a larger area than the North Rainier herd unit, incomplete replication was more prevalent historically in the South than the North herd unit.

Four indexes of elk abundance were computed for each herd unit from the replicated surveys conducted each year (Bradley 1982):

E1: Sum of the maximum counts obtained for each range unit in a year.

E2: Sum of maximum counts obtained for each management unit in a year.

E3: Maximum count of elk observed in a herd unit on any one flight.

E4: Average of E1-E3 indexes.

Each component of the E4 index can be influenced by search effort – that is, greater search intensity or replication contributes to higher values of the E4 index. Bradley (1982) recommended using the E4 index multiplied by a factor of 2 (E4*2) as the standard metric for comparison of elk abundance over time. The multiplier was intended to account for detection biases (that is, elk present but not seen by aerial survey crews) and was based on comparisons of counts and densities of elk computed from pellet group surveys in the Cedar River Watershed (Schoen 1977).

Methods

We calculated annual E4*2 indices for the North and South Rainier TCAs as described above following Bradley (1982). Due to past uncertainty in the accuracy of mapping elk group locations, elk groups whose locations were within 1,200 m of a Bradley (1982) herd unit were classified as being in the closest herd unit, range unit, and any associated management unit. We used the 1,200 m buffer distance to include areas that may have been surveyed in the past, even though the areas were outside of the herd unit boundaries drawn by Bradley (1982) (Figure A1). We strongly suspect that elk in such areas would have been included in E4 calculations in the past, and we did not want the high precision that GPS units allow today to prevent such groups from being included in these calculations.

We compared the time series of E4*2 values against the available values for estimated abundance, based on the DO-S model. We plotted both measures against time. For the North Rainier and South Rainer herds, we fit non-parametric local regression (loess) lines through E4*2 index values as a smoothing tool. We fit separate loess lines for surveys conducted from fixed-wing aircraft (1974 – 1988) and from helicopters (1989 – 2011).

Results

There was wide variation in the E4*2 index calculated from aerial surveys since 1974, in both the North Rainier and South Rainier TCAs (Figure A2). From 2008- 2011, the E4*2 index was greater than abundance estimated from the DO-S models (Figure A2, Table A1). In the North and South TCAs, the E4*2 index appears to have increased from low values recorded in the mid-2000s, similar to trends revealed from DO-S models applied to the best (highest count) surveys conducted from 2008-2011 (Figure A2).

