Appendix A: Mountain Goat Population Modeling

Methods

Initial population sizes of 384 and 419 animals used in the model were determined as described above. Animals were assigned to age classes so that a stable population structure, a similar number of young were produced once reproductive and survival rates were developed. The stable structure develops with a population consisting of 20 percent kids, 12 percent yearlings, 9 percent two-year-olds and 59 percent breeding aged animals.

Because of non-selective hunting, sex ratio was assumed to be equal. Johnson (1983) reported that state-wide, the sex ratio of harvested goats was 49 percent male and 51 percent female, so there is no reason to assume a skewed sex ratio for the population.

Survival rates for age groups of goats were determined by averaging rates reported in the literature. For kids, five survival rates were reported by Kholman and Bailey (1991) 60 percent, Dane (2002) 68 percent, Nichols (1980) 58 percent, Festa-Bianchet et al. (1994) 63 percent, and Cote and Festa-Bianchet (2001) 60.3 percent. The average survival rate of 61.9 percent from these studies was used for kids in the model.

Three yearling survival rates were found in the literature, 71 percent by Dane (2002), 73.4 percent by Nichols (1980), and 71 percent by Smith (1986[a]). The average survival rage of 71.8 percent from these studies was used for yearlings in the model.

Two adult survival rates of 90 and 99 percent were reported by Kholman and Bailey (1991) and Smith (1986), respectively. The model uses the average of these two rates (94.5 percent) for adult mortality for ages 2-8. For ages 9+, the sole reported survival rate of 68 percent (Smith 1986[a]) was used in the model. A survival rate from age 13 to age 14 of 0 percent was used to limit goat ages to those expected to occur in wild populations. For any given year step in the model, truncating the population after age 13 removed a maximum of 5 animals each year due to old age.

Two studies reported annual reproductive rates for identical ages of females (Bailey 1991, Houston and Stevens 1988). The means of these two reported rates were 0.645 kids per age 3 female, 0.735 kids per age 4-9 female, and 0.575 kids/age 10+ female. Age at first reproduction can vary from two to five years old (Festa-Bianchet 1994, Houston and Stevens 1988) and reproductive rates may be density dependent (Dane 2002, Bailey 1991, Houston and Stevens 1988, Adams and Bailey 1982). The mechanism for variable reproductive rate at differing levels of mountain goat density is likely nutrition (Cote and Festa-Bianchet 2001) which can also be affected by weather conditions (Bailey 1991). To keep the model simple, density dependent factors on reproductive rate and age at first reproduction were not used. The age of first reproduction in the model is 3 years and reproductive rates are constant from year-to-year.

The known number of animals harvested each year was determined from *Big Game Statistics* reports by the WDFW. Harvest locations in these statistics were location specific, allowing for the determination of whether harvest occurred within, or outside, of the population of goats on Mt. Baker. The only exception was goat harvest locations identified as Swift Creek which forms the eastern boundary of the Mt. Baker survey route.

To address this situation, every other reported harvest location of Swift Creek was included in annual harvest totals. Harvest records show no harvest of mountain goat from the Mt. Baker population from 1948 – 1963. One mountain goat was harvested from an unspecified location in the Baker River watershed in 1954, but because the Mt. Baker area was closed to hunting at this time, the harvest most likely did not occur in the Mt. Baker area.

In 1964, permitted harvest was reported in the Mt. Baker population in hunt units 23 and 24. Unit 24 is completely within the range of the Mt. Baker population, but unit 23 includes areas east of Swift Creek. Harvest locations for areas east of Swift Creek were not included in the model. In 1974, Unit 31 was established. This unit was formerly a part of Unit 24 and all harvest from this unit was included.

Site specific harvest information is not available for Unit 23 for 1982 and 1983. For these years, the model includes all harvest for Units 24 and 31, but does not include any harvest for Unit 23. Nine and 15 goats were reported harvested from these units in 1982 and 1983, respectively. Some of this harvest likely occurred in the Mt. Baker population based on harvest locations in prior years, so the model underestimates harvest in these years.

The number of individuals removed from each age class as a result of hunting (Table 27) was determined based on the average age of goats harvested from 1959-1962 reported by Johnson (1983, p. 23).

Table 27 Percent of Mountain Goat Harvest by Age Class.

Age	Kid	Yearling	2	3	4	5	6	7	8	9	10	11	12	13
Percentage of harvest	2	11	11	15	17	15	10	5	3	4	2	2	1	2

**Washington State from 1959-1963 using horn characteristics of harvested animals.*

Results and Discussion (Mt. Baker)

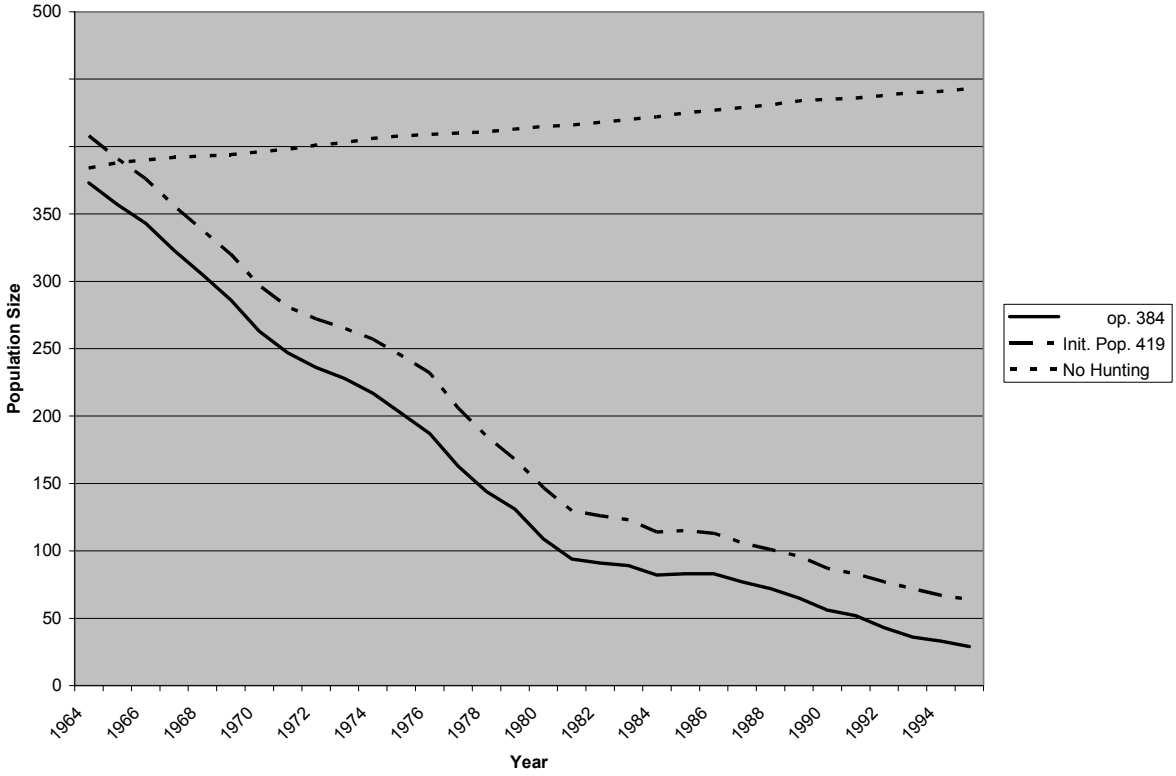
Using averages of published reports of age-specific survival, age-specific reproduction, and age of first reproduction, the model predicts an average rate of population increase of 0.5 percent per year (range 0.2–1.0 percent). This would reflect a population near its carrying capacity which should have been the condition around Mt. Baker in 1964, in which sport hunting had not occurred since 1925. Because the demographic rates used did not result in a population that greatly increased or decreased, they seem to reasonably approximate a realistic population.

