Managing for Population Recovery of Mountain Goats on the Kenai Peninsula, Alaska

JASON HERREMAN, *Alaska Department of Fish and Game, Homer, Alaska, 99603, USA; jason.herreman@alaska.gov*

JOHN P. SKINNER, *Alaska Department of Fish and Game, Anchorage, Alaska, 99518, USA*

ABSTRACT: Mountain goat (*Oreamnos americanus*) management on the Kenai Peninsula, Alaska has evolved over time as our understanding of the species has improved and environmental conditions continue to change. Populations were found to decline under management strategies once deemed successful. We compared mountain goat minimum count numbers, harvest levels, population trends, and survey techniques collected and used during 1980–2008 to data collected after the implementation of a new harvest strategy (2009–2021) to determine if mountain goat minimum count numbers recovered under the new strategy and if it appropriately manages goat populations. Recent surveys indicated the Kenai Peninsula wide minimum count numbers have returned to historic levels. Recovery of minimum count numbers occurred after nannies with kids were removed from the harvest and a new management system was instituted that included a 5-year no hunting penalty for any individual that harvested a nanny. Paired surveys and a general trend in counts with respect to time of year suggest that goat surveys on the Kenai Peninsula should be conducted in the fall to maximize sightability.

Biennial Symposium of the Northern Wild Sheep and Goat Council 24:86–97; 2024

KEYWORDS: Alaska, harvest, Kenai Fjords National Park, Kenai Peninsula, management, mountain goat, *Oreamnos americanus,* population decline, recovery.

Mountain goat (*Oreamnos americanus*) hunting on the Kenai Peninsula has been popular since statehood due to the accessibility of goats from the road system and the Kenai Peninsula's proximity to the state's highest population density in the Anchorage area. Human pressures have increased as human populations continue to grow and mountain recreational activities such as heli-skiing, snowmachining, backcountry skiing, heli-snowmachining, and general heli-recreation increase. Overharvest and other anthropogenic pressures have likely contributed to population fluctuations over time (McDonough and Selinger 2008, Herreman 2022). Managers have adjusted management schemes and survey techniques to address these fluctuations, and to maintain a sustainable hunting and viewing opportunity for goats across the Kenai Peninsula. In this paper, we retrospectively analyze trends in goats and changes in harvest during different time periods to contrast different management schemes and examine potential biases of shifting survey timing.

Mountain goat management at statehood began with liberal bag limits and season dates, but by 1970 the Alaska Department of Fish and Game (ADFG) recognized that these were unsustainable and changes in management regulations ensued (ADFG 1960, 1976; Del Frate and Spraker 1994). By 1980 a draw permit system was established in conjunction with registration permits. Draw hunts were split into 35 management units based on survey areas to help distribute hunting pressure (Delfrate and Spraker 1994). Late season registration hunts were held in management units in which harvest opportunity remained after the close of the draw season. Management unit boundaries have remained relatively stable since inception.

The number of management units open to hunting has varied slightly through the years (Delfrate and Spraker 1994, McDonough and Selinger 2008, Herreman 2022), with 32 units open as of 2021 to the possibility of a hunt if management criteria are met. The number of drawing permits allocated to each management unit was originally based on the number of goats observed during surveys, accessibility of the unit, and historical success rates for each unit. Harvest rates for draw hunts were set at 5% of the observed goats in a unit and later increased to 7% (Delfrate and Spraker 1994). The Alaska Board of Game authorized a maximum of 500 draw permits to be issued for all management units combined on the Kenai Peninsula in any given year.

The management objective during the 1990s was to maintain a population of 4,000–4,500 goats, with a predominantly male harvest of greater than 66% (Delfrate and Spraker 1994). Population estimates were calculated as a range, assuming 70–90% of goats were observed during aerial minimum count surveys. The combined draw-registration hunt system was deemed successful (Delfrate and Spraker 1994) until the early 2000s, despite indications of declining populations documented in the late 1990s (Healy 2002).

Due to documented population declines from 1992 to 2000, a regulation change was instituted in 2001 prohibiting hunters from harvesting nannies with kids. With this regulation change, efforts to educate hunters about the negative population effect of harvesting nannies were increased. As populations continued to decline, new managers sought means to reverse the population trend. Beginning in 2008, the ADFG developed and implemented a new management scheme using explicit criteria to determine the number of draw and registration hunting permits issued each year by management unit (McDonough and Selinger 2008). Criteria were based on population size and trends, past harvest rates, sex composition of the harvest, the age of survey data, access, and ecotype (McDonough and Selinger 2008). Additionally, a regulatory penalty for harvesting a nanny was instituted in 2009 that prohibits any hunter that harvested a nanny from hunting mountain goats on the Kenai Peninsula for 5 years. Season length has changed little over the years with draw and registration hunts remaining open from 15 August–14 November. Harvest monitoring has continued through permit reporting since the establishment of harvest permits.

Consistent survey methods for mountain goats on the Kenai Peninsula were established in the 1980s, when summer fixed-wing surveys with pilot-observer teams became the ADFG standard. Nichols (1980) described the ideal conditions under which surveys should be conducted as overcast skies, with soft light and no turbulence. Despite Ballard’s (1975) and Nichol’s (1978) findings that neither temperature nor time of day were correlated to the number of goats seen, early morning and late evening flights, before hunting season, with temperatures below 60°F became the standard on the Kenai Peninsula from the 1980s to early 2000s. However, early morning and late evening flights could result in poor sun angle for observers, and pilot availability during these time windows was often a problem in recent years. Accordingly, surveyors began looking at other survey timing possibilities.

