COLORADO
Department of
Natural Resources

Executive Director's Office
1313 Sherman Street, Room 718
Denver, CO 80203

November 18, 2020

Lisa Stoeffler
Acting Forest Supervisor
℅ Marcia Gillis
White River National Forest
900 Grand Avenue
Glenwood Springs, CO 81601

Dear Ms. Stoeffler,

Please accept this objection on behalf of the Colorado Department of Natural Resources (CDNR) to the White River National Forest's (WRNF) Berlaimont Estates Access Route Project Draft Record of Decision (ROD) and Final Environmental Impact Statement (Berlaimont FEIS), under 36 C.F.R. § 218. CDNR's mission is to develop, preserve and enhance the state's natural resources for the benefit and enjoyment of current and future citizens and visitors. As such, I appreciate the U.S. Forest Service's (USFS) consideration of our input throughout this environmental review process and the opportunity to provide feedback on behalf of the state of Colorado. While we are submitting this letter outside of the public comment period on the FEIS/ROD, we ask that our comments be considered as part of the formal decision record for this project.

Introduction: Declining Wildlife Habitat

Both CDNR and its division, Colorado Parks and Wildlife, have previously imparted our concerns about the proposed access road's anticipated impairments to recreation, wildlife populations and sensitive habitat in Eagle County. Most recently, a 2019 letter from CDNR provided supplemental information pointing to documented declines in the post-hunt elk population in game management unit 36 (GMU 36), which encompassses the project area.[1] The letter also referenced a 2019 executive order signed by Governor Jared Polis directing DNR and other state agencies to prioritize conservation of severe winter range habitat, production areas and migration routes utilized by elk and other big game species.[2] The proposed project and its surrounding lands, classified as deer and elk winter range and concentration areas, are a textbook example of the habitat that is being lost at an alarming rate to residential and other forms of human development.

[1] *Attachment A, Colorado Department of Natural Resources, Letter to Forest Supervisor Fitzwilliams, October 3, 2019*
[2] *Executive Order D-2019-011, Conserving Colorado's Big Game Winter Range and Migration Corridors*

CDNR defers to CPW's management authority and expertise with respect to assessing and recommending approaches for addressing the potential impacts of federal land use decisions on wildlife and habitat resource values. To this end, CPW's 2018 comments acknowledged the elevated risk to resident game populations posed by all three of the action alternatives (2-4) analyzed in the 2018 draft EIS (DEIS).[3] CDNR recognizes that the USFS has been responsive to many of CPW's specific recommendations for avoiding or mitigating some of these direct impacts of the project design in the selected alternative, Alternative 2. Nevertheless, after careful review, we conclude that the state's overarching concerns remain inadequately analyzed in the published draft ROD/FEIS, and no amount of mitigation can remedy the state's concerns.

The potential impacts to wildlife and wildlife habitat are not assigned an appropriate weight in the analysis presented in the Berlaimont FEIS. Much attention has been given in previous public comments to the existing pressures on big game populations and other wildlife within the Eagle Valley from development and recreation. Indeed, CPW data confirms that elk and deer populations declined between 50 and 60% between 2007 and 2018.[4] While it's difficult to pinpoint the exact cause of these declines, findings from a 2017 study and threats identified in a recent CPW report support the theory that increased disturbance from year-round recreation and habitat fragmentation and loss from ex-urban residential development are both likely contributors.[5] External research affirms the proposition that residential development density impacts animal behavior and is a likely factor in mortality and recruitment.[6] The FEIS references comments from CPW in 2016 in drawing the following conclusion:

> "The proposed upgrading and new construction of a road under any action alternative would result in the loss of elk winter range, elk winter concentration area, elk severe winter range, and other seasonal habitats that would be additive to declining effective habitat availability in DAU E-12, due primarily to winter range lost to development, habitat fragmentation, and year-round recreational impacts."[7]

Seasonal road closures are one of the most important tools that the USFS has at its disposal for minimizing these effects of development and disturbance, and conserving remaining, in-tact sensitive habitat such as the land surrounding the Berlaimont inholding. The FEIS and accompanying biological assessment (BA) recognize that the project area provides high quality winter range habitat for elk and deer, in large part, because of the seasonal closures implemented under the 2002 WRNF Forest Management Plan (Forest Plan):

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[3] *Attachment B, Colorado Parks and Wildlife, Berlaimont draft EIS public comments, March 9, 2018*
[4] *Attachment C, Vail Daily, "Where has al the wildlife gone: CPW officials cite 50% drop in Eagle Valley's elk population, June 16, 2018*
[5] *Attachment D, CPW, 2020 Status Report: Big Game Winter Range and Migration Corridors; Attachment E, Johnson et al., Increases in residential and energy development are associated with reductions in recruitment for a large ungulate, Global Change Biology, 23:578-591, 2017*
[6] *See Attachment F, Wyckoff et al., Evaluating the Influence of Energy and Residential Development on Mule Deer, Ecosphere, 2018, p. 8*
[7] *Berlaimont FEIS, 243; see also Attachment G, CPW 2016 Berlaimont Scoping Letter*

> "Habitat effectiveness of this winter range is relatively high because of motorized road closures, including the closure of FSR 780 to all motorized use, including snowmobiles, from November 24 to May 21. This closure was implemented specifically to protect this large, isolated block of elk and deer winter range within MA 5.41 from human disturbance."[8]

However, all of the action alternatives considered by the USFS in this decision, including Alternative 2, are inconsistent with forest management objectives because they would necessitate amendments to the Forest Plan in order to exempt the project from the seasonal use closures required under forest-wide Wildlife Standard 1 in the Forest Plan.[9] These unavoidable impacts would be mitigated, to an unknown degree, by required project design criteria and the issuance of a special order to restrict human access during winter months, but there is no plan to offset them, through increased protections on comparable habitat elsewhere in the forest or other measures.[10]

CDNR is concerned that the proposed selection of Alternative 2 has the potential to establish the disconcerting precedent that regional wildlife and wildlife habitat conditions are acceptable to exclude from decision evaluation criteria in the agency's exercise of its discretionary authority.

Objection

CDNR's objection is based on our conclusion that the proposed decision is based upon flawed or inadequate analyses and a misconception of discretionary authority under federal law. Specifically, the evidence presented in the Berlaimont FEIS is insufficient to justify the conclusion that the Lake Agnes/Lichen Ranch subdivision is a "similarly situated" land, let alone the only "similarly situated" land upon which the agency's determination of "reasonable use" under Alaska National Interest Conservation Act (ANILCA) of 1980, can be based.(15 U.S.C.3210 § 51.3102(a)) Additionally, the FEIS fails to comprehensively examine the potential impacts that improved, year-round access to recreational opportunities in and adjacent to the project area could have on wildlife and wildlife habitat. As a result of these shortcomings, the decision presents significant and unaccounted for risks to big game species and other wildlife species that rely on the deer and elk winter range and concentration areas in the project area and its surrounding lands. We elaborate on these arguments in greater detail below.

A. The Service's decision is based on a flawed interpretation of provisions of federal law

1. Determination of "Adequate Access"

The USFS' "adequate access" determination is grounded in a misconstrued interpretation of the agency's discretionary authority under ANILCA. The law only requires the USFS to "provide such access to non-federally owned land within the boundaries of the National

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[8] *Berlaimont FEIS, 233*
[9] *Berlaimont FEIS, Biological Assessment, ES-1; USFS White River National Forest Management Plan, 2002a*
[10] *Berlaimont draft ROD, Table ROD-2: Mitigation measures, BMPs, PDCs, 24*

Forest System as the [USDA] Secretary deems adequate to secure reasonable use and enjoyment…”.[11] The definition of “access” is limited to “ingress or egress” (i.e., not applicable to rights of way for power lines or utilities).[12] Federal regulation leaves the conditions that constitute “adequate” open to agency discretion, consistent with “contemporaneous uses made of similarly situated lands [in-holdings] in the area and any other relevant criteria,”[13] but the agency’s exercise of that discretion is subject to the Administrative Procedures Act (APA), and may not be arbitrary, capricious, or otherwise contrary to law.[14]

In this case, the selected alternative would replace the existing, dirt road that currently provides access to the Berlaimont Estates inholding with a paved road. Access to the Lake Agnes/Lichen Ranch subdivision -- the one example of a “similarly situated” inholding that serves as the basis for the USFS’ ANILCA determination -- is provided by a dirt road.[15] In justifying the similarity between the two projects, the analysis indicates that access in both cases would consist of a “snow-plowed Forest Service Road allowing year-round use by wheeled vehicles.” The USFS arbitrarily omits a variety of characteristics from its “adequate access” determination criteria that would be within the agency’s discretion to examine, and neglects to explain why these characteristics are irrelevant to the analysis.[16] These characteristics include *dissimilar aspects* between the Lake Agnes/Lichen Ranch access road and proposed Berlaimont access road, such as proposed road’s paved construction compared to the existing road’s unpaved construction. Other seemingly relevant road design characteristics that are similarly ignored include the roads’ length, incline, number of switchbacks, etc.

In the absence of a discussion about whether and how these road design features affect access in the examples of “similarly situated” properties, it is impossible to definitively conclude that the specific characteristics of the road proposed in Alternative 2 are necessary for satisfying the conditions of “adequate access” while minimizing “damage or disturbance” to NSF lands and resources. On the contrary, it would seem that these other design features would undoubtedly have implications for accessibility as well as environmental impacts, and should have been assessed as relevant evidence in the agency’s “similarly situated” comparisons in the ANILCA “adequate access” determination.

2. Determination of “Reasonable Use”

Moreover, the USFS abused its discretion in determining that the proposed Berlaimont Estates development is a “reasonable use” of the in-holding.

a. ***The USFS failed to provide meaningful discussion or justification for its selection of the characteristics used to identify “similarly situated” properties***.

[11] *15 USC § 51.3102(a)*
[12] *36 CFR § 251.111*
[13] *36 CFR § 251.114(a)*
[14] *5 U.S.C. § (706)(2)(A)*
[15] *USFS Berlaimont FEIS, Appendix C: Addendum B, Table for Analysis of Similarly Situated Lands*
[16] *USFS Berlaimont FEIS, Appendix C, C-13*

The USFS failed to justify the characteristics upon which it based its "reasonable use" analysis, and it failed to consider other factors directly relevant to its analysis. For example, the USFS failed to account for the degree to which this and other potentially comparable properties provide critical wildlife habitat and the relative importance of the project area to wildlife given the extent of existing impacts to surrounding properties. This factor is directly relevant to the USFS's obligation to minimize damage or disturbance to surrounding lands and resources, including wildlife.

The USFS acknowledges that motorized access provided by the proposed project will result in increased, year-round recreational activity, vehicle traffic, and habitat fragmentation, and as mentioned above, that the property is located in an area for which the extent of development and disturbance have likely contributed significantly to wildlife population declines, and the surrounding lands and inholding itself serve important habitat functions. But, *while these conditions are given consideration as "other relevant criteria," the analysis offers no comparison between the wildlife-related characteristics of the proposed project area and the wildlife-related characteristics of the other properties examined in the "similarly situated" evaluation.*

b. ***The USFS failed to justify its conclusion that only properties satisfying <u>all</u> the criteria were "similarly situated."***

The USFS considered 23 subdivisions in its evaluation of "similarly situated lands," and despite numerous similarities between the proposed project and the other evaluated subdivisions, it only considered one subdivision that it concluded satisfied all of the evaluation criteria. Even assuming that the evaluation criteria were proper, it is unclear why the USFS completely excluded subdivisions that met many of those criteria from its "reasonable use" analysis. *The fact that the USFS was only able to identify one property meeting all of the criteria suggests either that its criteria were impermissibly narrow, the means of evaluating those criteria was impermissibly narrow, or the proposed use itself is not reasonable*..

c. ***There is inadequate information to support the conclusion that the property on which the ANILCA determination is based is "similarly situated."***

The USFS fails to sufficiently address differences between the proposed use and the Lake Agnes/Lichen Ranch subdivision that are within the agency's discretionary authority to consider and relevant to the outcome of its ANILCA determination. For instance, the difference in road construction, as mentioned above, represents one apparent dissimilarity between the proposed project and the "similarly situated" example.[17]

The ANILCA determination analysis neglects to acknowledge the distinction between the two properties' respective proximities to lands containing Threatened, Endangered or Sensitive (TES) species, despite the explanation that this criteria is relevant

[17] *Berlaimont FEIS, Appendix C: Addendum B*

because a “land use which may be reasonable on an inholding property surrounded by general NFS lands may be determined to be unreasonable on an inholding surrounded by TES habitat specifically because of its location within that TES habitat.”[18] It should be noted that the Table for Analysis of Similarly Situated Lands cites only the federally endangered lynx habitat and critical habitat datasets in order to substantiate an inaccurate claim that neither property is adjacent to NSF lands containing TES species habitat, and thus, similarly situated in this regard. In doing so, the agency arbitrarily excludes any dataset(s) containing documented or suitable habitat for sensitive species in its analysis, and furthermore, overlooks the findings in the FEIS.[19] In fact, the FEIS lists eight avian and one mammalian species classified as sensitive by USFS Region 2 for which NFS lands in the immediate vicinity of the Berlaimont property serve as known or suitable habitat and may be impacted by the selected alternative, along with four aquatic species found in nearby waterways.[20]

d. ***Other relevant criteria are not sufficiently analyzed in the ANILCA determination***.

The consideration in the ANILCA determination of “other relevant criteria” -- particularly historical development in the I-70 viewshed and the attendant impacts -- ignores changes in local priorities and circumstances, and more recent improvements in the understanding of the direct and cumulative impacts of such development on wildlife. A preponderance of research suggests that increased, low-density, exurban residential development affects wildlife habitat viability in a variety of ways.[21] For instance, a 2008 USFS study suggests that “[h]ousing developments and associated roads may prevent wildlife from migrating or moving through areas outside forest boundaries and thus affect species that rely on a variety of ecosystems or large areas to survive.”[22] The ANILCA determination methodology gives insufficient treatment to wildlife population and habitat conditions in the surrounding area, the extent of human recreational and development uses, and related contextual criteria.

A more comprehensive evaluation of relevant characteristics reveals that the proposed use may, in fact, be incomparable to the example that was deemed “similarly situated”, if not to any other examples in the area, and therefore, that the USFS has not adequately substantiated its special authorization “reasonable use” determination. Further, it suggests that “reasonable access” might be more in-line with the properties that were dismissed as a result of an improper analysis and arbitrary exercise of authority.

Conclusion

The USFS has provided insufficient evidence to support its proposed decision to grant a special use authorization to develop the access road described in Alternative 2. The rationale

[18] *Berlaimont FEIS, Appendix C, C-5*
[19] *Berlaimont FEIS, Appendix C: Addendum B, footnote 16*
[20] *Berlaimont FEIS, Chapter 3: Affected Environment, Table 3L-6, p. 240*
[21] *A summary of research can be found in Attachment H: U.S. Department of Agriculture (Maestas), Effects of Exurban Development on Wildlife and Plant Communities, 2016*
[22] *Attachment I: USFS (Stein et al.,) National Forests on the Edge, 2008*

for this decision is grounded in a flawed application of the provisions of federal law, including various aspects of the analysis that serve as the basis for the agency's "reasonable use" determination under ANILCA. In exercising its discretionary authority, the USFS has given short shrift to other relevant criteria that are vital to consider in this determination, most notably, the wider context of human development and recreational pressures, and their effects on wildlife in the Eagle Valley. The agency's approval of the selected alternative despite these shortcomings stands to create dangerous precedent for future decisions.

As Colorado's population continues to grow in both urban and rural areas, federal land use decisions will become increasingly important for conserving our state's lands, natural resources and wildlife. I appreciate your attention to CDNR's comments and look forward to our continued partnership with the WRNF and USFS.

Sincerely,

Dan Gibbs

Executive Director

CC: Tricia O'Connor, Acting Rocky Mountain Regional Forester, USFS; Scott Fitzwilliams, WRNF Forest Supervisor; JT Romatzke, CPW

Attachments:

- Attachment A: Colorado Department of Natural Resources, Letter to Forest Supervisor Fitzwilliams, October 3, 2019
- Attachment B: Colorado Parks and Wildlife, Berlaimont draft EIS public comments, March 9, 2018
- Attachment C: *Vail Daily*, "Where has all the wildlife gone: CPW officials cite 50% drop in Eagle Valley's elk population, June 16, 2018
- Attachment D: CPW, 2020 Status Report: Big Game Winter Range and Migration Corridors
- Attachment E: Wyckoff et al., Evaluating the Influence of Energy and Residential Development on Mule Deer, *Ecosphere*, 2018
- Attachment F: Johnson et al., Increases in residential and energy development are associated with reductions in recruitment for a large ungulate, Global Change Biology, 23:578-591, 2017
- Attachment G: CPW 2016 Berlaimont project Scoping Letter
- Attachment H: U.S. Department of Agriculture (Maestas), Effects of Exurban Development on Wildlife and Plant Communities, 2016
- Attachment I: USFS (Stein et al.,) National Forests on the Edge, 2008

Attachment A

COLORADO
Department of Natural Resources

Executive Director's Office
1313 Sherman Street, Room 718
Denver, CO 80203

October 3, 2019

Mr. Scott Fitzwilliams
Forest Supervisor
White River National Forest
Supervisor's Office
900 Grand Ave
Glenwood Springs, CO 81601

Dear Supervisor Fitzwilliams,

On behalf of the Colorado Department of Natural Resources (DNR), we are grateful for the work you do and the partnership that exists between the U.S. Forest Service and the State of Colorado.

As you know, DNR has been engaged in the consideration and analysis of a proposed access road across National Forest land near Edwards to facilitate development of a new subdivision called Berlaimont Estates. Our prior comments acknowledge the impacts this access road would have on wildlife. We are writing to provide you with new information that was not available when we commented on the Draft Environmental Impact Statement and that is relevant to your consideration of the proposal.

Recent Colorado Parks and Wildlife (CPW) population counts show a considerable decline in post hunt estimates for game management unit 36 elk herds between 2005 and 2018. Additionally, there is information showing a meaningful correlation between habitat fragmentation and the resilience of elk populations – suggesting we may have reached a threshold of disturbance that undermines the ability of local elk populations to recover to historic levels.

In addition, on August 21, 2019, Governor Polis signed the enclosed Executive Order (EO) D 2019-011, which underscores the importance of conserving big-game wildlife corridors and winter range habitat in Colorado. We ask that you strongly take the EO into account as you consider the removal of the seasonal closure of the current road that protects important winter wildlife habitat, and also evaluate to what degree this action may set an undesirable precedent for future development proposals in the state.

Thank you for your additional consideration regarding this matter. Your service to Colorado and our public lands is greatly appreciated.

Sincerely,

Dan Gibbs
Executive Director

COLORADO
Governor Jared Polis

D 2019 011

EXECUTIVE ORDER

Conserving Colorado's Big Game Winter Range and Migration Corridors

Pursuant to the authority vested in the Governor of the State of Colorado and, in particular, pursuant to Article IV, Section 2 of the Colorado Constitution, I, Jared Polis, Governor of the State of Colorado, hereby issue this Executive Order to conserve Colorado's big game winter range and migration corridors.

I. Background and Purpose

Colorado's natural environment and numerous native wildlife species contribute greatly to the economy and enhance Coloradans' quality of life. Sportsmen, outdoor enthusiasts, and tourists from across the world visit Colorado to experience our State's outdoor landscapes and abundant wildlife. Colorado boasts the largest Rocky Mountain elk herd in the world, which contains over 250,000 animals. The State is also home to significant populations of other iconic big game species like mule deer, bighorn sheep, pronghorn, moose, and numerous other endemic wildlife species. Simply put, wildlife is essential to Colorado's outdoor recreation economy and landscape heritage.

The conservation of big game migration corridors and seasonal habitat for big game has been a focus of the Department of Natural Resources (DNR) and Colorado Parks and Wildlife (CPW) for many years. The mission of CPW is to perpetuate the wildlife resources of the State, to provide a quality State parks system, and to provide enjoyable and sustainable outdoor recreation opportunities that educate and inspire current and future generations to serve as active stewards of Colorado's natural resources. To achieve this mission, CPW works to conserve habitat essential to the survival of the State's wildlife. Intact seasonal habitats, and the migratory routes that connect those habitats, are vital to ensuring that Colorado's wildlife populations continue to thrive. Habitats that support big game wildlife migration in Colorado also support many other migrating and non-migrating species.

Colorado's population continues to grow, placing pressure on the natural habitats that wildlife depends upon for survival. Habitat loss and fragmentation affects wildlife populations in general, and particularly species that migrate annually between seasonal habitats. Specifically, roadways disrupt annual big game migration, and vehicular collisions with wildlife pose risks to people, property, and the animals that contribute so much to Colorado's reputation as a place to admire natural wonders. In Colorado, nearly 4,000 vehicle crashes involving wildlife are reported to law enforcement every year, resulting in injuries and fatalities to humans, and costing an estimated $80 million annually. This figure does not include the value of wildlife killed in vehicular collisions, the impact on the health of wildlife populations, or the loss and fragmentation of the vibrant habitats wildlife call home.

In 2018, the Colorado Wildlife and Transportation Alliance (Alliance) was established to improve human safety while ensuring safe and successful migration of Colorado's big game wildlife each year. The Alliance includes CPW, Colorado Department of Transportation (CDOT), Tribal Governments, federal agencies, and non-governmental partners that represent academia, nonprofit organizations, and biological and engineering sciences. The Alliance has already successfully reduced wildlife-vehicle collisions and has helped maintain robust wildlife populations.

Further, incentive-based conservation programs for habitat management have a long track record of success in Colorado. Coordination with government agencies, non-governmental organizations, and private landowners is critical to the safe migration of wildlife across numerous jurisdictions. Many heavily used migration routes were created through voluntary, proactive, and on-the-ground conservation measures.