Incorporating known hunting mortality changed the modeled population trajectory from a slightly increasing population to a population in decline. An initial 1964 population of 384 animals declines to 29 animals in 1995 (Figure 25). With an initial population of 419 animals, the population declines to 64 animals in the same time frame. The modeled populations in 1995 decline 92 percent and 85 percent for initial populations of 384 and 419, respectively. The modeled annual average rate of decline is 7.6 percent and 5.7 percent for initial populations of 384 and 419 animals, respectively.

The 1995 inventory estimated a population of 59 goats on Mt. Baker. This estimate is very close to the 64 animals modeled to occur in 1995 from an initial population of 419 animals. Provided that the information used to model the population is reasonably accurate, a substantial portion of the population decline of mountain goats on Mt. Baker can be explained by sport hunting. Although other factors undoubtedly affected mountain goat population dynamics from 1960–1995, it would appear that their impact was small relative to the effect of sport hunting. New road construction during this period greatly facilitated access to mountain goat habitat and likely increased hunter harvest in some areas.

Using model estimates of population size and harvest data from the State of Washington, harvest mortality was likely higher than 6 percent of the population in most years that hunting occurred and greater than 10 percent in 10 of the last 19 years that sport harvest occurred. In a summary of mountain goat harvest strategies, Bailey (1986) cites other studies that suggest that harvest no more than 4-5 percent of the population is necessary to maintain a stable population. In the Mt. Baker area, this level of harvest occurred in only 6 of the 30 years where complete data were available.

Figure 25 Modeled Mt. Baker Mountain Goat Population Size With Initial Population Sizes of 384 and 419 Animals.



The model is simplistic and does not include many factors that likely influenced mountain goat population dynamics of the Mt. Baker population from 1964 to 1995. Reproduction and survival rates employed in the model were constant, but yearly variation would be expected in an actual population. Reproduction and survival rates would be expected to generally increase at lower population levels when more resources were available to individual animals, provided that harvest was distributed throughout the geographic range of the population. However, concentrated harvest may not have resulted in lower goat density on all areas of the modeled population. Most likely the modeled population consists of more than one subpopulation with little movement of animals between some areas. If a density-dependent response was operating that resulted in lower survival rates and higher reproductive rates, the actual population would be larger than what was modeled for the hunted population.

However, because the model only incorporates reported harvest mortality, the model underestimates all harvest related mortality. Some hunters that did not return the hunter questionnaire may have been successful in their hunt and no harvest in unit 23 is modeled for 1982 and 1983, although some likely occurred. Other mortality from tribal and illegal harvest likely occurred from 1964 to 1995 and is not reflected. In addition, sport harvest related mortality from crippling, animals not found, and kid mortality due to the loss of their nanny may have

occurred but are not included in the model. All of these factors would result in a population smaller than model results indicate.

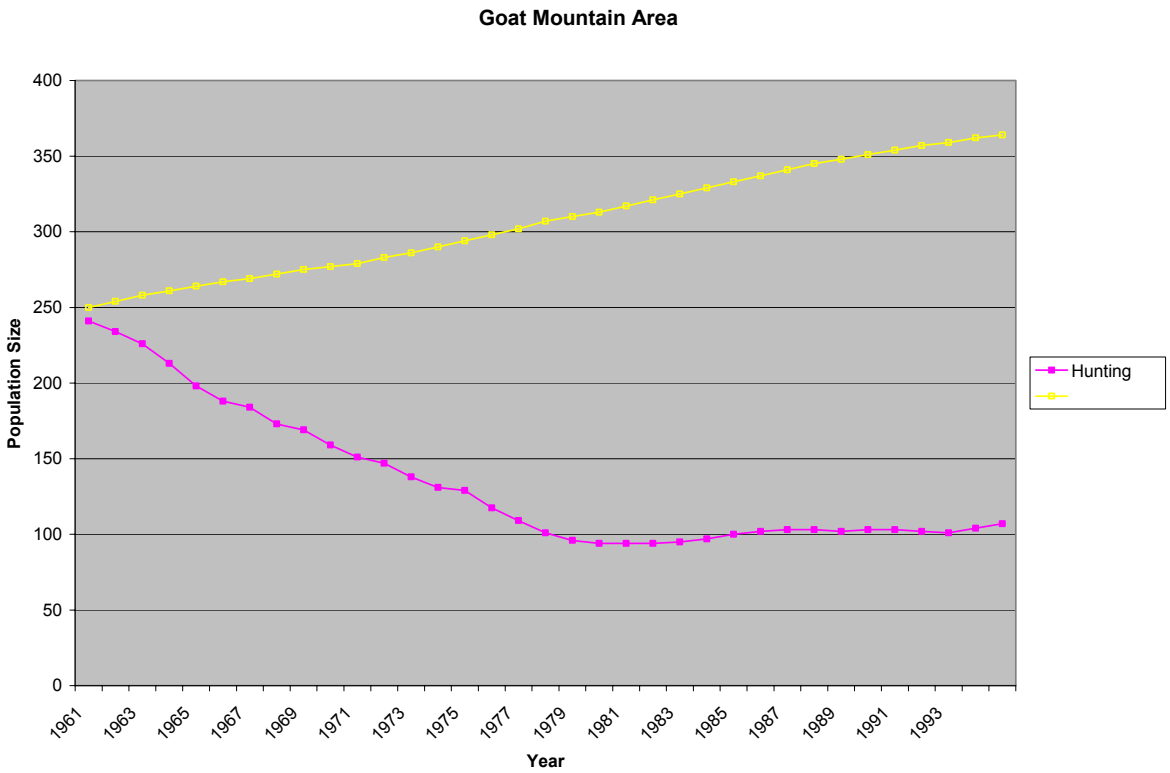
The intent of the model, given its simplistic approach to a complex system, is to provide a coarse assessment of the role of hunting in the dramatic population declines experienced by the Mt. Baker mountain goat population from the early 1960s to 1995. Based on this model, it appears that unsustainable levels of harvest explain most of the decline.

