Reintroducing and augmenting mountain goat populations in the north Cascades: Translocations from the Olympic Peninsula, 2018-2020

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ABSTRACT: In response to a long-term decline in abundance of mountain goats (*Oreamnos americanus*) in many parts of their historic range within Washington's Cascade Mountains, and taking advantage of Olympic National Park's desire to remove non-native goats, the Washington Department of Fish and Wildlife led an effort to restore goat populations via reintroductions sourced from the Olympic Peninsula during 2018-2020. Following analyses that suggested where goats were most needed and would likely fair best, 326 goats (182 ♀, 144 ♂) were released at 17 sites ($\bar{x}$ = 20.4 goats, minimum = 5, maximum = 49) over the course of 4 summer-time bouts; 262 were equipped with GPS collars allowing monitoring of survival and movements. Because most goats moved considerably after release, we found it useful to view them as having formed 6 population clusters ($\bar{x}$ = 54.3 goats released/cluster). We analyzed adult (age 1+) survival and associated covariates at 3 temporal scales 1) 150 days, which we considered the acclimation period, 2) 150 days to 1 year, and 3) after 1 year. Overall annualized adult (age 1+) survival was 0.53 for females and 0.58 for males; survival was slightly lower during the initial acclimation period, but at ~ 0.8-0.9 approached rates needed for population growth among those surviving a year in some population clusters. Adult females with higher body condition score survived better than those with lower scores. Kids were always abandoned by their mothers upon release, but at 0.25, estimated survival of orphans we monitored was higher than expected. The degree to which the translocation program succeeded in restoring inter-connected mountain goat populations in Washington's Cascade mountains will not be known for a few more years.

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INTRODUCTION

Mountain goats (*Oreamnos americanus*), native to the entire Cascade Range of Washington, declined considerably during 1940s-1980s (Johnson 1983), at least in part due to excessive legal recreational harvest (Rice and Gay 2010, Rice 2012). Throughout western North America most jurisdictions with mountain goats misunderstood goat biology during those earlier decades (Toweill *et al.* 2004), typically offered greater harvest opportunities than populations could withstand (Kuck 1977, Hamel *et al.* 2006), and most native populations experienced reductions (Decesare and Smith 2018). Beginning about 2000, the Washington Department of Fish and Wildlife (WDFW) has managed recreational goat harvest conservatively, and goats in some areas of the North Cascades have recovered (WDFW 2015). However, recovery in other portions of the North Cascades was very slow or absent. Rice (2012) combined rigorous estimates with educated guesses in postulating a total mountain goat population in Washington State during the 2004-2007 period at 2,400–3,200 animals. This estimate incorporated national parks (including the introduced goats in Olympic National Park) and illuminated marked heterogeneity in the status of populations managed by WDFW. By 2011, based on aerial surveys indicating specific sections of Washington's Cascades either avoided the general decline or recovered naturally, WDFW began offering limited (lottery permit-only) licenses within 10 hunting districts in the Cascade Mountains. However, excluding these hunting districts and national parks, estimates by Rice (2012) suggested only 530-930 mountain goats remained, scattered within the remainder of Cascade Range in Washington from the British Columbia boundary in the north to Mt. St. Helens in the south.

Genetic diversity among goats in the Washington Cascades also was a concern. Heterozygosity and allelic diversity were lower among a small sample of these goats than larger, more connected populations in Alberta and British Columbia (Shafer *et al.* 2011), with genetic diversity within Washington declining from north to south (Parks *et al.* 2015). Cowan and McCrory (1970) noted that skulls from three Washington mountain goats were missing the first two molars on one or more tooth rows and suggested the possibility of a genetic mechanism for these abnormalities. However, if so, this was unlikely to be a selective adaptation; it seems more likely an expression of deleterious alleles. Parks *et al.* (2015) suggested that geographic and topographic characteristics limited gene flow among goat groups at a fine geographic scale. Additionally, Interstate Highway 90 was identified as an impediment to gene flow between northern and southern portions of the Washington Cascade Range (Shirk *et al.* 2010, Parks *et al.* 2015).

For these reasons, WDFW has long considered translocation an appropriate tool to restore this valuable component of the alpine ecosystem to its historic abundance (WDFW 2015), an objective shared and supported by the consortium of Native American tribes in the region (co-managers and signatories to the Point Elliott Treaty of 1855). Because the abundant mountain goats on the Olympia Peninsula (OP), particularly within Olympic National Park (ONP) were not native (introduced in the 1920s, Houston *et al.* 1994), when the opportunity arose to procure goats to replenish depleted populations in the Cascades, WDFW entered into a cooperative agreement with the National Park Service and the U.S. Forest Service. National Park Service (2018) provides additional details on the rationale for removing mountain goats from the OP, as well as the work conducted during 2018-2020 to provide animals for this translocation.

Considerations regarding source goats for translocation

Disease

Mountain goats can have diseases and parasites that cause morbidity and mortality for individuals. Until recently, when pneumonia associated with the bacterium *Mycoplasma ovipneumoniae* was implicated in a local die-off in Nevada (Wolff *et al.* 2014, 2016), neither diseases nor parasites were considered major mortality factors with population-level consequences (Côté and Festa-Bianchet 2003). We were unable to perform a thorough screening of the source population prior to translocations, but reasoned that whatever diseases and parasites may have affected OP goats failed to preclude marked population growth. Additionally, we had no reason to suspect that OP goats carried diseases or parasites not already present among resident animals in the Cascades because i) from 1972 to 1985, ONP conducted 7 translocations of mountain goats into the Washington Cascades (totaling 149 animals), so any diseases and parasites OP goats carried had long-since been introduced, and ii) work by Johnson (1983) and Foreyt (1989) quantified that parasites present in ONP goats were always present (and often in higher prevalence than on the OP) among native Cascade goats.

Nonetheless, our processing protocols included examining all goats at capture for evidence of disease, and testing all kids captured for genetic evidence of *Cryptosporidium* and *Giardia* sp., as well as Johne's disease (*Mycobacterium paratuberculosis*; Williams *et al.* 1979) and *M. ovipneumoniae* (present in mountain goats outside Washington State). The decision to translocate or euthanize individuals was made by project veterinarians on-site.

Genetics

We expected that augmenting Cascades populations with OP goats could restore missing alleles that may have been lost to drift and could reduce the probability of inbreeding. Although no subspecies of mountain goats are recognized (Côté and Festa-Bianchet 2003), OP goats were derived from Alaskan and British Columbia founders, and were differentiable from native Cascades goats at the molecular level (Shirk 2009). Thus, we considered possible adverse consequences if any local adaptations in Cascades goats were susceptible to being swamped or overridden by maladaptive traits among OP mountain goats. Balancing these two unknowns, we concluded that the probable genetic benefits outweighed the potential risks associated with outbreeding depression (National Park Service 2018: J-21).

Habituation, salt conditioning, and aggressiveness

National Park Service (2018) identified issues of mountain goats being habituated to humans on foot, conditioned to seeking salt, or being aggressive to people within ONP and potentially after being translocated. Because ONP could not identify the habituation or salt-conditioning status of each mountain goat prior to the project, goats residing in areas known to have high human visitation and a history of containing habituated goats were classified as "habituated"; all others were classified "non-habituated". Translocation protocols called for "habituated" goats to be released only in remote areas, and for subsequent monitoring in light of each individual's pre-translocation habituation characterization. In addition, any goat considered by NPS staff to be "aggressive" (having direct contact with a person) would be euthanized rather than translocated.

Selection of release sites

Simply knowing that large-scale declines occurred within broad sections of the North Cascades constituted only the starting point in our assessment of optimal sites for field releases. Analyses of previous mountain goat translocations into native habitat (Harris and Steele 2014) showed that long-term success was likely only if each selected area could receive at least 30 adult females and 15 adult males (we expected fewer than 400 goats). Consequently, we attempted to prioritize the top ~12 sites within the project area to function as presumptive population nuclei. To identify suitable sites for mountain goat translocation, we evaluated habitat suitability, connectivity, historic harvest, potential population density, whether the polygon containing the site was occupied by mountain goats, an extrapolated assessment of forage abundance and quality based on geological characteristics, and finally, the logistics of getting goats to the site (details in Harris and Rice 2018).

Occupied or unoccupied

We classified patches as occupied (estimated population >25% of potential population) or unoccupied (all others) by comparing the estimated densities from Rice (2012) with the potential densities (see below). We also sub-classified occupied patches as 25-50% of their potential population and >50%. Unoccupied patches were sub-classified as either 10-25% or <10% of their potential population size.