Through partnerships, technology, and collaborative funding efforts, there are emerging opportunities for Colorado to further support big game wildlife migration and protect wildlife habitat. Recent technological advancements allow wildlife managers to better understand big game wildlife migration patterns. In addition, big game corridor work in Colorado has recently been bolstered by new funding opportunities from the United States Department of the Interior Secretarial Order 2018-3362. As such, it is timely for the State to conserve our migrating big game populations and their habitats. This Executive Order will ensure that future generations of Coloradans will enjoy a safe, prosperous relationship with the natural world and Colorado's native wildlife species.

II. Directives

To conserve Colorado's big game winter range and wildlife migration corridors, I hereby issue the following directives:

A. DNR shall compile a status report on Colorado's big game migration patterns and related scientific materials on seasonal habitats for the Governor by April 1, 2020. This report will include:

1. Information regarding the location and known threats to seasonal big game habitat and migration corridors in Colorado;

2. Data gaps and barriers to identifying the location and known threats to Colorado seasonal big game habitat and migration corridors; and

3. A recommended timeframe and action plan outlining how frequently CPW will need to update its list of high-priority big game migration corridors and seasonal habitats throughout Colorado.

B. DNR shall identify policy, regulatory, and legislative opportunities to ensure the ongoing conservation of seasonal big game habitat and migration corridors. DNR shall compile a report of such opportunities for the Governor by July 1, 2020 that includes:

   1. Opportunities to include big game migration corridors in new or existing division policies and regulatory permitting processes;

   2. Opportunities to work with private landowners, local governments, public landholders, and tribes through existing or other voluntary, non-regulatory programs to sustain migration corridors; and

   3. Opportunities to work with neighboring states on cross-boundary migration corridors.

C. DNR shall work with CPW to incorporate information concerning big game migration corridors into relevant public education and outreach efforts and shall meet with stakeholders to discuss big game migration corridors to implement this Executive Order.

D. CDOT shall enable safe wildlife passage and reduce wildlife-vehicle collisions, and incorporate consideration of big game migration into all levels of its planning process, to the greatest extent possible. In implementing this directive, CDOT should undertake the following:

   1. Identify policy, regulatory, and legislative opportunities to ensure the ongoing conservation of seasonal big game habitat and migration corridors;

   2. Consider incorporating big game migration and associated conservation measures into planning processes in locations where regulatory processes do

not currently formally require wildlife mitigation measures; and

3. Seek outside funding partners if conservation measures require financial support.

E. CDOT and DNR shall enter into a Memorandum of Understanding (MOU) by December 31, 2019. The MOU should outline expectations for collaboration on the following actions:

   1. Identify priority areas for the implementation of big game crossings over and under roadways in Colorado. Priorities should be set using the best available science regarding wildlife migration patterns and vehicle collision data. CDOT and DNR shall identify priorities and opportunities that are cost-effective, and establish wise stewardship of State financial resources and natural resources; and

   2. Continue to support the Alliance, and utilize the Alliance to raise awareness, forge partnerships, and identify potential public and private funding opportunities to construct new wildlife crossing structures in priority areas.

F. DNR and CDOT shall implement current fiscal year actions within existing budgets and authorities. If necessary, DNR and CDOT shall engage with the Office of State Planning and Budgeting to identify resource requirements and incorporate those requirements into the annual budget development process for any actions to be implemented in future fiscal years.

II. <u>Duration</u>

This appointment and this Executive Order shall remain in effect unless modified or rescinded by future Executive Order of the Governor.

GIVEN under my hand and the Executive Seal of the State of Colorado, this 21st day of August, 2019.

Jared Polis
Governor

COLORADO
Parks and Wildlife
Department of Natural Resources
Northwest Regional Office
711 Independent Avenue
Grand Junction, CO 81505

Attachment B

March 9, 2018

White River National Forest (WRNF)
Scott Fitzwilliams, Forest Supervisor
c/o Matt Klein, Realty Specialist
PO Box 190
Minturn, CO 81645

RE: Berlaimont Estates Access Route Draft EIS - CPW Comments

Dear Mr. Fitzwilliams,

Thank you for the opportunity to review the proposed access route for the Berlaimont Estates private inholding in the White River National Forest. Colorado Parks and Wildlife (CPW) appreciates the opportunity to be actively engaged throughout the NEPA process. CPW has a statutory responsibility to manage all wildlife species in Colorado; this responsibility is embraced and fulfilled through CPW's mission to protect, preserve, enhance, and manage the wildlife of Colorado for the use, benefit, and enjoyment of the people of the State and its visitors. Colorado Parks and Wildlife staff has reviewed the Draft Environmental Impact Statement (DEIS) and we offer the following comments and recommendations for your consideration.

Our review of the project confirms that there will be direct impacts to deer and elk winter range and migration habitats/corridors regardless of which alternative is selected. The impacts will affect deer and elk at the population level as stated on page 250 of the Draft EIS. However, with the applicant's use of BMPs and PDCs we believe that Alternative 3 will result in the least impacts to wildlife. CPW believes that the residual impacts will still require mitigation or habitat offsets.

We appreciate the applicant's willingness to work with us to plan, design and implement wildlife habitat mitigation that address the crucial habitat loss resulting from this project depending on the final alignment selected. Also, we expect the applicant to fully uphold our verbal commitment to fund the mitigation as the mitigation is determined.

Wildlife specific recommendations follow.

Mule Deer and Elk:

CPW concurs with the list of wildlife mitigation measures, Best Management Practices (BMPs), and Preferred Design Criteria (PDC) provided in Table 2-6 of the draft EIS. CPW welcomes the opportunity to work with the applicant and WRNF staff to implement the items in Table 2-6 and to assist in developing effective habitat enhancement ideas to offset any residual impacts to wildlife. Furthermore, CPW staff is willing to assist in the design review process for the spanning bridge at Beard Creek to provide an effective wildlife crossing structure.

Habitat enhancements should be completed within the Game Management Unit (GMU) 36, but not directly adjacent to the road/disturbance areas to prevent habitat improvement projects from attracting wildlife to the roadway or construction/staging areas. CPW suggests that the following additional BMPs and PDC be added to Table 2-6:

- Limit road construction from January 1 to May 1 to protect wintering wildlife.
- Limit blasting during avian nesting periods (generally, May 1 to June 15).
- Consult with local CPW staff on placement of wildlife crossing areas and signage.

Greater Sage-Grouse:

Much of the proposed access road of the proposal is mapped as General Management Habitat Area (GHMA) in the BLM Northwest Colorado Greater Sage-Grouse Approved Resource Management Plan Amendment (ARMPA). CPW recommends that the WRNF follow the guidelines provided in the BLM ARMPA. The plan seeks to minimize impacts in occupied habitat on BLM and USFS lands that require special management to sustain GrSG populations. The ARMPA recommends avoiding any major or minor new infrastructure disturbance in GHMA.

Black Bears:

CPW recommends the proponent follow all Eagle County guidelines for bear resistant trash cans. A centralized trash collection and disposal system is recommended for the development. CPW staff is available to help establish and refine such a system or process for the development. Further, during the construction phase of the development, CPW recommends that all employees and contractors store food within locked vehicles. Pets should be prohibited on the construction site.

Fencing and/or guardrails along proposed road:

The recommended height for wildlife friendly fencing is 42". As shown in Figure 1 (attached), slope makes a significant difference in the ability for wildlife to cross such barriers. The following table shows the estimated effective fence height based on the slopes referenced within the engineering report and a 27" guardrail.

Slope	Effective Height
Flat Ground (no slope)	27 inches
3 : 1 Slope	47 inches
2 : 1 Slope	60 inches
1.5 : 1 Slope	70 inches

- *Even at a 3:1 slope (33% gradient), the effective height of a 27 inch guardrail surpasses CPW's recommended fence height of 42 inches.*

Aquatic Concerns:

The proposed access road will parallel the lower section of Berry Creek and bisect the Beard Creek and Thames Creek drainages. CPW appreciates the extensive list of PDC and BMPs to reduce sedimentation and effectively manage stormwater runoff from the new roadway. The following measures are recommended for your consideration as inclusions to the aquatic protections provided in the DEIS.

- Include an analysis of different snowmelt options (i.e. salt, sand, chemical, etc.) and the potential impacts on the aquatic systems in the area. Include testing for these substances within the water quality monitoring program.
- In addition to water quality monitoring, add metrics for measuring sediment transport, streambed composition, and aquatic invertebrates within Berry Creek both before and after construction of the access road, new trails, and parking areas.

Thank you for the opportunity to review the Draft EIS for this project and provide recommendations and feedback. CPW looks forward to future involvement during the ongoing design and implementation of this project. If you have questions please contact DWM, Bill Andree, at (970) 328-6563.

Sincerely,

JT Romatzke,
NW Regional Manager

Cc: Dean Riggs, Deputy NW Regional Manager
Perry Will, Area 8 Wildlife Manager
Bill Andree, District Wildlife Manager
Taylor Elm, Land Use Specialist
File

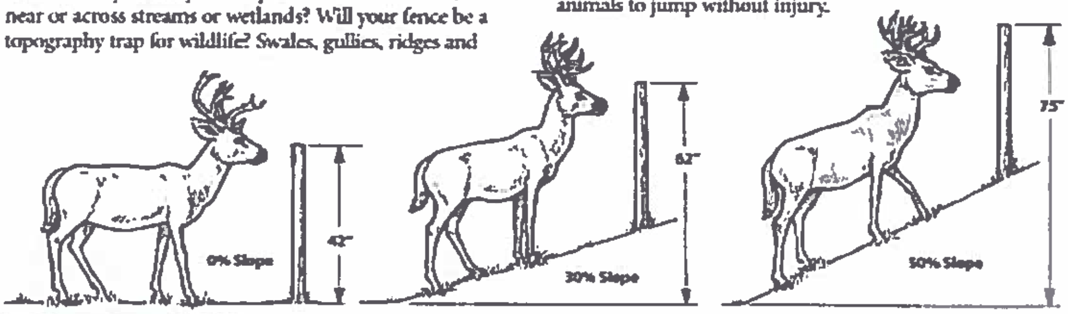
Figure 1:

to riparian habitats, water holes and other high quality habitats. Place crossings, jumps, open gates and other wildlife openings in appropriate locations. Deer, elk, and pronghorn are more likely to use openings at fence corners than in the middle of a fence run, unless there is cover, habitat or natural corridors or trails to attract them through. Intermittent openings should be placed where animals naturally travel: in riparian corridors, along gullies and ridges, and on existing game trails.

Topography

Work with your land's topography. Are you fencing on hills, in rocky country where posts cannot be driven, or near or across streams or wetlands? Will your fence be a topography trap for wildlife? Swales, gullies, ridges and stream corridors can funnel wildlife through an area—keep these open to allow wildlife passage and avoid topography traps.

A fence of any height is more difficult to cross when placed across a steep slope. As ground slope increases, the distance an animal must jump to clear the fence increases considerably (see illustration below). For instance, a 42" fence may be passable on level ground, but a slope of only 10% increases the effective fence height to 48.6"; a slope of 30% increases effective height to 62", and on a 50% slope animals encounter an obstacle 75" high. Fences on steep slopes become nearly impossible for animals to jump without injury.



Wildlife-Friendly Fencing

The ideal wildlife-friendly fence:

- *Is highly visible to ungulates and birds*
- *Allows wildlife to jump over or crawl under*
- *Provides wildlife access to important habitats and travel corridors*

The "friendliest" fences for wildlife are very visible and allow wild animals to easily jump over or slip under the wires or rails. The Colorado Division of Wildlife recommends:

- Fencing wire placed on the side of the fence posts where the domestic animals are located;
- Smooth wire or rounded rail for the top, smooth wire on the bottom;
- Height of top rail or wire should be 42" or less;
- At least 12" between the top two wires;
- At least 16" between the bottom wire or rail and the ground;
- Posts at minimum 16' intervals;
- Gates, drop-downs, removable fence sections or other passages where animals concentrate and cross;
- Using a rail, high-visibility wire, flagging or other visual markers for the top.

Visibility

High visibility helps wildlife negotiate fences. Visibility is especially important in grasslands and near creeks and wetlands to protect low-flying birds, such as grouse, owls and waterfowl. For big game, increased visibility helps animals judge their jumps better so that they can clear the fence or use another location to cross. Using a vinyl coated high tensile wire for the top wire, or covering the existing top wire with PVC pipe, flagging, or tape helps wildlife see fences and dramatically reduces wildlife damage to fences of all heights. Another solution is using a rounded top rail, which will shed snow easily.

For wire fences, the least expensive solution is to simply hang flagging, or other materials along the top, although many materials can fade or be lost and need regular replacement. Another alternative is to slip sections of small diameter PVC pipe over the top strand. High-

Attachment C

Where has all the wildlife gone: CPW officials cite 50 percent drop in Eagle Valley's elk population

News FOLLOW NEWS | June 16, 2018

Pam Boyd FOLLOW
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This elk, spotted near Red Cliff, is stuck in the snow and weakened from winter. Harsh conditions, as well as human interference with the animals' habitat, have caused big declines in herd numbers near Minturn.
Daily file photo

EAGLE COUNTY — Imagine if, over a 10-year period, half of Eagle County's human population disappeared.

We would be using the terms "drastic," "alarming" and maybe even "catastrophic" to describe the situation.

During the past decade, that exact scenario has played out for one group of county residents. Today's elk population in the area — from Vail Pass to Glenwood Canyon — is 50 percent lower than it was in 2007. This precipitous drop has personnel from Colorado Parks and Wildlife concerned.

"I don't think people realize the dramatic amount the elk population has decreased," said Craig Wescoatt, wildlife manager for Colorado Parks and Wildlife.

"The numbers we have counted have dropped some 50 (percent) to 60 percent in the last 10 years," Wescoatt said. "We are not seeing the animals migrate to another area or permanently move somewhere else. They are just dead and gone."

Bill Andree is also a CPW wildlife manager stationed in the area. He noted elk counts are done from helicopters in the winter, and during the census, managers record age and sex information about the animals. Based on the same number of flight hours with the same personnel doing the counting, the Vail Pass to Aspen count, south of Interstate 70, recorded 3,500 elk in 2006. In 2016, only 1,400 elk were sighted in the same area.

Andree continued, noting that the aerial count numbers, combined with harvest data and winter condition information, is used to run a computer model that provides a population estimate. In 2002, an estimated 10,600 elk resided in the valley. By 2016, the number had dropped to an estimated 6,554 elk.

What's more, looking at the trend of elk calf production, the news is grim.

Previously, CPW's data showed numbers of roughly 50 calves per 100 cows. Those figures are now in the low 30s. CPW wildlife manager Bill Andree noted that at about 34 to 35 calves per 100 cows, its possible to maintain a herd. But with a herd that has already dropped by half, maintenance isn't the goal.

“The chance of numbers returning to the population of 2007 is pretty difficult,” Andree said.

WHAT HAPPENED?

“There is no one, individual reason for this population decline,” Andree continued.

Eagle County hasn’t experienced a cataclysmic fire or a calamitous flood, for example. The area has seen drier conditions including drought in 2012, but a single drought year isn’t a big enough event to wipe out half of the region’s elk population. Likewise, the region has seen an increase in predatory issues with more mountain lions and bears moving to the area. But at most, the presence of more predators is a contributing factor to the elk population decline.

The biggest issue affecting the local elk population is disruption.

“It’s not only that there are more people and more houses. There are more areas being used by people,” Wescoatt said.

Recreationalists rejoice when they gain access to former ranch land, both for the opportunities the property itself offers and also for its gateway potential to federal lands. But what’s great for people isn’t great for wildlife.

Andree noted it is becoming increasingly difficult for animals to find respite from humans.

“People are out there all the time any more,” he said. “There are people snowshoeing by moonlight and training for ultramarathons There is no time period when the animals don’t have to compete with humans for habitat.”

Wescoatt noted that communities throughout Eagle County promote ecotourism in an attempt to maximize local sales tax collections by marketing the natural environment.

“All that is well and good, but there is an impact that comes from that, as well,” he said. “When it comes to wildlife, what does the public want to see happen?”

MANAGEMENT ISSUE

Because the local elk loss is a significant issue, the CPW is responding with the one tool at its disposal. The agency is reducing the number of antlerless elk hunting licenses available. Before 2007, there would be 2,000 or more cow elk permits available for the fall hunting license draw. This year, there will be fewer than 200 allocated.

The other tool CPW has is education. That means both letting people know about the problem and urging them to change behaviors that are a detriment to wildlife. It also means advocating for deer and elk when development plans are discussed.

“We all know what happens when you build your house somewhere. You want to recreate out your back door,” Andree said. As a result of that thinking, houses and trails have sprouted south of I-70 and elk have disappeared.

“We are just starting to see those impacts on the north side of I-70, too,” Wescoatt said.

Because local communities do value wildlife, various mitigation programs have been launched to address development impacts. At Eagle Ranch, for example, money collected from a real estate transfer tax is earmarked for wildlife mitigation. Both Andree and Wescoatt noted that more than $1 million has been spent on wildlife mitigation projects around Eagle, but those improvements have not stabilized the elk population loss. The town of Eagle has instituted seasonal closures on its popular open space trails, but people don’t always comply with the rules.

And when it comes to owning up to the harm their actions are causing, recreationalists are likely to blame other groups for the problem.

HARASSMENT

Wescoatt and Andree said ignorance likely plays a big role in animal disturbance. People tend to think that harassing wildlife means chasing after them on ATVs or allowing a dog to run headlong into a herd. Yes, those are egregious examples, but they aren’t the only ones.

“Just because you think you didn’t bother wildlife doesn’t mean you didn’t,” Andree said. “Not every animal runs away when approached.”

Seasonal closures are instituted to protect pregnant cows at a time when their survival is tenuous. By late winter, food supplies are scare and cows need all the calories they can to birth a healthy calf and then produce the milk to feed it. If a cow is stressed out by nearby snowshoers, cross-country skiers or early-season mountain bikers, then that interaction will take a toll on both the cow and calf’s mortality chances.

Some local organizations are stepping up to help educate the public about the reasoning for seasonal closures and to police trailheads, Wescoatt and Andree noted. That’s a start.

In the bigger picture, if elk are going to survive in Eagle County, there needs to be land set aside for wildlife that is off limits to humans.

“Solitude and space are necessities for wildlife herds,” Wescoatt said.

That’s not an easy sell in a valley where recreation rules.

But as Andree noted, there is a carrying capacity for various environments. There is only so much water available in the Colorado River, for example, and people know they can’t plan for more use than what’s flowing in the riverbed. There is only so much land in Eagle County, and at some point people will have to determine if they value wildlife enough to make sure there is room for elk and deer herds in this valley.

“How many miles of trails and development is enough? Sooner or later, you are going to have to say ‘no more,’” Andree said.

COLORADO PARKS & WILDLIFE

2020 Status Report: Big Game Winter Range and Migration Corridors

Attachment E

STATE OF COLORADO • DEPARTMENT OF NATURAL RESOURCES

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List of Acronyms

BBMM .... Brownian Bridge Movement Model

BLM .... Bureau of Land Management

CDOT .... Colorado Department of Transportation

CDOW .... Colorado Division of Wildlife

COGCC .... Colorado Oil and Gas Conservation Commission

CPW .... Colorado Parks and Wildlife

CSFS .... Colorado State Forest Service

CWHP .... Colorado Wildlife Habitat Program

CWTA .... Colorado Wildlife and Transportation Alliance

DAU .... Data Analysis Unit

DOI .... Department of Interior

DRMS. .... Colorado Department of Reclamation Mining and Safety

ESRI .... Environmental Systems Research Institute

GIS .... Geographic Information System

GMU .... Game Management Unit

GOCO .... Great Outdoors Colorado

GPS .... Global Positioning System

HMP. .... Herd Management Plan

MDF .... Mule Deer Foundation

List of Acronyms (cont.)

NFWF .... National Fish and Wildlife Foundation

NGOs .... Non-governmental organizations

NRCS .... Natural Resources Conservation Service

PUD .... Planned Unit Development

PV .... Photovoltaic

RESTORE .... Restoration and Stewardship of Outdoor Resources and the Environment

RMEF .... Rocky Mountain Elk Foundation

SAM .... Species Activity Mapping

SCORP .... Statewide Comprehensive Outdoor Recreation Plan

SLB .... Colorado State Land Board

SO 3362 .... Secretarial Order 3362

SUIT .... Southern Ute Indian Tribe

USFS .... United States Forest Service

VHF .... Very High Frequency

WSMDS .... West Slope Mule Deer Strategy

WSWPS .... West Slope Wildlife Prioritization Study

WVC .... Wildlife-vehicle collisions

USFWS. .... United Fish and Wildlife Service

USFWS-PFW .... United States Fish and Wildlife Service-Partners for Fish and Wildlife

Introduction

Purpose

Colorado Parks and Wildlife (CPW) manages wildlife for the use, benefit and enjoyment of the people of the state, in accordance with the CPW's Strategic Plan and direction from the Parks and Wildlife Commission and the Colorado Legislature. Colorado boasts a diversity of habitat types ranging from prairie grasslands to sagebrush plateaus, from pinyon-juniper woodlands to montane and subalpine forests, and semi-desert shrublands to alpine tundra. This diverse landscape is the primary reason that Colorado is home to some of the largest big game herds in North America, as well as to a growing human population. Colorado's majestic beauty and abundant natural resources continue to draw an increasing human population.

Colorado's wildlife resources require careful and increasingly intensive management to accommodate the many and varied public demands and growing impacts from people. CPW is actively working to balance the ever-increasing human presence on the landscape with conservation of our state's world-class natural resources.