If sport harvest was the limiting factor in the mountain goat population size, one would expect to see an increase in animals following the end of sport hunting, which last occurred in 1995. Surveys five to nine years later in 2000, 2001, and 2004 indicate that the population has increased substantially. The 2001 survey counted 121 animals, which is a four-fold increase in the population in five years. In 2004, 229 mountain goats were observed. This is almost double the numbers observed three years earlier and nearly six times the number of goats observed nine years earlier in 1995. This rate of increase is much higher than predicted by the model (78 goats in 2001) and would suggest that density dependent responses to survival, reproductive rate, and/or age at first reproduction occurred at low population densities. Higher rates of increase have been observed in mountain goat populations. An introduction of 21 goats over three years into the Crazy Mountains of Montana grew to a population of at least 278, a 13-fold increase, in 12 years (Lentfer 1955). Model results and the apparent increase in the Mt. Baker population of mountain goats detected during surveys suggest that hunting had a large influence on the mountain goat population on Mt. Baker.

Results and Discussion (Goat Mountain)

The second largest historic goat population on Mt. Baker Ranger District was located in the North Fork Nooksack River from Ruth Mountain, north to Skagway Pass. This population was estimated to be 250 animals in 1961 (Wadkins 1962). As with the model result for Mt. Baker, in the absence of hunting, the model predicts that the population would grow on average one percent per year. However, when known hunting mortality is incorporated into the model, the population declines (Figure 26). The model maintains a stable population when harvest is two to three percent of the total population size and increase when harvest is lower than two percent.

Figure 26 Modeled Mountain Goat Population Size in the Goat Mountain Area.



The modeled decline in the population due to hunting is less on Goat Mountain (60 percent) than the modeled Mt. Baker population (> 80 percent), but the starting population size was not estimated with any degree of certainty. If the 1961 overestimated the Goat Mountain population, the decline due to hunting would have been much greater than the model predicts and would more resemble the very low numbers (fewer than 15) that have occurred lately in this area in the recent past. Conversely, other factors in addition to hunting may have been affecting the mountain goat population in this area.

Anecdotal sightings and helicopter surveys prior to 2004 never located more than six mountain goats in this area. In 2004, a hiker reported a group of 14 near the Lone Jack Mine. An intensive helicopter survey in 2005 counted 49 mountain goats. Based on this information, it appears that this population is also increasing. Perhaps because this population declined to such a small number, it has taken more years for the population to recover to a noticeable extent. With no increase in habitat quality or no decrease in recreational hiking, these factors were not likely large contributors to the significant population decline.

Appendix B: Influence Of Immature Forest Cover In The Rain-On-Snow Zone On The Probability Of Landslides From Unstable Soils (With Thinning Recommendations)

by Roger Nichols

In the upper South Fork Nooksack watershed, the valley floor is located on glacial lake deposits (fine silts and sand) overlain by glacial outwash (sand and gravels). These deposits are located between Forest Service Road 12, the South Fork Nooksack mainstem to the West, Wanlick Creek to the South, and below 2500' elevation. These deposits are subject to failure (e.g. landslides) when they exist on slopes greater then 30%.

The outwash material which comprises the surface material, consists of sand and gravel, a non cohesive soil type which fails when saturated on slopes greater than 30%, (Hale 1992). Failure locations are typically on the margins of terraces and in and along stream channels. Failure from this soil unit delivers coarse sediment to streams.

The underlying glacial lake sediments consist of alternating silts and fine sands. It is cohesive and fails in large mass failures contributing fine sediments to the streams. This soil unit fails more often when soil moisture content, and therefore pore pressure, is elevated or stream bank erosion occurs to remove the toe of the slope. Near the toe, bank erosion lowers the estimated stability by nearly 75%, and upslope, high pore pressures can lower soil stability by 30% or more (Miller 1997).

The probability of a landslide is related to soil depth and depth of soil saturated. Small increases in water delivery during wet periods are enough to increase the amount of saturation sufficient to destabilize sensitive soils (Berris and Harr 1987).

Rain-on-snow events occur in an elevation zone where temperature hovers around 32 degrees F where snow accumulations can experience rapid snow melt when cold fronts are followed by tropical warm fronts. The term "rain-on-snow event" is actually a misnomer, because it is the wind and not rain that actually melts the snow. In this area, these winds are usually a product of a rapid change in weather fronts. The largest floods in the Pacific Northwest are caused by rain-on-snow events, and landslides are more likely to occur during these events.

A forest that consists of mature timber with a layered canopy can modify the effect of rain-on-snow events due to its ability to intercept snow and moderate the affects of wind. The canopy of a mature forest provides a great deal of surface area for interception, and stronger branches which often support large amounts of snow. Because a mature forest differs in stand structure from a young forest plantation, air flow through the two can also differ. Young plantations offer little

surface area to intercept snow and little strength to support the intercepted snow. This difference can last up to 80 years (Coffin 1992).

Periodically snow is shed from the weaker crowns of young forest stands, and it accumulates under the stands. When this accumulated snow melts, it adds to the soil moisture content thus adding to soil instability through increased pore pressure.

The amount of forest cover at a site can affect a number of snowmelt processes and the relative importance of the various heat sources. Initially, the forest canopy plays an important role in altering both the amount and distribution of snow over the landscape. Then, because the microclimate within a forest differs depending on canopy closure and other factors, rates of snowmelt can vary substantially.

The rest of this discussion is taken from Coffin (1991):

The large surface area of a coniferous forest canopy is capable of intercepting and storing large quantities of snow. Interception reported from a number of studies has generally fallen between 10 and 35% of total snowfall measured in the open (Wilm and Dunford 1984, Rowe and Hendrix 1951, Kittredge 1953, Satterlund and Haupt 1970).

However, Ingebo (1955) measured interception ranging from 5% to 45% over a number of different plots with different canopy densities. Connaughton (1935) found that a virgin stand of timber intercepted an average of 24% of the snow fall, but a young reproduction stand intercepted an average of only 5%. These results support observations by Haupt (1972) and Berris and Harr (1987) that limbs of younger trees are often incapable of supporting a snow load. Timber branches were observed to flex downward in response to snow loading, and snow masses would fall to the ground.

The amount of snow retained in a canopy is a function of the air temperature during snowfall and the amount of interception storage capacity of the canopy. At lower temperatures, less snow has been found to remain in the forest canopy because it does not adhere to the branches as well and is more easily blown off (Miller 1964, Satterlund and Haupt 1967). Interception storage capacity for a canopy is a function of canopy density, stiffness of branches, branch angle, type of needle or leaf, and the age, height and type of vegetation, (USACE 1956).

Snow that is held in the canopy can be melted and released to the forest floor as drip, evaporated, or unloaded in clumps before completely melting (Miller 1966, Berris 1984). When snow is retained in the canopy, it may be subject to increased melt rates as compared to snow accumulated on the ground, because of the larger surface area per unit volume exposed, and the higher temperature often found in the canopy (Miller, 1966). Berris (1984) and Beaudary (1984) both measured snowmelt from forest canopies occurring sooner than snow accumulations on the ground.

