**Wandering Wild Sheep Policy: A Theoretical Review**

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*Abstract:* Removing wandering bighorn sheep (*Ovis canadensis*) to manage transmission and spread of disease is a common and widespread management policy in the western U.S. Wandering bighorn sheep are removed when found in close proximity to domestic sheep or goats to prevent disease transmission from domestic livestock to bighorn sheep herds. The policy is most appropriately applied as an interim emergency measure when management has failed to maintain effective separation between domestic sheep or goats and bighorn sheep. In practice, however, this policy has been applied in a broad range of circumstances where its effectiveness is questionable. The policy is often viewed as a stand-alone management tool for providing long-term separation rather than an interim emergency measure. In some cases it has been implemented without consideration of its appropriateness, effectiveness, or impacts on bighorn sheep management goals and long-term conservation. The purpose of this review is to evaluate the effectiveness and appropriateness of this policy relative to the distribution of bighorn sheep, their habitat, and public-land domestic sheep allotments across the landscape. Effectiveness was measured in terms of providing separation, preventing disease transmission, and maintaining or enhancing bighorn sheep population viability. Management recommendations for appropriate application are advanced. Federal and state resource management agencies are encouraged to clarify appropriate implementation of the policy to foster the restoration and long-term conservation of bighorn sheep across the western U.S.

*Key words:* bighorn–domestic sheep interaction, bighorn sheep, disease transmission, domestic sheep, management, risk of contact, separation, wandering bighorn sheep

It is widely accepted among wildlife researchers and managers that bighorn sheep (*Ovis canadensis*) and domestic sheep are incompatible on sympatric range and must be spatially or temporally separated to prevent disease transmission and catastrophic population-wide bighorn sheep die-offs (Foreyt and Jessup 1982; Goodson 1982; Coggins 1988, 2002; Martin et al. 1996; Schommer and Woolever 2001, 2008; Singer et al. 2001; USDA Forest Service 2006a, b; Western Association of Fish and Wildlife Agencies 2007; George et al. 2008). Effective spatial or temporal separation between these species is now commonly recommended as the most prudent management approach (USDA Forest Service 2006a, b; Western Association of Fish and Wildlife Agencies 2007; Miller et al. 2008; Schommer and Woolever 2008).

Removing (placing in captivity or killing) bighorn sheep known or suspected to have contacted domestic sheep or goats is a common management practice among western U.S. states, and is commonly referred to as the "wandering wild sheep policy" (Policy). This Policy is endorsed by the Western Association of Fish and Wildlife Agencies, an association comprised

of 23 state and provincial wildlife agencies from western U.S. and western Canada (Western Association of Fish and Wildlife Agencies 2007). Toweill and Geist (1999) identified 15 U.S. western states managing bighorn sheep. In 14 of those states, interaction between domestic and bighorn sheep is a management concern and all of these states have endorsed (either formally or informally) and/or practiced removing wild sheep interacting with domestic sheep or goats (Table 1).

The primary purpose of this Policy is to manage transmission and spread of disease within and between bighorn sheep herds. Individual bighorn sheep found in close proximity to domestic sheep or goats are removed because of the potential for disease transmission from these domestic livestock to bighorn sheep. By removing potentially infected bighorn sheep, the Policy aims to prevent the spread of disease to other bighorn sheep herds and avoid potentially catastrophic population-wide die-offs. The Policy is most commonly and appropriately applied to "wandering wild sheep" defined for this review as bighorn sheep exhibiting infrequent but often long-distance movements outside their normal population range and habitat, and coming in close proximity to domestic sheep or goats. Wandering wild sheep are commonly young dispersing rams. The Policy is most often implemented in a passive and reactive way with managers responding as reports of wandering wild sheep are received. However, the probability of detecting and reporting bighorn and domestic sheep or goat interactions is inherently low because many bighorn sheep populations are not actively monitored; terrain can be rugged and inaccessible; bighorn sheep can move extensively over a short time period, passing through domestic sheep areas quickly; and domestic sheep bands can be scattered, with interactions occurring far from herders' control.

