

Mountain Goat Conservation in the Washington Cascades: a Genetic Approach

A Proposal Submitted to the Wildlife Research Program

Seattle City Light

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II. Problem Statement

Mountain goats (*Oreamnos americanus*) are native to the Cascade mountain range of Washington from the Canadian border to Mount Adams, including the Skagit Valley watershed. In 1961 the state's population was thought to number approximately 10,000, but by 2003, that number had dropped to an estimated 3700 animals, excluding the Olympic range (Côté et al. 2003). This dramatic decline was not uniform across their range. Areas like Mount Baker and Goat Rocks retain substantial populations today, while portions of the Darrington ranger district and the Snoqualmie game management unit, for example, have experienced declines of 90% or more. Additionally, using the locations of hunter harvest from 1948 to 1970 as an approximation of their historic distribution, the current distribution of mountain goats in Washington shows a substantial range retraction (Figure 1). This apparent range retraction is particularly striking in the Skagit watershed.

Although the cause of this decline remains uncertain, recent evidence suggests a likely factor has been the high level of hunter harvest over this time period (Rice and Gay 2007). Mountain goat populations are sensitive to hunting pressure (Côté et al. 2003, Hamel et al. 2006) and the sustainable level of harvest from native populations may be as low as 1% (Hamel et al. 2006). Harvest in past decades probably exceeded 4% annually. Despite the steady drop in hunting pressure since 1961, however, many of the numerous small herds of the Cascades have not recovered, and large areas that historically supported mountain goats remain unoccupied. The failure to reoccupy historic habitat and the lack of recovery in these small populations is troubling.

An answer to this paradox may lie in the way mountain goat populations are structured. Alpine habitat is patchily distributed throughout the Cascades in an archipelago of high elevation "islands." Mountain goats living in these islands form a metapopulation – a network of populations linked by dispersal (Hanski and Gilpin 1991). Metapopulation theory predicts that the dispersal corridors linking the network are absolutely critical to the long term survival of the species (Gustafson and Gardner 1996). Historically, these corridors have likely been shaped by landscape factors such as elevation, slope, and land cover. In addition to these factors, anthropogenic changes to the Cascade landscape that have occurred over the past several decades may be imposing additional constraints on dispersal. If this new landscape lowers dispersal success, the current metapopulation framework may not be functioning in a way that would support historic numbers of mountain goats. In particular, increased road building, logging, and recreation in the Cascades all have the potential to limit dispersal across the matrix between habitat patches and thereby fragment and isolate mountain goat populations (Harrison and Bruna 1999).

Small remnant populations isolated from dispersal face a number of serious threats to their persistence. For some species, at low population densities, reproductive and/or survival rates decline, leading to an inverse density-dependence known as the Allee effect (Dennis 2002). Other alpine ungulates such as bighorn sheep and ibex have been shown to exhibit increased susceptibility to predation and lower success rates for finding mates at low densities (Mooringa et al. 1991, Saether et al. 2002). Mechanisms such as these may also impact mountain goat populations, however, Allee effects have not yet been investigated for this species.

In addition to Allee effects, stochastic events, including disease, predation pressure, and climate can further reduce population sizes to the point where small herds may not have sufficient individuals to repopulate following such events. Recovery is also impeded by genetic loss of fitness in small populations (Frankham 1995). Once below a critical threshold population size, the processes of inbreeding and genetic drift can lead to lower survival and fecundity. As a result, the population declines further, exacerbating Allee effects, genetic drift, and inbreeding until ultimately the population goes extinct (Lacy 1997). This downward cycle has been termed an extinction vortex (Fagan and Holmes 2006), and may be responsible for the failure of mountain goats to reverse their decline over the past 50 years.

If the recovery of small populations and the reoccupancy of vacant habitat is impeded by either natural or anthropogenic factors that reduce dispersal success, two management approaches might reverse this trend. First, it may be possible to restore broken links between metapopulation patches through changes in land management. Currently, the locations of corridors linking mountain goat habitat are not known, nor have the historic and anthropogenic landscape factors that may limit dispersal between patches been identified. Dispersal dynamics are likely to differ between male and female mountain goats (Hutchins and Geist 1987). Because recolonization of vacant habitat requires both sexes, understanding how gender affects dispersal would be an important aspect to consider in management plans. An assessment of the genetic health of the state's herds would also be useful to understand the scope of the problem and to focus limited available resources on populations that are threatened by loss of fitness. Thus, without further study, restoring corridors is not a viable approach. Even with this information, however, it may not be practical to restore some links due to political, legal, and economic realities.

An alternative may be to relocate mountain goats from genetically diverse and growing herds to small populations and vacant habitat that are isolated from dispersal. Relocation would increase the size of the isolated population and thereby oppose Allee effects while at the same time increase genetic diversity. A ready source of animals for this purpose could come from the Olympic mountain range. Twelve mountain goats were introduced there from Alaska and northern British Columbia by sport hunters during the 1920's. Since then, their numbers have increased dramatically due to the abundance of high quality unoccupied habitat. This non-native population now threatens the local alpine flora, which is poorly adapted to goat browsing (Hutchins 1995, Lemke 2004). This led National Park officials to initiate a program aimed at limiting the Olympic mountain goat population during the late 1980's. The park's efforts involved relocating goats to areas throughout the western United States, including 130 animals to the Washington Cascades. Today, around 400 animals still remain in Olympic National Park. Due to their unique genetic heritage and unwelcome presence there, this population is ideally suited for use in conservation efforts in the Cascade Range. However, the efficacy of this approach has not been validated by studying the fate of the animals relocated during the 1980's and the spread of their unique alleles into Cascade populations.

III Study Objectives

The genetic structure of the Cascade mountain goat population integrates dispersal events that have coincided with the recent decline of this species. Unlike dispersal studies that involve tracking the movement of tagged animals, the use of genetic information focuses only on dispersal events that result in survival and successful reproduction. Therefore, a genetic approach has the potential to distinguish exploratory movements from the successful reproduction and reveal the resistance of a landscape to gene flow. Furthermore, a genetic approach can be used to assess the genetic health of the state's herds, and explore the legacy of past relocations from the Olympic mountains to Cascade populations. To assist wildlife management agencies in their efforts to restore mountain goats to their historic numbers and range within the Cascades, we propose three specific aims based on the following hypothesis:

Hypothesis 1: Currently, after the decline of the past 50 years, much of the state's mountain goat population now exists in small remnant herds inhabiting a landscape fragmented by natural barriers as well as recent anthropogenic limits to dispersal. This fragmentation threatens source-sink dynamics, dispersal, and gene flow, resulting in limited immigration, loss of fitness, and possible Allee effects. These factors are limiting the recovery of mountain goats to historic numbers and may eventually threaten the persistence of this species in the Cascade Range.