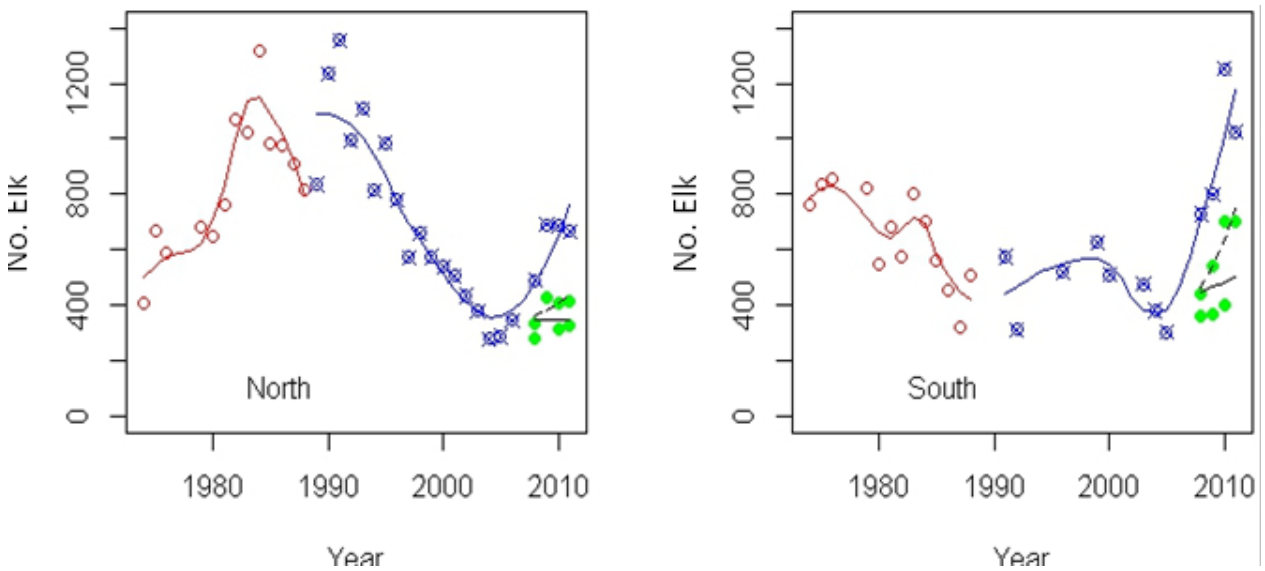


Figure A2. Indices and estimates of elk abundance plotted against year for the North Rainier TCA (left) and South Rainier TCA (right), 1974-2011. The red and blue symbols represent indices of abundance (E4*2) as estimated from fixed-wing (red) and helicopter (blue) surveys. The red and blue lines are smoothed trends derived from nonparametric local regression (LOESS). The green symbols represent elk abundance estimated based on the DO-S models applied from 2008-11. The solid black line fitted to green circles is the linear regression fit to estimated abundance values (Figures 7,8) whereas the dashed black line is the unweighted linear regression through the maximum abundance estimates for each year (Figures 7,8).

Discussion

We offer the following caveats for managers who may refer to the E4*2 indices of elk abundance in Mount Rainier NP. First, we faced some difficulty knowing to what degree of precision former surveyors included observations of elk within herd unit boundaries. We buffered each of the herd units with a 1,200-m strip to account for uncertainties in the boundaries used by former aerial survey crews, particularly in the era before the widespread use of on-board Global Positioning System (GPS) units and Geographic Information Systems (GIS). Because we included observations from within the buffered strip in the index counts, we may have biased counts upwardly. Past survey crews likely included observations near the herd unit boundaries in the E4 calculations. We also caution that the E4 metric is not an estimator with a clearly defined estimate of uncertainty, and it does not account for variations in detection bias. We do not recommend continuing to compute and summarize the E4*2 index in future reports.

Table A1. Average abundance estimates ($\widehat{N}_{imputed\ ,t,mean}$) and standard error of average abundance (SE($\widehat{N}_{imputed,t,mean}$), compared with E4*2 values, according to year. For years before 2008, no estimates of abundance are available. For each year, values for the North Rainier trend count area (TCA) and South Rainier TCA are in separate columns.

Year	$\widehat{N}_{imputed\ ,t,mean}$ North	SE($\widehat{N}_{imputed\ ,t,mean}$), North	North E4*2	$\widehat{N}_{imputed\ a,t,mean}$, South	SE($\widehat{N}_{imputed\ a,t,mean}$), South	South E4*2
1974	--	--	408	--	--	766
1975	--	--	670	--	--	834
1976	--	--	590	--	--	858
1979	--	--	680	--	--	822
1980	--	--	650	--	--	550
1981	--	--	764	--	--	682
1982	--	--	1070	--	--	576
1983	--	--	1026	--	--	800
1984	--	--	1318	--	--	706
1985	--	--	980	--	--	564
1986	--	--	974	--	--	456
1987	--	--	912	--	--	322
1988	--	--	818	--	--	510
1989	--	--	836	--	--	--
1990	--	--	1236	--	--	--
1991	--	--	1356	--	--	576
1992	--	--	994	--	--	312
1993	--	--	1108	--	--	--
1994	--	--	814	--	--	--
1995	--	--	986	--	--	--
1996	--	--	782	--	--	520
1997	--	--	574	--	--	--
1998	--	--	660	--	--	--
1999	--	--	576	--	--	628
2000	--	--	540	--	--	510
2001	--	--	506	--	--	--
2002	--	--	436	--	--	--
2003	--	--	379	--	--	478
2004	--	--	280	--	--	382
2005	--	--	288	--	--	303
2006	--	--	347	--	--	--
2007	---	-	184	--	--	--
2008	308	24.5	492	404	40.5	730
2009	427	22.8	690	455	86.0	802
2010	362	49.5	686	555	150.0	1252
2011	370	44.5	667	700	59.2	1025