The Policy is typically envisioned as a tool to address situations where the risk of contact between bighorn sheep and domestic sheep or goats is low (i.e., expected infrequent interaction events) and occurs outside of normal bighorn sheep range. In these typical applications, the Policy is thought of as a stand-alone management tool providing effective long-term separation and prevention of disease transmission. In practice, however, the Policy has been implemented in a broad range of circumstances beyond its original intent without consideration of its appropriateness, effectiveness, or impacts on bighorn sheep management goals and long-term conservation. Although the application of this Policy has merit in certain circumstances when applied to wandering bighorn sheep outside their normal range, in some cases, the Policy has been relied upon for maintaining long-term separation, or used as rationale for precluding the need for separation within occupied bighorn sheep range.

The institutionalized acceptance of and unquestioned reliance on this Policy may, in some cases, (1) encourage inappropriate and ineffective application, (2) provide rationale for complacent status quo management when more effective separation measures are needed, (3) perpetuate continued risk of contact and disease transmission, and (4) hinder long-term conservation of bighorn sheep. A critical review of this Policy is needed to better understand the appropriate applications of this management tool in the context of long-term bighorn sheep conservation throughout the western U. S.

**Landscape Considerations**

Appropriate application of the Policy depends on the relative juxtaposition and

characteristics of 3 primary landscape-level parameters: (1) bighorn sheep distribution and connectivity (isolated vs. interconnected populations), (2) bighorn sheep habitat distribution and connectivity (fragmented vs. continuous), and (3) distribution of active domestic sheep allotments (allotment). Variation in relative juxtaposition and characteristics of these 3 landscape parameters results in a continuum of landscape configurations across the west, requiring critical case-by-case analysis to determine the appropriate application and effectiveness of the Policy. The extremes of the continuum can be classified as the Discrete Parameter Model (DPM) on one end and the Continuous Parameter Model (CPM) on the other. As discussed below, application of the Policy is most appropriate under the DPM but becomes problematic as landscape configurations tend towards the CPM.

## Discrete Parameter Model

The DPM describes landscapes where bighorn sheep populations and habitats are isolated and fragmented, and neither overlap allotments. The origin of the Policy is rooted in such a stereotypic model of bighorn sheep distribution across western landscapes. Bighorn sheep populations are typically envisioned as small isolated herds scattered across fragmented habitat patches associated with isolated mountain ranges throughout the west (Van Dyke et al. 1983; Risenhoover et al. 1988; Bleich et al. 1990; Singer et al. 2000a, b). This stereotypic landscape view reflects a common pattern across the west of dramatic historic bighorn sheep population reductions followed by subsequent restoration of small isolated populations. Under the DPM, allotments are disjunct from occupied bighorn sheep range and habitats, often located in lower elevations within valley bottoms or along foothills

between mountain ranges occupied by bighorn sheep (Figure 1).

Isolated bighorn sheep populations may have historically functioned as metapopulations connected by intermountain dispersal of ewes and rams (Schwartz et al. 1986, Bleich et al. 1996; Singer et al. 2000b). Today however, isolated bighorn sheep populations are typically managed independently according to population-specific management goals, with each population having its own unique history and management concerns.

## Continuous Parameter Model

The CPM describes landscapes on the other end of the continuum where bighorn sheep populations and habitats are interconnected and continuous, and allotments overlap occupied bighorn sheep range and their habitats. This situation is commonly found where bighorn sheep occupy low-elevation grasslands along river canyons where suitable habitat is continuous and bighorn sheep populations are interconnected throughout linear river corridors. Under the CPM, bighorn sheep populations tend to function in large metapopulations (Hells Canyon Bighorn Sheep Restoration Committee 1997, USDA Forest Service 2006a, Hells Canyon Bighorn Sheep Restoration Committee 2004; Figure 2).