Research Aim 1: Survey the genetic health and structure of the state's herds and compare the genetic diversity of expanding populations to populations that are stable or declining.

Hypothesis 2: Mountain goat dispersal is sensitive to historical landscape factors such as habitat quality, as well as anthropogenic factors such as roads, recreational activity, and land use practices. These varied landscapes have the potential to impede or facilitate dispersal, leading to the formation of barriers and corridors between habitat patches. Furthermore, there may be gender differences in dispersal success across these landscapes.

Research Aim 2: Create gender-neutral (based on autosomally inherited microsatellite markers) and female specific (based on maternally inherited mitochondrial markers) models of landscape resistance that correlate with the genetic structure of the Cascade mountain goat metapopulation.

Hypothesis 3: It is possible to alter mountain goat population dynamics by relocating animals. The ability of introduced animals to survive and interbreed with native populations will determine if this approach is a viable management strategy.

Research Aim 3: Determine the genetic legacy of animals introduced to the Cascades from the Olympic range during the 1980's, verify their survival, and quantify the degree to which their genetic variation spread through populations near those sites.

The above aims are based on the premise that recent barriers to dispersal and poor genetic health may be acting together with other factors such as disease, climate change, and increased predation rates to limit the recovery of small mountain goat populations in Washington. The aims of this proposal are designed to inform future management decisions, rather than to support any particular theory regarding the factors fueling the decline of this species. Thus, regardless of the underlying mechanism, pursuing the above aims will offer long-term value for the conservation of mountain goats, as the next section describes.

IV. Application of Results

The results of this study will yield the following benefits:

1. An assessment of the level of inbreeding and allelic diversity will reveal whether genetic variability has reached critically low levels, potentially identifying genetic health as a factor fueling the decline. Though genetic fitness may not presently be a threat, the impacts of inbreeding and genetic drift on small populations are well established, and, in the absence of a recovery, the probability of loss of fitness increases with each generation. Therefore, the proposed study will serve as a valuable baseline for future monitoring efforts.
2. Generating a landscape resistance model will identify both barriers to dispersal and corridors for gene flow. This information can be used by wildlife management agencies to guide conservation. If, for example, the model reveals that a major highway acts as a barrier to dispersal, it may be possible to build a wildlife overpass to mitigate the impact. This model can also be used to prevent development of new anthropogenic barriers within key dispersal corridors. Furthermore, the landscape model will be used to objectively define each of the state's major genetic units. The current boundaries used by WDFW to manage harvest are based on arbitrary divisions, and are therefore inadequate to manage this species on the individual herd level. Because the state's populations are on varying trajectories, this is currently a major unmet need.
3. Introduction of animals into small, threatened populations is an often discussed but poorly understood management strategy. The efficacy of this approach is likely to depend heavily on the life history traits of the species involved, and thus, generalizations from other species may not apply. By studying the genetic legacy of the 1980's translocations from the Olympic range to the Cascades, we will provide wildlife management agencies with a species-specific preview of the potential for relocation strategies to alter population dynamics. Furthermore, the proposed study could serve as a baseline for evaluating the success of future relocations, or optimizing their implementation.
4. In addition to the direct benefits for mountain goat conservation, this study also offers several indirect benefits. The aims of this proposal are all prominent applications of the new field of landscape genetics, with broad applicability to numerous species in addition to mountain goats. The paucity of research in this area to date means that each new study has the potential to greatly expand our understanding of how populations respond to landscapes, and to refine how we use genetic tools to meet conservation needs. To our knowledge, no landscape genetics study of this scale has been conducted in the Pacific Northwest. It is our hope that our research will serve as a template for future studies of other species in decline in Washington and elsewhere.
5. One graduate student and ten interns will gain substantial research experience, and several new collaborations between federal, state, and tribal wildlife agencies will accrue from this study. Training new scientists and establishing collaborations are important contributions to the future of conservation biology in our state.

V. Scope and Methods

Genetic sampling and genotyping

We currently have 63 blood samples collected from mountain goats previously captured and released during a 2003-2005 GPS collar tagging effort by WDFW. We also have 61 tissue samples collected from hunters as part of a voluntary participation program run by WDFW, 18 tissue samples collected by the National Parks Service, and one tissue sample taken from a goat that died in the field and was collected for necropsy. To fill in the geographical gaps in the sample set (Figure 2), we need to collect a minimum of 125 additional genetic samples in the form of scat or tissue collected using biopsy darts. The number of samples is dictated by the need for samples spaced no more than 8 km apart (as access and mountain goat distribution allow) to maximize statistical power in our analyses (Cushman et al. 2006). We will obtain 12 additional genetic samples from Olympic range animals to support aim 3 of this proposal. Cumulatively, the total sample size will number at least 280. Ground teams will be used to collect the majority of samples, however, a helicopter will be used to reach areas with poor access. The use of biopsy darts to collect tissue samples for this project has been reviewed and approved by the WWU Animal Care and Use Committee and by WDFW.

Once samples have been collected, DNA will be extracted from tissue, blood, or scat using the commercial DNeasy® blood and tissue, or stool DNA isolation kit (Qiagen) according to the manufacturer's protocol. Polymerase chain reaction will be used to amplify 20 previously characterized polymorphic microsatellite markers known to yield products from mountain goat DNA according to methods developed by Mainguy et al. (2005). We will employ a fluorescence-based approach, multiplexing up to 4 markers per reaction using labeled primers. After PCR product purification, electrophoresis and digital measurement of length polymorphisms will be performed using an ABI 3730 (Perkin Elmer). Additionally, we will PCR amplify and sequence the mitochondrial hypervariable region for each sample according to published methods (Spaulding et al. 2006). Quality control will include appropriate controls, standards, and estimating error by randomly re-genotyping 5% of our samples. All genetics services will be performed at the WDFW Molecular Genetics Laboratory under the supervision of Dr. Warheit.

Assessing genetic health

To quantify the genetic health of each population, F_{IS} (inbreeding coefficient), A (allelic diversity), and H_e (expected heterozygosity) values will be estimated from the genotypes of each population using the GENEPOP software suite (Raymond and Rousset 1995). These parameters will then be correlated with population size, patch size, patch isolation, and population trajectory.