Habitat and identification of habitat polygons containing potential sites

We defined summer mountain goat habitat based on the raster map of mountain goat habitat developed by Wells *et al.* (2011). At a broad scale, we aggregated the habitat pixels to 125 × 125 m using the median value of the 25 original cells. The aggregated pixels were grouped (using 8 adjacent cells) to identify habitat pixels adjacent to one another. The grouped pixels were converted to a polygon shapefile. The resulting shapefile contained 13,592 polygons of mountain goat summer habitat. Most of these were small, so to concentrate on main areas of habitat we removed all that were <0.25 km^2 (0.1 mi^2) in area. This resulted in 36 habitat polygons with areas ranging from 0.25 to 185 km^2 (0.1 to 71.4 mi^2).

Connectivity

Many of the resultant 36 habitat polygons were near others. Because mountain goats cross unsuitable habitat to access nearby patches (Côté and Festa-Bianchet 2003, Rice 2008), we evaluated connectivity of the habitat polygons. We used Least Cost Path analysis to determine resistance to movement between polygons based on the isolation-by-resistance model of Shirk *et al.* (2010). We removed 4 polygons from consideration because they were in unsuitable locations. Among the 32 remaining patches, 10 were occupied and 22 were unoccupied. Connectivity was assessed for every pair of these 32 patches using Linkage Mapper Connectivity Analysis Software (McRae and Kavanagh 2011). Linkage Mapper produced a table of the least cost path movement costs for each patch pair.

In addition to dispersal resistance to other patches, we considered the amount of habitat or the expected mountain goat population in other patches, and whether the connection was to another unoccupied patch or an occupied patch (i.e., connections between patches with large potential populations were considered better than between patches with small population potential). Also, a patch highly connected to an occupied patch would not be a high priority for translocation. Potential natural dispersal to that patch by our released goats could compete with potential natural dispersal and colonization. To quantify these considerations, we calculated an inter-patch connectivity score as follows:

$$ConIndex = \frac{PopEstA + PopEstB}{KmEq}\begin{pmatrix} UnoccupiedA \land UnoccupiedB \to 1 \\ OccupiedA \lor OccupiedB \to -1 \end{pmatrix}$$

where: *ConIndex* = the connectivity index
KmEq = *A* to *B* isolation kilometer equivalents
PopEstA and *PopEstB* = estimated population potential for patches *A* and *B*
Unoccupied, Occupied = whether patches *A* and *B* were occupied.

Values of ConIndex were near zero when patches were separated by large distances (e.g., >100 km), especially if the potential population sizes were small (e.g., estimated at < 25 individuals). Large potential populations connected by small distances had a high index value if both were unoccupied, but a highly negative index if either was occupied. The score applied to each patch was the median ConIndex from it to all other unoccupied patches.

Historic harvest

We enumerated the historic harvest for each area as an indicator of prior abundance (subject to interpretations we added about hunter accessibility and popularity). From 1947 through 1970, hunters reported mountain goat kills by providing a place name and drainage (n = 4,373 records).

Potential population size

We matched population estimates by Rice (2012) with habitat polygons, and those considered depressed populations were removed from analysis. We estimated the density (mountain goats/km^2 of habitat) for each polygon. Because the distribution of these densities was highly skewed, we log-transformed the data. Log-densities were not significantly different between surveyed and expert-estimated areas ($F_{1,24}$ = 1.278, P = 0.2695), so we used the overall mean log-density of 0.871 (SE = 0.253, n = 26; i.e., 2.3 mountain goats/km^2, 95% CI = 1.3-3.9). We then estimated the population potential of each habitat patch by multiplying its area by mean population density. Because mountain goat translocations ideally focus on areas with significant population potential, we selected all patches with a population potential of >25 mountain goats. However, 6 patches were added because it appeared, based on personal knowledge of those areas and the number of mountain goats within them, that the habitat model under-represented the area, and hence population potential in those patches. Each of these 32 patches was named based on the geographic features it contained.

Extrapolation of forage suitability based on geological substrate

Preliminary observations indicated that areas that had adequate escape terrain, but historically low density mountain goat populations (particularly in and around North Cascades National Park), were characterized by predominately plutonic geological formations. Therefore, we examined our hypothesis that geological substrate could serve as an additional indicator of mountain goat habitat quality, and thus indirectly predict long-term carrying capacity for goats. Based on these results

(Harris *et al.* 2017) the proportion of overlaying geological substrates positively (volcanic, sedimentary, and shale), and negatively (plutonic, metasedimentary, schist, gneiss, potassium-feldspar, and sodium-rich igneous rocks) associated with preferred mountain goat forage were added to each candidate translocation patch. Each patch was assigned a geological score defined as the sum of the proportions of areas with positive associations minus the sum of the proportions with negative associations.

Ranking of candidate habitat patches

Having aggregated all available biological and social criteria describing each patch, we concluded that further attempts to systemize ranking via a numerical scheme was counterproductive. We found no satisfactory way to objectively weight biological measures with one another (e.g., patch size vs. patch connectivity), nor to objectively merge quantified biological characteristics with unquantifiable ones (or social considerations). We thus circulated a summary of all 32 patches to the interdisciplinary team (e.g., Tribal biologists, Forest Service, biologists, university researchers), and ultimately selected a consensus ranking of the patches.

Field logistics

WDFW staff accessed each site by helicopter (landing where permissible, outside designated wilderness) in July 2016. We identified potential landing sites and measured the distances from these to the nearest road access, rejecting sites with distances > ~11.3 km (7 miles) to reduce the ferry time needed to transport goats.

Based on these site visits, the number of candidate patches was reduced to 12, and exact sites for goat release and staging areas were identified (Olympic, Mt. Baker-Snoqualmie, and Okanogan-Wenatchee National Forests, 2018). To provide options during poor flying weather, we added 5 nearby substitutes (including some accessible by road when weather precluded any flying) (Figure 1).

METHODS

Pilot study

In preparation for translocating animals from the Olympic Peninsula, WDFW and the Muckleshoot Tribe conducted a pilot translocation of mountain goats from the Elkhorn Mountains of eastern Oregon, near Baker City in July 2016 (Harris 2016). This was accomplished with close cooperation and invaluable assistance from the

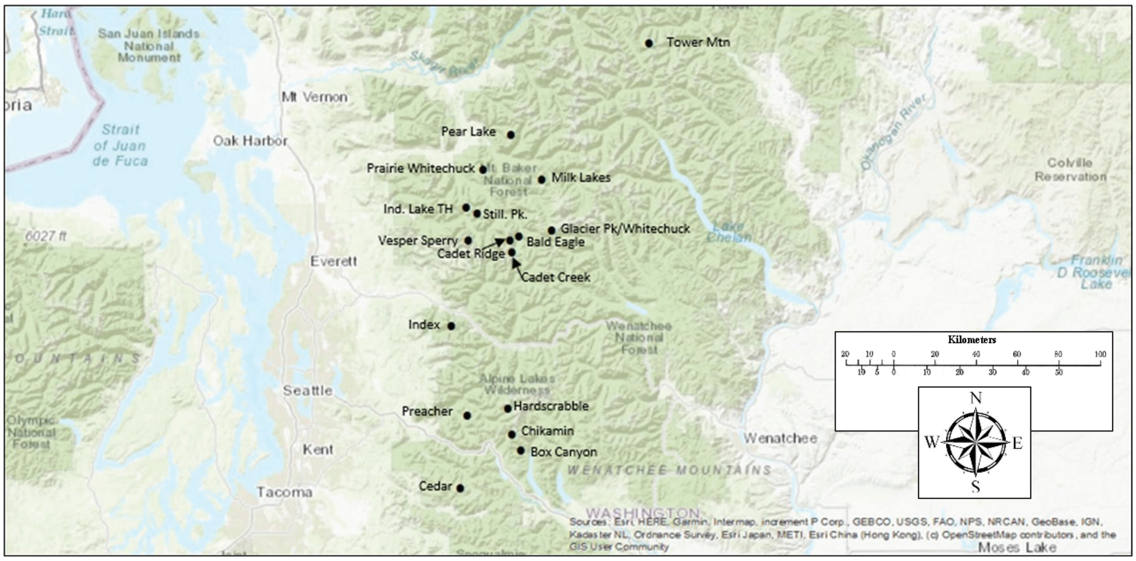

Figure 1. Release sites for translocating mountain goats in Washington State, 2018-2020.