**Management Application**

Critical underlying management assumptions of the Policy are (1) the Policy is applied to wandering sheep moving outside of their normal population boundaries and habitats (movements most often associated with young dispersing rams), (2) wandering sheep movements are infrequent and aberrant, (3) the Policy is applied outside of occupied bighorn sheep range, (4) removal of wandering sheep does not substantially impact population viability or hinder attainment of management goals,

and (5) removal of wandering sheep will provide long-term effective separation and prevention of disease transmission. Application of the Policy must be questioned when 1 or more of these management assumptions are not met. The degree to which application of the Policy will meet these management assumptions depends on the particular landscape configuration relative to the 3 primary landscape parameters identified above.

## Discrete Parameter Model

Application of the Policy is most appropriate as a stand-alone management tool on western landscapes approaching the DPM, particularly when isolated bighorn sheep populations are meeting identified management goals and are not reliant on inter-population movements (natural dispersal) for maintaining viability and/or genetic diversity. Critical management assumptions of the Policy have the highest probability of being met under the DPM. Because allotments are disjunct from occupied bighorn sheep range and suitable habitats, interaction events are more likely to involve wandering bighorn sheep. As young dispersing animals do not contribute significantly to the reproductive success of the source population, removal of these wandering sheep would have fewer impacts on population viability or attainment of management goals.

Under the DPM, less frequent interaction events would be expected and, depending on the distance between allotments and suitable habitat, application of the Policy as a stand-alone management tool may provide long-term separation and prevention of disease transmission. In addition, consequences of undetected interaction events are lower under the DPM. As bighorn sheep are managed as isolated populations within fragmented habitats, a

disease outbreak can usually be contained to a single isolated population.

## Continuous Parameter Model

Application of the Policy is less appropriate as landscape configurations approach the CPM. Under this model, critical management assumptions will likely be violated. With allotments located within occupied bighorn sheep range, interaction events are more likely to involve adult resident, rather than wandering, wild sheep. Removing this reproductively important population segment could have negative impacts on population viability and attainment of management goals. Furthermore, impacts to population viability may be exacerbated for at-risk populations that are at low population levels, experiencing declining population trends, impacted by disease, and/or in need of enhancement.

A substantially increased frequency of interaction events would be expected under the CPM. With resident bighorn and domestic sheep concurrently occupying the same range, the risk of contact and disease transmission would be elevated (due to increased proximity) and prolonged (due to increased duration of co-mingling opportunities throughout the grazing season). A greater number of expected interaction events coupled with the inherent low probability of detection would result in a continual high risk of disease transmission. Under the CPM, application of this policy would not provide short- or long-term separation or prevention of disease transmission. In addition, consequences of undetected interactions are far greater under the CPM. As bighorn sheep populations are interconnected across continuous habitats, a single disease transmission event in one population has a high probability of being transmitted to adjacent connected populations, precipitating a chain reaction,

affecting metapopulation viability across a wide geographic area.

Intermediate Landscape Configurations

As landscape configurations diverge from the DPM, the effectiveness of this Policy will wane. In general, the risk of contact and disease transmission (frequency of interactions) will increase and the effectiveness of the Policy will decrease as (1) distance between areas grazed by domestic sheep or goats and bighorn sheep decreases and (2) bighorn sheep habitat connectivity increases between occupied bighorn sheep range and allotments. Also, consequences of undetected interaction events (impacts to bighorn sheep viability) increase as wild sheep populations become more connected and their habitats more continuous.

For example, application of the Policy may be problematic when domestic sheep grazing occurs outside of occupied bighorn sheep range, but within adjacent and continuous suitable wild sheep habitat. Under this situation, if bighorn sheep management goals include expanding bighorn sheep populations into unoccupied suitable habitats, implementation of the Policy, by removing pioneering bighorn sheep as they attempt to colonize new habitat, may preclude attainment of management goals. At the same time, if interactions between these pioneering individuals and domestic sheep go undetected, the source population's continued viability could be threatened.