Landscape resistance analysis

Our approach to modeling landscape resistance to gene flow will be based on the methods used by Cushman et al. (2006) in a study of black bear gene flow in northern Idaho. Briefly, we will generate a Bray-Curtis dissimilarity matrix (Legendre and Legendre 1998) based on the genetic distance between the microsatellite genotypes (or mitochondrial haplotypes, to generate a female specific landscape model) of all samples using the ecodist package in R (Legendre and Vaudor 1991). This genetic distance matrix will be compared by mantel and partial mantel tests (Mantel 1967) to other matrices that represent the following hypotheses of landscape resistance:

1. Genetic distance is a linear function of Euclidean distance. We will generate a Euclidean distance matrix calculated based on the location of every genetic sample using the PATHMATRIX extension (Ray 2005) in ArcInfo 3.3 (ESRI).
2. Genetic distance is a function of landscape resistance. Previous work from our lab funded, in part, by Seattle City Light, has generated a habitat map for the west side of the Cascade range of WA (Wells 2006), and continuing work on this project will lead to a complete habitat map for both sides of the range by the end of 2007. This map is an ArcGIS grid raster data set, which we will use as a starting point for a landscape resistance model under the hypothesis that poor habitat has a higher resistance to dispersal than good habitat. Using the PATHMATRIX extension, we will calculate the least cost path distance across that landscape resistance model between all sample points, resulting in a matrix of landscape distance. The weighting of all of the inputs into the landscape resistance model, including slope, land cover, aspect, and elevation, can be changed to form new model variants, which will then be evaluated to determine if they increase the fit of the model to the observed genetic distance.
3. Genetic distance is a function of barriers to dispersal. Under this scenario, populations would be panmictic on one side of the barrier but would not interbreed with populations on the other side of the barrier. Potential barriers to explore under this hypothesis include low elevation valleys, major roads, or large expanses of poor habitat. These hypotheses will be generated in ArcGIS by reclassifying barrier cells with resistance values of infinity while classifying every other cell as zero resistance. PATHMATRIX will then be used as above to generate a matrix of distances between all sample locations.

We will follow the approach of Cushman et al. (2006) to create a causal modeling framework, establish statistical expectations for each organizational model, and then evaluate the support for each model. Models that meet all statistical expectations will be used to map the identity and locations of significant dispersal barriers, locate corridors linking habitat patches, and define population boundaries.

Evaluating the impacts of 1980's relocations

To achieve the third aim of our proposal, we will use two approaches. First, we will identify any unique alleles present in the genotypes of the 20 samples collected from Olympic range animals but not found in Cascade populations (except near sites of relocation). We will then calculate the frequencies of these novel alleles in populations near past relocation sites, noting the extent of their spread and contribution to allelic diversity. Additionally, we use linear discriminant analysis to ordinate our samples based on allele frequencies. We will use a portion of the data to train the model to discriminate between Olympic and Cascade genotypes (chosen randomly from sites far removed from past relocations). Running the model on the full dataset should reveal clustering of Olympic and Cascade populations/subpopulations, with descendants of relocated animals ordinating between these clusters. Focusing on these descendants, we will determine the extent to which they spread from the original sites of reintroduction, and assess the proportion of their genetic diversity attributable to their Olympic range ancestors. This approach has been used successfully in other studies to identify translocated individuals (Frantz et al. 2006).

VI. Impacts to Listed Species

Mountain goats, when locally abundant, have been shown to be important prey for the endangered wolf (Fox and Strevler 1986), and the threatened grizzly bear (Cote and Beaudoin 1997) and lynx (Rideout and Hoffmann 1975). If this study were to provide information leading to a recovery of mountain goats in Washington, a secondary benefit may be the potential to help support populations of these predators in areas where their ranges overlap.

VII. Evaluation

Periodic meetings between co-investigators will occur to monitor the progress of the study. This study will form the basis of Andrew Shirk's master's thesis at Western Washington University, and, therefore, will also undergo monitoring and review by a thesis committee that includes all three principle investigators. Success will ultimately be defined as meeting the three research objectives and disseminating the results to state, federal, and tribal wildlife management entities as well as the greater scientific community and public at large.

VIII. Personnel and Project Organization

David Wallin is a Professor in the Department of Environmental Sciences, Huxley College of the Environment, Western Washington University. He has a Ph. D. in Environmental Science from the University of Virginia. Dr. Wallin is an expert in landscape ecology, GIS modeling, and multivariate statistics, and has published 20 scientific articles. His contribution will include managing the interns, supervising the graduate student, and assisting with data analysis, report writing, and publications.

Clifford G. Rice is a Research Scientist in the Wildlife Management Program of the WDFW and is currently working full time on mountain goat research. He has a Ph.D. in Wildlife Science from Texas A&M University. Dr. Rice is an expert in wildlife biology, conservation, and management, and has published 32 scientific articles. His contribution will include conducting aerial biopsy darting, as well as assisting with data analysis, report writing, and publications.

Kenneth I. Warheit is the director of the WDFW genetics core in Olympia Washington. He has a Ph.D. from U.C. Berkeley. Dr. Warheit is an expert in molecular genetics, population genetics, and wildlife biology, and has published 24 scientific articles. His contribution will include directing and supervising the DNA isolation and genotyping of all genetic samples, as well as assisting with data analysis, report writing, and publications.

Andrew Shirk is a Master's in Environmental Science candidate at Western Washington University. He has a Bachelors of Science in biology and an Associate degree in Geographical Information Systems. Prior to graduate school, Andrew worked as a molecular biologist at the University of Washington in Seattle for 8 years, and published 6 scientific articles. He has extensive experience in molecular genetics research and GIS modeling. He will collect genetic samples, analyze the genetic data, write reports, prepare presentations for meetings, and write manuscript(s) for publication.

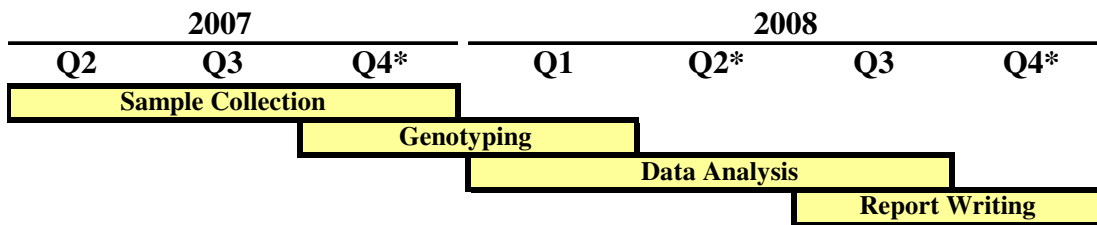
IX. Deliverables

Funding agencies will be provided with progress reports semiannually during the course of the research. At the end of the project, a final report will review and assess all project activities. This report will include an assessment of the genetic health of the state's populations, the relationship between genetic diversity and population trajectory, maps of landscape resistance to dispersal (including marked corridors and major barriers), maps demarcating the major genetic divisions between populations, and an assessment of the genetic impact of the 1980's relocations. We will also prepare and disseminate a list of recommendations for conservation of mountain goats in Washington based on our findings. Data generated in the course of this research will be curated by the co-investigators and disseminated along with the final report as described below.