In 2011, work by Jenkins et al. showed less diurnal variation in the presence of goats in alpine survey grids during September versus July and goats being more available in September. The ideal conditions noted by Ballard (1975) and Nichols (1978), anecdotally were more common during fall and late summer than during traditional survey periods centered around the month of July. Temperatures were also cooler during the late summer and fall period than during the traditional survey period, which despite the lack of correlation found in earlier work, may have led to goats being more out in the open and visible. Additionally, if surveys are conducted late enough in the fall, leaf drop may have occurred making goats typically obscured by canopy cover more visible. This information, coupled with the variability of count data between early/midsummer and late summer/fall surveys done several years apart in the same survey area, led the ADFG to initiate paired surveys within the same year to address the question of whether shifting surveys to later in the season would provide better minimum count data.

STUDY AREA

The Kenai Peninsula lies south of Anchorage, Alaska and encompasses an area of approximately 21,748 km^2. Mountain goat habitat is found in the eastern portion of the Kenai Peninsula and was split into 32 different management units ranging in size from 100–1,363 km^2, Kenai Fjords National Park (KFNP) which includes 3 additional management units, and the Cooper Landing Closed Area (CLCA). KFNP and CLCA have been closed to goat hunting since their establishment in 1980 and 1960 respectively (Figure 1). The primary agencies responsible for land management within goat range outside of KFNP are the Chugach National Forest, Kenai National Wildlife Refuge, and Kachemak Bay State Park.

METHODS

We conducted a comparison of mountain goat minimum count numbers, harvest levels, population trends, and survey techniques collected and used prior (1980–2008, Delfrate and Spraker (1994)) to the implementation of the harvest strategy of McDonough and Selinger (2008) with data collected after the implementation of the new strategy (2009–2022) to determine if the population has stabilized under the new management strategy. All analyses were using ADFG goat harvest and survey data collected from 31

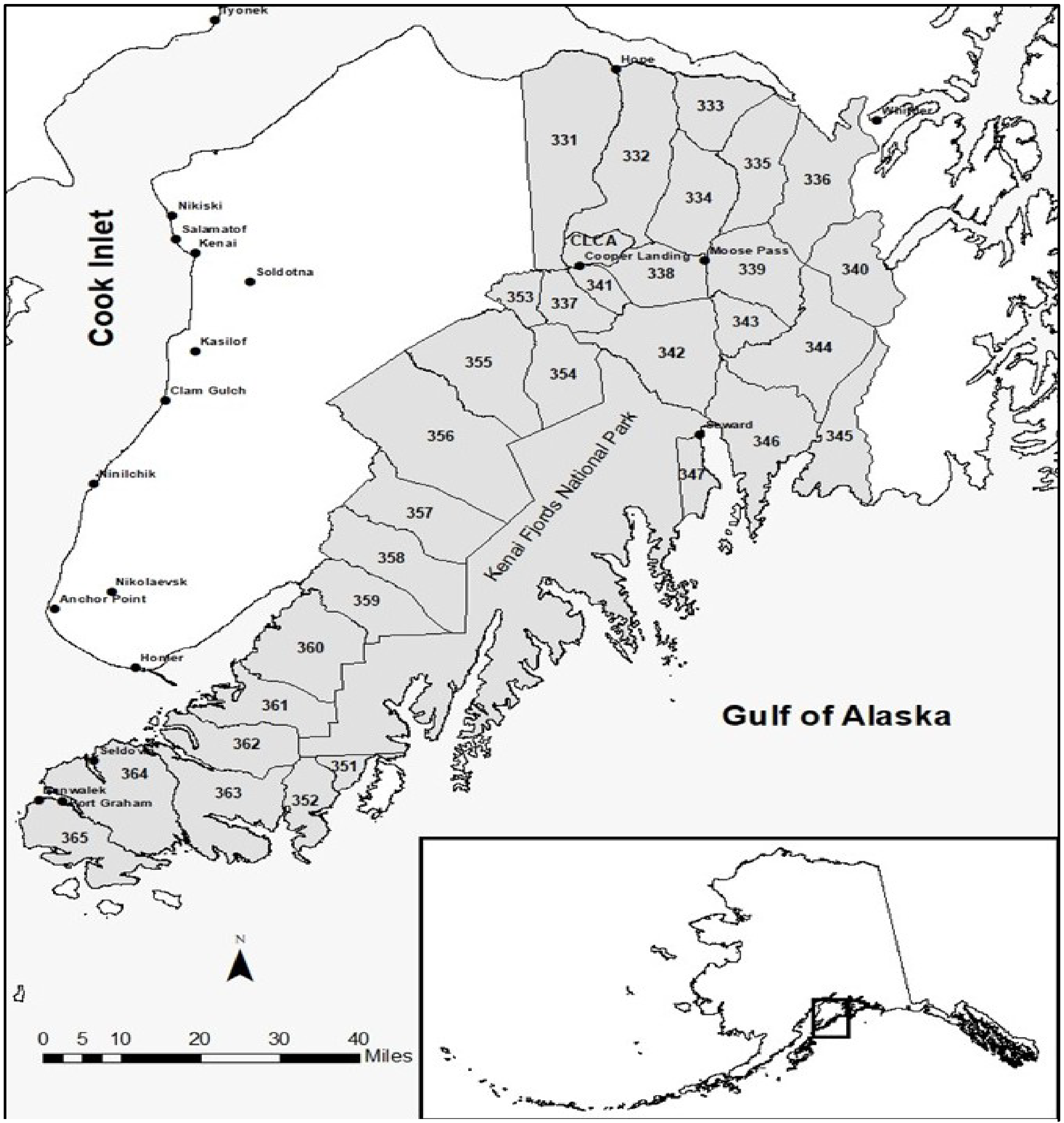

Figure 1. Kenai Peninsula, Alaska mountain goat management units 2022. Note, Kenai Fjords National Park, the Cooper Landing Closed Area (CLCA), and Unit 353 were excluded from all analyses due to a lack of harvest data.

management units (Unit 353 was excluded due to a lack of harvest data) during the period 1980 to 2022. We performed all data manipulation and statistical modeling using R statistical software (R Core Team 2023).