**Management Recommendations**

The need to remove wild sheep that have come into contact with or are in close proximity to domestic sheep or goats is well understood. However, this review indicated the effectiveness (providing separation and preventing disease transmission) of the Policy is limited to landscape configurations approaching the DPM. Under most other landscape configurations, application of the Policy would fail to meet critical management assumptions, be ineffective in providing separation or preventing disease transmission, and have a high likelihood of negatively impacting bighorn sheep viability.

Managers should rely on the Policy as a stand-alone management tool to provide separation and prevent disease transmission only when applied to wandering wild sheep and only when applied outside of occupied bighorn sheep range (domestic sheep and goat grazing is spatially separated from occupied bighorn sheep range across non-bighorn sheep habitats). For all other cases, the need to remove bighorn sheep because of interactions with domestic sheep or goats should be viewed as a management failure triggering implementation of more effective separation strategies to prevent contact and preclude the need for further removal of wild sheep.

The post hoc nature and retroactive implementation of the Policy (bighorn sheep are removed after separation has failed and disease transmission has potentially occurred) and resulting potential impacts to bighorn sheep viability through direct removal of resident wild sheep or disease outbreaks, precludes this strategy as an effective management tool where domestic sheep or goats are grazed within or adjacent to occupied bighorn sheep range. This review indicated the Policy should not be used, even in conjunction with other management practices, as a rationale for precluding the need for spatial separation. Management strategies should focus on preventing the need for implementation of the Policy by providing effective temporal or spatial separation between bighorn sheep and domestic sheep and goats.

Under all landscape configurations, the Policy should not be relied on as a stand-

alone management approach if reoccurring or frequent bighorn sheep-domestic sheep or goat interactions persist. Continued need to remove wild sheep within a management area should trigger management review for developing and implementing more effective separation measures.

Prior to Policy implementation, managers should consider conducting case-specific assessments for the appropriate application of the Policy based on the 5 critical management assumptions and 3 landscape parameters identified above. To promote bighorn sheep conservation, state and federal agencies should re-evaluate the proper context for application of this common management tool based on these guidelines. Effective spatial and/or temporal separation of bighorn and domestic sheep should be the primary management goal to foster abundant self-sustaining bighorn sheep populations across the western U.S.