Appendix B: Beta coefficient estimates for updated Mount Rainier NP double-observer sightability model

Table B1. Table of beta coefficients for logit link formulae in the 15 models fit to the data. Coefficients are described Table 1. Beta coefficients for G:Radio O:Radio and G:NoRadio O:Radio relate to the fixed sighting probabilities for the radio observer. Coefficients shaded in grey are not a component of the given model's structure.

Coefficient	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15
G:Radio, O:Radio	99[1]	99	99	99	99	99	99	99	99	99	99	99	99	99	99
G:No Radio, O:Radio	-99[2]	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
O:F=B	-0.270	0.063	0.027	0.000	0.000	0.000	-0.078	0.000	0.000	0.000	0.000	0.064	0.000	0.000	0.000
O:Front	0.000	0.000	0.000	-0.314	-0.292	0.019	0.000	-0.017	0.042	0.006	-0.123	0.000	-0.099	0.020	0.043
O:Back	0.000	0.000	0.000	-0.225	-0.249	0.109	0.000	0.073	0.084	0.049	-0.033	0.000	-0.057	0.110	0.086
G:Radio	-0.515	-0.520	-0.557	0.000	-0.516	0.000	-0.519	0.000	-0.521	-0.558	0.000	-0.520	-0.520	0.000	-0.520
G:Radio, O:Front	0.000	0.000	0.000	-0.286	0.000	-0.292	0.000	-0.325	0.000	0.000	-0.289	0.000	0.000	-0.291	0.000
G:Radio, O:Back	0.000	0.000	0.000	-0.744	0.000	-0.750	0.000	-0.789	0.000	0.000	-0.749	0.000	0.000	-0.749	0.000
ln(N)	0.522	0.499	0.492	0.523	0.523	0.500	0.498	0.492	0.499	0.492	0.499	0.499	0.498	0.499	0.499
F:IXP	-1.557	-1.567	-1.559	-1.535	-1.527	-1.545	-1.573	-1.539	-1.537	-1.529	-1.552	-1.567	-1.543	-1.545	-1.537
B:C	-3.237	-3.272	-3.258	-3.306	-3.270	-3.340	-3.256	-3.326	-3.304	-3.290	-3.324	-3.272	-3.288	-3.340	-3.304
V	-1.047	-1.047	-1.085	-1.049	-1.047	-1.048	-0.857	-1.087	-1.047	-1.085	-0.858	-1.039	-0.858	-1.040	-1.039
H	0.000	0.000	0.000	0.000	0.000	0.000	0.206	0.000	0.000	0.000	0.207	0.000	0.206	0.000	0.000
F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.007	0.000	-0.009	-0.007
L	0.399	0.000	0.000	0.399	0.399	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
M	0.000	0.000	0.351	0.000	0.000	0.000	0.000	0.353	0.000	0.351	0.000	0.000	0.000	0.000	0.000

[1] A coefficient of 99 ensures that the estimated probability of detection is essentially equal to 1.0.

[2] A coefficient of -99 ensures that the estimated probability of detection is essentially equal to 0.0.

Appendix C: Evaluation of "First Seen % Vegetation Cover" as a covariate

Introduction

Since we first began developing the DO-S models for estimating observational biases of aerial elk surveys in the NCCN, all the survey crews recorded two measures of vegetation cover in the vicinity of recorded elk groups. The first is the percentage of vegetative cover within 10 m of those elk in the group that were first seen (IV). The second measure is the percentage of vegetative cover within 10 m of the whole elk group (V). In other studies, the vegetation cover is most commonly recorded at the level of the whole group; in 2008 we were unsure whether this measure was superior to a measure of those elk first seen. We examined model support for identical models developed using both IV and V as the vegetation cover covariate. With the benefit of data collected from 2008-2012, we are now able to test whether one or the other measure of vegetative cover is superior.