While limiting the timing and amount of snow reaching the forest floor, the canopy also affects the quality of the snow pack and the rate of melt in the forest. As snowmelt occurs in the forest canopy, it contributes drip water to the snow pack below. The drip water increases the water content of the snow pack, but can also contribute to raising the snow temperature through the release of latent heat of fusion when the rain freezes in the snowpack.

As the snow water content rises underneath the dripping canopy, subsequent canopy drip may exceed the liquid water holding capacity of the snow pack, and water may flow directly into the soil (Smith, 1974) or across the surface if the ground is frozen. In this way, a forested site can begin routing water offsite before a site in the open does (Berris and Harr, 1987). If some of the forest's water has been routed offsite in this manner prior to rain-on-snow event, then the forest has less snow to melt and less water available for increasing soil moisture content, and therefore pore pressure and subsequently the probability of a landslide are lower during a rain-on-snow event.

Two primary factors affecting water outflow during rain-on-snow events are the amount of prior snow accumulation (esp. its water content) and the subsequent rate of melt. As a plantation grows from individual seedlings to mature trees, the individual tree canopies enlarge and coalesce, forming a more complete and dense canopy layer. Throughout this process, the increased density of vegetation and branch strength alters interception and accumulation rates within the stand as well as the penetration of wind into the stand.

In the upper South Fork Nooksack watershed, most of the timber stands located on the deposits mentioned above were harvested in the late 1960s and early 1970s. These areas are now occupied by plantations consisting of pre-commercially thinned stands of Douglas fir, western hemlock and silver fir with diameters greater than 11". These young forest stands exist on flatter ground, on south, southeast and east aspects with slopes of 5-15%. Canopy density is 75-100% with very little under story vegetation. The canopy cover is complete and the stands have high stem densities. Because the trees are young and spindly, they cannot support much snow in the canopy.

Thinning is currently being used to try to increase limb diameter, and thus stiffness, on Weyerhauser lands to improve habitat for spotted owls and marbled murrelets. If this is accomplished, and a layered canopy created, interception storage capacity could be increased. Hypothetically, this could accelerate stand development enough to effectively change the amount of snow at a given site. If rain-on-snow events occur long enough after the snow accumulation has occurred, the magnitude of increase in soil pore pressure could be reduced to the point of decreasing the probability of landslides occurring on the unstable soils to a measurable degree.

Prescription

Commercially thin the stand s to 20’ X 20’ or 25’ by 25’ spacing which is between 70-110 large diameter trees per acre. Most of the area in question is suitable to modern feller bunch machine harvest. No additional roads are foreseen to be needed. Selection for dominant larger diameter trees and resistant species (fir) is desirable. If the stand consist of hemlock then intermediate thinning may be necessary to allow for increase in root mass to prevent substantial wind throw. The objective is to obtain optimal thermal cover defined as a layered canopy where the dominant trees average at least 21" diameter and the stand has at least 70% crown closure (Brown 1985). Crown closure to 70% is expected to occur in 5 years (Nichols 1990, Cambers 1980).

Literature Cited

50 CFR 226. 2005. Endangered and Threatened Species; Designation of Critical Habitat for even Evolutionarily Significant Units of Pacific Salmon and Steelhead in California AGENCY: National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration, Commerce. ACTION: Final rule. [Docket No. 041123329–5202–02; I.D. No.110904F] Federal Register Vol 70, No 170, Friday September 2, 2005, pp 52488 – 52627.

Adams, L. G. and J. A. Bailey. 1982. Population Dynamics of Mountain Goats in the Sawatch Range, Colorado. Journal of Wildlife Management 46:1003-1009.

Agee, J. K. 1993. Fire Ecology of Pacific Northwest Forests. Island Press, Washington D.C. p.493.

Anchor Environmental, LLC. 2003. Fish Periodicity in WRIA 1. January 2003 draft. Prepared for City of Bellingham Public Works Department.

Bailey, J. A. 1986. Harvesting Mountain Goats: Strategies, Assumptions, and Needs for Management and Research. Proceedings of the Fifth Biennial Sypmposium of the North American Wild Sheep and Goat Council. pp.37-47.

Bailey, J. A. 1991. Reproductive Success in Female Mountain Goats. Canadian Journal of Zoology 69:2956-2961.

Bailey, J. D. and J. C. Tappiener. 1998. Effects of Thinning on Structural Development in 40- to 100-year-old Douglas-fir stands in Western Oregon. Forest Ecology and Management 108:99-113.

Banci, V. 1994. Wolverine. Pages 99-127 in L. F. Ruggiero, K. B. Aubry, S. W. Buskirk, L. J. Lyon, and W. J. Zielinski, eds. The Scientific Basis for Conserving Forest Carnivores: American Marten, Fisher, Lynx and Wolverine in The Western United States. USDA Forest Service, general technical report RM-254, Rocky Mountain Forest and Experiment Station, Ft. Collins, CO. 152 p.

Beaudry, P.G. 1984. Effects of forest harvest on snowmelt during rainfall in coastal British Columbia. M.S. Thesis, University of British Columbia, Vancouver, 185 pp.

Beechie, T.J. 1998. Modeling recovery of large woody debris and pool abundance after disturbance. Ph.D. Dissertation, University of Washington, Seattle, WA.

Beggs, L. R. 2004. Vegetation Response Following Thinning in Young Douglas-Fir Forests of Western Oregon: Can Thinning Accelerate Development of Late-Successional Structure and Compostion? M. S. Thesis, Oregon State University, Corvalis, OR. pp. 87.

Berris, S. N. 1984. Comparative snow accumulation and melt during rainfall in forest and clear-cut plots in Western Oregon. M. S. Thesis, Oregon State Univ., Corvallis, 152 pp.

Berris, S.N. and Harr, R. D. 1987. Comparative snow accumulation and melt during rainfall in forested and clear cut plots in the western Cascades of Oregon. Water Resources Res. 23 (1): 135-142.

Bloomquist, R. Gordon. Undated. Geothermal Energy in Washington. Oregon Institute of Technology. Brochure prepared for USDOE, Contract No. FG 06-79ET-27256. Operations Office. Richland, Washington.

Blukis Onat, Astrida and Jan L. Hollenbeck, ed. 1981. Inventory of Native American Religious Use, Practices, Localities and Resources on the Mt. Baker-Snoqualmie National Forest. Prepared for the Mt. Baker-Snoqualmie National Forest, Contract #53-05M6-0076N. Institute of Cooperative Research, Seattle.

Blukis Onat, Astrida R. 1987. Resource Protection Planning Process Indentification of ArchaeologicalResources in the Northern Puget Sound Study Unit. An RP3 document prepared for the Washington State Office of Archaeology and Historical Preservation by BOAS, Inc., Seattle.