On August 21, 2019, Governor Jared Polis directed both CPW and the Colorado Department of Transportation (CDOT) to work cooperatively to conserve Colorado's valuable big game resources through executive order D 2019 011: Conserving Colorado's Big Game Winter Range and Migration Corridors. This executive order directs CPW to compile a big game status report to guide both agencies, as well as our partners, to collectively improve the conservation of big game winter range and migration corridors.

The intent of this report is to provide a baseline of scientific information related to the following big game populations in Colorado: mule deer, elk, pronghorn, bighorn sheep and moose. CPW compiled the best available science on Colorado's big game populations, including: population status and trends, monitoring and inventory methods, seasonal habitats and migration corridors, and conservation threats and actions. This report also outlines current research and data gaps associated with Colorado's big game winter range and migration corridors. CPW concludes this report with recommendations on a path forward to conserve these valuable habitats and populations.

Background

Conservation of Colorado's big game herds and protection of habitat is of the highest priority for CPW. Big game populations across Colorado have been the topic of extensive scientific study for several decades. CPW has biologists and research staff dedicated to investigating specific wildlife management issues, and uses this data to inform wildlife management throughout the state.

In 2018, the Department of Interior (DOI) released Secretarial Order 3362: Improving Habitat Quality in Western Big Game Winter Range and Migration Corridors (SO 3362). SO 3362 directed appropriate bureaus in the DOI to work in partnership with Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming to improve big game winter range and migration corridors. As part of SO 3362, two funding opportunities emerged to provide support for western states to work on proactive habitat management and identification of big game migration corridors.

The DOI provides a grant to research big game movement patterns in priority landscapes. The second grant is from the National Fish and Wildlife Foundation (NFWF) to conduct proactive winter range habitat restoration projects. SO 3362 also directed the United States Fish and Wildlife Service-Partners for Wildlife (USFWS-PFW) program to allocate a portion of their funding toward big game winter range work on private lands in the focal western states.

Colorado has taken advantage of the SO 3362 grants in several ways. In 2018, CPW received funding ($272,000) to deploy Global Positioning System (GPS) collars in two landscapes in Colorado, North Park and San Juan (Figure 1). CDOT received funding ($317,734) to install wildlife fencing along U.S. Highway 160. In 2019, CPW received additional funding ($249,000) to deploy GPS collars to understand big game movement patterns in the South Park and the Front Range landscapes.

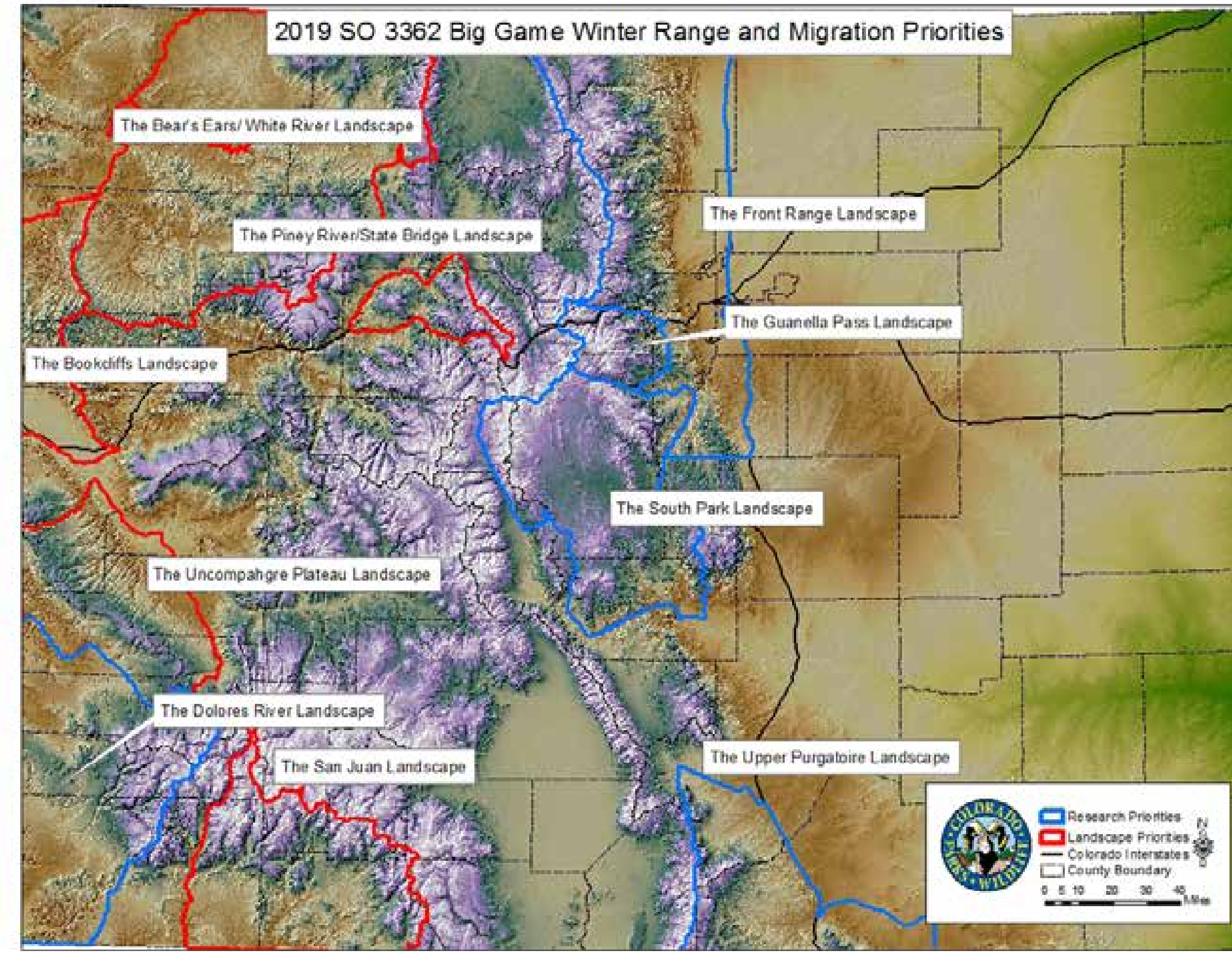


Figure 1. 2019 Colorado priority landscapes and research areas related to SO 3362.

Big Game Species Assessments

To manage big game populations, CPW uses a "management by objective" approach for each Data Analysis Unit (DAU). A DAU is the geographic area that represents the year-around range of a big game herd and delineates the seasonal ranges of a specific herd, while keeping interchange with adjacent herds to a minimum. A DAU includes the area where the majority of the animals in a herd complete their life cycle. Most DAUs are composed of multiple Game Management Units (GMUs), which are designed to distribute hunters within the DAU. In a few cases, only one GMU makes up a DAU.

Management of DAUs is guided by Herd Management Plans (HMPs), which contain target ranges for population size and herd composition for each population. The purpose of a HMP is to integrate CPW's management objectives with the concerns of other land management agencies and interested publics in determining how a big game herd in a specific geographic area (DAU) should be managed. CPW attempts to balance the biological capabilities of the herd and its habitat with public demand for wildlife recreational opportunities.

The primary metrics defined within each HMP are the desired population objective range within the DAU, and the desired sex ratio for that population (e.g., the number of males per 100 females). These numbers are referred to as the population objective and the sex ratio objective, respectively. CPW surveys big game populations in the winter, when snow concentrates animals at lower elevations. CPW conducts aerial post-hunt herd inventories for mule deer and elk to estimate sex ratios and age ratios (young/100 females.) These ratios are utilized, along with survival rates, to estimate population sizes and trends using population models. Post-hunt winter population estimates from 2018 are the most recent estimates available because 2019 post-hunt surveys are still being collected and processed

These objectives drive the process for setting numbers of hunting licenses based on harvest objectives in order to maintain the desired population size and herd composition. Each HMP is revised approximately every 10 years, while hunting license numbers are adjusted annually.

Mule Deer

Mule deer populations across the western states have shown declines on several occasions since CPW started monitoring their populations. In 1999, the Colorado Division of Wildlife (CDOW) submitted a report to the Colorado Legislature describing declines in mule deer populations, identifying issues and causes, and outlining proposed management actions to increase populations. Mule deer numbers declined most recently starting in 2007, not just in Colorado, but across all of the western United States. These mule deer population declines caused concerns within CPW and among Colorado's constituents with an interest in mule deer.

Nora Logue, CPW

Between 2007 and 2013, Colorado's estimated statewide deer population declined from roughly 600,000 deer to approximately 390,000 deer (Figure 2). Some herds have yet to recover from the severe winter of 2007-2008. Western Colorado has historically supported some of the largest mule deer herds in the state and across the western United States, such that these declines are of both statewide and regional significance. Deer populations fluctuate naturally in response to changing environmental conditions; however, the most recent (2007-2013) decline in the state's largest deer herds is atypical, leaving several mule deer herds well below their population objectives. Recognizing the need for additional action, CPW embarked on a comprehensive effort in 2013 to gather input from internal staff, researchers and the public to investigate the root cause of the most recent decline.

The product of this public process was the 2014 West Slope Mule Deer Strategy (WSMDS). The WSMDS identifies seven management priorities to address mule deer declines on the West Slope of Colorado.

- Landscape-scale habitat management to improve habitat quality
- Predator management where predation may be limiting deer survival
- Protection of habitat and mitigation of development impacts
- Reducing the impacts of highways on mule deer survival, movements and migration
- Reducing the impacts of human recreation on mule deer
- Regulation of doe harvest and providing youth hunting opportunity
- Maintaining a strong big game population and disease monitoring program and conducting applied research to improve management of deer populations

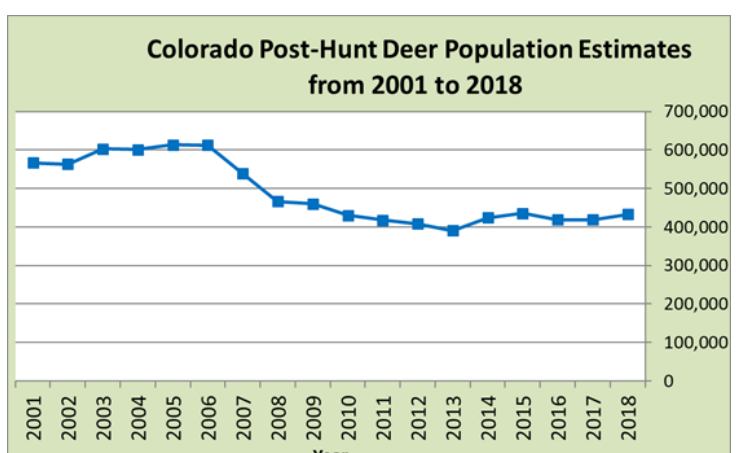


Figure 2. Colorado post-hunt deer population estimates from 2001 to 2018.

CPW has been implementing these priorities as outlined by the WSMDS since its adoption in 2014. CPW continues to work closely with hunters, landowners, community leaders and partner agencies to identify major areas of impacts to deer herds in Colorado, using the WSMDS to help guide management decisions. Together with stakeholders, CPW is working to sustain and increase mule deer populations in western Colorado and, in turn, increase hunting, viewing and wildlife-related recreational opportunities.

Populations

The current statewide post-hunt deer population estimate is 433,000, which is well below the population objective range of 500,000-560,000 mule deer. In 2018, 23 of 54 (43%) deer herds are below their population objective ranges (Figure 2).

Population performance varies considerably throughout the state due to diverse habitat types, environmental conditions, disease, and human impacts. While some deer herds are performing well and population sizes and license numbers are stable or increasing (east of Interstate 25), there remains an overall decline across collective mule deer herds in Colorado. Many deer herds west of Interstate 25 are well below objective (Figure 3).

Wayne D. Lewis, CPW

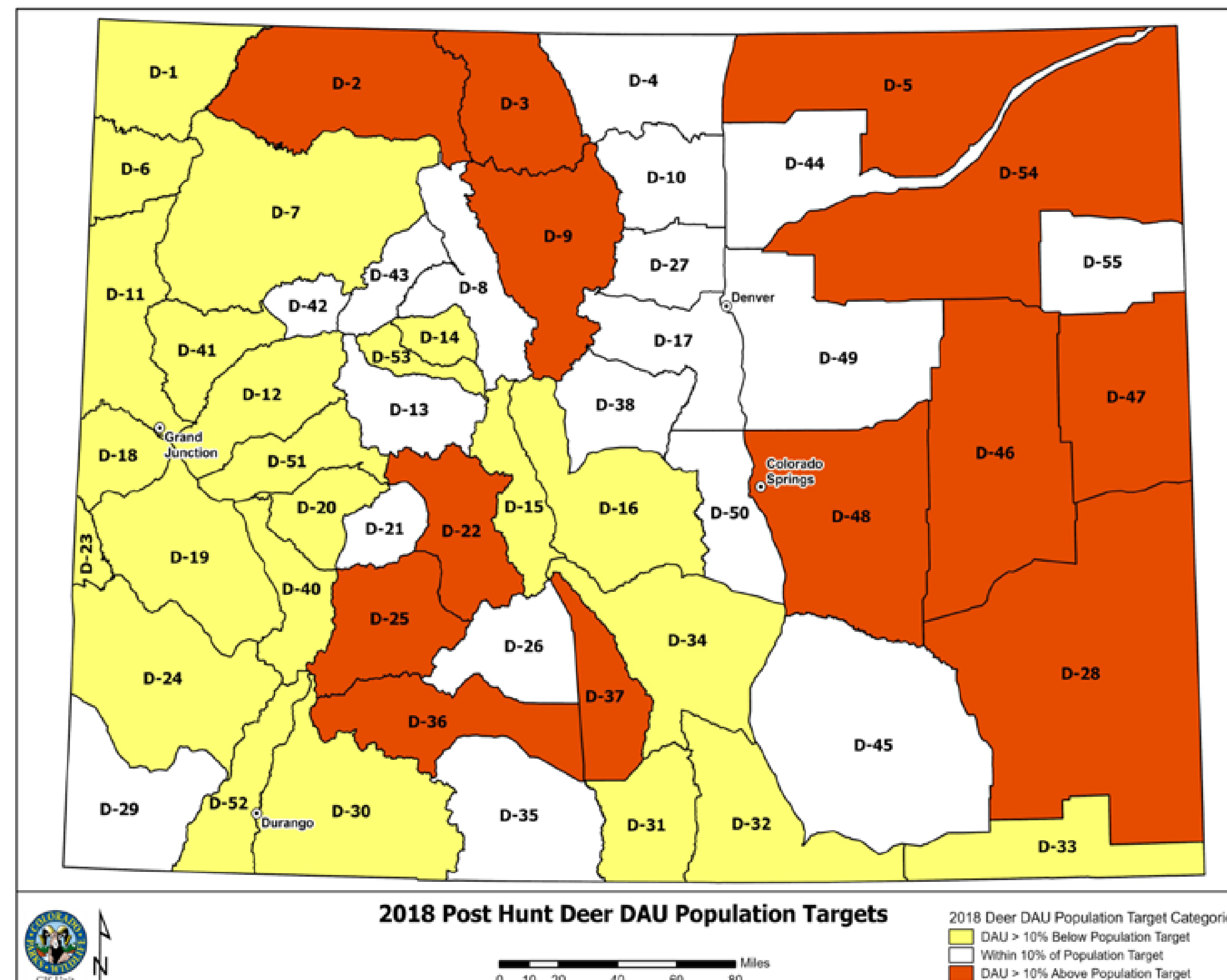


Figure 3. Colorado 2018 post-hunt deer DAU population objectives.

Monitoring and Inventory

CPW intensively monitors annual adult doe survival and winter fawn survival in five mule deer herds (White River D-7, Middle Park D-9, Cripple Creek D-16, Uncompahgre D-19, and Gunnison Basin D-21, D-22, D-25). CPW also monitors buck survival in two of these herds, White River and Middle Park. CPW annually monitors over 1,000 VHF radio-collared mule deer throughout Colorado. Survival rates from these sentinel herds are used as a parameter in deer models to estimate populations. Survival rates within the monitored herds vary by DAU. Survival in D-9 (Middle Park) is well above average, D-7 (White River) is somewhat below average, and the other three monitoring areas fall within the long-term average.

The current average sex ratio objective for deer herds statewide is 30 bucks/100 does. During the post-hunt herd inventories in 2018, CPW staff classified 71,000 deer and observed an average sex ratio of 35 bucks/100 does and age ratio of 59 fawns/100 does (Figure 4). The ratio of fawns per 100 does is an index of annual fawn production and survival, which is an indicator of the "fitness" of an individual herd. Fawn/doe ratios in many of Colorado's deer herds have been declining since the early 1970's.

Vik Schendel, CPW

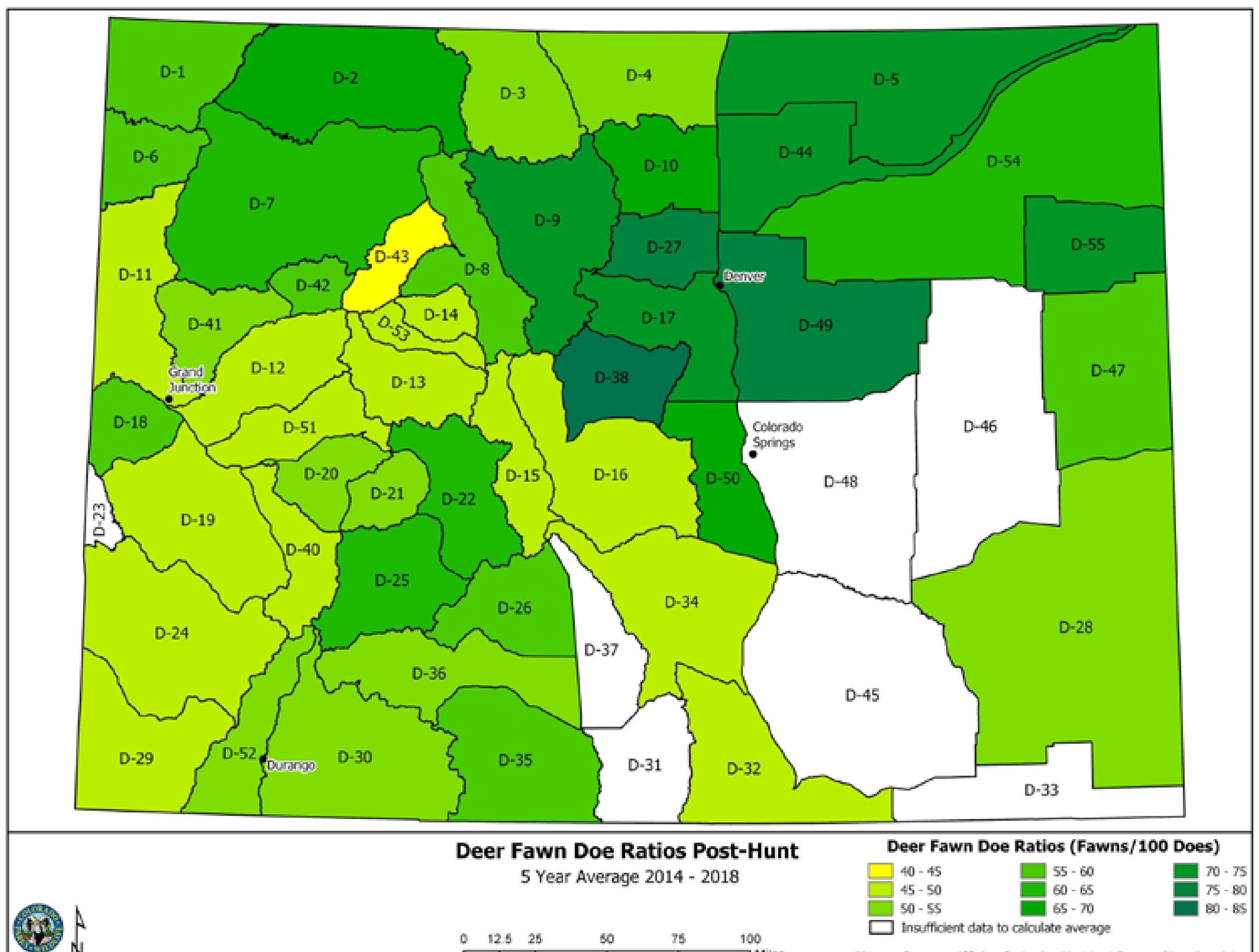


Figure 4. Colorado 2018 post-hunt deer fawn/doe ratios.

Elk

Populations

Colorado's statewide elk population, the largest in the United States, most recently peaked in 2001 at 305,000 animals. The statewide 2018 post-hunt population objective range is 233,000-282,000. The 2018 post-hunt estimate was 287,000, up slightly from 282,000 in 2017 (Figure 5). CPW utilizes season structure and hunter harvest, specifically antlerless harvest, to maintain or achieve population herd objectives. CPW has intentionally reduced elk populations to achieve population objectives. Reductions in antlerless licenses are anticipated as elk populations reach objectives or as population objectives increase.

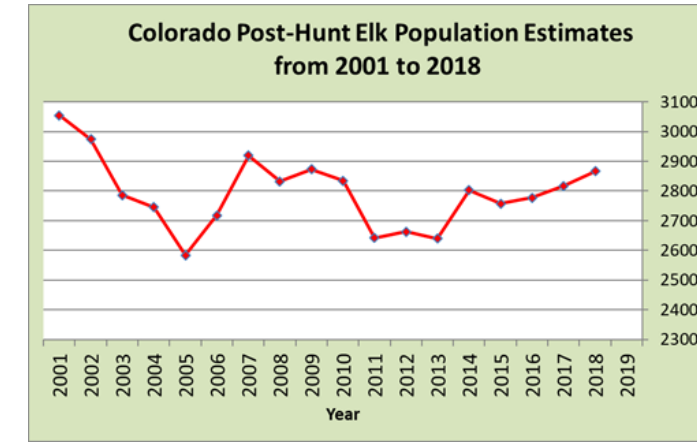


Figure 5. Colorado post-hunt elk population estimates from 2001 to 2018.