Analytical Method

Data. DO-S and DO trials in which both measures of vegetative cover were available from all survey flights from 2008-2012, with the exception of two surveys of the North Rainier herd in 2008. We used data from these observations (n=833), queried via a slightly modified version of qs_Model_building that also output the initial vegetation cover percentage (IV) for each observation. We prepared the data for input in program MARK, with 11 covariates. We substituted the IV covariate value in the same column of the input file where the "Shrub" covariate was stored in the original analyses because Shrub is a covariate that is not used in any of the 15 top-ranked models now used in the protocol.

Modeling. The rationale for the modeling was to assess whether model parsimony was improved by one or the other measure of vegetative cover. We entered the input data in program MARK, using two attribute groups ("Radio" group and "NoRadio" group). We ran the same 15 Huggins (1989, 1991) models in MARK as were used for model averaging in the protocol and in the analysis of confidence intervals in this synthesis report. To those 15 models we added 15 more that were identical, except that the additional models used IV in the place of V. We compared model parsimony by inspecting differences in AICc values. In principle, two models of parallel structure, differing only in the use of V or IV should differ in AICc value only as a result of the differential contribution of V versus IV to model fit.

After comparing model fit, we also examined the estimates of the coefficients for the covariates in models with parallel construction. We paid particular interest to any differences in intercept terms, and coefficients of V and IV.

Results

Model Support. Models structured with V were considerably more strongly supported than models structured identically, but with IV in the place of V (Table C1).

Table C1. Thirty models structured to explain detection probabilities of observed elk groups in Mount Rainier NP, 2008-2012. The 15 top-ranked models were fit with reference to the whole group vegetative cover percentage (V), whereas the 15 bottom-ranked models were fit with reference to the vegetative cover percentage for the first elk seen (InitialVeg). For each model, ΔAIC_c is the difference between the top-ranked model and the given model, and AIC_c weight is the relative strength of evidence in support of the given model, given the candidate set. Each model description is followed by the model number, according to Table C.3 of the protocol (Griffin et al. 2012), except that the models using IV are numbered with the suffix _IV. Model components are defined in Table 1 in the body of the report.

Model	ΔAIC_c	AIC_c Weight
4. {F/B*Hetero + ln(N) + F:IXP + B:C + V + L}	0.0000	0.56734
1. {F=B + Hetero + ln(N) + F:IXP + B:C + V + L}	2.4653	0.16539
5. {F/B + Hetero + ln(N) + F:IXP + B:C + V + L}	3.3982	0.10374
8. {F/B*Hetero + ln(N) + F:IXP + B:C + V + M}	4.3069	0.06586
11. {F/B*Hetero + ln(N) + F:IXP + B:C + V + H}	5.8346	0.03068
3. {F=B + Hetero + ln(N) + F:IXP + B:C + V + M}	6.8600	0.01837
10. {F/B + Hetero + ln(N) + F:IXP + B:C + V + M}	7.7994	0.01149
6. {F/B*Hetero + ln(N) + F:IXP + B:C + V}	7.9460	0.01068
7. {F=B + Hetero + ln(N) + F:IXP + B:C + V + H}	8.3406	0.00876
13. {F/B + Hetero + ln(N) + F:IXP + B:C + V + H}	9.2797	0.00548
14. {F/B*Hetero + ln(N) + F:IXP + B:C + V + F}	9.5613	0.00476
2. {F=B + Hetero + ln(N) + F:IXP + B:C + V}	10.4208	0.00310
9. {F/B + Hetero + ln(N) + F:IXP + B:C + V}	11.3499	0.00195
12. {F=B + Hetero + ln(N) + F:IXP + B:C + V + F}	12.0447	0.00138
15. {F/B + Hetero + ln(N) + F:IXP + B:C + V + F}	12.9751	0.00086
11_IV. {F/B*Hetero + ln(N) + F:IXP + B:C + InitialVeg + H}	17.4091	0.00009
7_IV. {F=B + Hetero + ln(N) + F:IXP + B:C + InitialVeg + H}	19.8688	0.00003
14_IV. {F/B*Hetero + ln(N) + F:IXP + B:C + InitialVeg + F}	20.7843	0.00002
13_IV. {F/B + Hetero + ln(N) + F:IXP + B:C + InitialVeg + H}	20.8299	0.00002
12_IV. {F=B + Hetero + ln(N) + F:IXP + B:C + InitialVeg + F}	23.2376	0.00001
15_IV. {F/B + Hetero + ln(N) + F:IXP + B:C + InitialVeg + F}	24.1829	0.00000
4_IV. {F/B*Hetero + ln(N) + F:IXP + B:C + InitialVeg + L}	26.4898	0.00000
1_IV. {F=B + Hetero + ln(N) + F:IXP + B:C + InitialVeg + L}	28.8504	0.00000
5 _IV. {F/B + Hetero + ln(N) + F:IXP + B:C + InitialVeg + L}	29.8117	0.00000
8_IV. {F/B*Hetero + ln(N) + F:IXP + B:C + InitialVeg + M}	33.4936	0.00000
6_IV. {F/B*Hetero + ln(N) + F:IXP + B:C + InitialVeg }	34.9129	0.00000
3_IV. {F=B + Hetero + ln(N) + F:IXP + B:C + InitialVeg + M}	35.9064	0.00000
10_IV. {F/B + Hetero + ln(N) + F:IXP + B:C + InitialVeg + M}	36.8725	0.00000
2_IV. {F=B + Hetero + ln(N) + F:IXP + B:C + InitialVeg }	37.2860	0.00000
9_IV. {F/B + Hetero + ln(N) + F:IXP + B:C + InitialVeg }	38.2414	0.00000