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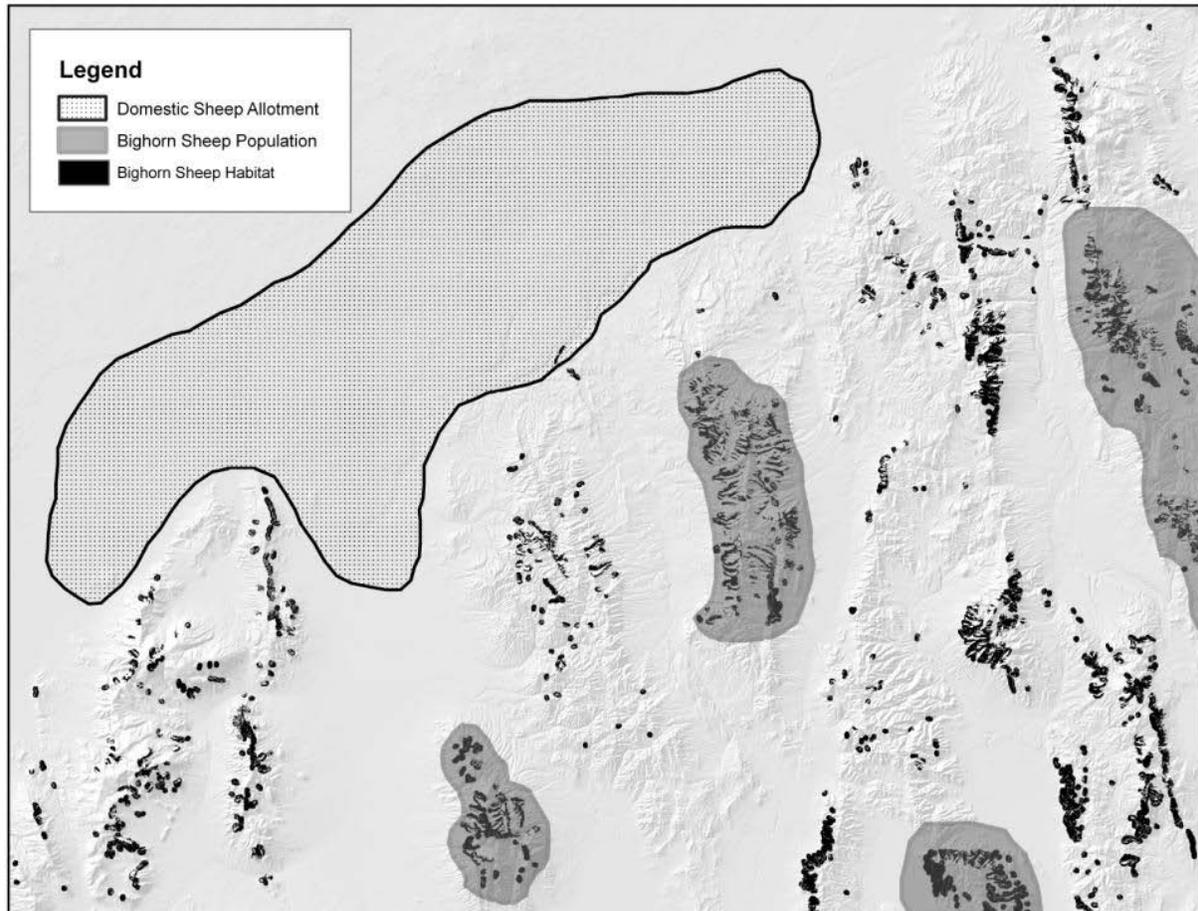
Figure 1. Conceptual Discrete Parameter Model showing isolated bighorn sheep populations, fragmented bighorn sheep habitats, and disjunct domestic sheep allotments.
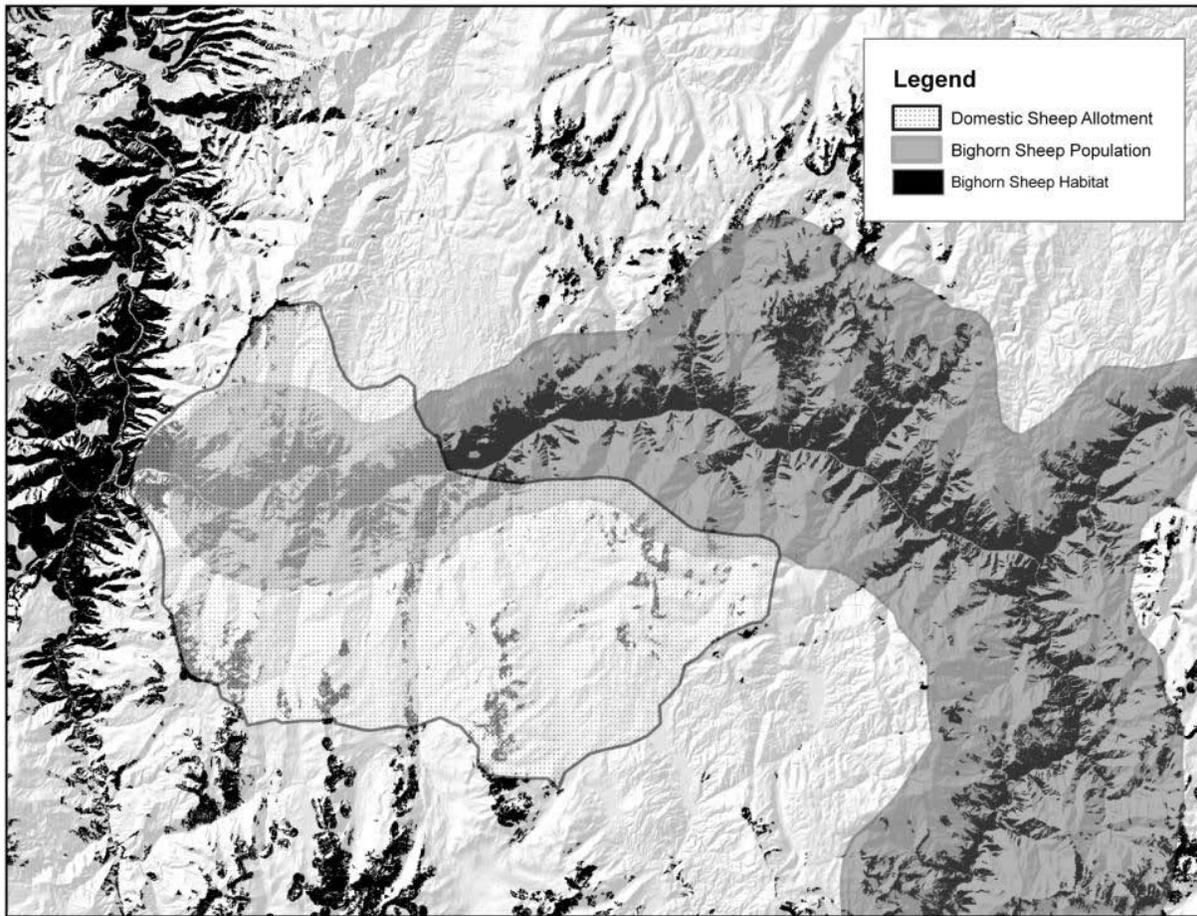
Figure 2.  Conceptual Continuous Parameter Model showing interconnected bighorn sheep populations, continuous bighorn sheep habitat, and overlapping domestic sheep allotments.