X. Dissemination

The data and final report for this project will be freely distributed to pertinent wildlife management agencies, including WDFW, the National Parks Service, the US Forest Service, Washington Department of Natural Resources, Washington Department of Ecology, and state tribal agencies. Additionally, at least 2 peer-reviewed publications and one presentation at a national scientific meeting are expected to be produced from this research.

XI. Schedule



* Semi-annual reports issued (final report in Q4 2008)

XII. Other Financial Support

We have obtained a total of \$94,632 from other sources to support this project. \$21,000 has been obtained to support the development of laboratory protocols as well as genotyping, and sequencing 200 samples (\$4800 from the Mountaineers Foundation, \$2400 from the Mazamas Foundation, \$12,000 from WDFW and \$1,800 from WWU). WDFW has also supplied \$24,088 to provide sample collection mileage and per diem for interns and the graduate student, as well as \$20,000 for helicopter services during the summer of 2007.

XIII. Map

see attached.

XIV. Budget

See attached

XV. Letters of Commitment

See attached

XVI. Letters of Support

See attached

XVII. Peer Review Recommendations

See attached

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Peer Review Recommendations

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- 8) Name: Scott Schuyler Title: Nat. Res. Policy Coordinator
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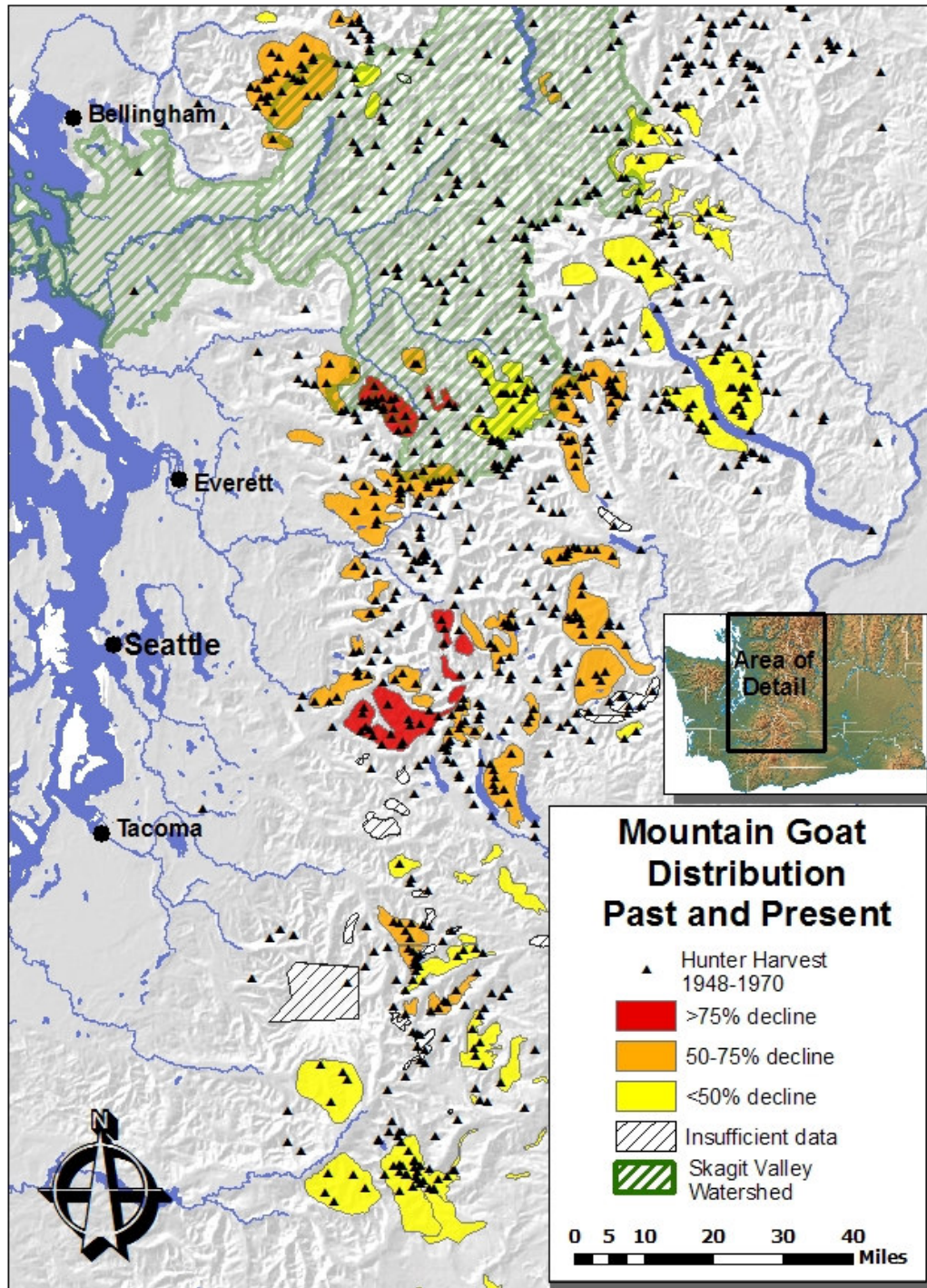


Figure 1. Mountain goat range, past and present. Colored polygons represent currently occupied mountain goat habitat and the extent of the decline that has occurred since the 1961 census. Black triangles represent a proxy of historic range based on hunter harvest. Each triangle represents between 1 and 198 animals killed, depending on the location, between 1948 and 1970.