Surveys and effects of survey timing

Survey flight paths followed the topography of the landscape. Transects were flown along elevational contours starting at the tree/alder line working up the mountain. Each mountain face received 2–3 passes depending on the mountain height and observability. When animals were observed, pilots circled the location so that the observer could note the number and classify animals in each group. The location and movement of animals in the group were noted so that on consecutive passes animals were not recounted. By starting transects at low elevation, animals higher on the ridge were less likely to move down into the tree/alder line where they would be unobservable on consecutive passes. Goats were classified as either kids or adults (i.e., yearlings, subadults and adults combined).

Between 2011 to 2019 we opportunistically surveyed 11 management units twice in the same year. Once early in the season between July 14 and September 6 (median, August 1), and once late in the season between September 29 to October 12 (median, October 4). Pilots and observers were not the same between years due to logistical constraints, but all pilots and observers had prior mountain goat survey experience. We compared minimum counts between survey periods using generalized linear mixed (GLM) models as implemented by R-package 'glmmTMB' (Brooks et al. 2017). The response variable, minimum count, was analyzed with respect to factor variable period with 2 levels (early and late). The model included a fixed effect of period, random intercepts for each year and management unit, assumed a negative-binomial distribution of the response variable, and used a logarithmic link function.

Analysis of minimum counts

To analyze trends in total goat minimum counts, we used 459 survey records collected after June 20 of each year as raw data in generalized additive mixed (GAM) models (R-package 'mgcv'; Wood 2011), to estimate the change in minimum count (response) with respect to predictor variables year and day of year (doy) of each survey. The potential for non-linear effects from these variables were characterized using cubic regression spline functions (smooth terms) with 20 and 3 degrees of freedom, respectively. Additionally, the model included random intercept and non-linear slope effects (i.e., factor smoothers) for both doy and year for each management unit. All models used negative-binomial distributions and logarithmic link functions. Using the fitted model, we then created adjusted minimum counts for each year and management unit by using the slope (i.e. β_{doy}), of the doy effect to scale the original minimum counts by the estimated difference in expected count between October 1 and the date the survey occurred.

Analysis of changes in goat harvest

We assembled harvest data from permit reports. We then matched annual goat harvest records with adjusted minimum counts within the same management unit and year to produce 330 records that spanned years 1982 through 2021. We analyzed changes in total adult and nanny harvest rates using 2 GAM models. Each model included either total adult or nanny harvest count as response variable and year as the predictor variable coded as a cubic regression smooth term with 20 degrees of freedom. These models included adjusted minimum count as an offset term (converting the response to a rate), random intercepts and year effect factor smooths for each management unit and used a negative-binomial distribution and logarithmic link function.

Finally, using harvest data from 1982 through 2021, we analyzed the 869 records where at least one goat was killed to estimate the proportion of nanny harvest. We used a GAM model to estimate changes in harvested nannies relative to total harvested goats (response) in association with year (predictor) coded as a cubic regression smooth term with 20 degrees of freedom. This model included random intercepts and year effect factor smoothed for each management unit and used a binomial distribution and logit link function.

All models were fit using restricted maximum likelihood, and goodness-of-fit was evaluated against the random effects only (i.e., null) equivalent by likelihood ratio test. Additionally, residuals were inspected to ensure assumptions were not violated using R-package 'DHARMa' (Hartig 2022). Non-significant terms were removed stepwise based on α = 0.05 for linear terms and α = 0.01 for non-linear (i.e., GAMM smoother) terms. In GAM models, we recoded smooth terms to linear terms when they were found to have an estimated degree of freedom (edf) of nearly 1 (i.e., an indication that the response was linear). Simulations based on model posterior estimates were used to produce mean and 95% lower and upper confidence limits estimates for minimum counts, percent nanny harvest, and harvest rates across years within each of the 3 time periods of interest.

RESULTS

Survey timing

The GLM model describing the association between minimum counts and time period (late versus early) was found to have acceptable goodness-of-fit based on null likelihood ratio test ($\chi^2_{df=1}$ = 9.9, *P* = 0.002) and model residuals. Minimum counts were found to be positively associated with doy (β = 0.75, σ = 0.22, *P* = 0.001). The expected mean minimum goat count was 30 (95% confidence interval 15–61) during early season (median: August 1) and 62 (95% confidence interval: 40–102) during late season (median: October 4) surveys (Figure 2).

The model for describing trends in goat minimum counts had acceptable fit (LR: $\chi^2_{df = 28.1}$ = 49.9, *P* = 0.007) and properly distributed model residuals. Furthermore, this model explained a large amount of variance in minimum counts (deviance explained = 88.8%). Based on approximate significance for model terms, minimum counts were strongly associated with both doy ($\chi^2_{edf = 1.4}$ = 8.2, *P* = 0.007) and year

($\chi^2_{edf = 7.4}$ = 80.5, P < 0.001). The effect of doy on minimum counts was found to be positive but only marginally non-linear based on edf = 1.4. We, therefore, re-fit the model including doy as a linear term to help simplify the description of this effect (β = 0.0035, σ = 0.0012, P = 0.003). We presented the non-linear and linear effects of doy in Figure 3.