Table 1.  Informal survey of 15 western U.S. states regarding bighorn sheep management, bighorn-domestic sheep interaction concerns, and application of a wandering wild sheep policy.

| State | Managing bighorn sheep[1] | Bighorn-domestic sheep concerns[2] | Endorse wandering wild sheep policy[2] | Source |
|---|---|---|---|---|
| Arizona | RM[3], DS[4] | YES | YES[6] | Bob Henry, Arizona Game and Fish Department |
| California | CA[5], DS | YES | YES | Tom Stephenson, California Department of Fish and Game |
| Colorado | RM, DS | YES | YES | Janet George, Colorado Division of Wildlife |
| Idaho | RM, CA | YES | YES | Dale Toweill, Idaho Department of Fish and Game |
| Montana | RM | YES | YES | Tom Carlson, Montana Fish Wildlife and Parks |
| Nebraska | RM | YES | YES | Kit Hams, Nebraska Game and Parks |
| Nevada | RM, CA, DS | YES | YES | Mike Cox, Nevada Department of Wildlife |
| New Mexico | RM, DS | YES | YES | New Mexico Department of Game and Fish 2004 |
| North Dakota | CA | YES | YES | Brett Wiedmann, North Dakota Game and Fish |
| Oregon | RM, CA | YES | YES | Victor Coggins, Oregon Department of Fish and Wildlife |
| South Dakota | RM | YES | YES | John Kanta, South Dakota Game, Fish and Parks |
| Texas | DS | NO | N/A | Calvin Richardson, Texas Parks and Wildlife |
| Utah | RM, CA, DS | YES | YES | Anis Aoude, Utah Department of Natural Resources, Division of Wildlife Resources |
| Washington | RM, CA | YES | YES | Paul Wik, Washington Department of Fish and Wildlife |
| Wyoming | RM | YES | YES | Kevin Hurley, Wyoming Game and Fish Department |

[1] From Toweill and Geist 1999
[2] Data sources identified in the "Source" column
[3] Rocky Mountain bighorn sheep
[4] Desert bighorn sheep
[5] California bighorn sheep
[6] Includes informal, draft and pending, and formal policies