Hunters and outfitters have increasingly expressed concerns that elk populations are becoming too low in some herds, despite the fact that 22 of 42 (52%) of the elk herds are above their current population objective ranges (Figure 6). Based on feedback from the public, CPW gives serious consideration to raising population objectives in herds as HMPs are updated. The agency must balance requests from hunters with landowner concerns about damage to their properties or crops, land management agencies concerns regarding habitat conditions, and preferences identified by local communities. Hunter experience helps to inform the upper and lower social thresholds for elk population size in many herds, which benefits herd management planning efforts.

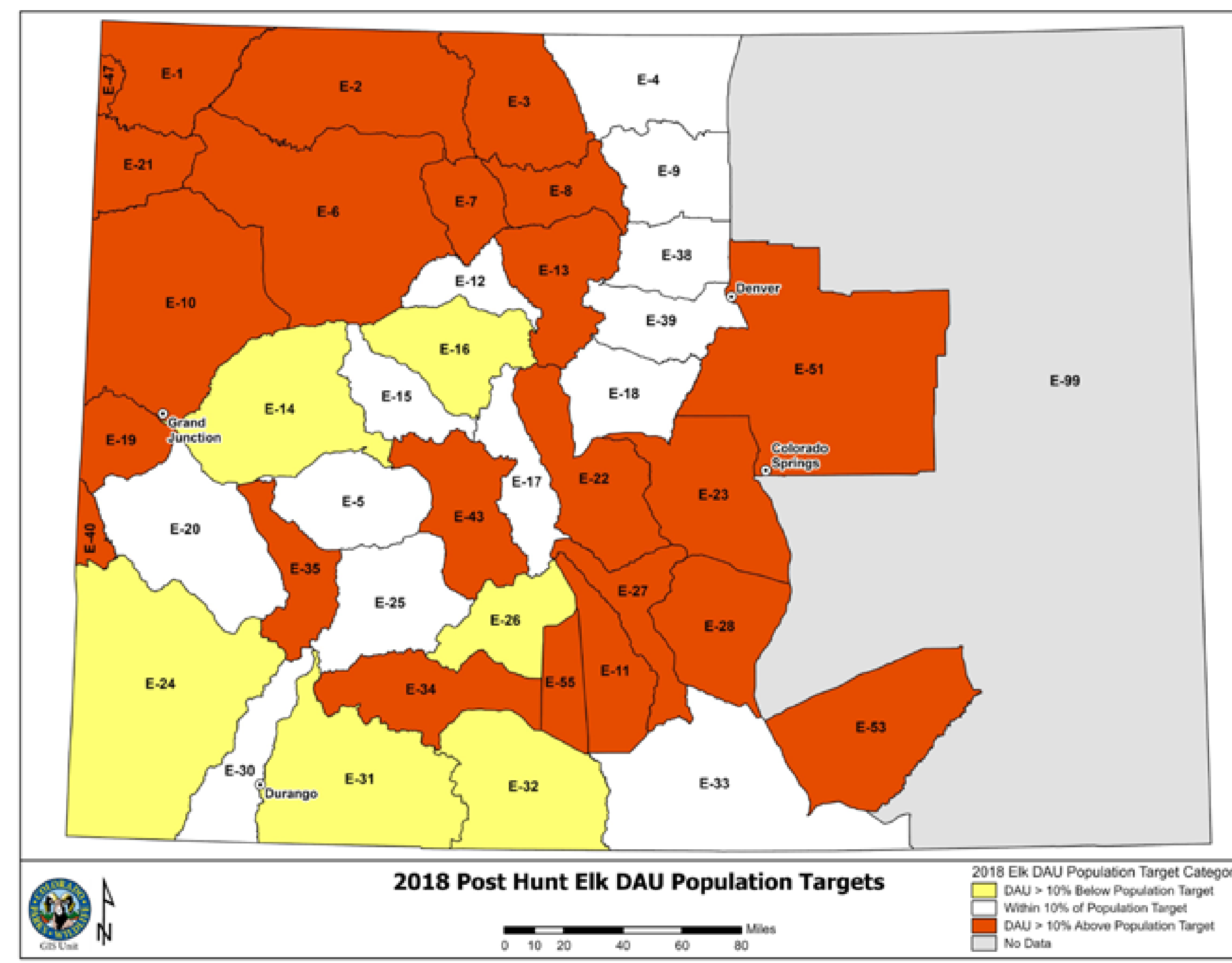


Figure 6. Colorado 2018 post-hunt elk population objectives.

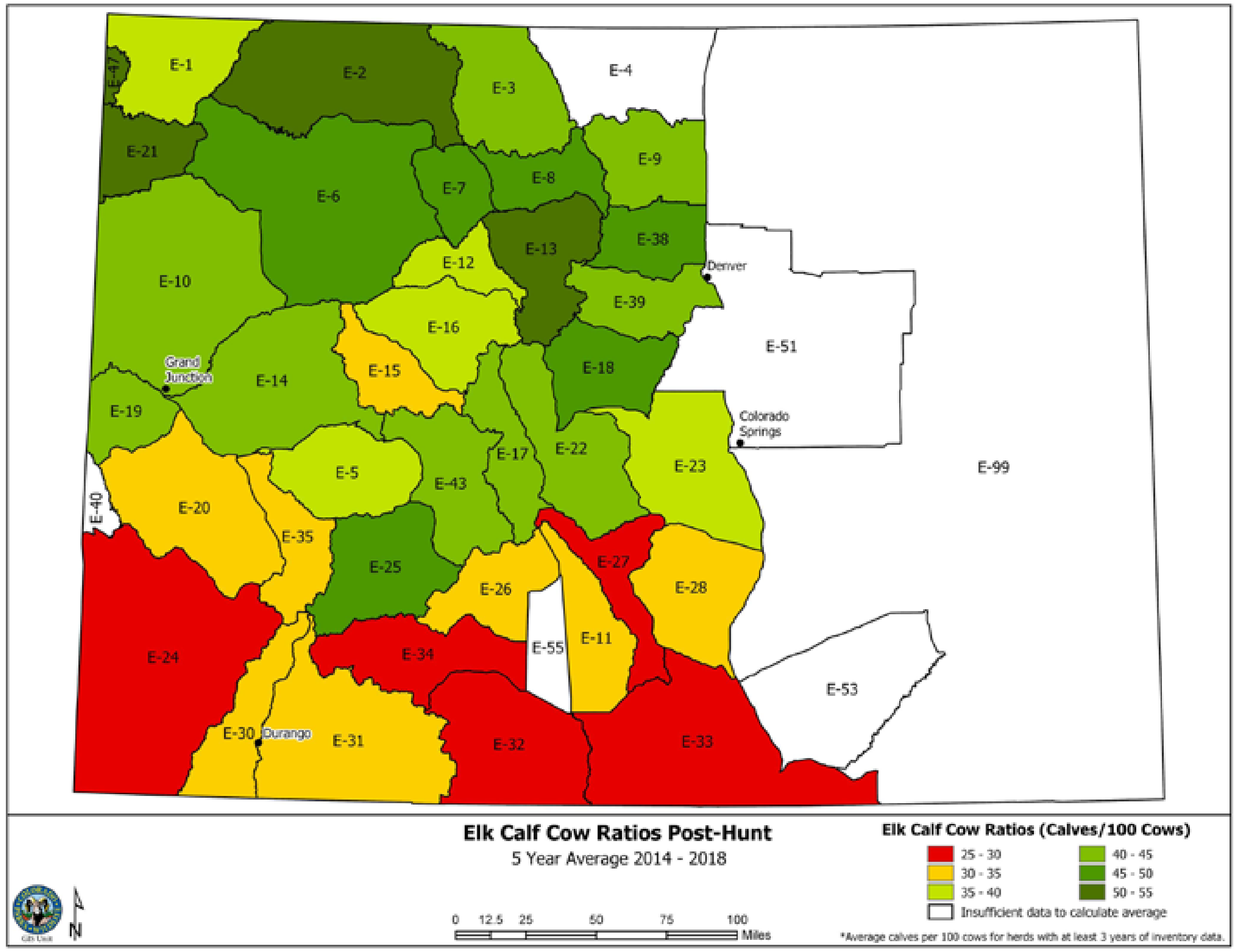


Figure 7. Colorado 2018 post-hunt elk calf/cow ratios.


Wayne D. Lewis, CPW

Monitoring and Inventory

During 2018 post-hunt herd inventories, CPW staff classified 96,000 elk and observed a statewide average sex ratio of 23 bulls/100 cows. Calf/cow ratios are an index of annual calf production and survival to mid-winter, which is an indicator of the “fitness” of the herd. During post-hunt surveys over the past decade, CPW has observed a decline in calf/cow ratios in several DAUs in the southern portion of the state (Figure 7). Consequently, the number of antlerless elk licenses available to hunters has decreased in these DAUs, which ultimately reduces hunting opportunity. In comparison, the average calf/cow ratios in Northwest region are 47 calves/100 cows, and the Northeast Region is 41 calves/100. Historically, northern Colorado has had higher calf ratios. Further research and management adjustments are necessary to address the ongoing low calf production in several herds.

Pronghorn

Populations

Colorado’s statewide post-hunt pronghorn population objective range is 68,000 – 78,000, which is divided among 30 herds across the state (Figure 8 and Figure 9). The 2018 statewide post-hunt pronghorn population estimate is 79,000, down from the record high of 86,000 in 2017 (Figure 8). Thirteen of 29 (45%) pronghorn herds are above their population objective range (Figure 9). Approximately half of the state’s pronghorn herds reside in the Southeast Region, where the greatest number of licenses are available. Licenses are issued to provide the maximum opportunity for hunters without negatively affecting success rates or exceeding landowner tolerance for pronghorn hunters.


Vik Schendel, CPW

Monitoring and Inventory

During pre-hunt herd surveys in 2018, CPW staff classified 16,000 pronghorn. The average observed pre-hunt sex ratio was 49 bucks/100 does, down from 51 bucks/100 does in 2017. The average observed pre-hunt fawn/doe ratio was 43 fawns/100 does, much lower than the 57 fawns/100 does in the previous year. Drier range conditions may be contributing to a reduction in the fawn/doe ratio.

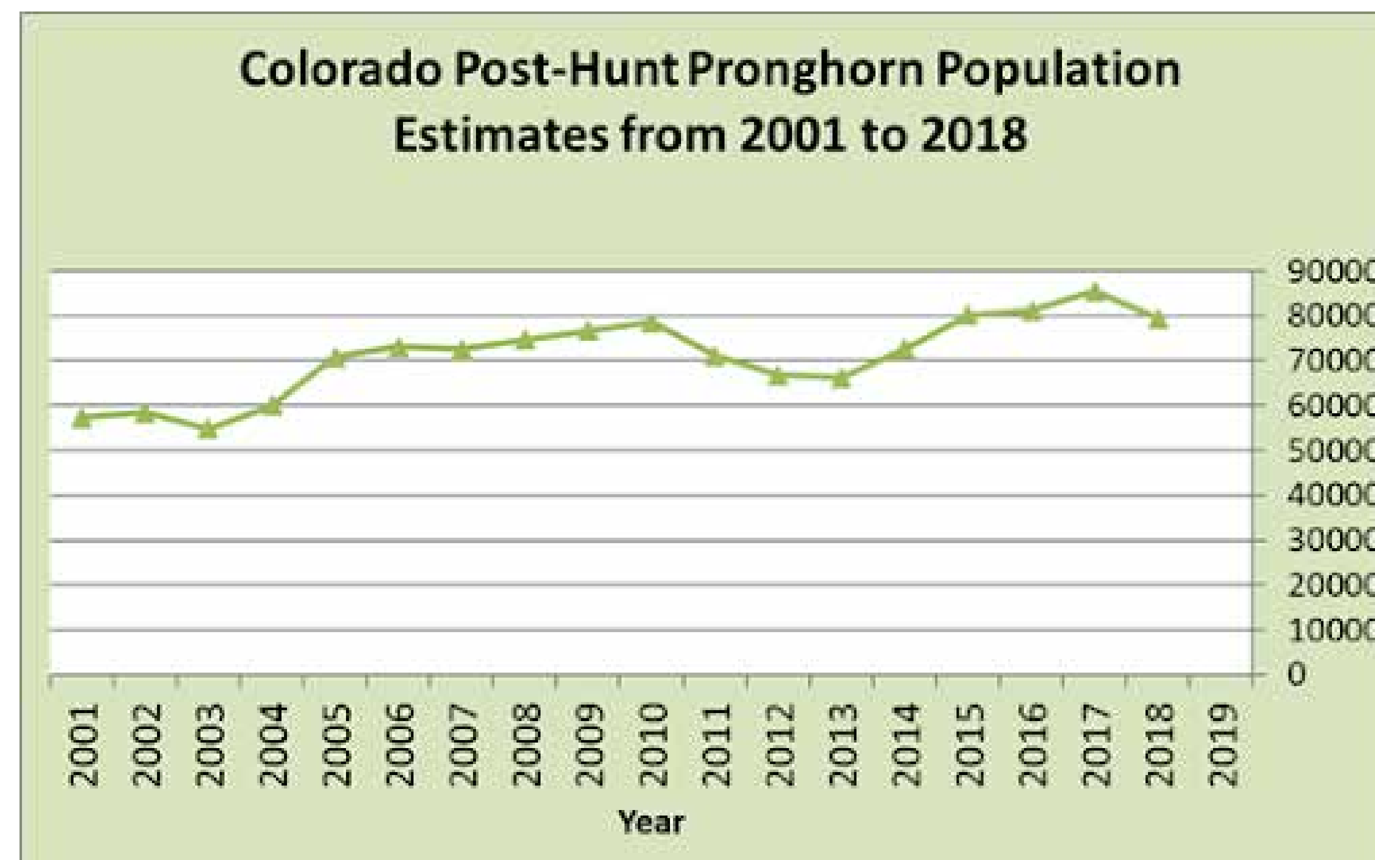


Figure 8. Colorado post-hunt pronghorn population estimate from 2001-2018.

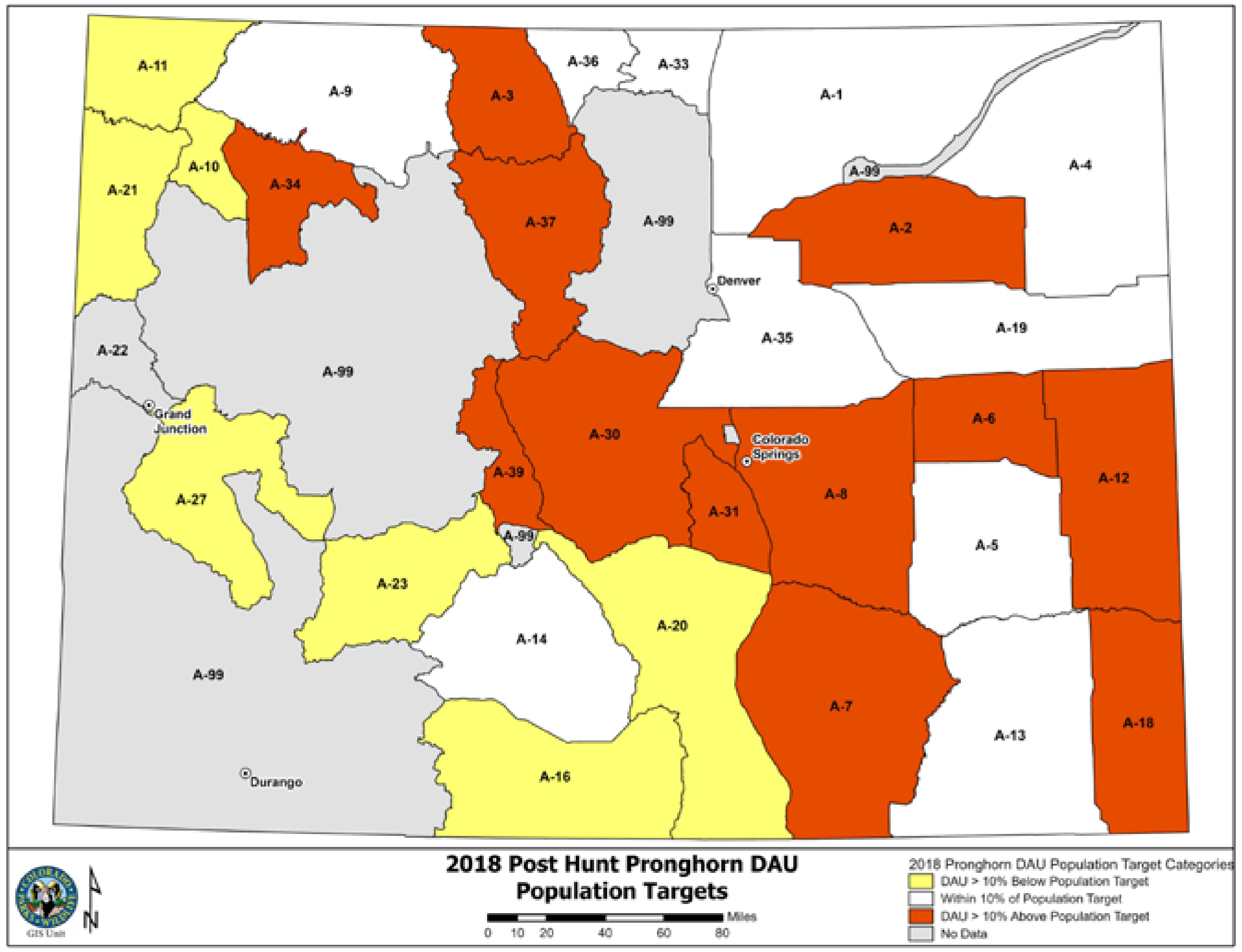


Figure 9. Colorado 2018 post-hunt pronghorn population objectives.

Bighorn Sheep (Rocky Mountain and Desert)

Populations

The 2019 post-hunt estimate for Rocky Mountain bighorn sheep populations is 6,940 (Figure 10). Rocky Mountain bighorn sheep hunting opportunities are divided into 39 different DAUs (Figure 12). There are approximately 550 desert bighorn sheep in 2 DAUs in Colorado (Figure 11).

It is difficult to estimate how many wild sheep were present in Colorado in pre-settlement times. Journals of explorers indicate great numbers of sheep in both the mountainous areas and along the Front Range of Colorado. Since the late 1800's the general trend of wild sheep populations in Colorado and throughout the west has been downward. Historical statewide estimates of 7,230 bighorn sheep in 1915, 3,200 in 1958 and 2,200 in 1970 reflect this trend. However, there were an estimated 6,045 bighorns in Colorado in 1988, and in 2007 there were an estimated 7,040 bighorn sheep statewide (George et al. 2009). One reason for the increase in Colorado's bighorn sheep population is a longstanding effort to trap and translocate wild sheep to establish new populations or supplement existing populations. Based on available records, only 18 of the Rocky Mountain bighorn sheep herds existing in 2007 have not been established or supplemented by translocations since 1945. All of the desert bighorn sheep herds in Colorado have resulted from translocations (George et al. 2009).

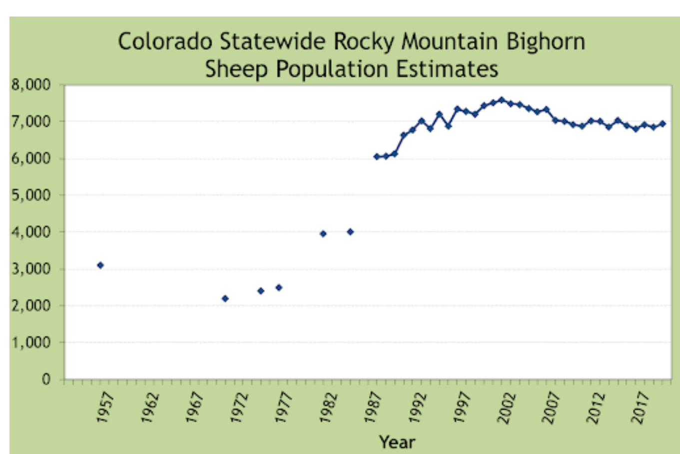


Figure 10. Colorado Rocky Mountain bighorn sheep population estimates from 1987-2019.

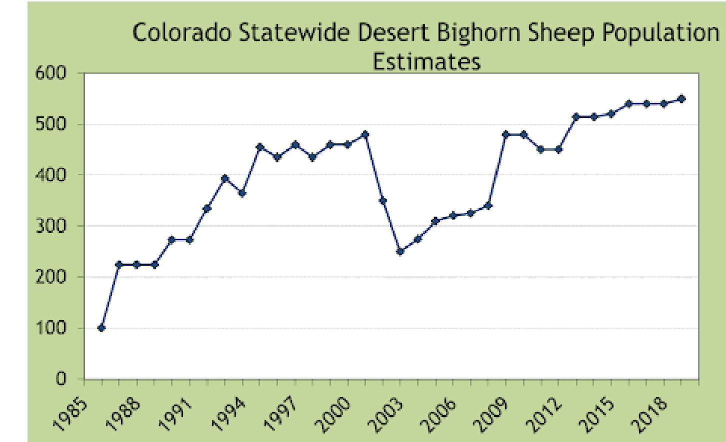


Figure 11. Colorado desert bighorn sheep population estimates from 1986-2019.

Disease has often been implicated in periodic "all-age" die-offs and sustained bouts of poor lamb survival in Colorado bighorns. The causes of these early die-offs are hard to verify retrospectively, but contact with domestic livestock that led to the introduction of exotic diseases and parasites seems the most logical explanation (George et al. 2009).