Oregon Department of Fish and Wildlife and Seattle Public Utilities. Six goats (3 adult ♀, 2 subadult ♀, 1 subadult ♂) were captured with a fixed tangle net (Myatt *et al.* 2010), transported by vehicle and helicopter to a site in the Cedar River Watershed, and released (detailed methods below on transport and release). The remainder of this report deals only with goats obtained during the cooperative project with Olympic National Park and the U.S. Forest Service during 2018-2020.

Capture and handling

Happe *et al.* (2020) describe effort and methods to capture mountain goats. Generally, each goat was evaluated by staff veterinarians for emergency medical conditions and treated if necessary. In addition to sex and age, body mass, condition score (Iowa State University 2011), horn dimensions, body measurements, and lactation status were recorded. Nasal swabs, tissue for DNA analysis (facilitating subsequent analysis of translocation success), blood, hair, and fecal samples were collected. All goats were given BoSe® (selenium and Vitamin E to reduce muscle damage associated with capture myopathy), fluxinin (nonsteroidal anti-inflammatory and analgesic), ivermectin (anti-parasitic), and oxytetracycline (antibiotic). All adults and yearlings were administered midazolam (35 mg for adults, 15 mg for yearlings) and 20 mg haloperidol (Hofmeyr 1981, Wolfe and Miller 2014) to help maintain tranquility. In addition, most received 1 L fluids subcutaneously to reduce the potential for dehydration during transport. Body temperature, respiration, and capillary refill time were monitored throughout the process. Each animal received an ear tag with a unique number corresponding to the animal number in the records.

After processing, goats were moved into individual transport crates (Figure 2) kept in a secluded and shaded area until loaded into the transport trucks. All adults and large-sized yearlings (except 3 goats that ONP previously equipped with VHF collars) were fitted with Vectronics Survey GPS collars. Vectronics "mini-GPS" collars were used on selected kids and yearlings in 2019. These collars were small, lightweight, and could safely be placed on small, growing animals because they stretch as the neck grows. When stretched maximally, they break off the animal to avoid harm. Goats with injuries sufficiently severe to compromise survival probability post-release were euthanized, as were a few individuals suspected of infection (see results).

Figure 2. Crates with goats. Left crate has a "howdy door" allowing mother and kid to see and smell each other during transport; right crate has a normal door.

Mountain goats were transported in refrigerator trucks that carried up to 9 goats in each truck, or by pick-up trucks carrying up to two goats. Pick-up trucks were used only when ambient temperatures were cool enough (typically <10°C) to allow safe transport without additional controlled cooling. Communication between capture and release crews was accomplished with personal cellular phones as well as InReach® GPS units (Garmin Ltd, Olathe, KS). Crated goats were off loaded and prepared for helicopter transport to high elevation release sites either early the following morning ($n = 323$) or, when time allowed, late the afternoon of their capture date ($n = 23$).

At helicopter-accessed release sites, we first confirmed that it was safe to land. We then flew to the staging area to confirm plans with the crews tending the goats overnight. We ferried the release crews and field gear to the release sites prior to slinging in the crated goats. In 2018 we used a Bell Jet Ranger that can safely accommodate 3 passengers, thus requiring 2 round-trips for personnel. In 2019 and 2020 we used a Bell 407 that allowed a single trip. All helicopter services were provided by HiLine Helicopters, Darrington, WA. See Harris *et al.* (2019) for additional details on methods used to transport and release mountain goats.

Analyses

Survival

Annualized survival rates were estimated as the reciprocal of the sum of mortalities divided by the sum of exposure days, raised to the 365th power. We used Cox Regression, implemented in R ("res.cox" within the Survival library) to assess if selected attributes of goats (or their handling) hypothesized to effect survival, were significantly associated with the number of days until death. We broadly categorized hypotheses explaining risk of mortality into 3 groups: i) factors theoretically under our control (or influence) during the capture and handling on the OP, ii) factors theoretically under our control during the transport and release of the goats (in the north Cascades), and iii) factors inherent to the goats themselves over which we had no control. In models under the first group, we examined the capture method (darting vs. netting), whether goats were injured on arrival at the processing site, and the time taken to process the animal before it entered the crate. In the second group, we examined models including the time in transport (between crating and releasing), whether there was an overnight wait before release, whether transportation to the release site was by helicopter or vehicle, whether the release site was in designated wilderness, and finally, the specific location of release. In the third group, we examined potential covariates of mortality risk including gender, age at capture, whether habituated, body condition index, and if female, whether lactating or had a kid with her at capture. We examined 2-way interactions where main effects were significant or where a cross-over effect was possible.

Climate

White *et al.* (2011:1739) found that survival of most sex/age classes of mountain goats was related

Table 1. Mountain goats from the Olympic Peninsula released[1] in the north Cascades, 2018-2020 (aggregated release sites, Harris *et al.* 2019).

Population Cluster	**Release site**	***Nanny***	***Billy***	***Female yearling***	***Male yearling***	***Female kid***	***Male kid***	***Total females***	***Total males***	***Total***
Cedar	Cedar River	**11**	**6**	**0**	**1**	**0**	**1**	**11**	**8**	**19**
Alpine Lake South	Chikamin	5	8	1	0	0	2	*6*	*10*	**16**
	Box Canyon	13	7	0	3	0	1	*13*	*11*	**24**
	Preacher	1	3	1	1	0	0	*2*	*4*	**6**
	Cluster Total	**19**	**18**	**2**	**4**	**0**	**3**	**21**	**25**	**46**
Suak River South	Stillaguamish Peak	9	2	0	1	2	0	*11*	*3*	**14**
	Independence Lake	4	0	2	0	0	1	*6*	*1*	**7**
	Vesper-Sperry	20	6	7	9	2	2	*29*	*17*	**46**
	Cadet Ridge/Creek	9	15	2	3	0	3	*11*	*21*	**32**
	Bald Eagle Trailhead	4	1	0	1	0	0	*4*	*2*	**6**
	Cluster Total	**46**	**24**	**11**	**14**	**4**	**6**	**61**	**44**	**105**
Alpine Lakes North	Index	7	6	2	1	2	1	*11*	*8*	**19**
	Hardscrabble	1	6	0	0	0	1	*1*	*7*	**8**
	Cluster Total	**8**	**12**	**2**	**1**	**2**	**2**	**12**	**15**	**27**
Glacier Peak/Sauk North	Glacier Pk Upper Whitechuck	4	0	0	0	0	1	*4*	*1*	**5**
	Milk Lake	15	11	3	3	0	4	*18*	*18*	**36**
	Prairie Mtn-Whitechuck[2]	11	5	1	1	3	3	*15*	*9*	**25**
	Pear Lake	7	5	0	1	0	1	*7*	*7*	**14**
	Cluster Total	**37**	**21**	**4**	**5**	**3**	**9**	**44**	**35**	**80**
Upper Methow	Tower Mtn	**24**	**7**	**5**	**1**	**5**	**7**	**34**	**15**	**49**
Total		**145**	**88**	**24**	**26**	**14**	**28**	**183**	**142**	**326**

[1] Sixteen kids were transferred to accredited zoological institutions

[2] Total includes one intersex (pseudohermaphrodite) animal

negatively to the yearly accumulation of snow. We thus queried USDA websites for snow water equivalent records in the translocation region during 2018-2020 and considered survival of translocated goats in this context.

RESULTS

Releases: animals and locations

We released 326 goats (Table 1) during 4 periods over 3 years (98 in September 2018, 76 in July 2019, 102 in August 2019, and 50 in July/August 2020; including one goat captured in August 2019 near North Bend, WA that does not appear in ONP progress reports). We translocated more females (183) than males (142). One translocated animal was categorized as "intersex" (pseudohermaphrodite), possessing phenotypic characteristics of both genders (see Harris *et al.* 2019 for details). Of the 326 goats, 42 were kids (14♀, 28 ♂), 50 yearlings (24♀, 26 ♂), and the remainder were >1 year-old adults (145♀, 88 ♂, 1 intersex).

There was no evidence of *M. ovipneumoniae, Cryptosporidium*, *Giardia*, or Johne's disease in any of the 35 goats tested. However, processing crews euthanized 3 goats because of disease concerns: 1) a nanny with severe hoof lesions in case she might have, or spread *Treponema* bacteria. She was subsequently diagnosed as having non-treponeme bacterial dermatitis; 2) two kids assessed with potential contagious ecthyma (orf). In addition, 1 adult billy was euthanized due to a history of aggressive interaction with humans (additional details in Happe *et al.* 2020).