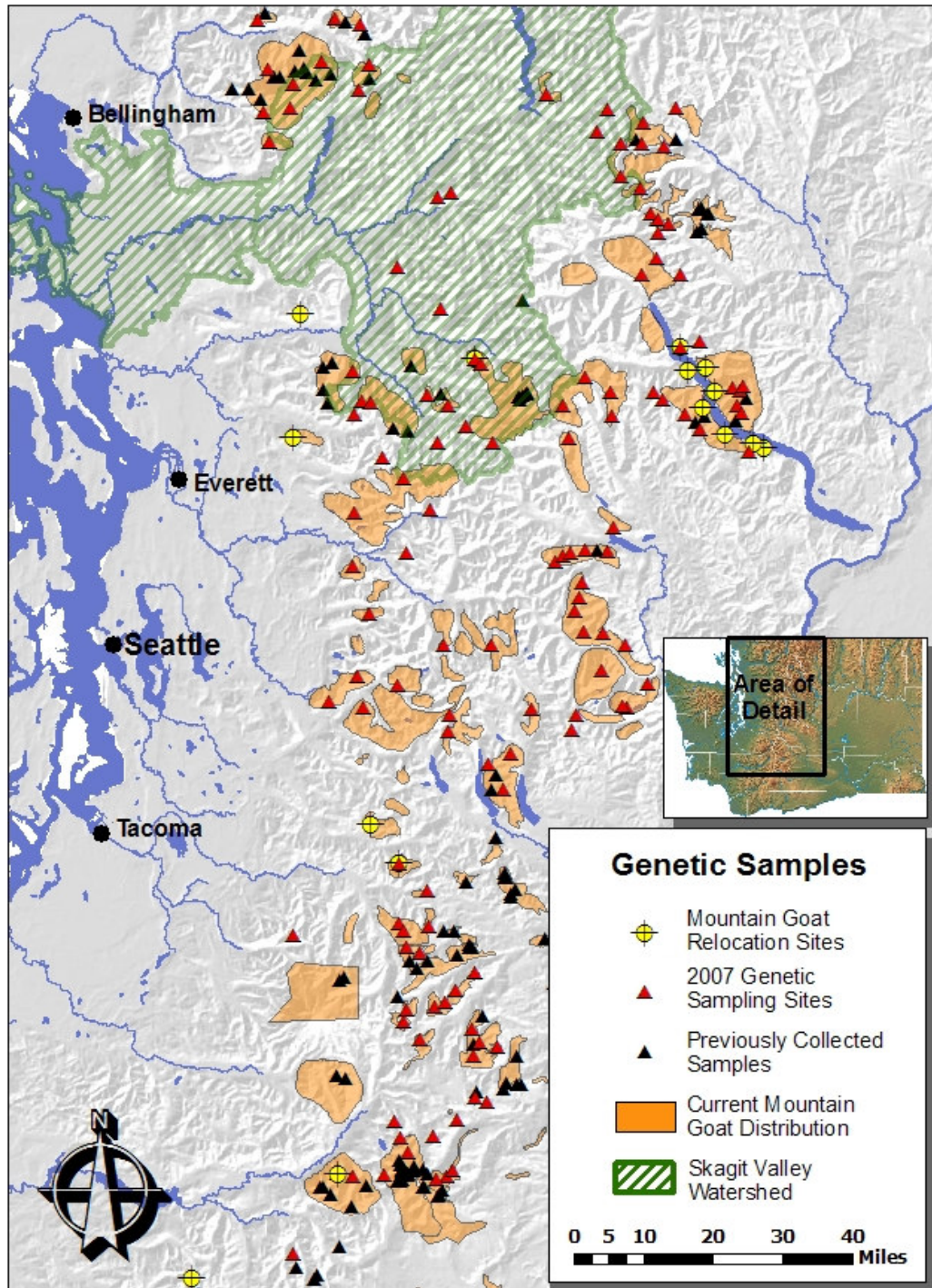


Figure 2. Genetic Samples. Black triangles represent the sites where we currently have collected genetic samples. Red triangles represent sites where we plan to collect samples during the summer of 2007. Yellow crosshairs represent sites where mountain goats were relocated during the 1980's. The current distribution of occupied mountain goat habitat is denoted in orange, while the Skagit Valley watershed is crosshatched in green.

CURRICULUM VITAE

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Education:

Ph.D., Environmental Sciences, University of Virginia, Charlottesville, VA, August 1990; Dissertation title: Habitat dynamics for an African weaver-bird: the red-billed quelea (*Quelea quelea*); advisor: Herman H. Shugart

M.A., Biology, The College of William and Mary, Williamsburg, VA, January 1982; Thesis title: The influence of environmental conditions on the breeding biology of the bald eagle in Virginia; advisor: Mitchell A. Byrd

B.S., Biology, Juniata College, Huntingdon, PA, May 1978

Professional Experience:

Western Washington University: Professor (5/2003-present); Associate Professor (9/98-5/03); Assistant Professor (9/95-9/98)

Oregon State University, Department of Forest Sciences: Courtesy Faculty (9/95-99); Research Assistant Professor (1/94-9/95); Postdoctoral Research Associate (2/91-1/94)

NASA Goddard Space Flight Center: NASA Visiting Fellow; One year in residence (spread over 1986-90)
Virginia Commission of Game and Inland Fisheries: Wildlife Biologist (1984-85);

Primary Research Focus:

Landscape ecology and remote sensing, land-use effects on ecosystem structure and function, regional analysis of biodiversity patterns, life history attributes and habitat heterogeneity in space and time as determinants of species distribution and abundance patterns, analysis of landscape pattern and pattern change under shifting management objectives, effect of land-use on carbon storage in forest ecosystems.

Selected Proposals (PI or Co-PI for over \$2,600,000 of funded proposals since 1992):

Mountain Goat Conservation and Restoration in Washington State: Field Sampling (Washington Department of Fish and Wildlife; ALEA Cooperative Project, \$24,088, summer 2007)

Mountain Goat Conservation and Restoration in Washington State: Genetic Analysis (The Mazamas Foundation Research Grant, \$2,400, 5/1/07 – 7/15/08), (The Mountaineers Foundation Research Grant, \$4,803, 5/1/07 – 12/31/08), (Washington Department of Fish and Wildlife, \$12,000, 3/1/07 – 6/30/07)

Helicopter-based Biopsy Darting of Mountain Goats for Genetic Analysis (Washington Department of Fish and Wildlife, \$20,000, 6/1/07 – 6/30/07)

Mountain Goat Behavioral Observations and Survey Ground Observations (Washington Department of Fish and Wildlife; ALEA Cooperative Project, \$14,262, summer 2006)

Assessment of Mountain Goat Habitat in the North Cascades (Sauk-Suiattle Indian Tribe, multiple contracts, \$54,000, 2002-2006)

Mountain Goat Ecology and Management (Washington Dept. of Fish and Wildlife, \$12,684, 3/06 – 9/06)

Mountain Goat Ecology in Washington (Seattle City Light, \$59,000, 2003-2005) Co-PI with Clifford G. Rice, Washington Dept. of Fisheries and Wildlife, Douglas McMurtrie, Sauk-Suiattle Tribe, Phyllis Reed Mount Baker/Snoqualmie National Forest, Robert C. Kuntz II, North Cascades National Park