Based on a substantial volume of literature, one of the most important aspects of wild sheep management is to keep these species separated from domestic sheep and goats. There are a number of bighorn herds in the state that are in close proximity to active or vacant domestic sheep grazing allotments, particularly on the West Slope. An extensive set of recommendations has been developed for managing bighorn and domestic sheep on shared ranges to help minimize the risk of epidemics in bighorns (George et al 2009).

Monitoring and Inventory

Classification surveys for Rocky Mountain bighorns are typically conducted during December when rams associate with ewes, and lambs have survived past the late summer time period when lamb pneumonia typically impacts mortality. However, late winter aerial and ground surveys are conducted in March for some herds due to higher sightability rates in some high elevation in alpine and timbered habitats (George et al. 1996). Winter classification surveys conducted December through March provide lamb/ewe ratios representative of annual recruitment, but late winter surveys (February through March) may result in underestimated sex ratios.

Summer surveys (July/August) are necessary in some high-elevation areas where winter conditions preclude access; however, parturition may occur as late as July in high elevation herds (Stevens and Stevens 1991, George 1997) and surveys done mid-summer (June through August) may significantly underestimate lamb mortality. Sightability increases in August and September when ewes and lambs aggregate into larger groups and move into more open terrain (George et al. 2009). For desert bighorns, late summer (August through September) may be more appropriate for conducting classification surveys (George et al. 2009).

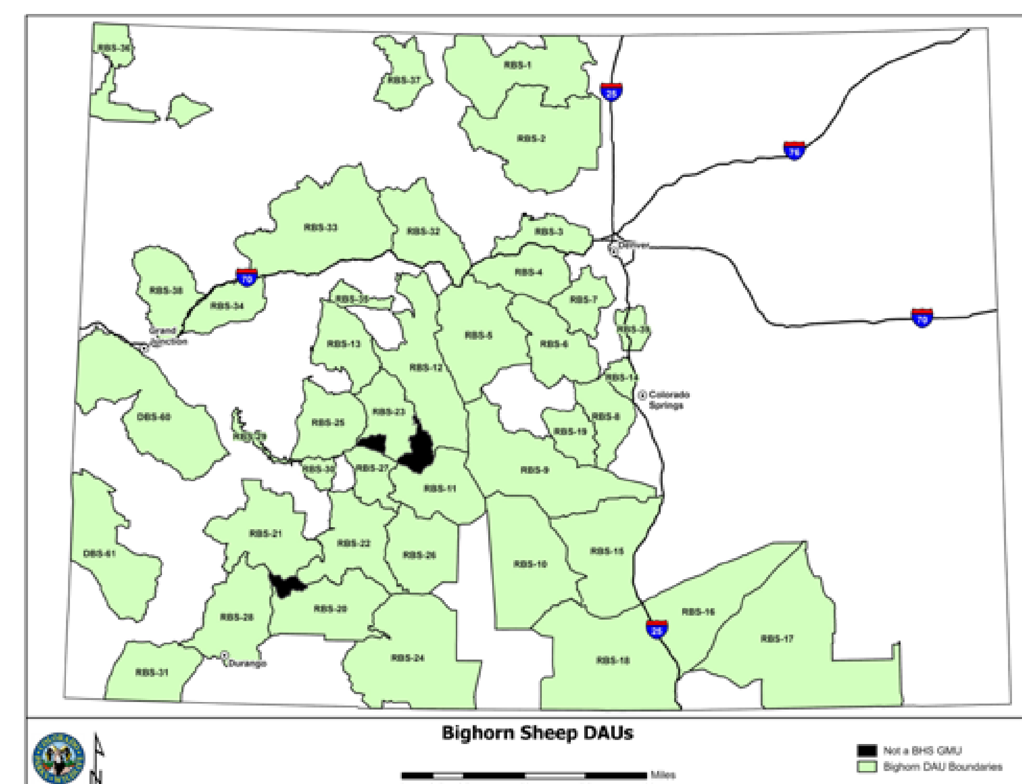


Figure 12. Bighorn sheep data analysis units.

Moose

Populations

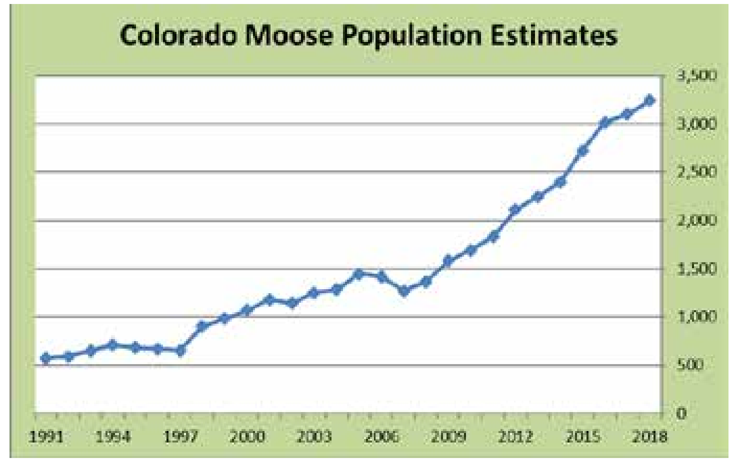


Figure 13. Colorado 2018 post-hunt moose population.

Historically, moose were only sighted occasionally in Colorado, with limited sightings in northwest and north-central Colorado (Armstrong et al. 2011). Over the past several decades, CPW has worked to establish sustainable moose populations in Colorado to provide additional hunting and wildlife viewing opportunities. The first translocation of moose occurred in 1978-1979 into North Park. This was followed by additional translocations of moose into suitable moose habitat in Colorado including the Laramie River drainage in 1987; the San Juan Mountains in the early 1990's; the Grand Mesa in the early 2000's; and the Flat Tops in the 2010's.

Colorado's overall moose population continues to increase in size as moose expand their range and pioneer new habitats. The estimated statewide 2018 post-hunt moose population is 3,240 (Figure 13). CPW has been increasing cow moose licenses to manage moose populations toward population objectives and to address moose conflicts in some areas. There are twelve moose DAUs in Colorado, 9 on the West Slope and 3 on the Front Range (Figure 14). Since 2017 CPW has allowed moose hunting in a total of 63 GMUs, an increase from 39 GMUs in 2013.

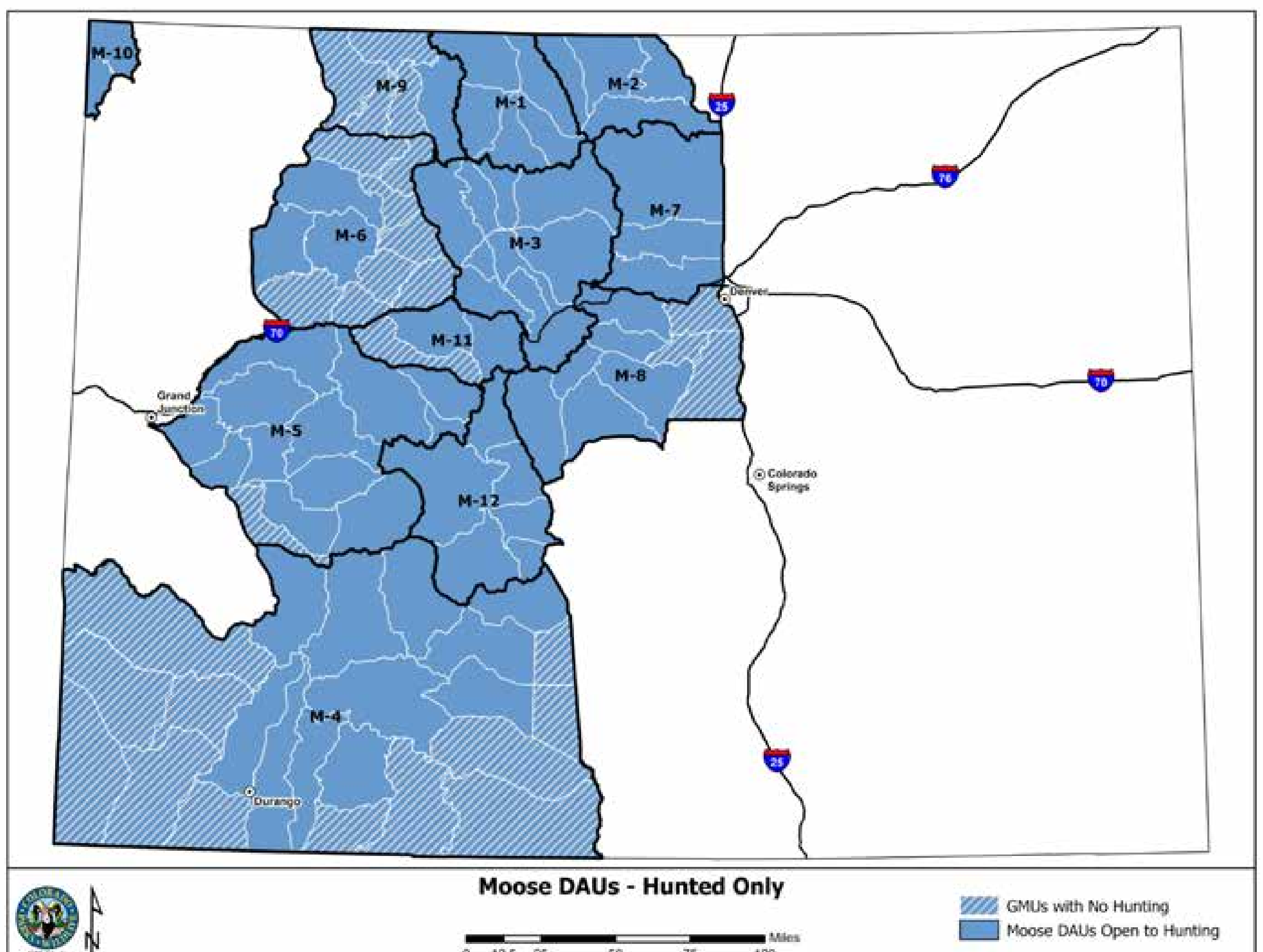


Figure 14. Moose data analysis units and game management units.

Colorado Parks and Wildlife Species Activity Mapping

CPW's Species Activity Mapping (SAM) process involves capturing the knowledge and experience of agency field personnel for wildlife populations in the areas they work. This mapping process was initiated in the 1980's and field personnel were asked to draw seasonal range polygons on Mylar topographic maps at the 1:50,000 scale. These mapped seasonal ranges were then digitized with the advent of Geographic Information System (GIS) software to create a spatially defined dataset.

In 2002, the method for data capture was updated in an effort to make the process more inclusive and accurate (Cowardin and Flenner 2003). With guidance from CPW GIS specialists, data is digitized directly by field personnel using a SMART Board (interactive whiteboard) and ESRI's ArcMap program. CPW personnel are able to update seasonal habitat use maps for each species by viewing the existing GIS data and making edits based on field experience, observations and knowledge of animal movements and locations. The decades of expert, on-the-ground knowledge contributed by CPW field personnel is invaluable. This institutional knowledge is augmented with other data such as annual winter classification flight data locations and radio/GPS collar data from various studies. Collar data is displayed with the current mapped seasonal ranges to verify, edit and update the SAM maps. SAM data is reviewed and updated by each region every four years, with one of the four regions completed each year.

Big Game Seasonal Habitats

Big game seasonal habitats identified by CPW vary by big game species but are generally defined by where each species spends the majority of the summer season or the winter season (Figure 15). Seasonal habitats are defined by several criteria: the number (density or percentage) of animals in an area, geographic location of animals during the calendar year, and the weather conditions that describe those calendar segments.

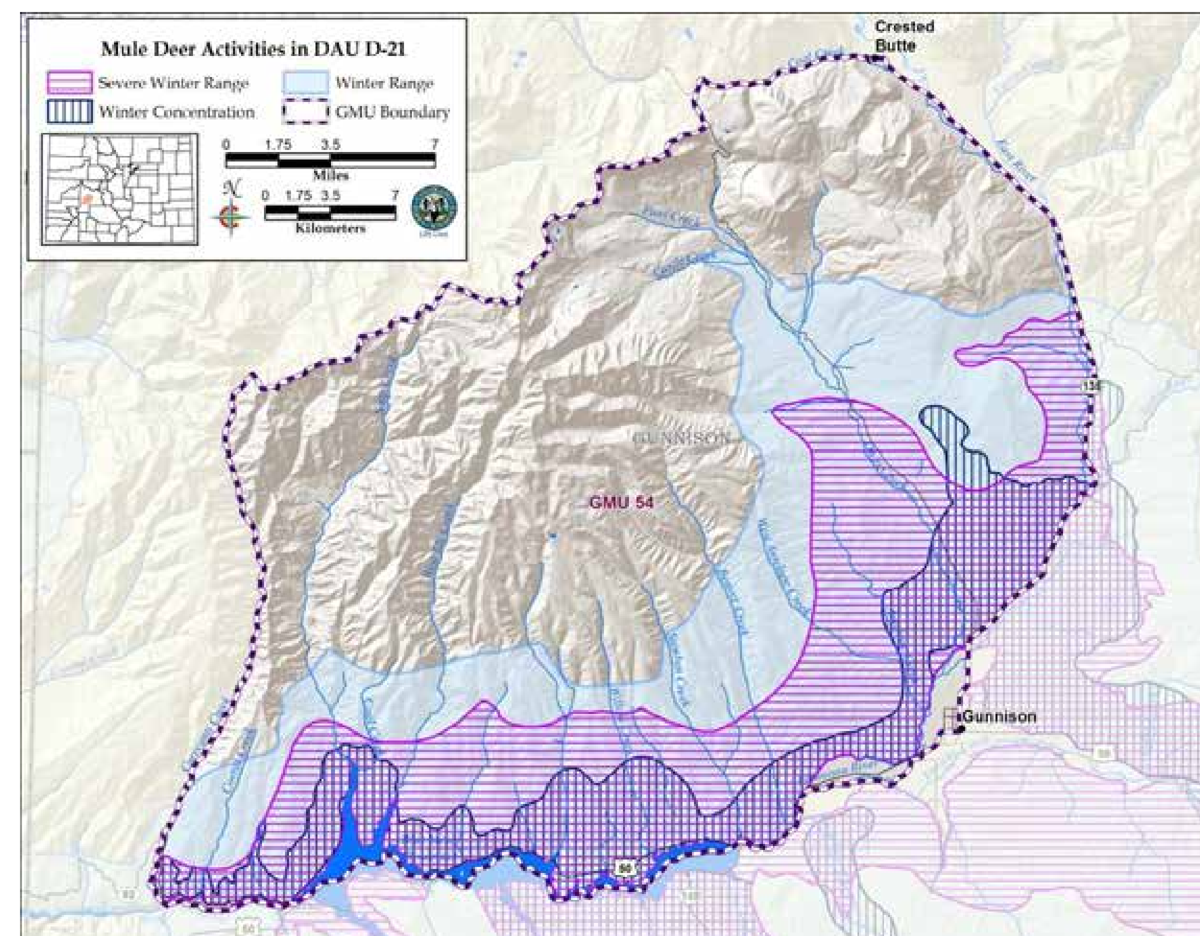


Figure 15. CPW's SAM of seasonal habitat for area north of Gunnison, CO

While there may be habitat cover types that also correspond to these seasonal locations (e.g. sagebrush, pinyon-juniper or aspen and spruce-fir), CPW defines the following seasonal habitats for big game:

Summer Range: That part of the overall range where 90% of the individuals are located between spring green-up and the first heavy snowfall. Summer range is not necessarily exclusive of winter range; in some areas winter range and summer range may overlap.

Winter Range: That part of the overall range where 90% of the individuals are located during the average five winters out of ten from the first heavy snowfall to spring green-up, or during a site specific period of winter as defined for each DAU. Winter range is only delineated for migratory populations. On the Eastern Plains, winter range is defined as areas that provide thermal cover for deer. Examples of this cover are: riparian areas dominated by trees and shrubs, areas of pinyon-juniper, topographic cover such as gullies, draws, canyons, and shelter belts, and Conservation Reserve Program fields that provide adequate forage and cover.

Severe Winter Range: That part of the overall range where 90% of the individuals are located when the annual snowpack is at its maximum and/or temperatures are at a minimum in the two worst winters out of ten.

Winter Concentration Area: That part of the winter range where densities are at least 200% greater than the surrounding winter range density during the same period used to define winter range in the average five winters out of ten.

Management and research have shown that winter range quality and quantity is one of the primary limiting factors for big game population performance. CPW has observed multiple severe winter events over the past several decades that have had significant impacts on big game populations. Human recreation and development; which are occurring at unprecedented levels in Colorado, increasingly overlap with, fragment and impact big game winter range habitats.

Mule Deer Winter Range Analysis

A study that utilized long-term data (1980-2010) on residential and energy development across western Colorado quantified annual changes and overlap of these land uses with mule deer seasonal habitats in each DAU west of I-25. Changes in land use and weather variables (seasonal temperature and precipitation) were modeled to evaluate possible correlated recruitment responses in each individual mule deer DAU (Johnson et al 2016).

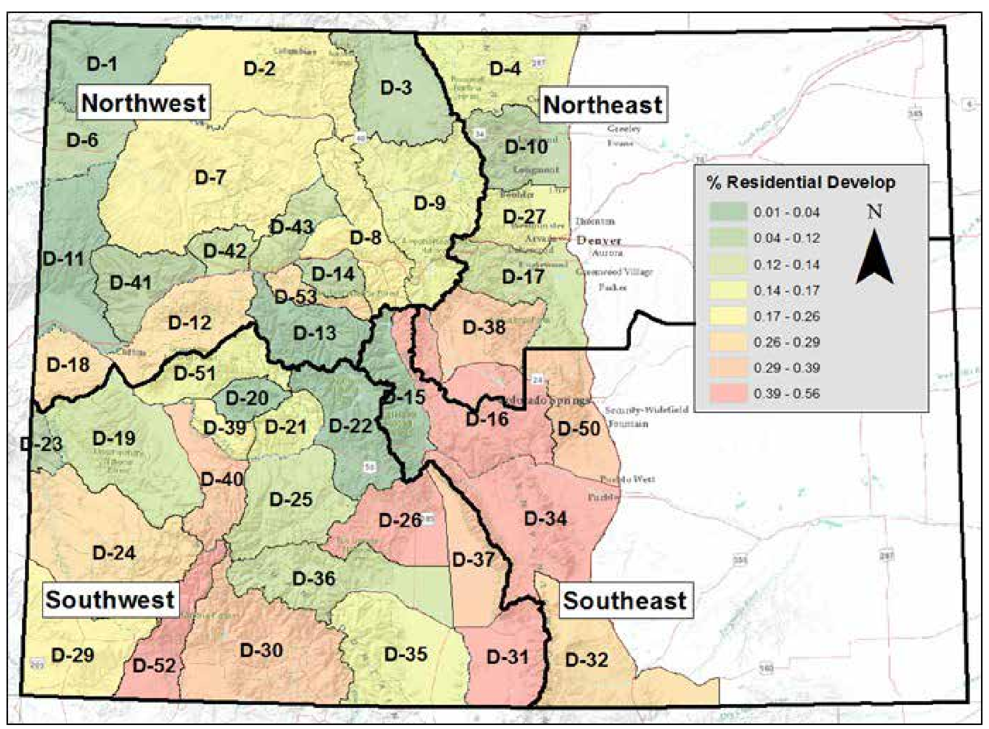


Figure 16. Colorado DAUs representing percent residential development.

Johnson et al. 2016 found that increasing human development within mule deer habitats was correlated with declining recruitment rates, particularly development within seasonal winter ranges. Residential development had twice the magnitude of effect of any other factor investigated. Energy development had a similar effect to key weather variables known to be important to mule deer herd population performance. Based on the results of this study, the researchers concluded that further increases in human development on deer ranges may not be compatible with the goal of maintaining highly productive deer populations. Over the period analyzed in the study, an additional 3.29 million acres (5,156 square miles) of winter range was negatively impacted by land use change, such that by 2010, an average of 31% of mule deer winter ranges were affected by residential development (Figures 16-17). These results underscore the negative impact of residential development could have on mule deer populations, a factor which has received minimal research attention in recent years, despite its rapidly increasing footprint across the landscape (Johnson et al 2016).