We monitored 262 of the 326 goats via GPS or VHF telemetry. Due to their small size or concerns about subsequent growth causing problems with fitness, some kids and yearlings were not equipped with radio collars. Analyses refer to this sub-sample of 262 animals. In summer 2020, Covid19-related restrictions precluded us from conducting telemetry flights to confirm the reproductive or survival status of non GPS-monitored mountain goats however a partial survey to document reproduction was accomplished in early September 2021.

Most monitored goats were in the prime ages of 3 to 7 years. The oldest documented animal was a 12-year old billy; we also monitored 2 10-year old nannies. Mean body condition indices were higher for males than females (Figure 3, Table 2). For both sexes, condition index was positively associated

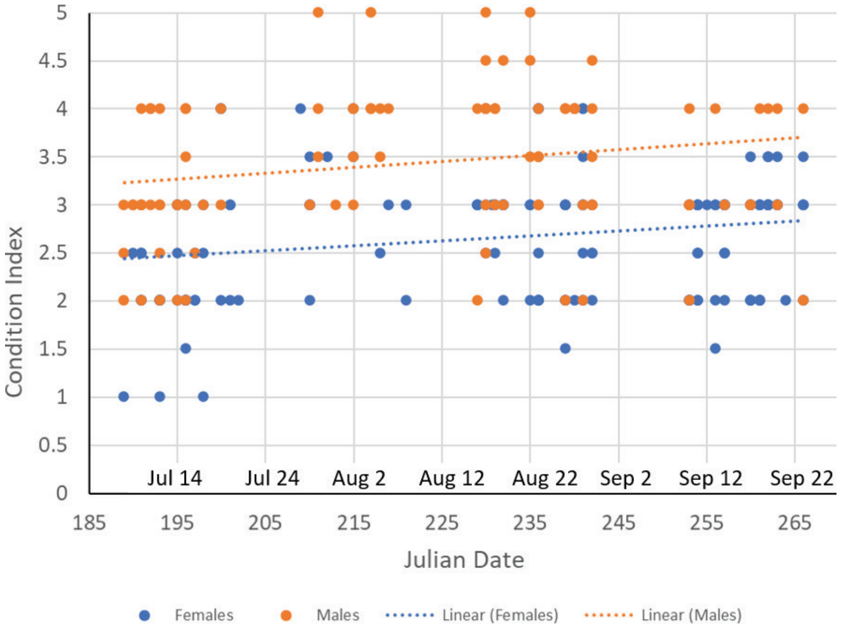

Figure 3. Body condition index as a function of Julian date. For adult males, condition index = Julian date X 0.00587, SE = 0.0035; *z* = 1.679, *P* = 0.0965. For adult females, condition index = Julian date X 0.00502, SE = 0.0021, *z* = 2.346, *P* = 0.0203.

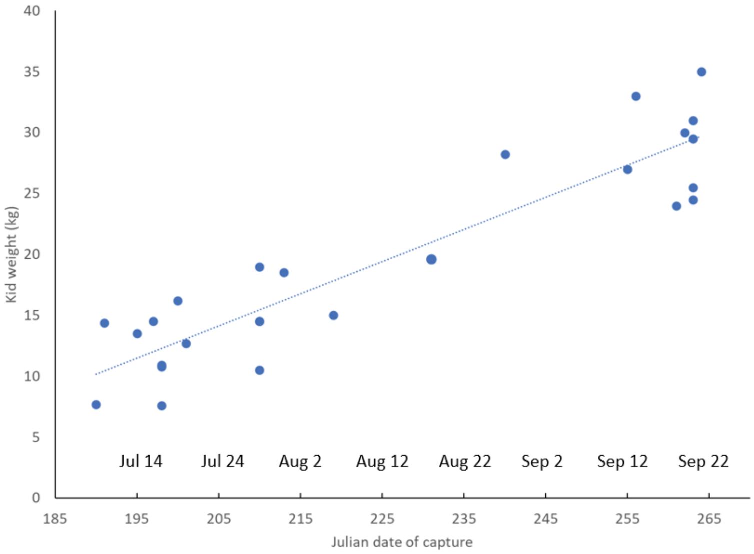

Figure 4. Kid body mass (e.g., weight) when captured as a function of capture date. Linear fit: -39.9 + 0.2637 X Julian date; $t = 11.26$, $P < 0.0001$. Neither gender, nor the gender X Julian date interaction were significant predictors.

with Julian date (i.e., goats captured later in the year tended to be in better condition than those earlier in the year). Kids generally were not scored for body condition index. However, as expected, kid body mass was heavier when captured later in the year (Figure 4).

Climate

Snow accumulation was generally about 85-90% of normal during early winter 2018 and considerably lower than normal (~ 60-70%) during March 2019. Snow accumulation was very low (<60%) in December 2019, but approached average by March 2020. Snow accumulation was slightly below normal in December 2020, but considerably above normal (~ 116-137%) by March 2021 (Figure 5).

Survival

We monitored adult (aged 1+) female mountain goats for 53,176 cumulative days post-release, producing an overall estimated annual survival of 0.53 (SE = 0.04). We monitored adult (aged 1+) male mountain goats for 34,019 days post-release, producing an overall estimated annual survival of 0.58 (SE = 0.04). Both survival rates were slightly higher than the initial 365-days post-release period, during which approximately 51% of adult females and 55% of adult males survived. We monitored kids for 3,963 days (censored for times during which we were unable to discriminate mortality from collar drop), generating an estimated annual kid survival rate of 0.25 (SE = 0.10).

Based on qualitative visual inspection (Figure 6), we identified 3 periods for further analyses of survival patterns: i) 150 days post-release, during which survival was low although seasonal conditions (roughly July through December) were expected to be best for goats (and thus we hypothesized survival may be affected largely by capture, translocation, and the stress of adapting to a new area); ii) the following ~ 200 days, which roughly coincided with the typically high mortality months of January through May; and iii) beginning a year after release, which we hypothesized sex/age-specific survival probability would largely reflect environmental conditions at the newly colonized sites.

Male and female survival was initially similar, but quickly diverged, with male survival notably higher than female survival between about 50 and 150 days post-release. Male survival declined more than female survival in late winter/early spring, and by 1-year post-release, male and female survival rates were similar (Figure 6).

Table 2. Released mountain goats alive or dead 150 days post-release, and alive or dead as of late March 2021. See text for details.

	Released	**Alive at 150 days**	**Dead at 150 days**	**Alive March 2021**	**Dead March 2021**
Adult Males	88	75	13	39	49
Adult Females	140	114	26	50	90
Adult Intersex	1	1	0	0	1
Kids	12	7	5	2	10
Yearlings	21	15	6	10	11
Total	262	212	50	101	161
$\bar{x}$ male age	4.17	4.34	3.45	4.04	4.26
SE	0.24	0.24	0.74	0.32	0.55
$\bar{x}$ female age	3.71	3.71	3.69	3.60	3.77
SE	0.14	0.15	0.69	0.23	0.18
Captured using					
Net gun	188	148	40	74	114
Dart gun	71	54	17	26	45
Released					
Same day	21	19	2	15	6
Next day	241	185	56	86	155
Goats considered					
Habituated	78	65	13	35	43
Not Habituated	178	135	43	63	115
Proportion Injured during capture	0.40	0.39	0.46	0.45	0.38
Male Condition Index	3.38	3.43	3.14	3.48	3.30
SE	0.08	0.09	0.21	0.13	0.42
Female Condition Index	2.65	2.73	2.29	2.79	2.56
SE	0.05	0.06	0.42	0.09	0.07

For goats surviving past the initial 150-day period, monthly mortality rates (assessed across all 3 years) increased through late winter, peaking in March before declining again through summer and autumn (Figure 7).

Translocated males were typically slightly older ($\bar{x}$ = 4.17, SE = 0.24) than females ($\bar{x}$ = 3.71, SE = 0.14; Table 2). More goats were captured with net gun than dart gun, most were released after an overnight stay, and most came from areas where goats were considered not habituated (Table 2). Additional insight into effects each of these may have had on short (150-day) and long-term (entire period) survival should be interpreted cautiously because raw numbers do not account for differences in the durations that individual goats were exposed to risk of death.