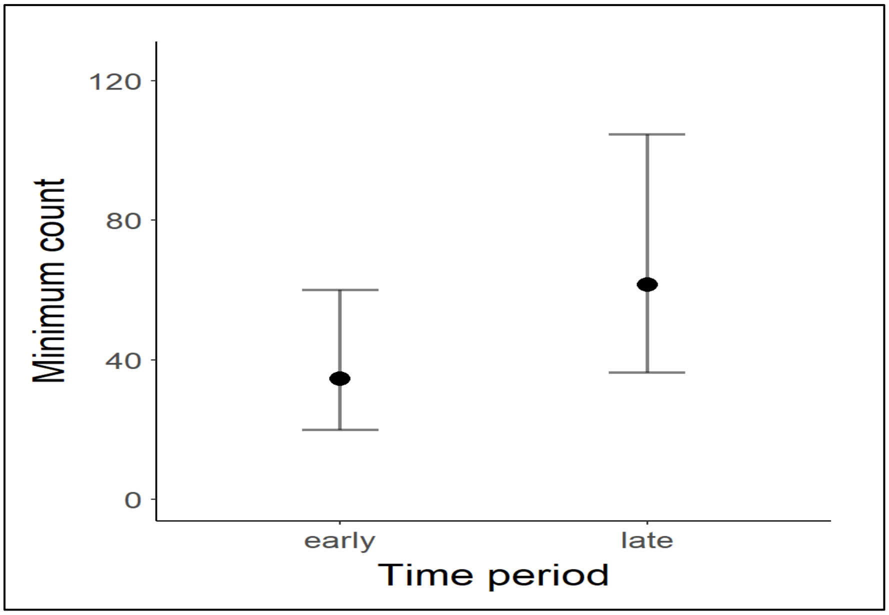

Figure 2. Mean (solid circle) and 95% confidence intervals for estimated mountain goat minimum counts during surveys conducted early (median date August 1) and late (median date October 1) in the same unit and year Kenai Peninsula, AK.

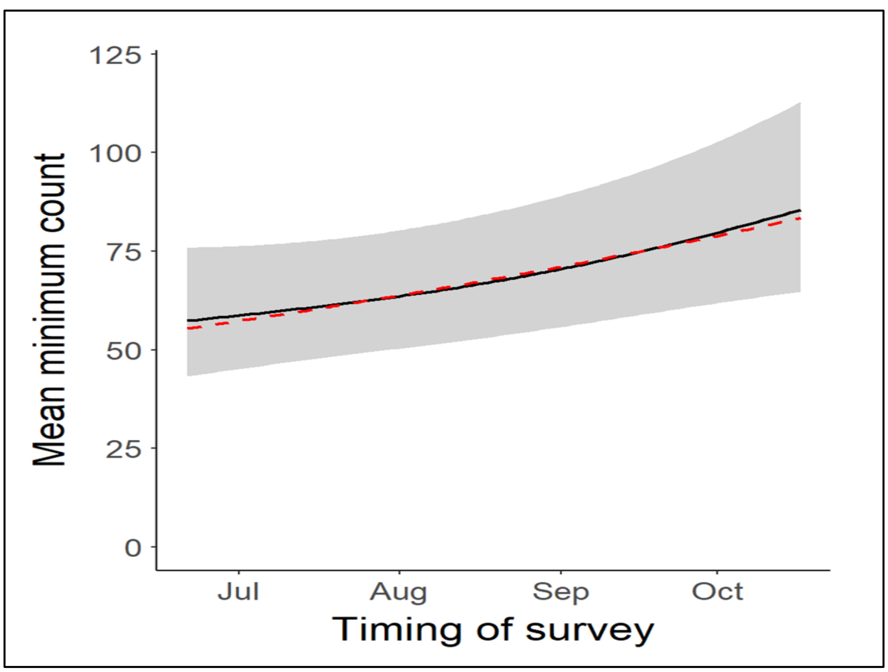

Figure 3. The estimated mean non-linear (solid curve) and linear (dashed line) effect of timing of survey (i.e., survey day of year) on mountain goat minimum counts as estimated by generalized additive mixed models. The 95% confidence limits are shown in in grey, Kenai Peninsula, AK.

Estimates for minimum count adjusted for doy of October 1 (Figure 4) showed a steep rise in counts from 1980 until 1992, a decline until 2005, and then a moderate rise until 2023, the end of the analysis period. There was considerable overlap in the confidence intervals and little trend in the adjusted minimum count estimates of 88.5 (95% confidence interval 39.2–133.7) during the period with no nanny restrictions, 72.0 (95% confidence interval 53.1–96.9) during the period with no harvest of nannies with kids, and 80.6 (95% confidence interval 58.9–118.8) during the period with a penalty for harvest of nannies with kids (Figure 5A).