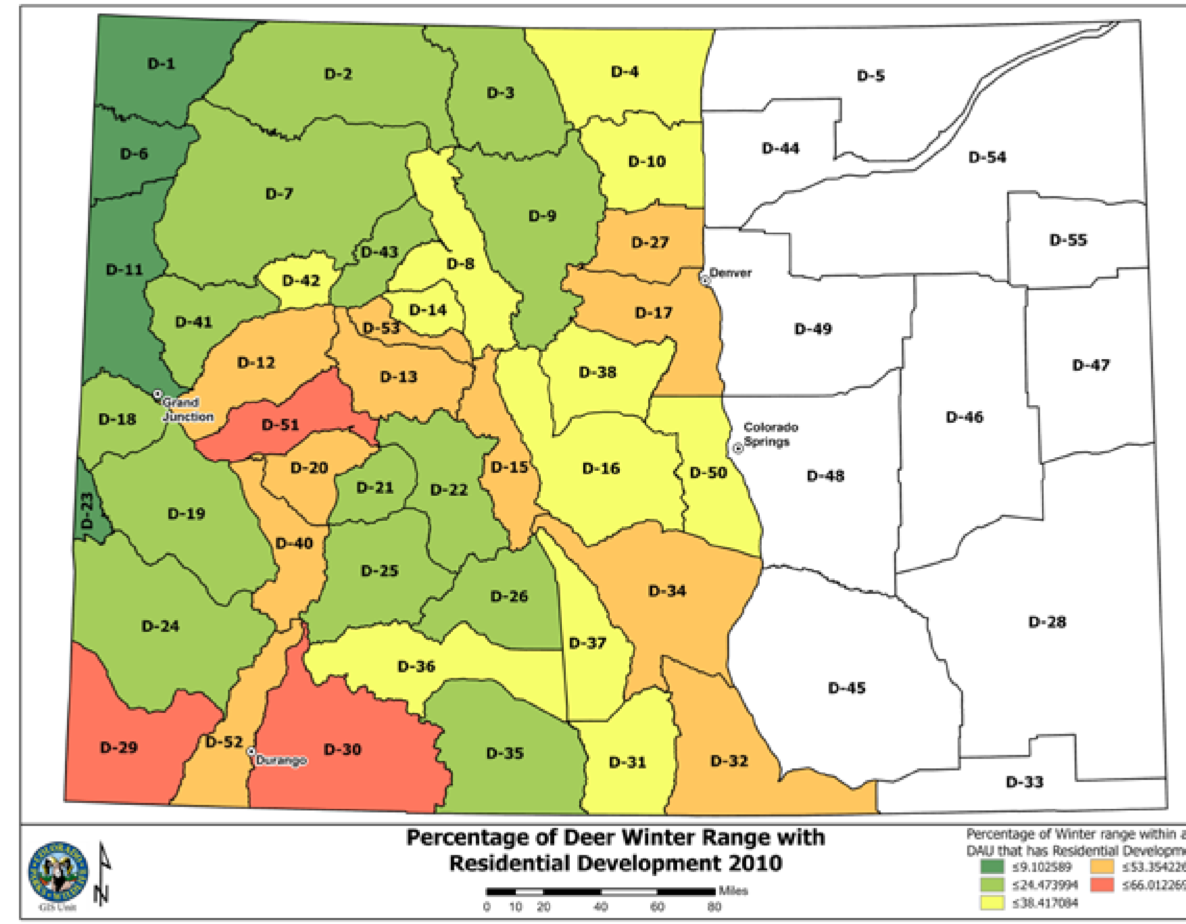


Figure 17. Colorado DAUs representing percentage of winter range and residential development overlap as of 2010.

Big Game Winter Range Habitat Restoration

Based on the recommendation of the WSMDS, CPW began work in 2015 to conduct winter range restoration treatments for deer and elk in high priority landscapes. These landscapes were selected based on CPW's professional judgement of deer and elk population performance, amounts of public land and land use threats. The intent of these restoration treatments were to increase the quality and quantity of available forage on remaining winter range. These restoration treatments have been implemented on both private (20%) and public lands (80%). Restoration treatments consist of a variety of habitat practices from restoring nonproducing agricultural lands back to sagebrush shrublands; to enhancing sagebrush shrublands productivity by altering age class diversity. Several restoration projects have been completed in partnership with the following organizations: BLM, USFS, Natural Resource Conservation Service (NRCS), United States Fish and Wildlife Service (USFWS), Colorado State Land Board (SLB), Colorado State Forest Service (CSFS), Great Outdoors Colorado (GOCO), Mule Deer Foundation (MDF), and private landowners.

Through habitat restoration efforts associated with the WSMDS, CPW has completed 29 projects treating a total 29,716 acres of big game winter range habitat. CPW's financial contributions have been $1.2 million while our conservation partners have contributed $1.4 million. CPW has planned 11,604 acres of habitat restoration treatments to be completed in the next 5 years. In addition, Colorado RESTORE is a new grant opportunity, through the National Fish and Wildlife Foundation (NFWF), which offers funding to restore winter range habitat and big game migration corridors. Although this is a commendable effort with limited dedicated staff and no permanent dedicated budget; the effort appears to be not keeping pace with the annual loss of big game winter range habitat. This type of habitat restoration work needs to increase in both pace and scale with additional financial and staff resources being allocated to avoid, minimize and mitigate the loss of quality winter range for big game in Colorado.

Big Game Winter Range Habitat Protection

CPW's Colorado Wildlife Habitat Program (CWHP) is a statewide program that provides funding opportunities for landowners who wish to voluntarily protect their private property containing important wildlife habitat, and/or provide sustainable wildlife-related recreational access to the public (Figure 18). By statute, the program's budget prioritizes funding big game winter range and migration corridors, public access for hunting, fishing, and wildlife viewing, and protecting habitat for species of concern. Since the program's inception in 2006, CPW has invested approximately $152 million across the state to secure conservation easements on 250,000 acres. In addition to securing the habitat, public access is allowed on 128,000 acres of the 250,000 acres protected. CPW holds the conservation easements on 100,000 acres of the properties while the conservation easement of 150,000 acres are held by third party entities. Of the total 250,000 acres protected by conservation easements, over 130,000 acres protects big game winter range with 90% of that protected winter range occurring on the West Slope of Colorado.

Brian Holmes, CPW

Figure 18. CPW conservation easement in winter range.

In 2018, the Parks and Wildlife Commission recommended funding conservation easement projects that support wildlife crossings, strengthening CPW's efforts to conserve migration corridors. During 2019, one project was selected in Chaffee County that includes the ability to build a wildlife crossing which will connect two parcels that have conservation easements along US Highway 285 near Salida. We anticipate a 2020 Request for Proposals for the CWHP, including an $11 million budget and funding priorities to include additional conservation of big game winter range and migration corridors.

Big Game Migrations

Many big game species exhibit annual migrations by moving along traditional routes between seasonal ranges, often associated with plant phenology and weather (Lendrum et al. 2014). Colorado's big game is no exception; CPW has been observing big game migrations for decades and documenting these movement corridors. Wildlife professionals, through observation, research and GPS tracking of movements, continue to identify where big game migrations are occurring across the landscape. Road kills and observations can be cost efficient surrogates for mapping migration routes. Big game migrations consist of animals transitioning between winter and summer habitats. Big game in Colorado typically migrate from higher elevations in the summer to lower elevations as winter approaches; and migrate in the spring from winter range back to summer range, following the spring green up. CPW uses the definitions below to describe, big game migration patterns and migration corridors for multiple species throughout the state.

Migration Pattern: A subjective indication of the general direction of the movements of migratory big game herds.

Migration Corridor: A specific mappable site through which large numbers of animals migrate and loss of which would change migration routes.

GPS Collar Technology

The integration of GPS technology in wildlife tracking has revolutionized our understanding of animal migrations (Millspaugh et al. 2012). GPS collars obtain location data through calculations from an array of satellites orbiting the earth. GPS collars will then transmit the location data from the collar back to a communication satellite. The communication satellite transmits the data to a server and wildlife biologists can then view and upload location data to their computers. This technology has allowed biologists to obtain large volumes of accurate location data anywhere across the globe. Through this technology, we have found that many species of animals move much farther than previously thought because it was difficult to track animals with older technology (e.g., VHF radio-collars) due to the large search areas and limited transmission of radio signals. For example, it was recently observed that a GPS collared pronghorn in eastern Colorado moved 55 miles in 10 days. That equates to a search area of 9,500 square miles and it would have been unlikely that we would have detected that movement using older technology.

GPS collars can be programmed to obtain locations at specified time intervals (for example, every 2 hours, 4 hours, or 13 hours) depending on the purpose of the study. The resolution of the data collected is much higher with shorter time intervals, with the trade-off being shorter battery life reducing the number of years of data collection for each collar. GPS locations on shorter time intervals are important when biologists are gathering data on fine scale questions, such as determining a location where an animal crosses a road. Two-hour intervals between locations and at least 30 GPS-collared animals are recommended when mapping migration corridors for deer, elk, pronghorn, and bighorn sheep in Wyoming (Wyoming Migration Initiative 2019). CPW believes that Colorado consists of relatively connected big game seasonal ranges and anticipates that more than 30 GPS collars will be needed to accurately map and understand animal movement patterns. Animals within the same herd may exhibit several types of migratory behavior; therefore, it is important to have a sufficient sample size. For example, approximately 25-30% of pronghorn from one study in eastern Colorado exhibited migratory behavior while the remaining 70-75% resided in the same area throughout the year.

GPS tracking-collars can be expensive and the cost of the collar is partially determined by the time-interval between location fixes. For example, the initial purchase price of a collar with 2-hour time intervals (>$1500/collar) can be more than double the price of a collar programmed for 13-hour time intervals (~$700/collar). There is an additional charge associated with transmitting the GPS location data to satellites that varies depending on the type of collar. Capturing animals can be expensive as well. Many of the animals collared for migration studies are captured with contracted helicopters crews, and capture rates range from $500/animal for deer to over $1000/animal for a moose.

As with any technology, GPS collars do not always work as intended. Sometimes collars fail to obtain locations. This can be due to the collar's

Jason Clay, CPW

Figure 19. Staff fitting GPS collar on cow elk

inability to connect to the satellite, which is a common problem with animals living in very dense vegetation or animals that live in deep canyons. Collars may also fail to obtain locations because of a collar malfunction. Sometimes collar malfunctions occur intermittently while other times the collar will completely fail and will no longer transmit data.

Given the expenses of both purchasing GPS collars and wildlife capture operations, wildlife biologists face a tradeoff between the number of animals that they can collar and the resolution of data that can be obtained from the collars. Additionally, biologists are often looking to answer multiple questions beyond just movement analyses when tracking collared animals. Other common questions include how many animals live through the year and how many females produce young. When the 13-hour time interval GPS collars were first made available, many biologists opted to purchase the $700 collars to increase the number of animals they could study versus getting more GPS locations in a day. Although the location data is coarser-scale and not ideal for answering questions about migration patterns, these collars can still provide data on movement patterns. The researchers at the Wyoming Migration Initiative have developed a tool to analyze migration corridors from data collected from 2 to 13 hour time intervals (Wyoming Migration Initiative 2019). A 13-hour time interval between locations is now considered to be the minimum rate necessary to map migration corridors, using programs R and Migration Mapper. Although a 13-hour time interval data is considered the minimum, CPW recommends 2-hour or 4-hour intervals to accurately map migration patterns. Along with the new collar capabilities, innovative methods to analyze big game movement data are evolving as well.

CPW GPS Collar Data and Analysis

CPW invests a large amount of time and financial resources capturing animals and deploying GPS tracking-collars to collect big game movement data. CPW captures 1,000 to 1,500 big game animals annually through a combination of helicopter net-gunning, trapping and darting. CPW currently has GPS collars collecting big game animal movements for mule deer, elk, pronghorn, bighorn sheep and moose. Table 1 below represents the number of current GPS collar projects by wildlife species.

These projects vary in size and scope with some focusing on wildlife management objectives, while others are long-term research projects (Figures 20-21).

Table 1. Number of GPS collar projects by big game species.

WILDLIFE SPECIES	NUMBER OF GPS COLLAR PROJECTS
Deer	15
Elk	18
Pronghorn	1
Rocky Mountain Bighorn Sheep	17
Desert Bighorn Sheep	2
Moose	1

Most of CPW's GPS collar projects are on-going with GPS data in the process of being collected. Once enough data becomes available to analyze, CPW will begin processing it and incorporating the results into wildlife management decisions. There are several projects that would not meet the minimal interval rate or number of animals (at least 30 individuals) necessary to map migration corridors as outlined by Wyoming researchers. The pronghorn and moose projects are in A6, A8, A35 and M9, respectively. CPW does have some GPS collar datasets that have been analyzed with either R or Migration Mapper across the West Slope of Colorado.

With a move towards using GPS collars to collect animal location data, CPW can more readily identify species movement corridors, seasonal ranges and home ranges. One method that CPW has been using is the Brownian Bridge Movement Model (BBMM). A Brownian Bridge is a continuous-time stochastic model of movement in which the probability of being in an area is conditioned on starting and ending locations, the elapsed time between points, and the mobility or speed of movement (Horne et al. 2007). The shorter the time between locations, the better the estimation of the movement, especially for species that are highly mobile, such as big game. Migration Mapper is another application that will run BBMM on GPS collar data. The Migration Mapper Application was developed by researchers at the University of Wyoming specifically to map migration corridors and winter range using GPS collar data (Wyoming Migration Initiative 2019). The application requires GPS location data to be collected at least every 13 hours, although more frequent locations are recommended. The Migration Mapper application analyzes data from multiple animals and creates movement patterns for each individual, and will perform a prioritization analysis that takes into account the number of animals using the same or similar paths of migration to show areas of high utilization for the herd (Figure 22). The analysis also identifies areas termed as stop-over areas, where animals spend more time during their transit to winter or summer range. Stopovers seem to be less common in Colorado where big game migrate more rapidly. Finally, the application helps better identify winter range habitats.

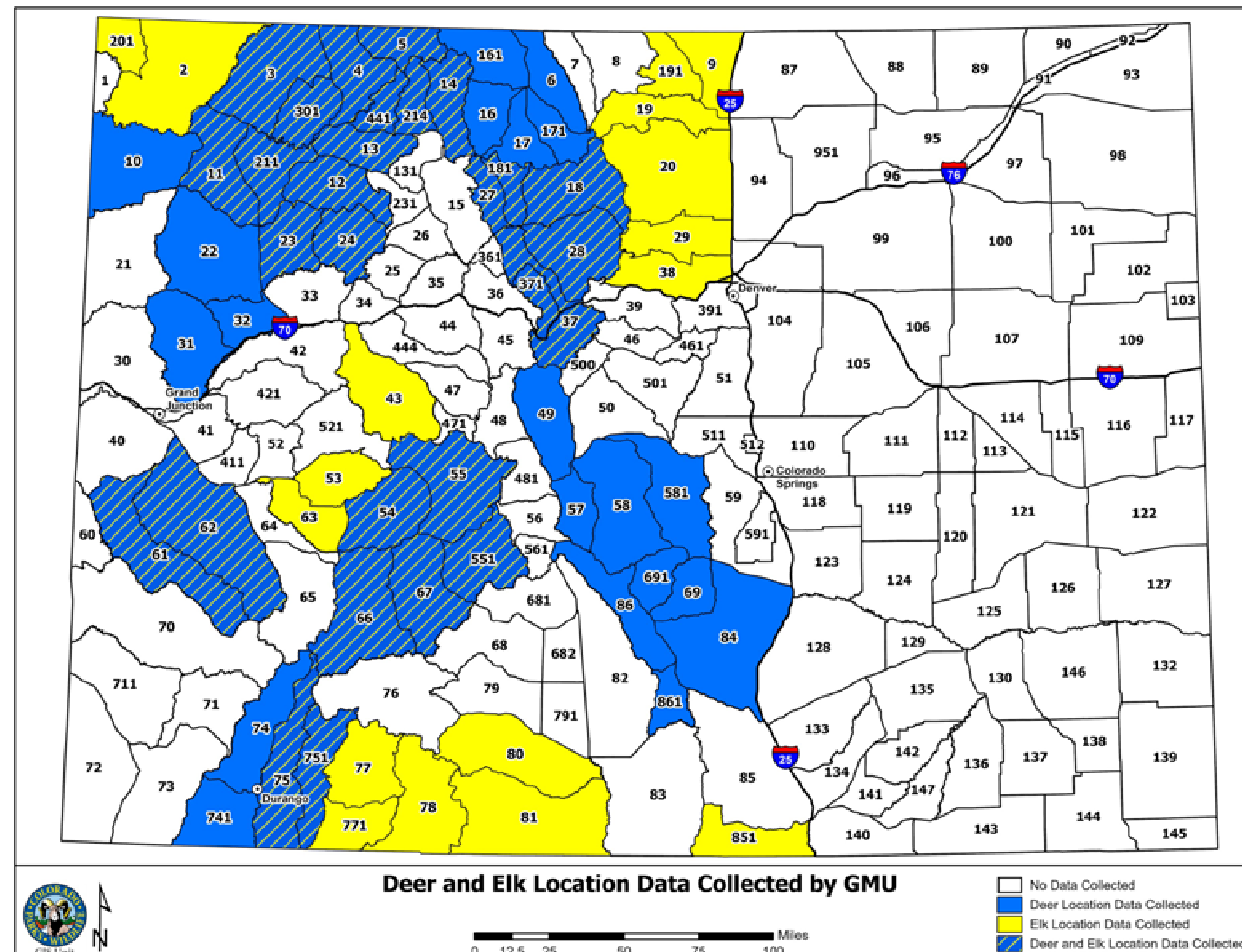


Figure 20. Deer and Elk GMU's with GPS collar data.

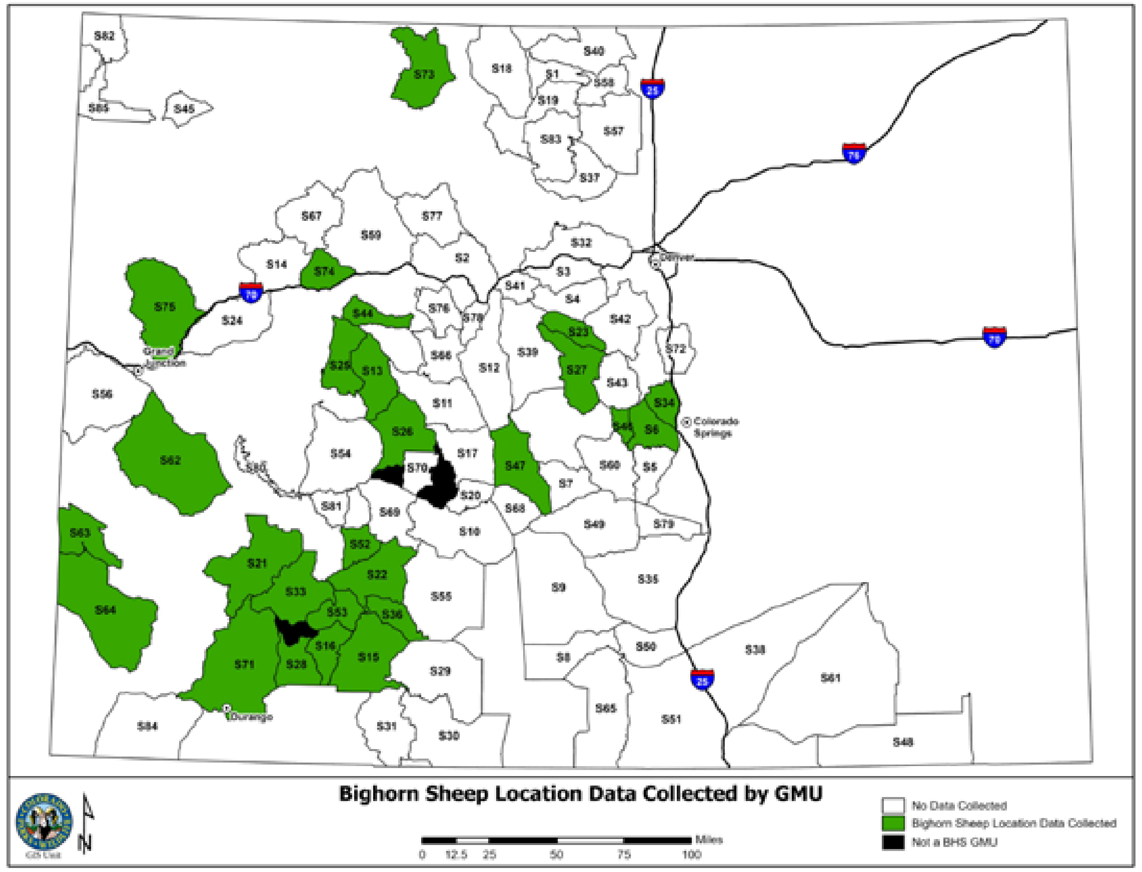


Figure 21. Bighorn sheep GMUS with GPS collar data.

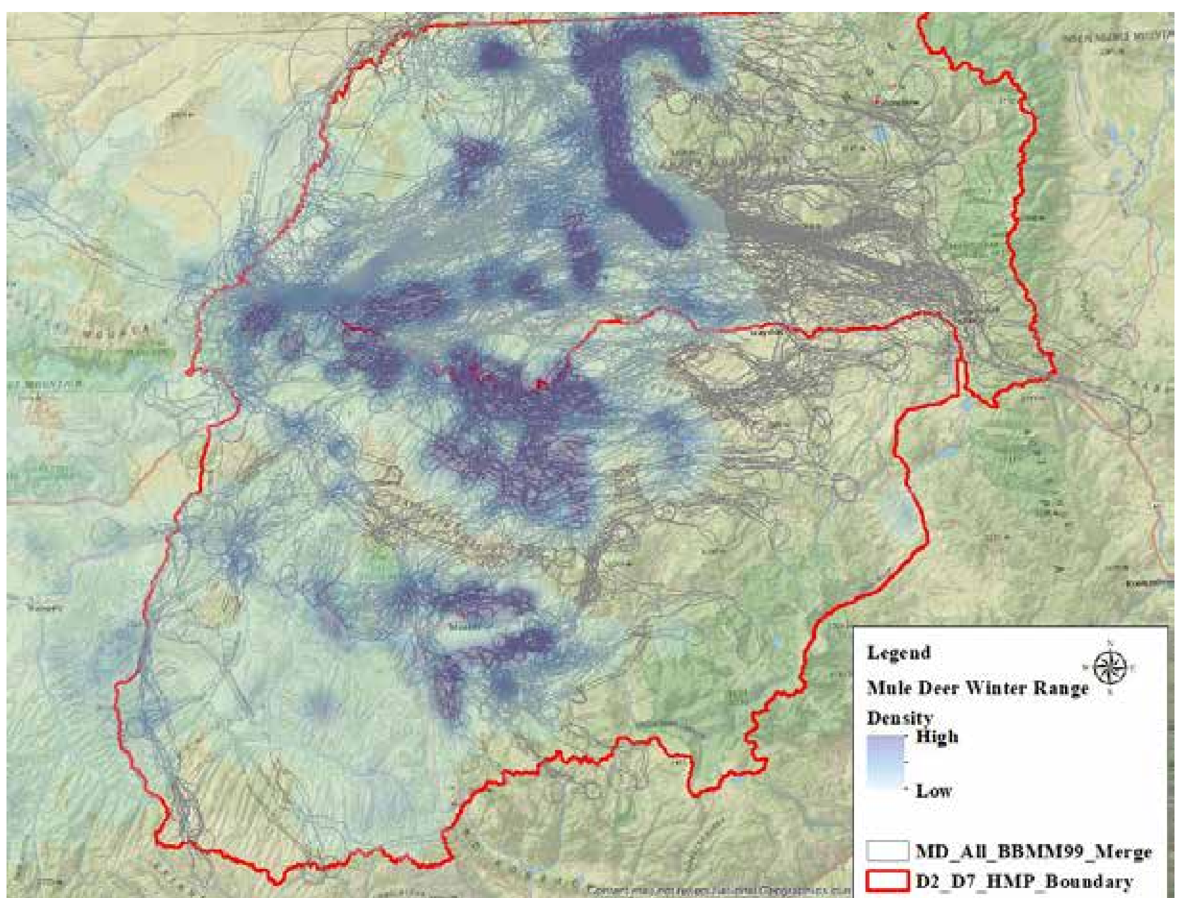


Figure 22. BBMM analysis for White River and Bear's Ear mule deer

Big Game Winter Range, Migration Threats and Conservation Actions

Colorado's big game populations face many threats and challenges as they move across the landscape seeking preferred seasonal habitats and resources for their survival. Threats and associated conservation actions to big game winter range and migration corridors are identified in Table 2. The listed threats and actions were intentionally developed to provide only general guidance. Future efforts to develop more specific threats and conservation actions should include involvement from internal and external stakeholders.