The strength of influences on survival is better provided by Cox Proportional Hazard modelling. In these analyses, negative coefficients (β values) indicate continuous variables negatively associated with the hazard (i.e., risk of death during the time period declined as the value of this variable increased). Odds ratios greater than 1.0 indicate categorical variables that were positively associated with the hazard (i.e., risk of death was greater than for the reference category).

We found no evidence that variables related to capture, handling, and transporting adult (aged 1+) goats (e.g., type of capture, whether injured, length of processing time, length of transport time) affected survival of translocated goats during the monitoring period, or during any of the sub-sections of the monitoring period (all $P > 0.10$, results not

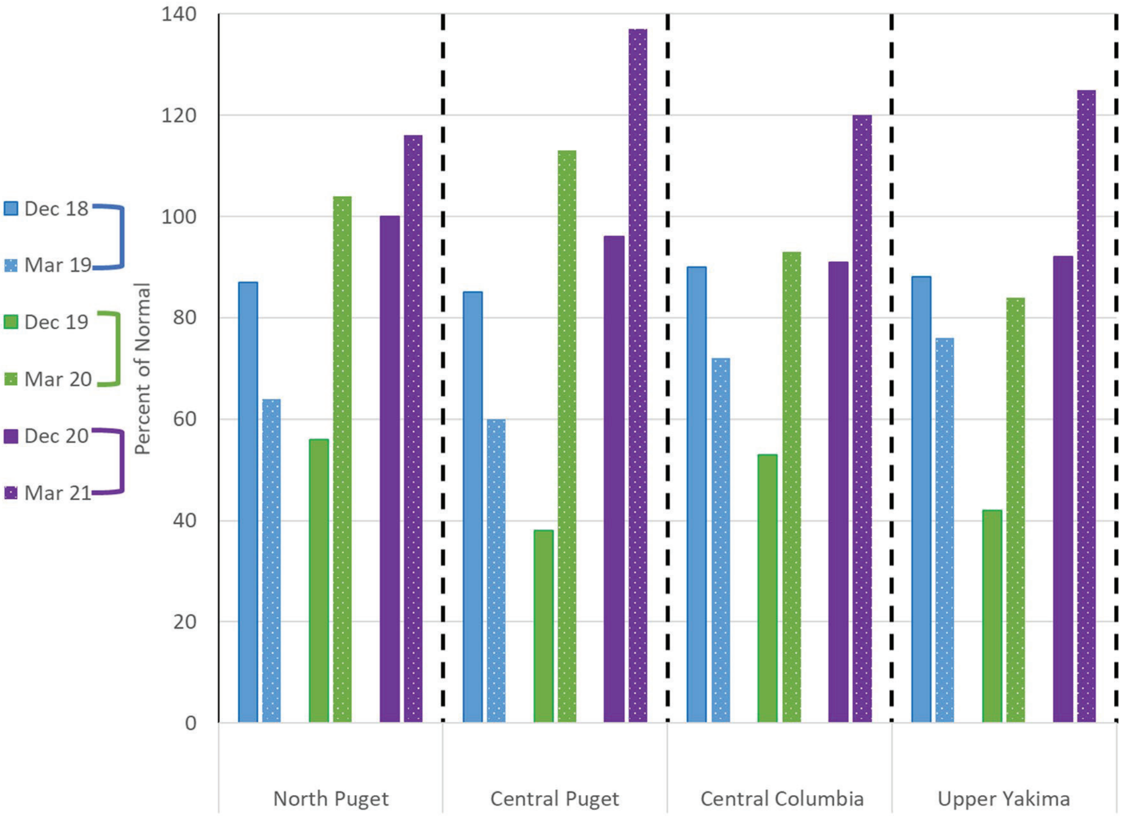

Figure 5. Snow-water equivalents as percentages of 30-year normal for 4 geographic subdivisions of northwestern Washington during the 3 winters of translocated mountain goat monitoring. Blue: winter 2018-19, Green: winter 2019-20; Purple: winter 2020-21; hatched: December, solid: March. Dashed line indicates 30-year average. Source: USDA NRCS National Water and Climate Center.

shown). However, we found a strong relationship between body condition score and subsequent survival of adult females: female goats with higher body condition scores survived better than those in poorer condition (Table 3; neither female body weight nor its interaction with body condition were significant). No relationships involving body condition, weight, or age were observed among adult males. Survival among adults during 2019 and 2020 was marginally lower than during 2018 (the reference year, Table 3). Among kids, both weight and date captured were significant predictors of survival (heavier kids were more likely to survive than lighter kids). As noted above, kid weight was not independent of capture date (kids captured later in each year being heavier; Figure 4). One additional variable was close to being significant at α = 0.10 level: nannies caring for a kid when

Table 3. Significant predictors of adult (age 1+) and kid mountain goat mortality hazard for the entire monitoring period, Cox proportional hazards models. For each, n = sample size, z = test statistic, P = probability, β = slope, SE = standard error of slope. Odds ratio statistics shown for categorical variables.

Variable	***n***	***β***	***SE***	***z***	***P***
Adult females only					
body condition	150	-0.429	0.160	-2.675	0.007
Kids only					
weight	26	-0.103	0.044	-2.324	0.020
capture date	28	-0.024	0.012	-2.018	0.044
Variable	***Odds ratio***	***Lower 95%***	***Upper 95%***	***z***	***P***
2019	1.357	0.934	1.973	1.601	0.109
2020	1.643	0.900	3.002	1.616	0.106

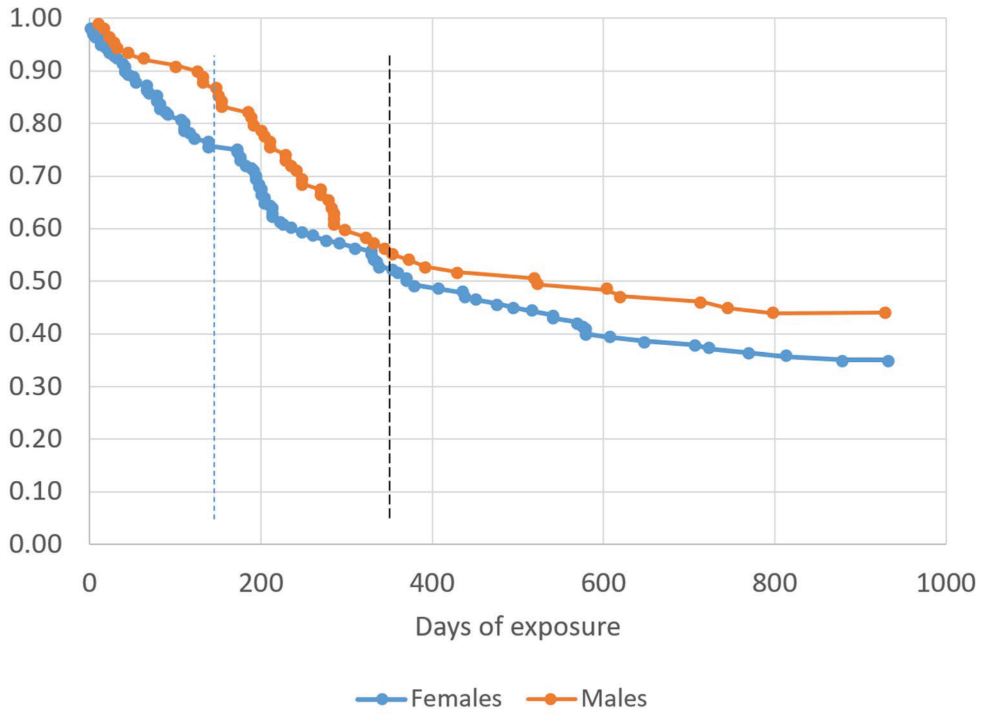

Figure 6. Kaplan-Meier type survival curve of adult (age 1+) mountain goats released in the north Cascades. We selected 150 days (short dashed vertical line) as a reasonable approximation of the time at which survival was decreasingly a function of capture and transportation effects, and increasingly a function of release site and adjacent areas. Mortality subsequently increased, but this coincided with late winter/early spring, when survival was at its lowest seasonal ebb (see Figure 7). Long-dashed vertical line indicates approximately 1-year post release.

captured were marginally more likely to die than other nannies.