Analysis of land-use effects on landscape patterns and biological diversity in Pacific Northwest forests: 1972-1992. (NASA, \$485,000, 1993-98) PI; co-PI's W.B. Cohen, G.A. Bradshaw, T.A. Spies, A. Hansen, M.H. Huff, J.F. Lehmkuhl, M.G. Raphael and W.J. Ripple

Selected Publications:

- Wallin, D.O., M.E. Harmon, W.B. Cohen (in press). Modeling regional-scale carbon dynamics in Pacific Northwest forests: 1972-95. Pages xx-xx *In*: O. Krankina and M.E. Harmon (eds.) Carbon Dynamics of Two Forest Regions: Northwestern Russian and the Pacific Northwest. Springer-Verlag, New York
- Wells, A.G., D.O. Wallin, C.G. Rice and W-Y Chang. (in prep) Wildlife telemetry global positioning system (GPS) bias correction in the Cascade Mountains of Washington State, USA
- Wells, A.G., D.O. Wallin, C.G. Rice and W-Y Chang. (in prep) Seasonal habitat analysis for Mountain Goats (*Oreamnos americanus*) in the Cascades of Washington State, USA.
- Cushman, S.A. and D.O. Wallin. 2002. Separating the effects of environmental, spatial and disturbance factors of forest community structure in the Russian Far East. *Forest Ecology and Management* 168(1-3):201-215.
- Richards, W.H., D.O. Wallin, and N.H. Schumaker. 2002. An analysis of late-seral forest connectivity in western Oregon. *Conservation Biology* 16(5):1409-1421.
- Cushman, S.A. and D.O. Wallin. 2000. Rates and patterns of landscape change in the central Sikhote-alin Mountains, Russian far east. *Landscape Ecology* 15(7):643-659
- Wallin, D.O., F.J. Swanson, B. Marks, J. Kertis and J. Cissel. 1996. Comparison of managed and pre-settlement landscape dynamics in forests of the Pacific Northwest, U.S.A.. *Forest Ecology and Management* 85:291-310.

Selected Presentations:

- Wasserman, T., S. Cushman and D.O. Wallin. 2007. Influences of Landscape Features on Gene Flow of American Marten in Northern Idaho, USA. International Association for Landscape Ecology Conference (IALE). Wageningen, Netherlands. July 8-13, 2007.
- Wasserman, T., S. Cushman and D.O. Wallin. 2007. Non-invasive Sampling of Fisher and Marten Using Hair Snares and Molecular Genetics. (invited talk) Annual Meeting of The Society for Northwestern Vertebrate Biology. Victoria, BC Canada. February 21-24, 2007.
- Wallin, D.O. and A. Wells. 2006. Habitat analysis of mountain goats in the Washington Cascades. Joint Annual Meeting of the Society for Northwestern Vertebrate Biology and the Washington Chapter of the Wildlife Society; March 27-31, 2006; Olympia, WA.
- Wells, A. and D.O. Wallin. 2006. GPS bias correction in the Washington Cascades. Joint Annual Meeting of the Society for Northwestern Vertebrate Biology and the Washington Chapter of the Wildlife Society; March 27-31, 2006; Olympia, WA.
- Wells, A. and D.O. Wallin. 2005. GPS Bias Correction and Seasonal Mountain Goat (*Oreamnos americanus*) Habitat Analysis in the Washington Cascades. Third Annual Research Advances in Fisheries, Wildlife and Ecology; November 9th, 2005; La Sells Stewart Center, OSU Corvallis, OR.
- Wallin, D.O. and C. Gardner. 2003. Modeling habitat availability for the Mountain Goat (*Oreamnos americanus*) in the North Cascades of Washington. (invited paper) Native American Fish and Wildlife Society, Pacific Region Conference, Ocean Shores, WA October, 2003.

Graduate Student Advisement; Major Professor: 17 students since 1994

Graduate Student Advisement; Graduate Committee Member: (19 students since 1996)

Clifford G. Rice

VITAE

Address: Clifford G. Rice
7239 48th Way NW
Olympia, WA 90502 USA

Telephone
Home: (360) 866-2468
Office: (360) 902-2245
e-mail:

ricecgr@dfw.wa.gov

Personal: Birth date: August 19, 1950
Birthplace: Bilaspur, Madhya Pradesh, India
Citizenship: U.S.A.

Experience:

2002-Present. Research Scientist, Mountain Goat Research Project	Washington Department of Fish and Wildlife Olympia, Washington
1997-2002. Game Surveys Coordinator	Washington Department of Fish and Wildlife Olympia, Washington
1994-1997. Ecologist	US Army Construction Engineering Research Laboratories Champaign, Illinois
1993-1994. Research Associate	Department of Range and Wildlife Management, Texas Tech University, Lubbock, Texas
1990-1993. Wildlife Biologist III, Wildlife Section Supervisor	Division of Fish and Wildlife, Commonwealth of the Northern Mariana Islands.
1988-90. Wildlife Biologist II	Division of Fish and Wildlife, Commonwealth of the Northern Mariana Islands.
1987-88. Research Fellow	Wildlife Conservation International, New York Zoological Society, Bronx, New York.
1986-87. Curatorial Intern	Department of Mammalogy, New York Zoological Society, Bronx, New York.
1984-86. Research Fellow	Wildlife Conservation International, New York Zoological Society, Bronx, New York.
1984. Instructor	Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, Texas.
1982-83. Research Assistant	Casear Kleberg Program in Wildlife Ecology, Texas A&M University, College Station, Texas.
1981. Consultant	Wildlife Conservation International, New York Zoological Society, Bronx, New York.

1979-81. Junior Fellow	American Institute of Indian Studies, New Delhi.
1978 & 77. Naturalist/Leader	Mountain Travel, Solano, California.
1977. Field Assistant	Smithsonian Tiger Ecology Project, Chitwan National Park, Nepal.
1975-77. Peace Corps Volunteer	Royal Sukla Phanta Wildlife Reserve, National Parks and Wildlife Conservation Office, Nepal.
1975. Volunteer	Office of Zoological Research National Zoological Park, Washington, D.C.
1975. Student Researcher	Student Program in Behavioral Research, Chicago Zoological Park, Chicago, Illinois.

Education:

Ph.D. 1984. Texas A&M University, College Station, Texas. (Wildlife Science). Dissertation title: The Ecology and Behavior of Nilgiri tahr (*Hemitragus hylocrius*).

Goethe Institute, Schwaebisch Hall, West Germany. 1982. Intensive German language instruction (Grundstufe I).