This section provides a brief overview of the primary threats associated with impacts to big game winter range and migration corridors. The information provided here is not exhaustive, but a synopsis of how primary threats can negatively impact big game species and/or their seasonal habitats. It is also important to note that a single threat likely has multiple adverse impacts, and multiple threats are often compounded causing cumulative impacts to a given herd. Many of the threats discussed below are expected to increase in the foreseeable future, further exacerbating the negative impacts.

Human Population Growth

Colorado's human population is currently (2019) around 5.7 million people, and is projected to reach nearly 8.5 million people by 2050, according to the Colorado's State Demography Office (CDOLA, 2018). Although the majority of growth will occur on the Front Range and existing urban areas, growth will likely continue in many counties across the state. The most growth outside of the Front Range will probably include counties along the western I-70 corridor and in the southwest corner of the state (CDOLA, 2016). The threats associated with a growing human population include habitat loss, degradation and fragmentation caused by increasing residential and commercial development, recreation activities, and road density. There is a finite amount of available land to accommodate a growing human population, housing needs, increasing visitors and recreation activities while also maintaining healthy and sustainable big game habitats and populations.

Recreation

According to the 2019 Statewide Comprehensive Outdoor Recreation Plan (SCORP), approximately 92% of Coloradans recreate at least every few weeks to four (or more) times per week. Projected available per capita recreation acres per capita are expected to decline from around 5.5 acres to less than 3.5 acres by 2050 as the number of people recreating increases (SCORP 2019). This loss of space will not only increase potential conflicts between recreationists but also with Colorado's wildlife populations and habitat. Recreation activities have direct impacts on wildlife and habitat by causing wildlife disturbance, habitat loss, habitat degradation, and habitat fragmentation. Indirect recreation impacts include but are not limited, to increased traffic and associated amenities such as hotels, restaurants and shops to accommodate recreationists. Therefore, it is imperative that CPW participates in recreational planning and works with partners to lessen these impacts to wildlife populations.

Transportation

Kevin Blecha, CPW

Many of Colorado's major roadways are in low-lying areas (such as canyons, waterways and riparian corridors) that are important big game winter range and movement corridors. The network of roads built across Colorado causes direct habitat loss and fragmentation and can create temporary or permanent movement barriers to wildlife species that desire to cross in order to access food and habitat resources. Wildlife-vehicle collisions (WVCs) can have detrimental consequences to both humans and wildlife when animals attempt to cross roadways and are struck.

In Colorado, nearly 4,000 WVCs are reported to law enforcement each year, with an estimated property and damage cost of $66.4 million. Research has shown that WVCs documented by law enforcement may be underreported by up to 80% or more (Kintsch et al. 2018, Olson 2013). Most of the reported accidents are primarily associated with larger big game species that cause damage and

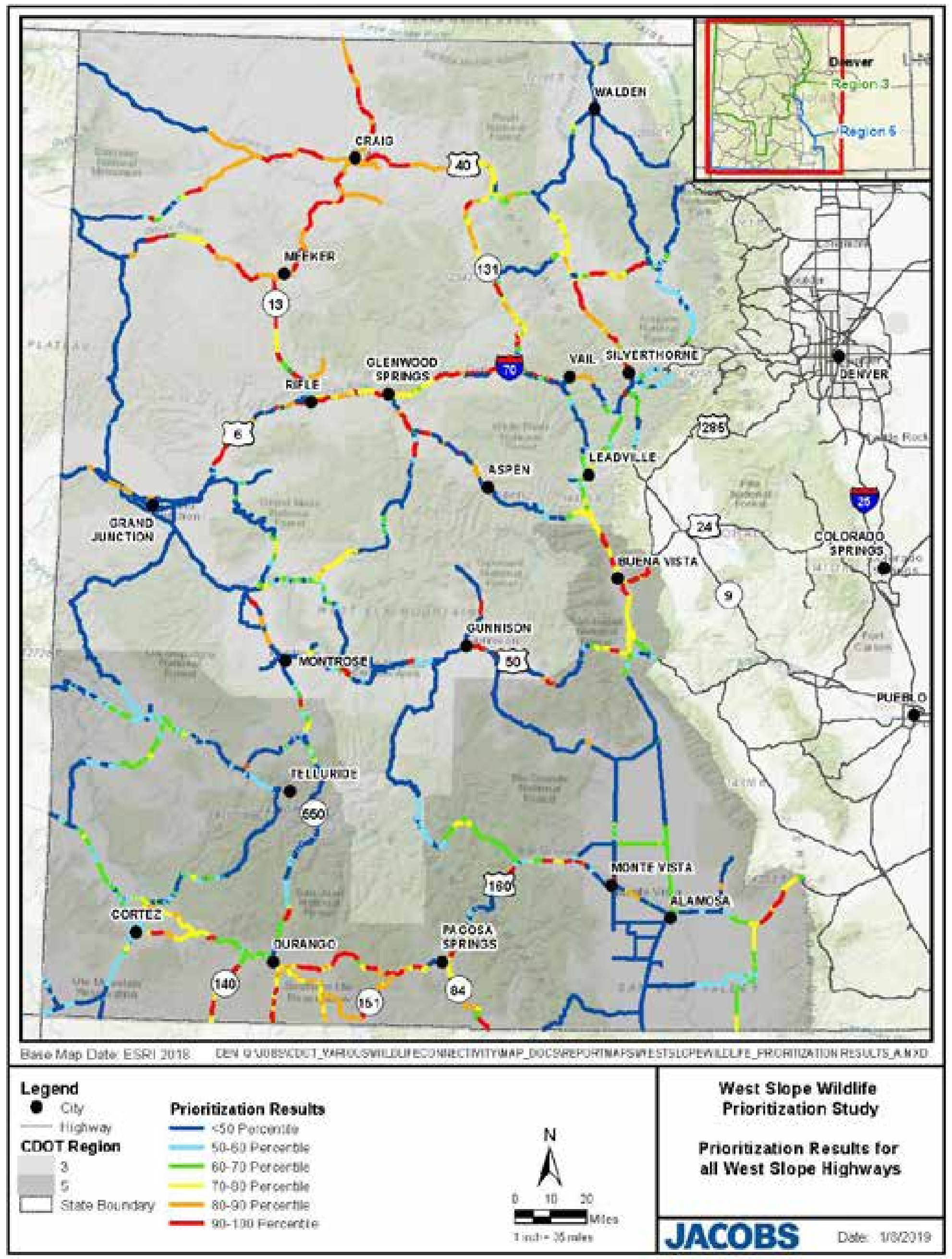


Figure 23. Aggregated highest priority highway segments for the West Slope (Kintsch et al. 2019)

often do not include smaller species such as mountain lions, coyotes, or foxes. In addition, the cost estimates do not include the value of wildlife loss, nor the positive impact of wildlife populations and their relation with society.

Based on CPW's mule deer intensive monitoring studies, 2% of collared doe mule deer are killed by vehicle collisions annually. This is more than the amount of doe deer harvested by hunters each year. Future traffic volumes are expected to rise as Colorado's population grows, as is the number of highways that will be expanded to add more lanes for capacity.

These actions will continue to have a significant, negative impact on big game herds from direct WVCs and present an increasing barrier to wildlife attempting to safely reach preferred seasonal habitats and resources. There are currently many efforts underway to address the threat of WVCs to Colorado's wildlife. In 2017, CPW and CDOT held a wildlife and transportation summit to identify themes, goals and suggested strategies to address the West Slope Mule Deer Strategy (WSMDS) management priority: reduce the impacts of highways on mule deer survival, movement and migration. One of the outcomes of the transportation summit was the development

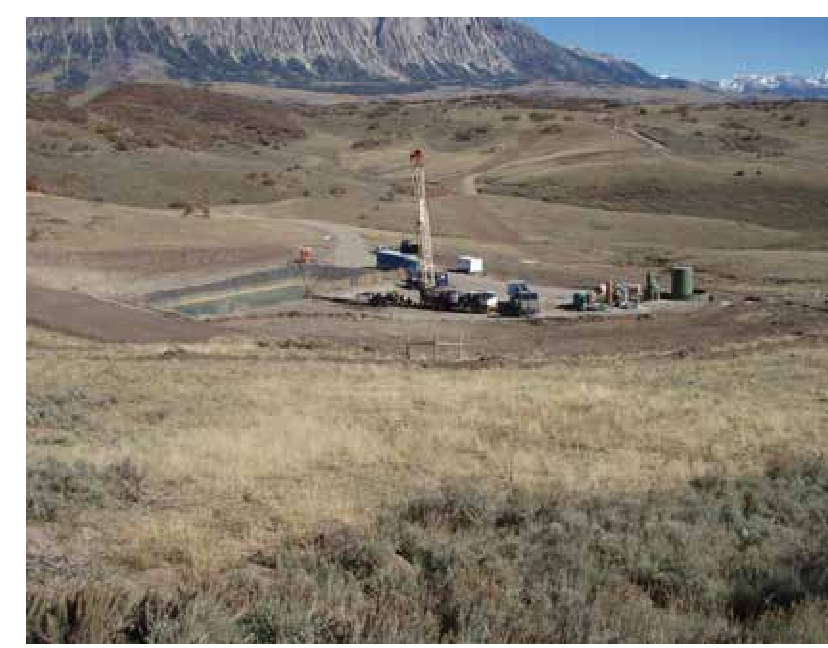
of the Colorado Wildlife and Transportation Alliance (CWTA). This alliance represents a coalition between CPW, CDOT, United States Forest Service (USFS), United States Department of Transportation-Federal Highway Administration, MDF, Rocky Mountain Elk Foundation (RMEF) and the Southern Ute Indian Tribe (SUIT). CWTA's mission is to provide safe passage for people and wildlife. This is a collaborative effort to improve human safety, while fully integrating wildlife movements into Colorado's transportation system. CDOT and CPW further partnered by co-funding the West Slope Wildlife Prioritization Study (Kintsch et al. 2019).The study's objective involved identifying wildlife-highway segments where targeted transportation mitigation could have the greatest impact on reducing WVCs. To meet this objective, the WSWPS identified, mapped and prioritized highway segments across the West Slope based on the risk of WVC and the need for mule deer and elk to make cross highway movements, particularly during migration or within winter range (Figure 23). CWTA is working to help implement the WSWPS findings and supporting efforts to conduct a similar East Slope Wildlife Prioritization study, which has been recently funded by GOCO.

In addition to the WSWPS, potential wildlife-highway mitigation areas are identified through other local and regional efforts including but not limited to CDOT's Statewide Transportation Plan, Planning and Environmental Linkage studies, I-70 Linkage Interference Zones, CDOT's regional transportation plans, and county-level connectivity plans (Eagle County Safe Passages and Summit County Safe Passages). CDOT and CPW signed a Memorandum of Understanding in December 2019, and are continuing to collaborate to reduce WVCs, including segments of Interstate 25, State Highway (SH) 9, SH 13, US Highway 160, US Highway 285, and US Highway 550.

Mining and Energy Development

Energy development in Colorado generally includes oil and gas exploration and production, coal and uranium mining, and installation of renewable energy facilities (photovoltaic (PV) solar and wind energy). Adverse impacts to big game from energy development result from the direct loss of habitat occurring from the development's footprint, and indirect impacts associated with the development (increased traffic, noise and light pollution, invasive plants).

Oil and gas development in Colorado generally requires between 5-40 acres (average 13 acres) to develop necessary infrastructure including well pads, access roads, flowlines, pipelines, compressor stations, tank batteries, and water processing facilities. Big game species typically demonstrate some level of avoidance to these locations due to increased noise levels and human presence. Individually, these facilities may not result in impacts to big game at a population level; however, the cumulative effects of all disturbance on a landscape can result in impacts that are more significant. Generally, as the density of oil and gas facilities increases, the resulting impacts to wildlife increase. High-density oil and gas development can fragment seasonal habitats and obstruct movement corridors utilized by big game species. For example, rates of travel for mule deer in the Piceance Basin were more rapid over shorter migration distances in areas of high natural gas development resulting in delayed departure and early arrival for females migrating in areas with high development, compared with less developed areas (Lendrum et al. 2013). CPW works with the Colorado Oil and Gas Conservation Commission (COGCC), Colorado SLB, BLM, and various counties, in addition to working with specific oil and gas operators to avoid, minimize, and mitigate impacts by locating facilities outside high priority habitats, implementing seasonal timing limitations, utilizing best management practices, and mitigating unavoidable impacts through habitat enhancement/protection projects.



Jon Holst, CPW

Energy-related mining in Colorado primarily consists of coal mining, with some uranium mining in the southwest corner of the state. Impacts to wildlife from mining are generally similar to oil and gas operations. Depending on the size of the disturbance, location, and type of mining operation (e.g. strip mining vs. subsurface longwall mining), the impacts to wildlife can vary. CPW currently works with the Colorado Department of Reclamation Mining and Safety (DRMS), various municipalities and project proponents to incorporate wildlife recommendations during the permitting process for new mining proposals.

Taylor Elm, CPW

Renewable energy development is increasing rapidly in Colorado. Wind and PV solar are the most common projects with project sizes ranging from a few acres to thousands of acres. Wind energy development has occurred almost exclusively on Colorado's eastern plains where golden eagles, pronghorn antelope, and white-tailed deer have the greatest potential to experience adverse impacts. Solar energy development in Colorado has been occurring at various scales. Local, small-scale "solar garden" projects have increased in popularity for many municipalities and generally result in minor impacts to big game, due to their small size. Large utility-scale solar projects can result in the direct loss of thousands of contiguous acres of wildlife habitat. Due to federal requirements for fencing around solar panel arrays, the footprint of a solar project typically results in the complete loss of habitat for big game species. The siting of new wind and solar energy projects should be done in close coordination with CPW staff during early planning stages to avoid the loss of sensitive habitats and minimize impacts to big game movement corridors.

Habitat Alterations and Loss

Colorado is home to a broad range of habitats; this habitat diversity results in an abundant variety of wildlife species. Colorado also contains a large amount of public land that helps to sustain large populations of wildlife. These two measures, habitat diversity and animal diversity, are the basis of healthy ecosystems. These habitats and ecosystems are being impacted by a host of threats (some of which have been discussed above) that cause habitat alterations and direct habitat loss, which are serious threats to big game populations in Colorado.

Altering habitat, in both quality and quantity, by land use activities can have significant and long-term effects (both positive and negative) on big game habitats and populations. Examples of habitat alteration include, but are not limited to, land use conversion from agriculture to residential, habitat type change by natural cause (wildfire, parasite infestation), habitat quality change as a result of land management, habitat fragmentation, and climate change. Many of these land use impacts are largely outside CPW's regulatory authority, but do have an influence on wildlife populations and habitat, which CPW addresses by providing input into land use decisions. Habitat quality can be degraded by changes in vegetative species composition and structure modification. Examples include invasive, non-native plants with little to no forage value, such as cheatgrass, that are increasing on the landscape. In some areas, fire suppression has allowed forested areas to mature and accumulate unnaturally high fuel loads. Another example is sagebrush habitat encroached by pinyon-juniper resulting in a loss of understory plant diversity and productivity, and decreased forage quality and quantity for wildlife (Watkins et al 2007).

Elissa Slezak , CPW

Table 2. Big Game Winter Range and Migration Corridor Threats & Actions

GENERAL THREATS	SPECIFIC THREATS	CPW CONSERVATION ACTIONS	
Agriculture	Loss of native vegetation (conversion to cropland, reduced grass/forb diversity, noxious weed establishment)	CPW will continue to work with landowners to enhance native vegetation for the benefit local wildlife species, particularly on winter range and migration corridors.	CPW will continue to promote noxious weed and cheatgrass control in all land use practices (public and private); this includes discouraging introduction of non-native ornamental species, mapping of weed infestations, implementing weed/pest management plan, and establishing sensitive zones.
	Grazing (timing, intensity, changes in vegetation)	CPW will continue to work with landowners to implement grazing practices that are sustainable and compatible with big game species (particularly on winter ranges and migration corridors).	CPW will encourage sustainable grazing as a tool for compatible vegetation cover, structure and composition to restore degraded habitats.
	Livestock fencing (abandoned fencing, new fencing)	CPW will continue working with landowners and land managers to implement wildlife-friendly fencing and remove abandoned fencing (particularly on winter ranges and migration corridors).	
Development - Commercial	Housing, Urban, and ex-urban development (suburbs, villages, PUDs, condos, ranchettes)	CPW will continue working with local municipalities (via land use review, code updates and Master Development Plans) to prioritize the protection of priority wildlife habitats including big game winter ranges and migration corridors	CPW will continue to work with private landowners to establish conservation easements to protect habitat in big game winter range and migration corridors (utilizing the CO Wildlife Habitat Protection Program and other mechanisms).

GENERAL THREATS	SPECIFIC THREATS	CPW CONSERVATION ACTIONS	
Development - Commercial	Non-housing development associated with urban growth (shopping centers, offices, schools, hospitals, industrial parks, hotels, factories, manufacturing plants, landfills, sewer treatment facilities, military bases, power plants, airports) Disturbance, habitat loss & fragmentation (roads, well-pads, facilities, pipelines, activities, noise)	CPW will continue working with local municipalities and counties (via land use review, code updates and Master Development Plans) to prioritize the protection of priority wildlife habitats including big game winter ranges and migration corridors.	
Energy Production - Oil & Gas	Disturbance, habitat loss & fragmentation (roads, well-pads, facilities, pipelines, activities, noise)	CPW will continue to work with COGCC, operators, land managers and local governments to establish and implement industry standards, best management practices and mitigation requirements to avoid, minimize and mitigate impacts to big game winter range and migration corridors.	CPW will actively work to educate operators and industries about impacts to wildlife from oil and gas production and related activities and seek cooperative methods to mitigate these impacts.
Energy Production – Mining	Disturbance, habitat loss & fragmentation (exploration, extraction, production activities)	CPW will continue working with DRMS, operators, land managers and local governments to establish and implement industry standards, best management practices and mitigation requirements to avoid, minimize and mitigate impacts to big game winter range and migration corridors.	CPW will actively work to educate operators and industries about impacts to wildlife and seek cooperative methods to mitigate these impacts.

GENERAL THREATS	SPECIFIC THREATS	CPW CONSERVATION ACTIONS	
Habitat Alteration & Loss	Parasites (beetle infestation)	CPW will continue to support land managers and landowners in managing beetle infestations to allow restoration of habitats, particularly big game winter range and migration corridors.	
	Logging & Timber Sales	CPW will continue to work with land managers to implement sustainable timber harvest that is compatible with big game habitat use and migration patterns.	
	Weather & Climate Change (drought, severe winter, extreme wildfire, floods, etc.)	CPW will continue to perform, support and collaborate on research and monitoring that explores wildlife species habitat distribution, critical life histories, habitat components, barriers to species movement, and response to habitat management for big game species, winter range habitats and migration corridors.	CPW will support actions to develop, change, influence, and help implement formal legislation, regulations, and voluntary standards to reduce the impacts of climate change on big game winter range and migration corridors.
Recreation	Non-motorized Trails (hiking, mountain biking, horseback, ski/snowshoe)	CPW will continue working with trail users, non-governmental organizations (NGOs), land managers, local municipalities, and other stakeholders to avoid, minimize, and mitigate negative effects from non-motorized recreation to big game, sensitive species and their habitats.	CPW will continue to educate recreationists regarding their impacts to wildlife and seek methods to effectively influence behavior of non-motorized trail users.
	Motorized Trails (OHV/ATV, motorbike, 4WD, snowmobile, ebike)	CPW staff will continue working with trail users, NGOs, local municipalities, and other stakeholders to avoid, minimize, and mitigate negative effects from motorized recreation to big game and migration corridors.	CPW will continue to educate recreationists regarding their impacts to wildlife and seek methods to effectively influence behavior of motorized trail users.