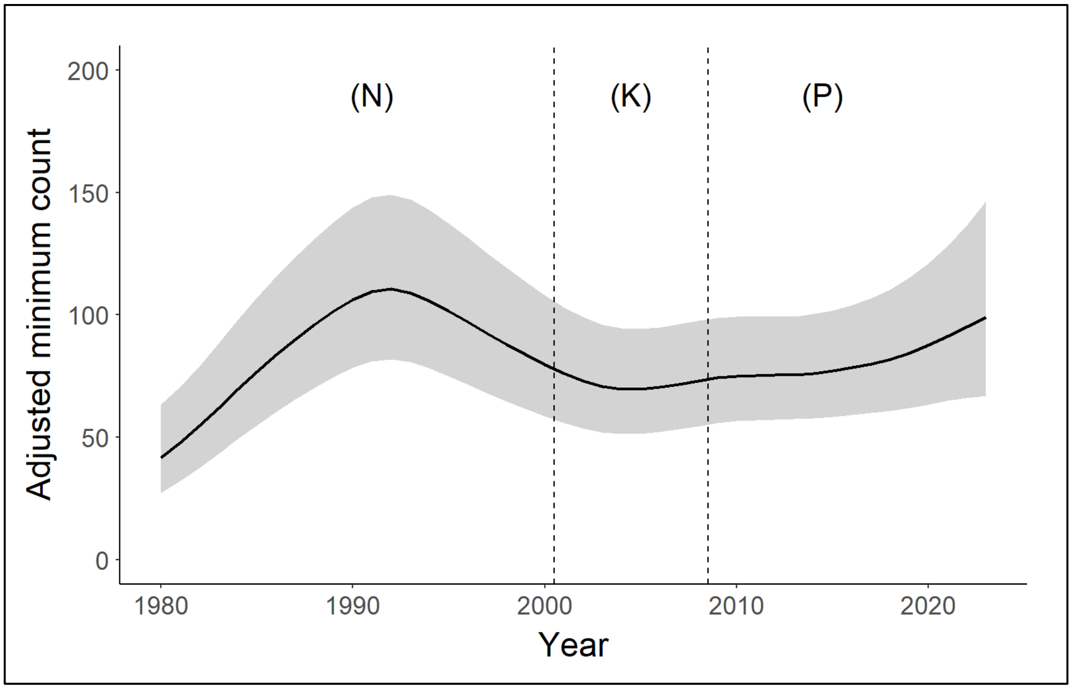

Figure 4. The estimated mean (black) and 95% confidence intervals (grey) for changes in adjusted mountain goat minimum counts over time and across 3 time periods that had no nanny harvest restrictions (N), restriction on harvest of nannies with kids (K), and a 5-y ear penalty for harvest of nannies with kids (P) Kenai Peninsula, AK. Estimates were based on the marginal generalized additive mixed model effects for year with timing of surveys of October 1.

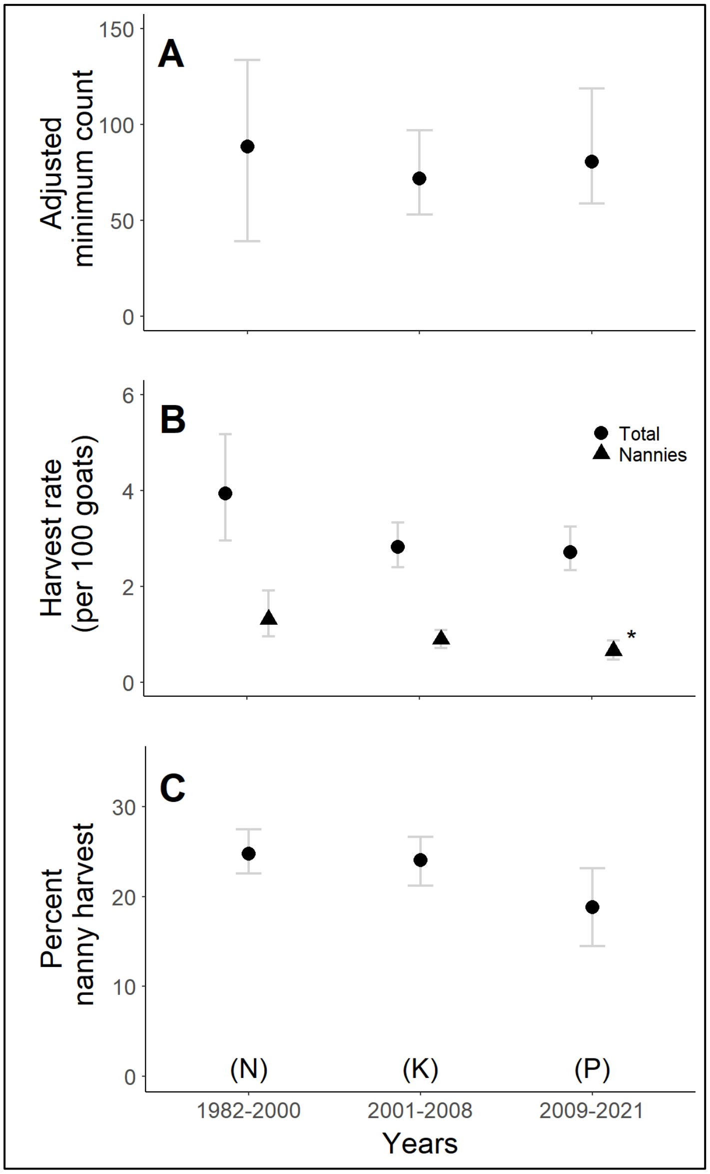

Figure 5. Estimated means (solid circles) and 95% confidence intervals (error bars) for adjusted mountain goat minimum counts (A), total and nanny harvest rates (B), and percent nanny harvest (C) across 3 time periods that had no nanny harvest restrictions (N), restriction on harvest of nannies with kids (K), and a 5-year penalty for harvest of nannies with kids (P) Kenai Peninsula, AK. All estimates were simulated using model posterior estimates for all years represented within each time period. As indicated by an asterisk (*), nanny harvest rates in the period with a 5-year penalty for harvest of nannies with kids was statistically lower than the period with no nanny harvest restrictions.

Total harvest rate had a strong, non-linear association with year ($\chi\chi^2_{eedddd = 2.7}$ = 36.1, *P* < 0.001) demonstrated in a moderate downward trend until flattening in 2009 (Figure 6), which coincided with implementation of the harvest strategy of McDonough and Selinger (2008). Although confidence intervals overlapped for estimates across time periods (Figure 5B), harvest rates tended to be lower during the periods with restriction on harvest of nannies with kids (mean = 2.82; 95% 95% confidence interval 2.40–3.33) and 5-year penalty for harvest of nannies with kids (mean = 2.71; 95% confidence interval 2.33–3.24) than during the period with no restrictions (mean = 3.93; 95% confidence interval 2.95–5.18).