Landour Language School, Landour, Mussoorie, U.P. India. 1977. Intensive Hindustani language instruction.

M.Sc. 1975. Colorado State University, Ft. Collins, Colorado. (Zoology). Thesis title: Temporal and Qualitative Behavior Patterns and Individual Distance in a Group of Captive Addax (*Addax nasomaculatus* De Blainville, 1816).

B.A. 1973. Macalester College, St. Paul, Minnesota. (Biology).

Publications

26 Scientific Publications (22 papers and 4 book chapters)
6 Popular Articles



State of Washington
DEPARTMENT OF FISH AND WILDLIFE

Mailing Address: 600 Capitol Way N • Olympia, WA 98501-1091 • (360) 902-2200, TDD (360)
902-2207

Main Office Location: Natural Resource Building • 1111 Washington Street SE • Olympia, WA

13 June 2007

Ela Esterberg
Seattle City Light, Environment and Safety Division
Wildlife Research Program
PO Box 34023
Seattle, WA 98124-4023

Dear Ms. Esterberg,

I am writing this letter to inform you that I am collaborating with David Wallin on a study focusing on mountain goat genetics which is the subject of his proposal to you entitles "Mountain Goat Conservation and Restoration in Washington State: A Genetics Approach". Dr. Wallin and I have discussed this project at length and I am enthusiastic about working with him and his graduate student to see it to completion. I will also be on the graduate student's advisory committee. In addition, I am providing genetic samples from mountain goats captured during or survey and habitat studies as well as those voluntarily submitted by hunters. I look forward to continuing to being involved in this important and interesting project.

Sincerely,

Cliff Rice, Ph. D.
Research Scientist
Mountain Goat Research Project
Wildlife Management Program

Kenneth I. Warheit

Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501
Phone 360-902-2595; FAX 360-902-2943; email warhekiw@dfw.wa.gov

EDUCATION

UNIVERSITY OF CALIFORNIA, BERKELEY. Ph.D. Integrative Biology/Paleontology, April 1990
UNIVERSITY OF MICHIGAN, ANN ARBOR. B.Sc. in Natural Resources, April 1979

PROFESSIONAL POSITIONS

- **DIRECTOR, MOLECULAR GENETICS LABORATORY - WASHINGTON DEPARTMENT OF FISH AND WILDLIFE.** Coordinate, direct, and supervise all fish and wildlife genetics research conducted by the Washington Department of Fish and Wildlife (Aug. 2005 – present).
- **SENIOR RESEARCH SCIENTIST - WASHINGTON DEPARTMENT OF FISH AND WILDLIFE.** Coordinate and supervise all wildlife-related research in the western half of Washington State; includes supervision and budget management of marine mammal, marine bird, carnivore, mountain goat, and animal health research, as well as statewide program in wildlife conservation genetics (Jan. 2002 – Aug. 2005)
- **SENIOR RESEARCH SCIENTIST - WASHINGTON DEPARTMENT OF FISH AND WILDLIFE.** Develop and coordinate statewide program in wildlife-related conservation genetics (Aug, 1998 - present)
- **RESEARCH SCIENTIST - WASHINGTON DEPARTMENT OF FISH AND WILDLIFE.** Coordinate statewide research in resource damage assessment and restoration activities, including population biology and genetics research (Aug. 1994 - Aug. 1998).
- **RESOURCE PROGRAM MANAGER - WASHINGTON DEPARTMENT OF WILDLIFE (NOW FISH AND WILDLIFE).** Designed and administered statewide oil-spill response technical support and baseline data programs (Nov. 1993 - Aug. 1994).

RESEARCH GRANTS RECEIVED (within past 10 years)

US Chinook Technical Committee. 2007-2009. COMPARISON OF FISHERY DISTRIBUTION PATTERNS BETWEEN CWT AND GSI DATA. A COMPARISON OF CODED WIRED TAGS AND GENETIC STOCK IDENTIFICATION. \$232,281

Pacific Salmon Commission – Southern Fund. 2007-2008. MIXED STOCK ANALYSIS OF SELECTIVE AND SPORT CHINOOK FISHERIES IN THE STRAIT OF JUAN DE FUCA USING MOLECULAR MARKERS. \$78,440

US Chinook Technical Committee. 2006-2007. MICROSATELLITE DNA ANALYSIS OF CHINOOK SALMON: STOCK CONTRIBUTION OF LEGAL AND SUB-LEGAL CHINOOK TO THE 2004 AND 2005 WASHINGTON AREA 2 COASTAL FISHERY \$99,020

Pacific Salmon Commission – Southern Fund. 2006-2007. GENETIC BASELINE ADDITIONS OF WASHINGTON CHINOOK SALMON POPULATIONS TO ENHANCE MIXED STOCK FISHERY ANALYSES IN THE SOUTHERN BOUNDARY AREA. \$108,460

U.S. DEPARTMENT OF INTERIOR – FISH AND WILDLIFE SERVICE. 2003-2004. Investigate reported sightings, and develop and refine field and laboratory protocols for identifying grizzly bear

forensic samples (e.g., scat and hair) from northern Washington using molecular techniques.
\$12,000

ROCKY MOUNTAIN ELK FOUNDATION. 2002-2003. Management of Washington Elk Herds using genetic tools. Part #2. \$30,000

NATIONAL FISH AND WILDLIFE FOUNDATION. 2000-2003. Sharp-tailed Grouse Genetic Survey.
\$68,000

ROCKY MOUNTAIN ELK FOUNDATION. 2000-2001. Management of Washington Elk Herds using genetic tools. \$19,000

U.S. DEPARTMENT OF INTERIOR – BUREAU OF LAND MANAGEMENT. 2000-2001. Genetic Analysis of Sharp-tailed Grouse Samples. \$2,275

TENYO MARU OIL SPILL TRUSTEES. 1996-1998. Population genetics analysis of Common Murre (*Uria aalge*) colonies in British Columbia, Washington, Oregon, and California. \$42,775.80

SELECTED PUBLICATIONS (within past 10 years)

Spaulding, A.W., K.E. Mock, M.A. Schroeder, and K.I. WARHEIT. 2006. Recency, range expansion, and unsorted lineages: implications for interpreting neutral genetic variation in the sharp-tailed grouse (*Tympanuchus phasianellus*). *MOLECULAR ECOLOGY* 15:2317-2332.

WARHEIT, K.I. 2002. The seabird fossil record and the role of paleontology in understanding seabird community structure. Pages 17-55 *in* Biology of Marine Birds (Schreiber, E.A., and J. Burger, Eds.). CRC Press, Boca Raton.