In examining mortality hazards during only the initial 150-day period, poor body condition was again strongly predictive of low survival among adult females ($\beta_{condition}$ = -2.985, SE = 0.884, z = -3.377, P < 0.001; Figure 8), but this effect was conditional on adult female weight (β_{weight} = -0.074, SE = 0.039, z = -1.913, P = 0.056; $\beta_{weight*condition}$ = 0.029, SE = 0.012, z = 2.389, P = 0.017). As with the analyses of the full duration, no similar relationships were observed among adult males. Adult mountain goats released in designated wilderness areas were somewhat more likely to survive the initial period than those released in non-wilderness areas (odds ratio 0.535, 95% CI = 0.271-1.056, z = 1.802, P = 0.072). During the period between 150 days and 1-year post-release, the only significant categorical variable predicting mortality

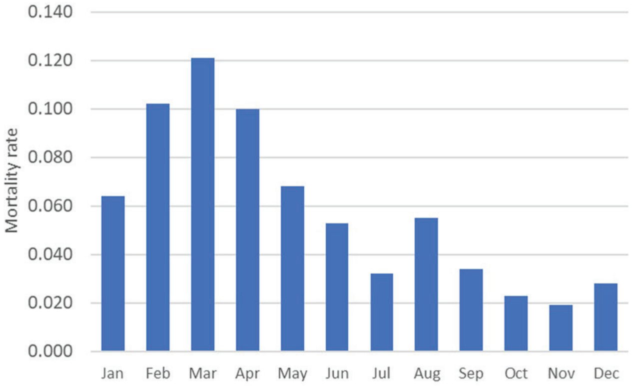

Figure 7. Monthly mortality rate of adult (age 1+) mountain goats released in the north Cascades that survived at least 150 days (thus reducing the effects of translocation on mortality and clarifying long-term seasonal dynamics, n = 205).

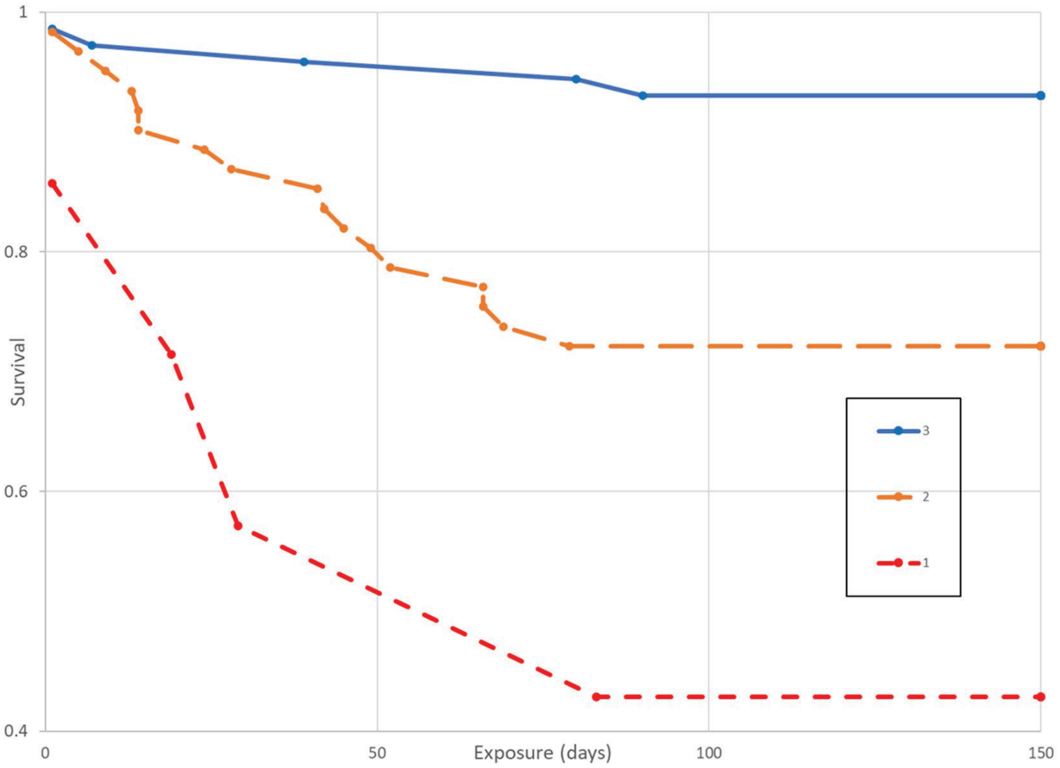

Figure 8. Kaplan-Meier type survival curves of adult female mountain goats released during 2018-2020 during their initial 150 days post-release, by body condition scores 1-3 (*n* = 7, 61, and 72, respectively) (sample sizes of females with body condition scores of 4 were too small for meaningful representation).

hazard was that adults released in 2019 were more likely to die than those released in the reference year of 2018 (odds ratio 2.345, 95% CI = 1.275-4.315 $z = 2.738$, $P = 0.006$). For adults surviving at least one year, mortality hazard was predicted by whether the release occurred in a designated wilderness area (odds ratio = 0.224, 95% CI = 0.113-0.977, $z = -2.003$, $P = 0.045$).

Survival was higher among goats released in the Alpine Lakes South, Cedar, and Glacier Peak clusters than those released in the Alpine Lakes North cluster (Table 4). Among adults that survived their first year, we found no evidence that subsequent survival was related to release site. However, when considered by aggregating sites into population clusters (more closely reflecting where animals ultimately settled, Harris *et al.* 2019): adult goats released at sites within the Glacier Peak zone had higher survival than those released in the Alpine Lakes North zone.

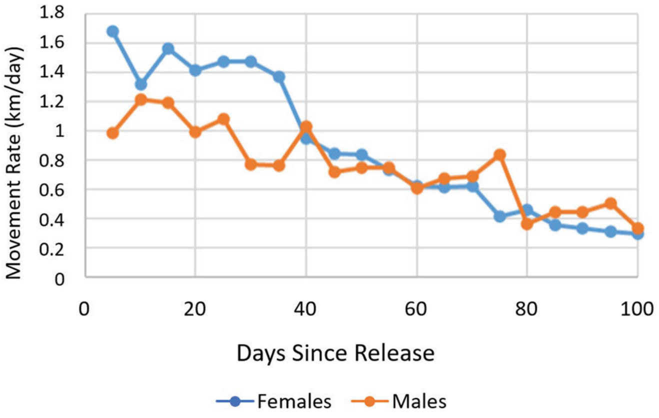

Figure 9. Movement rate (km/day) of translocated mountain goats by 5-day periods after release. Movement rates are underestimated because most collars provided locations only every 23 hours.

Table 4. Annualized survival of adult (age 1+) mountain goats released at each site (and aggregated into population clusters, Harris *et al.* 2019). For each category: Left column shows annualized survival for all goats (including those succumbing early when we hypothesize capture/transportation effects dominated), middle column shows survival for goats surviving the initial period to 150 days, and right column shows survival for goats surviving at least one year after release. Analyses of survival rate differences after 1 year had less power to detect true differences than others because of small sample sizes. Some goats moved away from the population cluster in which they were released; thus their fate depended in part on where they ultimately spent time.

Release site	Entire period	After 150 days	After 1 year	Release population cluster	Entire period	After 150 days	After 1 year
Hardscrabble Ridge	0.21	0.06	-	Alpine Lakes North	0.27	0.23	0.35
Index	0.29	0.31	0.35				
Box Canyon	0.57	0.55	0.80	Alpine Lakes South	0.64[b]	0.60[b]	0.79
Chikamin	0.72[a]	0.67	0.84				
Preacher	0.75	0.64	0.55				
Cedar	0.78[a]	0.79[a]	0.71	Cedar	0.78[b]	0.79[b]	0.71
Bald Eagle	0.76	0.65	0.61	Glacier Peak	0.62[b]	0.61[b]	0.92[b]
Milk Lakes	0.66[a]	0.55	1.00				
Pear Lake	0.75[a]	0.90	1.00				
Prairie-Whitechuck	0.44	0.40	1.00				
Whitechuck-Glacier	0.33	0.49	1.00				
Cadet Creek	0.44	0.24	0.53	Sauk River South	0.48	0.44[b]	0.53
Cadet Ridge	0.72	0.71	1.00				
Independence Lake	0.82	0.75	1.00				
Stillaguamish Peak	0.48	0.78	0.67				
Vesper Sperry	0.38	0.34	0.30				
Tower Mountain	0.57	0.56	0.66	Upper Methow	0.57	0.56[b]	0.66
				All	0.57	0.55	0.66

[a] *Higher than reference area Index (lowest survival with adequate sample size), $P < 0.05$*
[b] *Higher than reference area Alpine Lake North (lowest survival), $P < 0.05$*

Annualized survival rates of adults increased among goats that survived the early hazards; in some areas, survival rates approached those generally required for a sustainable population (Table 4).