Nanny harvest rates had a strong association with year ($\chi\chi^2_{eedddd = 1.001}$ = 31.6, *P* < 0.001) demonstrated in a relatively consistent and nearly linear decline over the period of analysis (Figure 6). After re-coding the year term to be linear in the model, the effect remained highly significant ($\beta\beta$ = -0.029, σ� = 0.0052, P < 0.001) and showed a 2.9% decline in nanny harvest per year over the entire period of analysis. Over the three different nanny harvest restriction periods, nanny harvest rates were 1.31 (95% confidence interval 0.96–1.91) when no restrictions were imposed, 0.89 (95% confidence interval 0.71–1.09) with restrictions on harvest with kids were applied, and 0.66 (95% confidence interval 0.47–0.87) when penalties were imposed on harvest of nannies. Based on non-overlapping confidence intervals, nanny harvest rate during the period with penalties was lower than the period with no restrictions (Figure 5B). Similar to the harvest rate models, the year effect factor smooths (random effects) did not contribute to the fit of the relative nanny harvest model ($\chi\chi^2_{dddd = 0.63}$ = 0.43, P = 0.35) and we removed it. The resulting model included year smoothed fixed-effects and random intercepts by management unit and had acceptable fit (LRT: $\chi\chi^2_{dddd = 4.82}$ = 29.6, *P* ≤ 0.001) and well-distributed residuals. Although this model only explained 5.6% of the deviance in relative nanny harvest, there was a strong non-linear association with year ($\chi\chi^2_{dddd = 3.74}$ = 26.1, *P* < 0.001). Model estimates showed that percent nanny harvest remained relatively constant until 2000 and then declined until the end of the analysis period in 2023 (Figure 7). Percent nanny harvest was 24.7% (95% confidence interval 22.6–27.5%), 24.0% (95% confidence interval 21.2–26.6%), and 18.8% (95% confidence interval 14.5–23.1%) over the three periods with differing nanny harvest restrictions (Figure 5C).

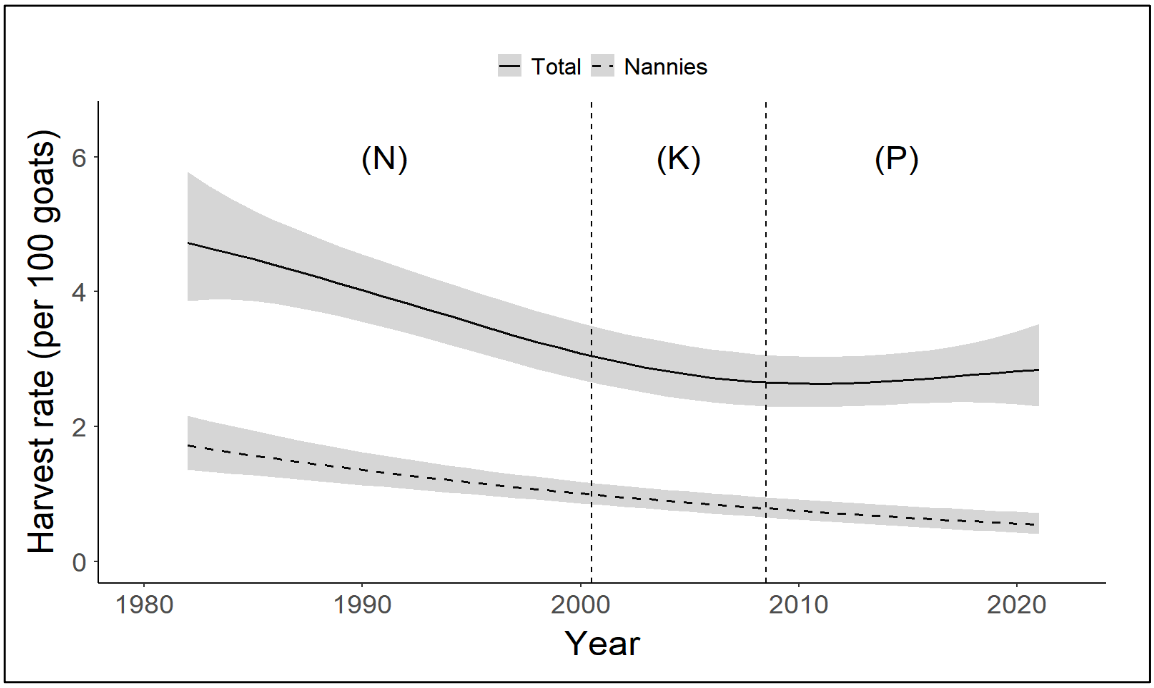

Figure 6. The estimated mean change in total mountain goat (solid) and nanny (dashed) harvest and 95% confidence intervals (grey) over time and across three time periods with no nanny harvest restrictions (N), restriction on harvest of nannies with kids.

DISCUSSION

Mountain goat minimum count numbers on the Kenai Peninsula peaked in the 1990s and then began a steady decline into the early 2000s (Figure 4). Managers needed an effective way to reverse the population trajectory. The most readily available tool that managers had to affect goat populations was through the manipulation of harvest. ADFG began incremental harvest changes to curb population decline and with the hopes of initiating population recovery. At the same time, there was a notable change in survey timing as managers attempted to maximize minimum count surveys. Although not consistent across time and survey units, past surveys tended to occur during the summer season with early morning or late evening flights whereas more recent surveys occurred in the fall during midday. Because time of day was not consistently recorded, we did not address the effect of time of day on survey results; however, we did show a positive effect of day of year on the minimum number of animals seen (Figure 2 and 3). For that reason, we adjusted minimum count levels by survey timing before comparisons were made to determine if goat numbers had improved. Adjusting the minimum count levels did not affect the overall trend in minimum count data seen before adjustments.

Management changes reducing harvest pressure (Figure 6) were not enough to stem population declines of Kenai Peninsula mountain goats. The subsequent protection of nannies with kids from harvest in 2001 appeared to slow declines (Figure 4) but only slightly reduced the percent of nanny harvest (Figure 7) and was not enough to reverse the population trajectory. Trends were not affected until the institution in 2009 of the 5-year penalty for harvesting a nanny. We hypothesize that the removal of nannies with kids from the harvest was insufficient to reverse the overall trajectory of the population due to mountain goat reproductive constraints such as late age of primiparity, small litter size, and reproductive pauses (Festa-Bianchet and Côte 2008). The addition of a penalty for harvesting a nanny and increased educational efforts on mountain goat sex identification; however, does appear to have allowed for the recovery of most goat subpopulations on the Kenai Peninsula. The harvest rate of nannies significantly declined (Figure 5B), which likely increased reproduction. The increased reproduction combined with the protection of nannies with kids led to increased recruitment. As suggested by Hamel et al. (2006), management of female harvest appears to have one of the greatest effects on the viability of mountain goat populations on