Brown, E.M., D.L. Blackwell, B. w. Christenson, F.I. Frase, R. A. Haugarud, J.T. Jones, P.A. Leiggi, M.L. Morrison, P.M. Rady, G.J. Reller, C.B. Seivighn. 1987. Geologic map of the Northwest cascades, Washington. Geological Society of American Masp and charts Series MC-61, scale 1:100000.

Brown, R.E. (ed). 1985. Management of wildlife and fish habitats in forest of western Oregon and Washington, Chapter Narratives, Part 1: USDA Forest Service, Pacific Northwest Region. 332 pp.

Bryant, M.D. 1984. The role of beaver dams as coho salmon habitat in southest Alaska streams. Pages 183-192 *in*, J.M. Walton and D.B. Houston (eds.). Proceedings, Olympic Wild Fish

Carey, A. B. and M. L. Johnson. 1995. Small Mammals in Managed, Naturally Young, and Old-Growth Forests. Ecological Applications 5:336-352.

Chambers, C.J. 1980. Empirical growth and yield tables for the Douglas fir zone: Washington state Department of Natural Resources Report n.41.

Coffin B.A, and Harr, R.D. 1991. Effects of Forest Cover on Rate of Water Delivery to Soil during Rain-on-Snow. M.S. Thesis, University of Washington Seattle WA , 106 pp.Coffin, B.A., R.D. Harr. 1992. Effects of Forest Cover on Volume of Water Delivery to Soil during Rain on Snow. Washington State Department of Natural Resources, Timber/Fish/wildlife program report TFW-SH1-92-001.

Conference. Peninsula College, Fisheries Technology program, Port Angeles, WA.

Connaughton, C.A.1935. The accumulation and rate of melting of snow as influenced by vegetation. J. Forestry 33: 564-569.

Cote, S. D. and M. Festa-Bianchet. 2001. Birthdate, Mass And Survival in Mountain Goat Kids: Effects of Maternal Characteristics and Forage Quality. Oecologia 127:230-238.

Curtis, R. O., G. W. Clendenen, and J. A. Henderson. 2000. True fir-Hemlock Spacing Trials: Design and First Results. USDA Forest Service, General Technical Report PNW-GTR-492. Pacific Northwest Research Station, Portland, OR. 35 p.

Dailey, T. V. and N. T. Hobbs. 1989. Travel in Alpine Terrain: Energy Expenditures for Locomotion by Mountain Goats and Bighorn Sheep. Canadian Journal of Zoology 67: 2368-2375.

Dane, B. 2002. Retention of Offspring in a Wild population of Ungulates. Behaviour 139:1-21.

Davis, R. W., J. G. Cook, R. C. Cook, L. C. Bender, and L. L. Irwing. 2003. Baker Lake Re-Licensing: Elk Forage Mapping Study. Final Report. Puget Sound Energy, Bellevue, WA. p. 22.

Davison, M. A. 2002. Washington State Elk Herd Plan: North Cascade (Nooksack) Elk Herd. Washington Department of Fish and Wildlife, Olympia, WA. pp. 53.

Dreidger, C.L. and P.M. Kennard. 1986. Ice volumes on Cascade volcanoes – Mount Rainier, Mount Hood, Three Sisters and Mount Shasta. U.S. Geological Survey Professional Paper 1365, 28 p. 6 plates.

Fahnestock, R.K. 1963. Morphology and hydrology of a glacial stream - White River, Mount Rainier, Washington, U.S. Geological Survey Prof. Paper. 422-A, 70p.

Festa-Bianchet, M., M. Urquhart, and K. G. Smith. 1994. Mountain Goat Recruitment: Kid Production and Survival to Breeding Age. Canadian Journal of Zoology 72:22-27.

Fiksdal, Allen J. and Brunengo Matthew J. 1981. Forest Slope Stability Project, Phase II. Department of Ecology WDOE 81-14 Volume I and II. Olympia, WA.

Folsom, M.M. 1970. Volcanic eruptions – The pioneer's attitude on the Pacific Coast, from 1800

to 1875; Oregon Department of Geology and Mineral Industries, The Ore Bin, v.32, no. 4, p 61-71.

Forsman, E. D. and A. R. Giese. f1997. Nests of northern spotted owls on the Olympic Peninsula, Washington. Wilson Bulletin 109:28-41.

Foster, B. R. and E. Y. Rahs. 1983. Mountain Goat Response to Hydroelectric Exploration.

Fox, J. L. 1977. Summer Mountain Goat Activity And Habitat Preference in Coastal Alaska as a Basis for The Assessment of Survey Techniques. Pages 190-199 in Samuel, W. and W. G. MacGregor, eds., Proc. First Intnl. Mountain Goat Symp., Kalispel, Mt. 243 p.

Frank, D., A. Post and J.D. Friedman. 1975. Recurrent geothermally induced debris avalanches on boulder glaciers, Mount Baker, Washington. U.S. Geological Survey, Journal of Research, v.3, no. 1, p 77-87.

Frank, D., M.F. Heier and, D.A. Swanson. 1977. Assessment of increased thermal activity at Mount Baker, Washington, March 1975 – March 1976, with contributions by J.W. Babcock, M.O.

Franklin, J.F, and C.T. Dyrness. 1988. Natural Vegetation of Oregon and Washington. Oregon State University Press. 452 pp.

Franklin, J. F., T. A. Spies, R. Van Pelt, A. B. Carey, D. A. Thornburgh, D. R. Berg, D. B. Linenmayer, M. E. Harmon, W. S. Keeton, D. C Shaw, K. Bible, and J. Chen. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas fir forests as an example. Forest Ecology and Management 155:399-423.

Fretwell, G.D.Malone, C.L. Rasenfeld, R.L. Shrene, and R.E. Wilcox; U.S. Geological Survey Professional Paper 1022-A. 49 p.

Funk, W.H. et al. 1987. Water quality Benchmarks in the North Cascades. State of Washington Water Research Center, Pullman, Washington.

Gardner, C., K.M. Scott, C.D. Miller, B.M. Myers, W. Hildreth and P.T. Pringle. 1976. Potential Volcanic Hazards from Future Activity of Mount Baker, Washington. Unpublished Report.

Hagar, J. C., W. C. McComb, and W. H. Emmingham. 1996. Bird Communities in Commercially Thinned and Unthinned Douglas-fir Stands of Western Oregon. Wildlife Society Bulletin 24:353-366.

Hale, James W. 1992. South Fork Nooksack Drainage, Mass-Wasting History Inventory. USDA Forest Service, Mt Baker Snoqualmie National Forest, Mt Baker Ranger Station, Sedro Woolley WA. 27p.

Hall, T. 2005. Likely Trends in National Forest Recreation in Region Six (Oregon and Washington) Draft Report, University of Idaho, Department of Conservation Social Studies.

Harr, R.D. 1981. Some characteristics and consequences of snowmelt during rainfall in western Oregon. J. Hydrology 53: 277-304.