Movements of translocated adults

Post-release movements

Immediately post-release, female goats moved more on average on a daily basis than males for the first ~ 40 days, after which movements rates were similar for the sexes (Figure 9). Considerable individual variability characterized movement patterns (Harris *et al.* 2019). Mean daily movement rates declined with time after release, although how much that reflected "settling down" and how much reflected the onset of winter (when movement of resident goats generally declines) cannot be distinguished with these data (Figure 10).

Seasonal elevational migrations

As expected, goats descended to lower elevations beginning in October, averaging about ~ 300 m feet lower during mid-winter than mid-summer (Figure 11). Similarly to findings of Rice (2008), translocated mountain goat females began their upward elevational movement in summer

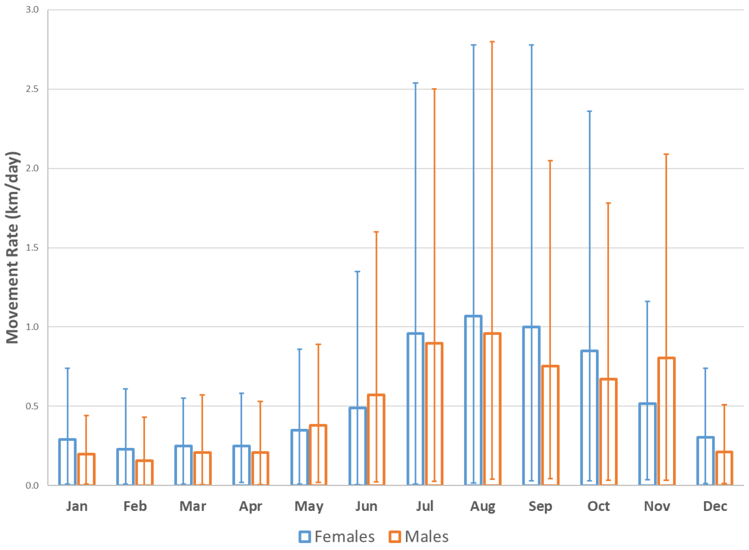

Figure 10. Mean (histogram) and 90% percentiles (error bars) of daily movement rates of mountain goats fitted with GPS collars.

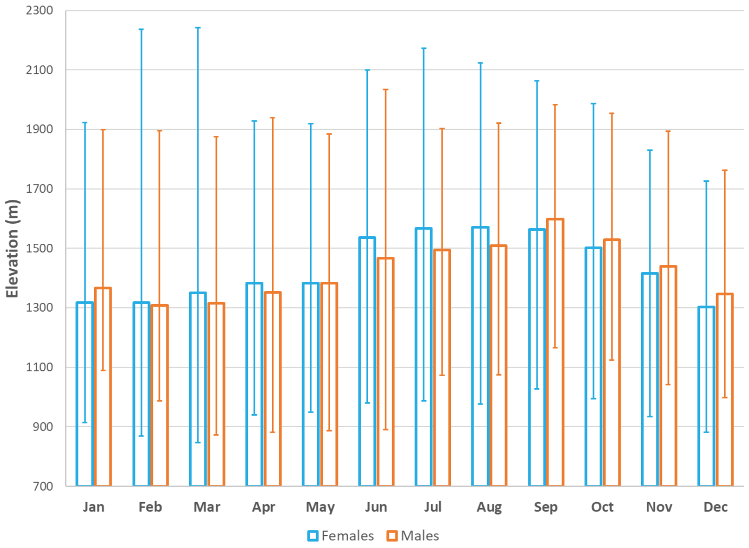

Figure 11. Mean (histogram) and 90% percentiles (error bars) of elevations of mountain goats fitted with GPS collars.

earlier than males, and spent more time at relatively low elevations than in the alpine.

Movements of translocated kid/nanny pairs

We found no evidence that nannies and kids (captured, transported, and released together) remained together for more than a day or two (see Figure 12). All kids released were effectively orphaned (although about 25% survived past the age of 1 year).

Locations used by mountain goats

As reported in Happe and Harris (2018), most goats moved considerably after release, adopting various patterns (Harris *et al.* 2019). Although the goats used a variety of habitats and elevations, we observed no movements suggestive of homing, nor of attraction to humans or human infrastructure (Harris *et al.*, in prep).

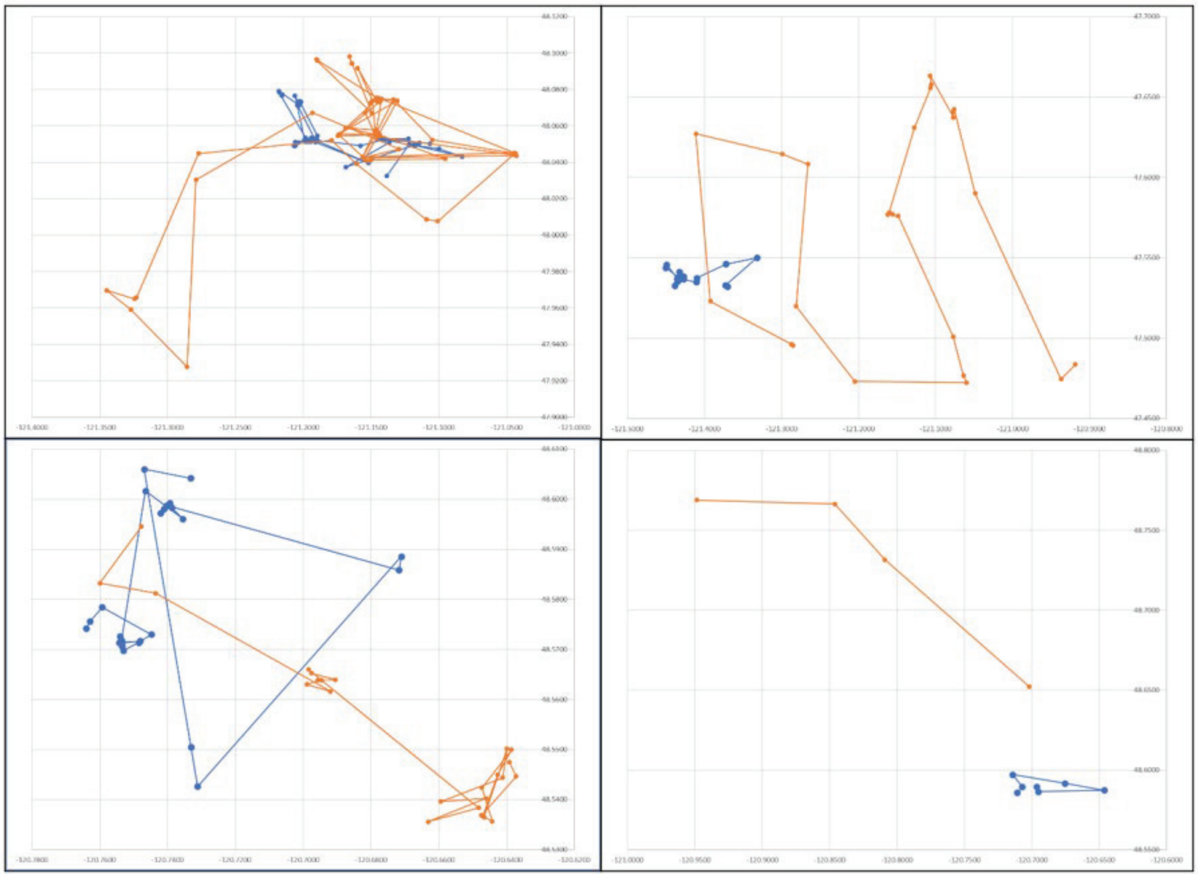

Figure 12. Post-translocation movements of nanny-kid pairs; nanny (orange), kid (blue). Upper left: nanny 5009, kid 5032, released at Tower Mountain, 7/28/20; upper right: nanny 5285, kid 5255, released at Hardscrabble Ridge, 8/28/19; lower left: nanny 5155, kid 5170, released at Upper Whitechuck, 7/20/19; lower right: nanny 5069, kid 5061, released at Tower Mountain, 7/28/20. Axes are latitude and longitude (decimal degrees). Durations and spatial scales differ.