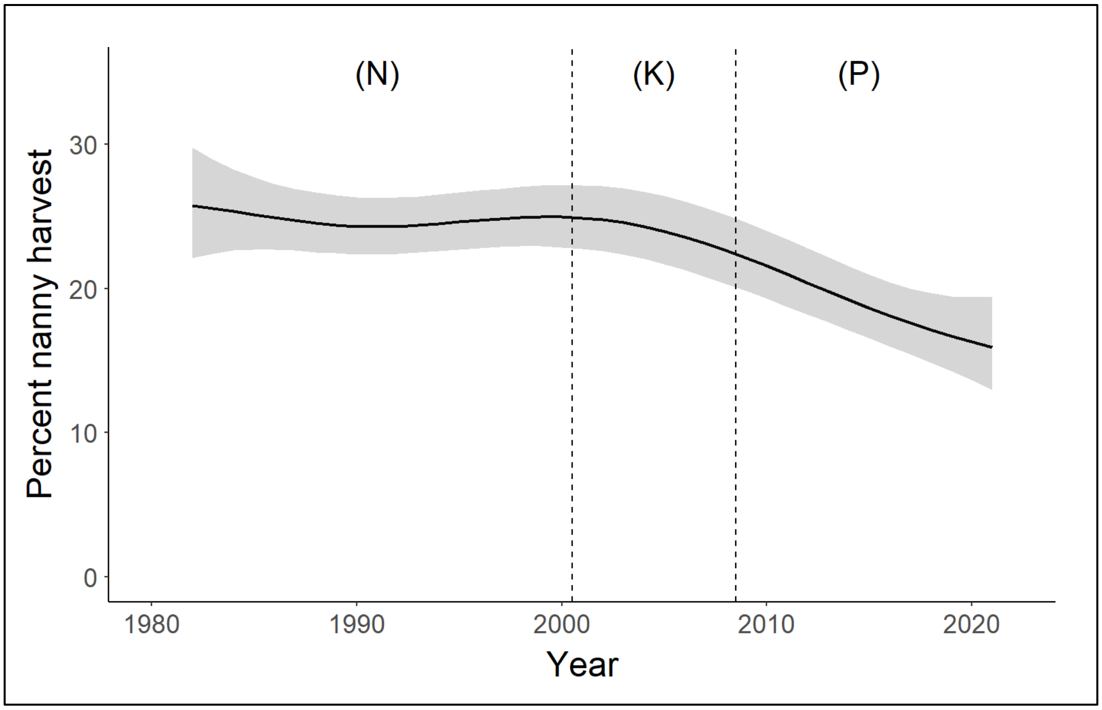

Figure 7. The estimated mean (black) and 95% confidence intervals (grey) for changes in percent of total mountain goat harvest represented by nannies across three time periods that had no nanny harvest restrictions (N), restriction on harvest of nannies with kids.

the Kenai Peninsula. Surveys beginning in 2021 indicated the mountain goat minimum count for the Kenai Peninsula had returned to near historic levels (Figure 4) and the peninsula wide harvest rate stabilized around 3% (Figure 6). Actual harvest rate varied by management unit but remained under 4% (J.K. Herreman, ADFG, Unpublished data) for all units since switching to the new management structure, which was lower than the 5–7% harvest targets set under the old management structure (Delfrate and Spraker 1994).

Although mountain goat numbers on the Kenai Peninsula recovered under the current hunt management structure, it may still be possible to improve on the system and increase harvest opportunity without detrimentally impacting goat numbers. For example, the current system relies on a limited late season hunt to maximize harvest opportunity. The late season currently overlaps with the rut, when billies are mixing more with nanny groups, which may increase the chance of sex misidentification by hunters. Access to many areas increases in difficulty during the late harvest season due to deteriorating weather conditions, increasing the chance that hunters may shoot the first available goat. Additionally, some hunters may choose to shoot a nanny to avoid the stronger taste of a rutting billy. Thus, moving the late season out of rut might further decrease female harvest and increase kid production. We recommend that managers continue to pursue avenues to improve harvest management such as restructuring management boundaries if deemed appropriate and pursing changes in season dates to further ensure sustainable nanny harvest and improve access.

Mountain goats and the biologists who manage them continue to face the unknown challenges and complications of changing environmental conditions. The effects of increasing summer and seasonal temperatures, changes in alpine plant communities, conversion of alpine habitats, increasing frequency of winter icing or rain-on-snow events, and changes in precipitation regimes (Dial et al. 2007, Ernakovich et al. 2014, Pan et. al. 2018, White et al. 2018, 2025) will all likely factor into the future changes of mountain goat population numbers. Additionally, changes in human use of mountain goat habitat as human populations increase and access to goat habitat increases will continue to add additional stressors. Managers will need to continue adapting to changing conditions to ensure the viability of mountain goats on the Kenai Peninsula and studies like this that increase the understanding of drivers of goat populations and hunter dynamics are important.

MANAGEMENT IMPLICATIONS

The manipulation of nanny take in the harvest appears to be the most important harvest factor managers can control to affect population trajectory of mountain goat populations. Effective management structures need to be flexible enough to allow managers to manipulate nanny harvest within short time frames to address population trajectory even when declines or increases are the effect of factors outside the managers control such as winter events or disease outbreaks. Standardizing surveys to the fall will maximize minimum counts and provide managers with more consistent information.

ACKNOWLEDGMENTS

We thank the many biologists, technicians, and pilots that helped collect the data used in this analysis. We are particularly grateful to N. Olson and the U.S. Fish and Wildlife Service for lending logistical support in our efforts to compare early and late minimum counts and to J. de Creeft who has piloted mountain goat surveys for ADFG for over 30 years.