Edwards, S.V., M.C. Silva, T. Burg, V.L. Friesen, and K.I. WARHEIT. 2001. Molecular genetic markers in the analysis of seabird bycatch populations. Pages 115-140 *in* Proceedings – Seabird Bycatch: Trends, Roadblocks, Solutions (Melvin, E., and J. Parrish, eds.). University of Alaska Sea Grant.

Losos, J.B., T.W. Schoener, K.I. WARHEIT, and D. Creer 2001. Experimental studies of adaptive differentiation in Bahamian *Anolis* lizards. *GENETICA* 113-114:399-415.

Ibarguchi, G., T.P. Birt, K.I. WARHEIT, P.T. Boag, and V.L. Friesen. 2000. Microsatellite loci from Common and Thick-billed murre, *Uria aalge* and *U. lomvia*. *MOLECULAR ECOLOGY* 9:638-639.

WARHEIT K.I., J.D. Forman, J.B. Losos, and D.B. Miles. 1999. Morphological diversification and adaptive radiation: a comparison of two diverse lizard clades. *EVOLUTION* 53:1226-1234.

Lindberg, D.R., J.A. Estes, and K.I. WARHEIT. 1998. Human influences on trophic cascades along rocky shores. *ECOLOGICAL APPLICATIONS* 8:880-890.

Losos, J.B., K.I. WARHEIT, and T.W. Schoener. 1997. Adaptive differentiation following experimental island colonization in *Anolis* lizards. *NATURE* 387:70-73

*State of Washington
Washington Department of Fish and Wildlife
Molecular Genetics Laboratory*



19 June 2007

Seattle City Light:

The Washington Department of Fish and Wildlife's Molecular Genetics Laboratory (WDFW-MGL) is a committed partner with Western Washington State University in the project described in the proposal "Mountain Goat Conservation in the Washington Cascades: a Genetic Approach." WDFW-MGL's contribution to this project will be to provide all DNA isolation and genotyping services for all mountain goat samples required for the successful completion of the project.

WDFW-MGL is located in Olympia, Washington, and operates a state-of-the-art molecular laboratory. The lab is constructed as a three-room concourse with separate DNA extraction, PCR, and freezer rooms/sections. The total size of the lab is 2700 sq ft, not including individual office space for technicians and biologists and an off-site storage facility. Currently, WDFW-MGL employs a staff of 10 full time employees and processes roughly 20-30,000 samples per year using primarily microsatellite, sequence, and SNP markers. During the past three years, laboratory personnel have completed or will complete over 150 projects, with financial support from the US Federal Government (e.g., US Fish and Wildlife Service, NOAA Fisheries, US Geological Survey, Pacific Salmon Commission, Bonneville Power Authority (BPA), Bureau of Land Management (BLM), State Wildlife Grants (SWG), and through the Anadromous Fish Act (PL-304) or Mitchell Act), Washington State (General Fund), county Public Utility Districts (PUDs – dam operators), Native American Tribes, and others.

Sincerely,

A handwritten signature in black ink that reads "Kenneth I. Warheit".

Kenneth I. Warheit, Ph.D.
Director, Molecular Genetics Laboratory

Kenneth I. Warheit
Department of Fish and Wildlife
Molecular Genetics Laboratory
600 Capitol Way N
Olympia, WA 98501-1091

360-902-2595 (voice)
360-902-2774 (lab)
360-902-2162 (fax)

warhekiw@dfw.wa.gov

Seattle City Light, Environment and Safety Division
Wildlife Research Program
PO Box 34023
Seattle, WA 98124-4023

June 18, 2007

Dear Ela and Research Committee Members,

The mountain goat is considered a unique wildlife resource and a management indicator species for the Mt. Baker-Snoqualmie National Forest. Due to concerns with declining populations in portions of the goats' native range, the USDA Forest Service has been collaborating with the Washington Department of Fish and Wildlife, the Sauk-Suiattle Tribe, Western Washington University and the National Park Service on studies to better assess goat populations and their use of habitat in the North Cascades.

While there have been increases in some local populations (Mt. Baker), the continued declines across much of Washington's mountain goat populations highlight the need to better understand population dynamics in relation to remaining habitat. Concern has been raised that changes in land use has resulted in isolation of populations with dispersal barriers limiting genetic diversity and fitness of animals.

I am writing in support of David Wallin's proposal "Mountain Goat Conservation and Restoration in Washington: A Genetic Approach.". This proposal will initiate studies that would provide a better understanding of the genetic structure and diversity of goat populations. The assessment of genetic structure in small populations would assist managers in understanding the significance of isolated populations and potential role of dispersal. I believe this study will provide managers with a greater understanding of goat population dynamics and assist in developing strategies for goat recovery.

For these reasons, I urge you to support this project. The information it will provide will be an important contribution to our limited knowledge of this little-studied species. The District is committed to supporting efforts to assess habitat and populations of the mountain goat, and believe the funding of this study proposal will greatly contribute to the understanding of goat populations and habitat management in the North Cascades.

Sincerely,

/s/

PHYLLIS REED
Wildlife Biologist/Environmental Coordinator



5318 Chief Brown Lane
Darrington, Washington 98241-9420

(360) 436-0131
Fax (360) 436-1511

June 18, 2007

Ela Esterberg
Seattle City Light, Environment and Safety Division
Wildlife Research Program
PO Box 34023
Seattle, WA 98124-4023

Dear Ms. Esterberg:

The purpose of this letter is to formally announce that the Sauk-Suiattle Tribe endorses and supports the joint proposal by Western Washington University (WWU) and the Washington Department of Fish and Wildlife (WDFW) for Wildlife Research Program funding for ongoing investigations of mountain goats in the North Cascades of Washington State. The proposal, entitled, "Mountain Goat Conservation in the Washington Cascades: a Genetic Approach" involves genetic analyses of mountain goat tissue samples obtained through past capture operations and future passive means throughout Washington State.

As a proponent for mountain goat recovery in the region, the Sauk-Suiattle Tribe has collaborated with WWU and WDFW personnel, as well as staff from the National Park Service, U.S. Forest Service, and U.S. Geological Survey to implement several mountain goat research projects in the past five years. Seattle City Light Wildlife Research Program funds have, in part, supported these successful efforts. The WDFW proposal is yet another fine example of the progressive research that will yield the baseline data necessary to further advance our understanding of the ecology of mountain goats in the North Cascades and help direct future conservation efforts needed to recover this species region-wide.

We hope the committee's review of the proposal is favorable.

Sincerely,

Richard Wolten
Natural Resources Director
Sauk-Suiattle Indian Tribe