Model Coefficients. Inspection of the model coefficients indicates how the fitted models differed in term of the predicted effects of sighting covariates on detection probability. For illustrative purposes, we compare model 1 and model 1_IV (Table C2), although the same pattern of differences in intercept coefficients and effects of vegetative cover were common to all model pairs.

Models that used IV had lower values for the observers' intercepts, and for the heterogeneity bias parameter. This means, in general, that the expected detection probability for a given group with zero vegetative cover would be less in the model with IV than in the model with V. The coefficient for IV had a smaller absolute value than the coefficient for V. This means that, for any given increase in

vegetative cover, there was comparatively less effect on detection probability under the IV model than under the V model. Values for the other coefficients were generally close in comparing any two models with parallel structure.

Table C2. Model coefficients for two models with identical structure, except for the use of V (Model 1) or IV (Model 1_IV) as the effect of vegetative cover. Values for the coefficients in bold font are notably different between the two models.

Coefficient; Description	Model 1 (V)	Model 1_IV
F=B; Front and back observers' intercept	-0.2384874	-0.4548216
G:R; Heterogeneity bias parameter	-0.5165544	-0.8472420
V or IV; Effect of vegetative cover	-1.1288726	-0.2958985
ln(N); Effect of Natural log of group size	0.4956026	0.5119410
F:IXP; Effect of inexperienced pilot	-1.5333715	-1.5508057
B:C; Effect of centerline observation	-3.4180962	-3.4716276

Conclusions

Our preliminary interpretation is that IV is less predictive of sighting probability than is V. In cases where the elk first seen had different values of vegetative cover than those for the whole group, the value of IV was almost invariably less than the value for V. As a result, IV tended to be closer to zero than V. Concomitantly, the variance in IV was less than the variance in V, so the IV covariate simply may not have had as much ability to explain variation in detection probability. The pattern in coefficients is consistent with this explanation; models with IV had lower intercept values for detection probability, and a lower range in expected detection probability as a function of vegetative cover. Conversely, models with V had higher intercept detection probabilities, but the potential effect of vegetative cover was greater, such that elk groups under the densest vegetative cover category would have dramatically lower expected detection probabilities than those in the open.

The survey crews should continue to record whole group vegetative percent cover. Recording the vegetative cover percent for elk first seen does not appear to be productive, given these data. Survey crews need no longer record "First Seen % Veg."

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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