ETHICS STATEMENT

This study adhered to all relevant regulations and guidelines regarding the ethics of animal welfare.

REFERENCES

Alaska Department of Fish and Game. 1960. Alaska game regulations 1960 Edition. Alaska Department of Fish and Game, Juneau, Alaska.

Alaska Department of Fish and Game. 1976. Alaska wildlife management plans: A public proposal for the management of Alaska's wildlife: Southcentral Alaska. Draft proposal subsequently approved by the Alaska Board of Game. Division of Game, Federal Aid in Wildlife Restoration Project W-17-R, Juneau.

Ballard, W. 1975. Mountain goat survey technique evaluation. Alaska Department of Fish and Game, Division of Game, Federal Aid Final Report 1 July 1974–30 June 1975, Federal Aid in Wildlife Restoration Job 12.2R, Juneau.

Brooks, M. E., K. Kristensen, K. J. van, A. Magnusson, C. W. Berg, A. Nielsen, H. J. Skaug, M. Maechler, and B. M. Bolker. 2017. "glmm TMB Balances Speed and Flexibility Among Packages for Zero-Inflated Generalized Linear Mixed Modeling" 9. https://doi.org/10.32614/RJ-2017-066.

Del Frate, G. G., and T. H. Spraker. 1994. The success of mountain goat management on the Kenai Peninsula in Alaska. Pages 92-98 [In] M. Pybus, editor. Proceedings of the ninth biennial symposium of the Northern Wild Sheep and Goat Council, 2–6 May 1994, Cranbrook, British Columbia, Canada.

Dial, R. J., E. E. Berg, K. Timm, A. McMahon, and J. Geck. 2007. Changes in the alpine forest-tundra ecotone commensurate with recent warming in southcentral Alaska: Evidence from orthophotos and field plots, J. Geophys. Res., 112, G04015. doi:10.1029/2007JG000453.

Ernakovich, J. G., K. A. Hopping, A. B. Berdanier, R. T. Simpson, E. J. Kachergis, H. Steltzer, and M. D. Wallenstein. 2014. Predicted responses of arctic and alpine ecosystems to altered seasonality under climate change. Global Change Biology, doi: 10.1111/gcb.12568.

Festa-Bianchet, M., and S. D. Côte´. 2008. Ecology, behavior, and conservation of an alpine ungulate, Island Press, Washington, DC.

Hamel, S., S. D. Côte´, K. G. Smith, and M. Festa-Bianchet. 2006. Population Dynamics and Harvest Potential of Mountain Goat Herds in Alberta. Journal of wildlife Management 70: 1044–1053.

Hartig, Florian. 2022. "DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models." https://CRAN.R-project.org/package=DHARMa.

Healy, C., editor. 2002. Mountain goat management report of survey-inventory activities 1 July 1999–30 June 2001. Alaska Department of Fish and Game, Division of Wildlife Conservation, Federal Aid in Wildlife Restoration Project 12.0, Juneau.

Herreman, J. 2022. Mountain Goat management report and plan, Game Management Units 7 and 15: Report period 1 July 2013–30 June 2018, and plan period 1 July 2018–30 June 2023. Alaska Department of Fish and Game, Species Management Report and Plan ADF&G/DWC/SMR&P-2022-8, Juneau.

Jenkins, K. J., K. Beirne, P. Happe, R. Hoffman, and J. Schaberl. 2011. Seasonal Distribution and Aerial Surveys of Mountain Goats in Mount Rainier, North Cascades, and Olympic National Parks, Washington. Open-File Report 2011-1107. U.S. Department of the Interior. U.S. Geological Survey.

Lentfer, J.W. 1955. A two-year study of the Rocky Mountain goat in the Crazy Mountains, Montana. Journal of Wildlife management. 19: 417–429.

McDonough, T. J., and J. S. Selinger. 2008. Mountain goat management on the Kenai Peninsula, Alaska: A new direction. Pages 50–67 [In] Proceedings of the 16th biennial symposium of the Northern Wild Sheep and Goat Council, 27 April–1 May 2008, Midway, Utah.

Nowacki, G., P. Spencer, M. Fleming, T. Brock, and T. Jorgenson. 2001. Ecoregions of Alaska: 2001. USGS Open-File Report 02-297 (map).

Nichols, L. 1978. Mountain goat aerial survey technique evaluation. Alaska Department of Fish and Game, Division of Game, Federal Aid Project Progress Report 1 July 1976–31 December 1977, Federal Aid in Wildlife Restoration Jobs 12.2R and 12.3R, Juneau.

Nichols, L. 1980. Aerial Census and Classification of Mountain Goats in Alaska. Proceedings Biennial Symposium. North American Wild Sheep and Goat Council. 2:523–589.

Pan, C. G., P. B Kirchner, J. S. Kimball, Y. Kim, and J. Du. 2018. Rain-on snow events in Alaska, their frequency and distribution from satellite observations. Environmental Research Letters 13 075004.

.

R Core Team. 2023. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria.

White, K. S., D. P. Gregovich, and T. Levi. 2018. Projecting the future of an alpine ungulate under climate change scenarios. Global Change Biology. 24: 1136–1149.

White, K. S., B. Cadsand, S. Côté, T. Graves, S. Hamel, R. B. Harris, F. P. Hayes, E. Hood., K. Hurley, T. Jessen, B. Jex, E. Peitzsch, W. Sarmento, H. Schwantje, and J. Berger. 2025. Mountain sentinels in a changing world: review and conservation implications of weather and climate effects on North American mountain goats (*Oreamnos americanus*). Global Ecology and Conservation. 57: e03364.

United States Census Bureau [USCB]. 2024. USCB homepage. <https://data.census.gov>. Accessed 3 April 2004.

Wood, S. N. 2011. “Fast Stable Restricted Maximum Likelihood and Marginal Likelihood Estimation of Semiparametric Generalized Linear Models” 73: 3–36.