Harr, R.D., B.A. Coffin and T.W. Cundy. 1989. Effects of timber harvest on rain-on-snow run-off in the transient snow zone of the Washington Cascades, Interim final report submitted of TFW Sediment, Hydrology, and Mass Wasting Steering Committee (Washington State).

Harr, R.D. and F.M. McCorison. 1979. Initial effects of clear-cut logging on size and timing of peak flows in a small watershed in western Oregon. Water Resource Res. 15 (10):90-94.

Harr, D. D., and R. A. Nichols. 1993. Stabilizing forest roads to help restore fish habitats: A Northwest Washington Example. Fisheries, Vol. 18, No. 4, April 1993, pp. 18-22.

Harris, S.L. 1980. Fire and Ice, The Cascades Volcanoes. The Mountaineers, Co-published by Pacific Search Press, Seattle, Wa. 316 p.

Haupt, H.F. 1972. The release of water from forest snowpacks during winter. U.S. Dept Agriculture, Forest Service. Research Paper INT-114, 17pp.

Heller, P.L. 1978. Paleocene geology and related landslides in the Lower Skagit and Baker Valleys, North Cascades, Washington. M.S. Thesis, Western Washington College, Bellingham. 154 p.

Henderson, J. A., R. D. Lesher, D. H. Peter, and D. C. Shaw. 1992. Field Guide to Forested Plant Associations of the Mt. Baker-Snoqualmie National Forest. USDA Forest Service, Technical Paper, R6-Ecol-TP-028-91, p.196.

Hessburg, P.F., B.G. Smith, and R.B. Slater. 1999. Detecting change in forest spatial patterns from reference conditions. Ecological Applications 9:1232-1252.

Hildreth, Wes. 1995 (in press). Kulshan Caldera: A Quaternary Subglacial Caldera in the North Cascades, Washington, U.S. US Geological Survey, Menlo Park, California. 20 p.

Hjeljord, O. 1973. Mountain Goat Forage and Habitat Preference IN: Alaska. Journal of Wildlife Management 37:353-362.

Holbo, H.R.D. 1984. Wind Study. Unpublished report, Comstock instrument Company, Albany Oregon, 6 p.

Hollenbeck, Jan L. and S.L. Carter. 1986. A Cultural Resource Overview: Prehistory and Ethnography, Wenatchee National Forest. USDA Forest Service, Pacific Northwest Region.

Houston, D. B., B. B. Moorhead, and R. W. Olson. 1991. Mountain Goat Population Trends in the Olympic Mountain Range, Washington. Northwest Science 65:212-216. IN: Northwestern British Columbia. Environmental Management 7:189-197.

Huckell/Weinman Associates. 2003. Traffic Monitoring Study (Study R9). Draft Report. Baker River Project Relicense, Recreational and Aesthetics Resources Working Group. Kirkland, Washington. March 2003.

Hyde, J.H., D.R. Crandell. 1978 Postglacial volcanic deposits at Mount Baker, Washington, and potential hazards from future eruptions; U.S. Geological Survey Professional Paper 1022-C. 17 p. 1 plate.

Ingebo, P.A. 1955. An instrument for measurement of density of plant cover over snow course points. In: Proc. 23rd Annual Western Snow Conference, pp 26-28.

Johnson, R. E. and K. M. Cassidy. 1997. Terrestrial Mammals of Washington: Location Data and Predicted Distributions. Volume 3 in Washington State Gap Analysis – Final Report. K. M. Cassidy, C. E. Grue, M. R. Smith, and K. M. Dvornich, eds. Washington Cooperative Wildlife Unit, University of Washington, Seattle, 304 p.

Johnson, R. L. 1983. Mountain Goats and Mountain Sheep of Washington. Washington Department of Game Biological Bulletin 18, Olympia, WA. pp.196.

Johnson, S. 1996. The Southern Whidbey Island Fault: An Active Structure in the Puget Lowlands, Washington. US Geological Survey. GSA Bulletin, March, volume 108, no. 3.

Keefer, D.K. 1983. Landslides, soil liquefaction, and related ground failures in Puget Sound earthquakes. *In* Yount, J.C., Crosson, R.S., editors, 1983. Proceedings of Conference XIV, Earthquake hazards of the Puget Sound region, Washington; U.S. Geological Survey Open-File Report 83-19, p 280-299.

Keefer, D.K. 1984. Landslides caused by earthquakes; Geological Society of America Bulletin 95(4):406-421.

Ketcheson, G. 1998. Flooding in west Cascade mountain river basins an update based on floods of November 1995 and February 1996. USDA Forest Service.

Ketcheson, G. 1992. Flooding in west Cascades mountain river basins; a perspective on the November 1990 flooding in Western Washington. USDA Forest Service.

Kittredge, J. 1953. Influences of forest on snow in the Ponderosa-Sugar Pine –Fir Zone of the central Sierra Nevada. Hilgardia 22(1): 96pp.

Knutson, K.L., S. Jackson, T. Lovgren, M. Hunter, and D. McDonald. 1992. Washington rivers information system (WARIS). Resident and anadromous fish data: 1:100,000 scale update.

Kohlmann, S. G. and J. A. Bailey. 1991. Population Ecology of Introduced Mountain Goats. Trans. Congr. Int. Union Game Biol. 18:583-585.

Kruckeberg, A.R. 1974. Natural Features Report. Olivine Bridge Natural Area Reserve. Report prepared for the Division of Land and Water Conservation, Department of Natural Resources. Olympia, Wa. 6 pp.

Kuntz, R. C. II and R. G. Christopherson. 1996. A survey of northern spotted owls in North Cascades National Park Service Complex, Washington. USDI National Park Service, unpublished report. P. 23.

Kunzler, LJ. 1991. Skagit River valley: the disaster waiting to happen. US Flood Research. Everett, Washington.

Legget, R.F., and M.W. Bartley. 1953. An Engineering Study of Glacial Deposits at Steep Rock Lake, Ontario, Canada. Economic Geology and the Bulletin of the Society of Economic Geologists 48(7): 513-540.

Leiggi, M.L. Morrison, P.M. Rady, G.J. Reller, C.B. Seivighn. 1987. Geology map of the Northwest Cascades, Washington. Geological Society of America map and Chart Series MC-61, scale 1:100000

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.

May, C.W. 1996. The Cumulative Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion. Applied Physics Laboratory, College of Ocean and Fishery Sciences, University of Washington.

Meyer, J. S., L. L. Irwin, and M. S. Boyce. 1998. Influence of habitat abundance and fragmentation on northern spotted owls in western Oregon. Wildlife Monographs 139:1-51.

Mierendorf, Robert R., D.J. Harry and G.M. Sullivan. 1998. An Archaeological Site Survey and Evaluation in the Upper Skagit Valley, Whatcom County, WA. National Park Service, Columbia-Cascades System Support Office

McClure, N. 1992. Washington's Wetlands. Washington State Department of Ecology. Publication #92-105.