Reproduction by translocated nannies

Because only 14 of the 98 goats released in September 2018 were adult billies, and because they had relatively little time to adapt to their new surroundings, we did not expect much reproduction from translocated nannies in spring 2019. Further, our monitoring budget was sufficient to allow visual confirmation of reproductive status of a selected handful of nannies. In summer 2019, teams of students from Western Washington University made 14 backpacking trips to observe selected nannies that could have produced kids and that were accessible within time constraints. The teams observed 8 of 18 candidate nannies. Of these, 3 were confirmed to have kids (Figure 13). Muckleshoot tribal biologists also confirmed kids with 3 of 6 nannies they visually identified in August 2019. Through radio-tracking, we observed an additional kid with the only nanny released in 2018 that we attempted to observe. Thus, we accounted for 7 kids born to nannies released in 2018 (out of 15 for which we had information). Covid-19 restrictions precluded field surveys for reproduction in summer 2020. On September 2 and 3, 2021, WDFW staff used aerial radio-tracking to observe 18 nannies (estimated ages 3–9, $\bar{x} = 6.0$), confirming kids produced by 7 (one of which had twins, total of 8 kids from 18 females).

Figure 13. Translocated nanny (left) with recent kid, summer 2019.

DISCUSSION

We faced considerable logistical difficulties in moving goats to the best possible places. Choosing which release site to use for a given release was a complex decision, involving our knowledge of the number and sex/age composition of goats previously moved, the number and sex/age composition of goats *en* route, as well as weather and logistics. In year 2020, efforts were further compromised by the need to reduce the risk of staff contracting COVID-19.

We were not surprised to find that summer body condition was better among males than females, and that condition in both sexes generally improved over summer, or that kids were heavier when captured later. We would generally expect females (many encumbered by pregnancy and lactation) to recover condition later than males through the summer months (when forage nutrition is optimal).

The body condition index at capture was the strongest and most consistent predictor of survival. Body condition, in turn, is typically a complex function of nutrition and energetic demands. Numerous studies on ungulates demonstrate that pregnancy and lactation are the single largest determinants of female body condition: Our data are consistent with these findings. We hypothesize that the stress of capture, transport, and learning how to find needed resources in a new place often manifested in lower survival, particularly in individuals already vulnerable. Similarly, we interpret the lower survival of females (particularly during the acclimation period) – the reverse of patterns typically seen among resident ungulates – as an additional signal that body condition at capture (lower among females than males) was an important influence on survival.

We made no attempt to quantify body condition among kids. We were not surprised to document higher survival among kids captured later in the summer, when they were larger and fully weaned. Indeed, our original intention – though not always realized – was to prioritize the youngest kids for captive placement precisely because we expected these individuals to face the longest odds of survival. As reported in more detail (Harris *et al.* 2019), our efforts to encourage nannies and kids to stay together post-release seemed unsuccessful as all released kids were effectively orphaned within days after release (see Olson *et al.* 2010). Consequently, the 25% annual kid survival was greater than expected (and some evidently survived their 2nd year). Festa-Bianchet and Côté (2008) reported 64% average first year survival for mountain goat kids accompanied by their nannies. Although we were unable to monitor kids closely in 2020, earlier monitoring indicated that some orphaned kids found and began travelling with other goats (both translocated and resident; Harris *et al.* 2019).

In planning this large and complex project, we gave considerable thought to the optimum timing for capture and release of goats. An overriding constraint was weather. Anticipating that most releases (and all captures) would require helicopter support, we prioritized a time window in which weather conditions – not known for clear skies in this part of the world – would most likely be safest for flying. We faced challenging weather conditions during all 4 field programs. In retrospect, knowing that survival was higher for goats in better body condition and that body condition in turn gradually increased through the summer months, a reasonable question arises as to whether released goats would have survived better if all field work occurred later during the snow-free months. Our analyses suggest they would, but we caution against a straight-forward conclusion. Goats translocated in September 2018 fared best, but also happened to face the least challenging weather conditions during their first winter at their new locations.

After accounting for the anticipated acclimation period, seasonal patterns of survival were broadly consistent with our expectations from native mountain goat populations. Mortality peaked in late winter/early spring, when animals were at their most susceptible. It is intriguing that survival was lower for goats whose first winters in their new environments were more severe than those whose first winter was the relatively mild one of 2018. However, other factors (such as timing of release, types of animals moved, and selection or release sites) may have played a role in the year-specific differences in survival probability.

Our finding that mountain goats released in designated wilderness fared better than those released in non-wilderness merits some scrutiny. We caution against adopting the intuitive but potentially misleading interpretation that isolation from motorized humans was the primary factor. We found no differences in survival between goats released in accessible areas and those released in remote areas. Although all release sites in designated wilderness were, by definition, remote from humans, our non-wilderness helicopter sites also were in remote areas, far from motorized access. We hypothesize that the strength of the categorical variable "wilderness" was associated with larger sample size inherent in comparing a simple, binary variable (in or out) than provided for in site-specific categorical analyses, and that it masked more subtle differences in survival among various release sites.

We documented proximate cause of death for a small minority of mortalities. Almost all deaths occurred in steep and remote terrain where accessing carcasses rapidly enough to diagnose cause of death was not feasible. Many mortalities occurred within designated wilderness, where our legal (USFS permitted) access using a helicopter was restricted to releasing goats and did not extend to retrieving carcasses or collars. No translocated goats were harvested by hunters permitted by WDFW during 2018-2020 (few translocated goats spent any time within designated goat hunt units), and we are not aware of any translocated goats taken under Tribal hunting programs. In the few cases where cause of death was determined, it was largely predation by cougar (*Puma concolor*).

From the outset, we anticipated that survival of translocated goats would be lower than that expected among comparable classes of goats unexposed to the stress of capture, transport, and a new environment. The overall annualized survival of 0.53 for females and 0.58 for males was, nonetheless, a disappointment. However, we are encouraged that annualized survival of goats past the initial 150-day acclimation period, and particularly those living at least 1 year, was approaching survivorship (~ 0.90) we would expect from a stable or increasing goat population. We also found it reassuring that any factors related to capture or transport were not significantly associated with mortality.

It appears that our objective of providing the seeds of populations that would display spatial integrity and facilitate breeding aggregations has been only partly successful. Thus far, most surviving mountain goats have spread surprisingly uniformly throughout the entire translocation area (see also Jorgenson and Quinlan 1996). Additionally, about 1/3 of the goats displayed impressive abilities to find other goats with which to form groups. Our initial interpretation suggests that some population clusters were better than others at attracting goats, and/or providing better conditions for survival. Consequently, site-specific differences in survival to date may reflect true differences in aspects of habitat quality that affect survival (but not necessarily reproduction, which we were able to quantify only partially).

In addition to site characteristics that potentially affect vital rates in a bottom-up manner (e.g., forage quality), we speculate the presence of geographic heterogeneity in the strength of top-down forces, i.e., predation. We anticipated that newly arrived mountain goats, naïve to local conditions, would be more susceptible to predation (particularly by cougars) than resident goats. That even a year after release the overall survival rate remained below that needed for population growth (particularly in some zones) suggests the possibility that experienced goats may also face unsustainable predation rates. Although cougars most commonly subsist on deer (*Odocoileus* spp.), the ability of specialist cougars to limit growth or induce declines in small, isolated, or reintroduced bighorn sheep (*Ovis canadensis*) populations is well known (Rominger *et al.* 2004, Festa-Bianchet *et al.* 2006). Cougar predation has also been implicated as a substantial mortality cause in a small, isolated, non-native mountain goat population (Lehman *et al.* 2020). Mountain goat populations are not typically considered predation-limited, with most predation coming from grizzly bears (*Ursus arctos*), occasionally wolves (*Canis lupus*), and – on young kids – golden eagles (*Aquila chrysaetos*; Festa-Bianchet and Côté 2008). Where dominant grizzly bears and wolves were eliminated or greatly reduced, cougars have sometimes expanded not only in abundance but in their trophic niche, adapting to use prey species other than the deer that fundamentally sustain their populations (Rominger 2017, Lehman *et al.* 2020). Limitations of our data preclude us from inferring whether such a dynamic played a role in this case, but we note that if it did, mountain goat populations in the Cascades may respond positively if grizzly bears and wolves ultimately return and reduce cougar abundance (Rominger 2017).

Periodic updates of survival among those goats still wearing GPS collars would be useful to confirm or alter these preliminary conclusions. As well, when schedules and COVID protocols allow, aerial monitoring to obtain rough estimates of reproductive rate among translocated nannies would add valuable insight into the prospects for long-term success of the translocation program.

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