McFetridge, R. J. 1977. Strategy of Resource Use by Mountain Goat Nursery Groups. Proc. Intnl. Mountain Goat Symp. 1:169-173.

McKenzie, D., C. B. Halpern, and C. R. Nelson. 2000. Overstory Influences on Herb and Shrub Communities in Mature Forests of Western Washington, U.S.A. Canadian Journal of Forest Resources 30:1655-1666.

Miller, D.H. 1964. Interception processes during snowstorms. U.S. Dept Agriculture, Forest Service. Res. Paper PSW-18, 24pp.

Miller, D.H. 1966. Transport of interception snow from trees during snow storms. U. s. Dept of agriculture, Forest Service Res. Paper.

Miller, D.J. and Sias, J. 1998. Deciphering large landslides: linking hydrological, groundwater and slope stability models through GIS. Hydrological Processes, 12, 923-923-941 pp.

Miss, Christian J. and Margaret M. Burns. 1989. Silver Creek Land Exchange Cultural Resources Survey. Report prepared for Wenatchee National Forest. Northwest Archaeological Associates, Inc. Report 89-9.

Miss, Christian J. and M.A. Nelson. 1995. Data Recovery at Site 45-KI-435, King County Washington. Northwest Archaeological Associates, Inc., Seattle.

Moen, Wayne S. 1969. Mines and Mineral Deposits of Whatcom County, Washington. Bulletin No. 57. State of Washington Department of Natural Resources, Division of Mines and Geology. Olympia, Washington. 84 p.

Naiman, R. J. and R. E. Bilby, eds. 1998. River ecology and management: Lessons from the Pacific coastal ecoregion. New York. Springer-Verlag.

Naiman, R. J., C. A. Johnston, and J. C. Kelly. 1988. Alteration of North American streams by beaver. Bioscience 38:753-762.

Naiman, R. J., G. Pinay, C. A. Johnston, and J. Pastor. 1994. Beaver influences on the long-term biogeochemical characteristics of boreal forest drainage networks. Ecology 75:905- 921.

Nelson, K. 1998. The Influence of sediment supply and large woody debris on pool characteristics and habitat diversity. Masters Thesis. University of Washington. 8/12/98. 73 p.

Nichols, L. 1980. Mountain Goat Management Technique Studies. Final report, W-17-9, W-17-10, and W17-11. Juneau, AK. p.50.

Nichols, R.A., A.D. Zander, and J.M. Shultz. 1990. A Methodology for Watershed Cumulative Effects Analyses Utilizing Vegetative Disturbances. USDA Forest Service, Mt. Baker-Snoqualmie National Forest. Mt. Baker Ranger District. Sedro Woolley, Washington. 6 p.

Nooksack Indian Tribe. 2001. Letter addressed to Jan Hollenbeck, Heritage Program, Mt. Baker-Snoqualmie National Forest, Mountlake Terrace, WA. September 28, 2001.

Nooksack Tribe and Lummi Indian Nation 2005. WRIA 1 Salmonid Recovery Plan: Preliminary Draft.

Noson, L.L., A. Qamar, G.W. Thorsen. 1988. Washington State Earthquake Hazard. Washington State Department of Natural Resources. Washington Division of Geology and Earth Resources Information Circular 85.

Olmsted, I. 1978. Mountain goat winter habitat study. Washington State Department of Game. 87 p.

Pacific Northwest River Basins Commission, Hydrology and Hydraulics Committee. 1968. River Mile Index Stillaguamish River, Skagit River, Samish River, Nooksack River. Puget Sound Basin, British Columbia and Washington. 42 p.

Parks, D.S. 1992. A Landslide Inventory of the Finney Creek Watershed, Skagit County Washington. M.S. Thesis, University of Washington, Seattle, Washington. 164 p.

Paull, Gary 2000. Trail Tidbits. Mt. Baker-Snoqualmie National Forest. Mountlake Terrace, WA.

Paulson, K. 1996. Estimates of land-use effects on sediment supply in the Finney Creek watershed, Skagit County, Washington. Prepared for the Skagit System Cooperative and submitted in partial fulfillment of U.S. Forest Service Cost Share Monitoring Agreement #CCS-94-04-05-01-050. College of Forest Resources, AR-10, University of Washington, Seattle, WA. 32

Peak Northwest, Inc. 1986. Nooksack River Basin Erosion and Fisheries Study: Boulder Creek, Canyon Creek, Cornell Creek, Howard Creek, and Racehorse Creek, Whatcom/Skagit Counties, Washington. Washington State Department of Ecology, 205 J Grant.

Perkins, J. M. 1988. Three-year bat survey for Washington National Forests: REsults of year two - Olympic and Mt. Baker-Snoqualmie National Forests. USDA Forest Service, unpublished report. P. 45.

Plotnikoff, R.W. and J. Polayes 1999. The Relationship Between Stream Macroinvertebrates and Salmon in the Quilceda/Allen Drainage. Publication No. 99-311. Washington State Department of Ecology, Environmental Assessment Program. Olympia, Washington.

Raedeke Associates. 1990. Assessment of Mountain Goats Wintering in the Wells Creek drainage, Whatcom County, Washington. Unpub. Report. 25 p.

Richter, B.D., J. V. Baumgartner, J. Powell and D.P. Braun. 1999. A method for assessing hydrologic alteration within ecosystems. The Nature Conservancy. Boulder,Colorado.

Riedel, J. 1990. Report on existing conditions of reservoir and streambank erosion, Skagit River Project FERC No. 553. USDI National Park Service.

Rosgen, D.L. 1988. Conversion of a braided River Pattern to Meandering A Landmark Restoration Project. California Riparian Systems Conference. Davis, California. 12 p.

Rowe, P.B., and T. M. Hendrix. 1951. Interception of rain and snow by second growth ponderosa pine. Trans Amer. Geophys. Union 32 (6): 903-908.

Samson, Rebecca C. Undated. The Twin Sisters Range, An Unusual High Montane Habitat. Komo Kulshan Chapter, Washington Native Plant Society.

Satterlund, D. R. and H. f. Haupt. 1970. The disposition of snow caught by conifer crowns. Water Resource. Res. 6 (2): 649-652.

Schoen, J. W. and M. D. Kirchoff. 1982. Habitat Use by Mountain Goats in Southeast Alaska. Alaska Department of Fish and Game. Federal Aid in Wildlife Restoration. Final Report. 67 pp.

Sidle, R.C. 1985. Factors influencing the stability of slopes. Proceedings of a Workshop on Slope Stability: Problems and Solutions in Forest Management. Pacific. USDA Forest Service.

Singer, F. J. and J. L. Doherty. 1985. Movements And Habitat Use in an Unhunted Population of Mountain Goats, *Oreamnos americanus*. Canadian Field-Naturalist 99:205-217.

Smith, C. A. 1986. Bi-Level Analysis of Habitat Selection by Mountain Goats in Coastal Alaska. pp. 366-380. Proceedings of the Fifth Biennial Symposium. Northern Wild Sheep and Goat Council.

Smith, C. A. 1986. Rates and Causes of Mortality in Mountain Goats in Southeast Alaska. Journal of Wildlife Management 50:743-746.

Smith, J.L. 1974. Hydrology of warm snow packs and their effects upon water delivery… some new concepts. In: advanced concepts and Techniques in the Study of snow and ice resources. National Academey of Sciences, Washington, D.C., pp 76-89.

Snyder, Sally 1981. Swinomish, Upper Skagit and Sauk Suiattle. *In* Inventory of Native American Religious Use, Practices, Localities and Resources on the Mt. Baker-Snoqualmie National Forest, Astrida R. Blukis Onat and Jan L. Hollenbeck, editors. Report prepared for the Mt. Baker-Snoqualmie National Forest, Seattle.

Snyder, R.V. and J.M. Wade. 1970. Mt. Baker National Forest Soil Resource Inventory. USDA Forest Service Pacific Northwest Region.

Tabor, R., R. Haugerud. 1999. Geology of the North Cascades; A Mountain Mosiac. Published by The Mountaineers. Seattle, WA.

Tabor, R.W, R.A. Haugerud, E.B. Brown and W. Hildreth. In press. Geologic Map of the Mount Baker one-half by one degree quadrangle, Washington. Open File Report 94-403. U.S. Geological Survey, Miscellaneous Investigations Map, I-2660.

Terzaghi K. and R.B. Peck. 1961. Soil Mechanics in Engineering Practice, second Edition. John Wiley and Sons, New York.

Tressler, R. and R. Davis. 2003. Elk Habitat Mapping Study: Final Report. Puget Sound Energy, Bellevue, WA. pp. 26.

USACE (U. S. Army Corps of Engineers). 1956. Snow Hydrology. U. S. Army Corps of Engineers, Portland, OR, 437 pp.

USDA Forest Service 1992. Final Supplemental Environmental Impact Statement on Management for the Northern Spotted Owl in the National Forests. USDA Forest Service. Volume 1. January 1992.

USDA Forest Service. 1993. Subregional Ecological Assessment for the Mt. Baker-Snoqualmie National Forest.

USDA Forest Service. 2001. Forest-wide Late Successional Reserve Assessment. USDA Forest Service, Mountlake Terrace, WA.

USDA Forest Service. 2002. Baker River Watershed Analysis. USDA Forest Service, Mountlake Terrace, WA.

USDA Forest Service. 2004. Regional Forester's Sensitive Species List. Portland, Oregon.

USDA Forest Service. 2005. Mt. Baker – Snoqualmie National Forest GIS Database query for salmonid distribution within the Middle Fork and South Fork Nooksack Rivers. Department of Agriculture – Forest Service. Pacific Northwest Region. Mt. Baker – Snoqualmie National Forest. Mountlake Terrace, Washington.

USDA, USDI. 1993. Forest Ecosystem Management: An Ecological, Economic, and Social Assessment. Report of the Forest Ecosystem Management Team. Portland, OR.

US Department of Commerce - National Oceanic and Atmospheric Administration. 2005a. Endangered and Threatened Species; Designation of Critical Habitat for 13 Evolutionarily Significant Units of Pacific Salmon (Oncorhynchus spp.) and Steelhead (O. mykiss) in Washington, Oregon, and Idaho. Department of Commerce - National Oceanic and Atmospheric Administration. Federal Register 69(239): 74572-74846.

US Department of Commerce - National Oceanic and Atmospheric Administration. 2005b. Endangered and Threatened Species; Extension of Public Comment Period on Proposed Critical Habitat Designations for West Coast Salmonids. Department of Commerce - National Oceanic and Atmospheric Administration. Federal Register 70(24): 6394-6395.

USDI BIA. 1977. Usual and Accustomed Fishing Places of Certain Western Washington Treaty Tribes Adjudicated in United States v. Washington No. 9213 as of January 1, 1977. Prepared by the BIA, revised July 1978.

USDI Fish and Wildlife Service. 2004. Endangered and Threatened Wildlife and Plants; Proposed Designation of Critical Habitat for the Jarbidge River, Coastal-Puget Sound, and Saint Mary-Belly River Populations of Bull Trout. Department of the Interior – Fish and Wildlife Service. Federal Register 69(122): 35768-35857.

USFWS. 2004. Draft Recovery Plan for the Coastal-Puget Sound Distinct Population Segment of Bull Trout (Salvelinus confluentus). Volume I (of II): Puget Sound Management Unit (Including the Chilliwack River and associated tributaries flowing into British Columbia, Canada). May 2004. U.S. Fish and Wildlife Service Region 1. Portland, Oregon. 389 pp. http://pacific.fws.gov/bulltrout/jcs/vol_I.html.

USGS. 1992. Washington: stream water quality. National water summary 1990-91. p 539-546.

USGS. 1999. Water Resources Data; Washington; Water Year 1998. Water data report WA-98-Tacoma, WA.

USGS. 2000. Mt. Baker - Living with an Active Volcano. USGS Fact Sheet – 059-00. May

WA DOE. 1998. Station 04B070: Six year water quality data summary Washington Department of Ecology Website.

Wadkins, L. A. 1962. Goat Population Study. Job Completion Report, W 66-R-3. Washington State Department of Game, Olympia, WA. 7 p.

Washington Natural Heritage Program. 2005. Rare Plants List. www.dnr.wa.gov/nhp/refdesk/plants/htm

WDFW 2001. 2001 Game Status and Trend Report. Washington Department of Fish and Wildlife, Olympia, WA.

WDFW. 2002. Washington State Elk Herd Plan for the North Cascade (Nooksack) elk herd.

WDNR (Washington Department of Natural Resources). 1981. Geothermal resources of Washington. Geologic Map GM-25. Olympia, Washington.

Westbrook, M. 1988. Western Power, Inc., Wells Creek Hydroelectric Project (FERC Project No. 4628): Erosion and Sedimentation Field Study Report. 98 p.

Williams Walter R., Laramie, Richard M., Ames, James J. 1975. A catalog of Washington Streams and salmon utilization, Volume 1, Puget Sound Region. Washington Department of Fisheries. Olympia Washington. 104 p.

Wilm, H.G., and E. G. Dunford. 1948. Effect of timber cutting on water available for stream flow from a lodge pole pine forest. U.S. Dept Agriculture., Tech Bull No 968, Washington D. C., 43 pp.

Wright, W. 1977. Ecology of the Cascade Mountain Goat, Mt. Baker-Snoqualmie National Forest, Washingon. M. S. thesis, Western Washington University, Bellingham, WA 93 p.

Zollweg, J.E., and Johnson, P.A. 1989. The Darrington Seismic Zone in Northwestern Washington. Bulletin of the Seismological Society of America 79(6):1833-1845.