GENERAL THREATS	SPECIFIC THREATS	CPW CONSERVATION ACTIONS	
Recreation	Established Recreation Sites (ski resorts, golf courses, campgrounds, parks)	CPW will continue to work with land managers and private entities for responsible development of established recreation sites to avoid, minimize and mitigate impacts to big game winter range and migration corridors.	CPW will continue to educate the public regarding their impacts to wildlife from recreational activities and seek methods to effectively influence behavior of recreationists.
	Ecotourism/Guided Recreation (backcountry skiing, rafting, bike tours, hiking fourteeners)	CPW will continue to work with land managers and developing enterprises whose livelihood is directly dependent on the sustainability of natural resources, and seek out methods to effectively change recreationist behaviors and attitudes to protect and conserve big game winter range, and migration corridors.	
	Illegal activity (off-trail use, violation of closures, dogs at large, harassment of wildlife)	CPW will continue to work with land mangers (federal, state, county, city/town) to enforce laws and curb illegal activities that negatively impact wildlife species (i.e.; violation of seasonal closures for winter range; dogs at large, harassment of wildlife, etc.).	CPW Officers will directly enforce Title 33, C.R.S. violations (poaching, harassment of wildlife, etc.).
Transportation (Highways, Railroads)	Habitat fragmentation	CPW will continue to identify important habitat linkages and work with CDOT (per Executive Order D-2019-011), the CO Wildlife and Transportation Alliance, land managers and landowners to conserve connected habitats.	CPW will continue to identify opportunities to conserve and protect intact habitat, including big game winter range and migration corridors, through partnerships, conservation easements, and fee title acquisition.

GENERAL THREATS	SPECIFIC THREATS	CPW CONSERVATION ACTIONS	
Transportation (Highways, Railroads)	Animal-vehicle collisions, associated wildlife mortality	CPW will continue to work with CDOT (per Executive Order D-2019-011), the CO Wildlife and Transportation Alliance, and other partners to identify locations to increase permeability for wildlife and increase human safety on roadways, and promote wildlife crossing projects (overpasses, underpasses, fencing) or other approved methods to reduce animal-vehicle conflicts.	CPW will continue to explore new and innovative options to fund projects that reduce wildlife-vehicle collisions and reduce wildlife mortality.

Big Game Winter Range and Migration Current Research Needs

Current research projects are addressing various aspects of wildlife management and ecology to enhance understanding and management of wildlife responses to habitat alterations, human-wildlife interactions, and investigating improved approaches for wildlife and habitat management. CPW's Research, Policy, and Planning Branch has the following on-going projects:

- Mule deer/energy development interactions to inform future development planning
- Addressing the utility of habitat treatments to mitigate energy development activity
- Evaluation of moose demographic parameters that will inform future moose management in Colorado
- Identify factors influencing elk calf recruitment
- Address elk response to human recreation to establish mitigation and planning options

Big Game Winter Range and Migration Data Gaps and Management Needs

Current data gaps inhibit our ability to identify and protect specific, high priority big game winter range and migration areas on a statewide or regional level (Table 3). Although there is local knowledge around the state of important winter range habitat, and in some cases migration corridors, it is difficult to prioritize these habitats on a landscape scale. Acquiring the data to address the data gaps will require funding support and cooperation with conservation partners.

Big game winter range and migration corridors have always been a priority for CPW. However, the signing of the SO 3362 and the Executive Order D 2019 011 have provided additional opportunities for CPW to further big game conservation of winter range and migration corridors. These orders have placed additional workloads and requirements that CPW is working towards addressing into the future. Moving forward, the following management needs were identified to accomplish CPW's responsibilities associated with the conservation of big game winter range and migration corridors. The short term needs are management actions or planning that will occur in the next one to three years by CPW. The long term needs are management actions or planning that would inform management decisions but CPW has nor the staff or the resources to complete at this time.

Table 3. Identified big game winter range and migration data gaps and management needs

Short Term (1-3 years)
Develop a prioritization process to collect additional big game movement data to identify big game migration (i.e. locations, species).
Standardize method and tools for CPW and CDOT to record WVCs and associated wildlife mortalities.
Conduct the East Slope Wildlife Prioritization study.
Research related to understanding wildlife movement patterns relative to roadways (Research Landscapes related to SO 3362).
Recommendations on consistent monitoring to determine effectiveness of wildlife-highway mitigation projects at reducing wildlife vehicle collisions.
Define and identify big game transitional range (migration swaths).
Develop a central database to house CPW's big game migration data.
Continue to analyze migration data as it becomes available and share with CDOT and other conservation partners.
Recommendation on standard data collection when mapping big game movement patterns for highway crossing (GPS collars should be programmed for 2-hour time intervals).
Landscape scale analysis to identify regional priority habitat restoration areas in relation to big game winter range and migration corridors.

Long Term (Indeterminate)
Data to identify physical barriers and land use practices that threaten movement corridors, and winter range (i.e., energy development, trails/recreation, fences, roads, roadway infrastructure, residential and commercial development).
Develop a risk assessment process with conservation partners for existing threats, potential threats, cumulative threats and opportunities for conservation actions.
Housing and urban development projections maps for Colorado identifying detailed growth areas.
Data and method to identify bottleneck areas for big game movements.
Landscape scale assessment of habitat quality associated with transitional range, stopovers along migration corridors and critical winter range.
Assessment to determine thresholds for levels of disturbance and fragmentation that impacts big game population health.
Landscape scale mapping and analysis of cumulative impacts (existing and potential) to big game winter range and migration corridors from identified threats.
Data and methods to determine impacts of train collisions on big game herds.
Updated landscape scale habitat mapping to assess long term habitat change.
Research into how to address habitat carry capacity, appropriate stocking rates (density), and animal body condition in the herd management planning process.

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Attachment F

Increases in residential and energy development are associated with reductions in recruitment for a large ungulate

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Abstract

Land-use change due to anthropogenic development is pervasive across the globe and commonly associated with negative consequences for biodiversity. While land-use change has been linked to shifts in the behavior and habitat-use patterns of wildlife species, little is known about its influence on animal population dynamics, despite the relevance of such information for conservation. We conducted the first broad-scale investigation correlating temporal patterns of land-use change with the demographic rates of mule deer, an iconic species in the western United States experiencing wide-scale population declines. We employed a unique combination of long-term (1980–2010) data on residential and energy development across western Colorado, in conjunction with congruent data on deer recruitment, to quantify annual changes in land-use and correlate those changes with annual indices of demographic performance. We also examined annual variation in weather conditions, which are well recognized to influence ungulate productivity, and provided a basis for comparing the relative strength of different covariates in their association with deer recruitment. Using linear mixed models, we found that increasing residential and energy development within deer habitat were correlated with declining recruitment rates, particularly within seasonal winter ranges. Residential housing had two times the magnitude of effect of any other factor we investigated, and energy development had an effect size similar to key weather variables known to be important to ungulate dynamics. This analysis is the first to correlate a demographic response in mule deer with residential and energy development at large spatial extents relevant to population performance, suggesting that further increases in these development types on deer ranges are not compatible with the goal of maintaining highly productive deer populations. Our results underscore the significance of expanding residential development on mule deer populations, a factor that has received little research attention in recent years, despite its rapidly increasing footprint across the landscape.

Keywords: Colorado, demography, fawn ratios, land-use change, *Odocoileus hemionus*, residential development, weather, winter range

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Introduction

The human footprint is expanding rapidly on landscapes across the globe (Vitousek *et al*., 1997; Leu *et al*., 2008), a pattern that has been associated with reduced biodiversity, range contractions, and increased extinction risk for wildlife (Ceballos & Ehrlich, 2002; McKee *et al*., 2004; Davies *et al*., 2006). Infrastructure and activities related to residential development, resource extraction, transportation, recreation, and other forms of human land-use can negatively influence wildlife through a variety of means. Animals can be affected through direct mortality, increased disturbance, altered relationships with competitors and predators, and through the loss and degradation of critical habitat resources (see reviews by Krausman *et al*., 2011; Northrup & Wittemyer, 2013). Given that people and wildlife often select similar biophysical features of the landscape, land-use change frequently occurs in areas of high biological productivity, potentially having disproportionate effects on wildlife (Hansen *et al*., 2005; Leu *et al*., 2008).

Changes in land-use are often observed to influence wildlife behavior (Tuomainen & Candolin, 2011), but relatively little is known about the influence of land-use change on the demography of populations. Animals frequently avoid human infrastructure and activities by

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modifying their patterns of movement (Sawyer *et al.*, 2013) and habitat use (Nellemann *et al.*, 2007), exhibiting large-scale displacement (Sawyer *et al.*, 2006), increasing vigilance activities (Mccleery, 2009), and altering foraging strategies (Robinson *et al.*, 2010). Such changes in behavior likely influence individual fitness, and ultimately, population performance, but research demonstrating these effects on the dynamics of animal populations is limited (Polfus & Krausman, 2012; Northrup & Wittemyer, 2013; Wong & Candolin, 2015). Because land conversion often occurs in spatially complex and temporally dynamic patterns (Ramalho & Hobbs, 2012), and animals alter their behavior to mediate the negative consequences of land-use change, demographic impacts may be weak, gradual, or exhibit lag effects (Hansen *et al.*, 2005; Harju *et al.*, 2010) that are difficult to detect during routine monitoring activities or over short time periods.

Residential housing and energy development are two types of land-use change that are increasing rapidly across the western United States (Vias & Carruthers, 2005; Leu *et al.*, 2008; Copeland *et al.*, 2009) and around the world (McMichael, 2000; Hansen *et al.*, 2005; International Energy Agency 2015). Over the past few decades, the intermountain west has experienced some of the highest rates of human population growth in the country (Vias & Carruthers, 2005) fueling dramatic increases in the number of residential housing units, particularly outside of metropolitan areas. Increases in rural and exurban development (low-density residential housing) have outpaced growth from other forms of residential land-use (Brown *et al.*, 2005). Low-density housing is characterized by having a highly dispersed spatial pattern, close juxtaposition to undeveloped public lands, and strong association with key habitat features (i.e., valley bottoms), factors that are likely to result in disproportionate impacts to wildlife (Theobald *et al.*, 1997; Leu *et al.*, 2008; Leinwand *et al.*, 2010). While research on the effects of rural and exurban development on wildlife is limited, there is evidence that low-density housing can reduce habitat use, survival, and reproduction for some species (Hansen *et al.*, 2005; Goad *et al.*, 2014). Infrastructure and activities related to oil and gas development (*hereafter* energy development) have also increased rapidly due to the rise in the global demand for energy (Copeland *et al.*, 2009). Between 1985 and 2006, energy development expanded by an estimated 20% per year in some areas (Walston *et al.*, 2009), with millions of additional hectares expected to be impacted in the future (Copeland *et al.*, 2009). The construction and use of wells, well pads, roads, and pipelines, along with the associated noise and vehicular traffic, have altered animal habitat-use patterns (Sawyer *et al.*, 2006; Northrup *et al.*, 2015), have reduced survival and reproduction (Holloran *et al.*, 2010; Dzialak *et al.*, 2011), and have been linked to population declines (Sorensen *et al.*, 2008).

Over the past few decades, while land-use change has been pervasive across the intermountain west, mule deer (*Odocoileus hemionus*) populations have generally declined (Idaho Department of Fish and Game 1999; Gill, 2001; Heffelfinger & Messmer, 2003; Bergman *et al.*, 2015). Mule deer populations are known to fluctuate, but significant decreases in population estimates across multiple western states have generated concern, as mule deer are an iconic species with tremendous ecological, recreational, and economic value. Drivers of mule deer declines are largely unknown, and likely multifaceted, but evidence suggests that habitat conditions play a pivotal role (Gill, 2001; Bishop *et al.*, 2009; Hurley *et al.*, 2014; Monteith *et al.*, 2014; Shallow *et al.*, 2015). To date, research on habitat has primarily focused on the influence of forage quality, cover type, and local climate conditions on mule deer dynamics, but land-use change may also be important (Polfus & Krausman, 2012). Studies have found that mule deer reduce their selection of habitat near residential and energy development, effectively decreasing the area that is functionally available (Vogel, 1989; Sawyer *et al.*, 2009; Northrup *et al.*, 2015). While few studies have investigated the consequences of this behavior on ungulate demography, urban housing has been associated with reduced recruitment in a local mule deer herd (McClure *et al.*, 2005) and energy development has been associated with reduced survival in a population of elk (*Cervus elaphas*; Dzialak *et al.*, 2011). Given the expanding human footprint across western landscapes, it is critical for wildlife and land management agencies to quantify the impacts of land-use change on mule deer habitat and understand the degree to which different types of development may be contributing to population declines.

To examine the influence of residential and energy development on mule deer populations, we employed a unique combination of long-term data on land-use change with long-term data on mule deer recruitment. We evaluated both data types annually across western Colorado between 1980 and 2010, a time period when major changes in development and deer populations occurred. The broad extent of our study area allowed us to account for temporal dynamics in land-use change (Ramalho & Hobbs, 2012) and demography across multiple deer populations. This design provided a powerful opportunity to examine multiple factors correlated with deer performance, which would be difficult to achieve over a short time period or within a single study population. We used deer recruitment (the proportion of 7–8 month olds/100 adult females) as our demographic rate of interest because this parameter exhibits high variation, is sensitive to environmental conditions, is minimally affected by harvest regulations, and is typically the most influential vital rate driving ungulate population growth (Gaillard *et al.*, 2000; Forrester & Wittmer, 2013).

In addition to assessing annual changes in residential and energy development on mule deer ranges, we also assessed annual variation in weather conditions and their relationship with deer recruitment. Weather factors, such as winter severity and summer precipitation, are well recognized to influence ungulate productivity through their direct effects on juvenile condition and survival and through their indirect effects on maternal condition (Hurley *et al.*, 2011, 2014; Monteith *et al.*, 2015). By including weather variables in our analysis, we were able to compare the relative associations between land-use change and recruitment to well-known associations between weather and recruitment. Specifically, we evaluated recruitment with respect to temperature and precipitation during the winter just prior to parturition, in June when fawns were born, and throughout the following summer, critical time periods for influencing both maternal condition and juvenile survival (Cook *et al.*, 2004; Gilbert & Raedeke, 2004; Hurley *et al.*, 2011). Given these considerations, our research objectives were to (i) quantify annual changes in residential development, energy development, and weather conditions within mule deer winter and summer ranges and (ii) test for associations between those annual changes in habitat conditions and annual rates of deer recruitment.

Materials and methods

Study area

We analyzed data from areas of Colorado west of Interstate 25 (164 346 km^2; Fig. 1). This area included 44 deer data analysis units (DAUs) delineated by Colorado Parks and Wildlife (CPW), which are intended to represent discrete deer populations and are the primary unit for deer management in the state. These DAUs included mule deer populations that are predominantly migratory, moving seasonally between distinct winter and summer ranges. The total number of deer estimated within these units varied between 348 200 and 585 200 over the study period and comprised approximately 90% of the mule deer in the state.

For each DAU, CPW has identified mule deer winter and summer ranges, delineations that are routinely used by public and private entities for environmental assessment, resource planning, and scientific inference. Winter ranges are defined as those areas where 90% of the deer are located during an average winter from the first heavy snow to spring green-up. Summer ranges are those areas where 90% of the deer are located during the remainder of the year. CPW used a variety of data sources to identify seasonal ranges including information from ground surveys, annual aerial surveys, telemetry collars, and expert opinion. On average, DAUs were 3735 km^2 in size, while winter and summer ranges were 1653 km^2 and 2900 km^2, respectively.

Land-use and weather data

We used the Spatially Explicit Regional Growth Model (SERGoM) dataset (Bierwagen *et al.*, 2010) to estimate changes in residential development over time. This nationwide dataset models housing density on private lands by decade at a spatial resolution of 100 m. At each time step, pixels were classified as either undeveloped (0 housing units/ha) or developed at rural (<0.03 units/ha), exurban (0.03–0.59 units/ha), suburban (0.60–5.00 units/ha), or urban (>5.00 units/ha) densities. We calculated the total area and proportion of each DAU, and winter and summer ranges within DAUs, covered by each category of residential development. We used linear interpolation to estimate annual values within each decade for all developed categories (i.e., not for pixels classified as 'undeveloped'). We also calculated the total proportion of developed land as the sum of all residential development categories.

Point locations of all oil and gas wells in the study area (conventional gas, oil and carbon dioxide, unconventional gas and oil, and disposal wells) were used to examine patterns of energy development on deer ranges. Well locations were obtained from the Colorado Oil and Gas Conservation Commission and were attributed with the first date of activity (initiation of drilling). Of the 86 999 wells drilled in Colorado, the date of first activity was unknown for 8% and we excluded these from our analyses. We identified areas within 200 m, 700 m, and 2700 m of all wells at a 100-m resolution; we chose these buffer distances based on prior studies demonstrating reduced selection of habitat by mule deer within those distances of wells (Sawyer *et al.*, 2006; Northrup *et al.*, 2015). On an annual basis, we calculated the proportion of each DAU, winter and summer range within the three buffer distances of a well, given the first year that drilling was recorded for individual well sites. These areas depicted cumulative impacts of energy development over time.

To assess weather conditions that may influence deer recruitment, we used historic data from the Parameter-elevation Regressions on Independent Slopes Model (PRISM; www.prism.oregonstate.edu). The model depicts precipitation and temperature on a monthly basis at an 800-m resolution. Across each summer range, we calculated the mean minimum temperature in June (°C), total precipitation in June (cm), cumulative average precipitation from May through September (cm), and the average maximum temperature from June through August (°C). June is the month that fawns are born, and we suspected that their survival may be reduced by cold, wet weather (Gilbert & Raedeke, 2004). Meanwhile, summer precipitation has been correlated with forage quality (Blanchard *et al.*, 2003), increased recruitment (Hurley *et al.*, 2011),

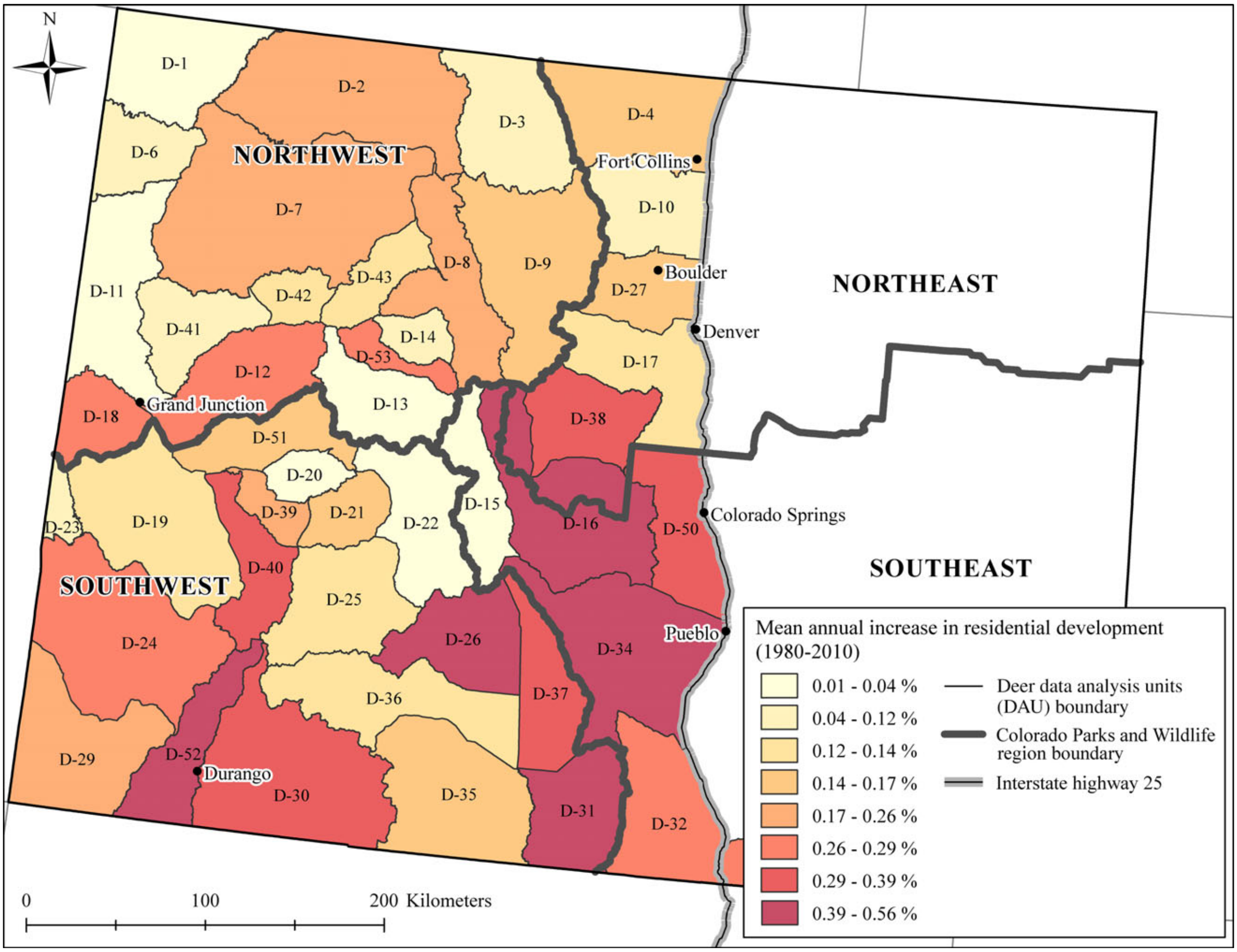

Fig. 1 Map of deer data analysis units (DAUs) and regions in Colorado designated by Colorado Parks and Wildlife. Colors represent the average annual rate of increase in total residential development between 1980 and 2010.

and maternal condition in ungulates (Cook *et al*., 2004), while high summer temperatures have been associated with smaller litter sizes (Monteith *et al*., 2014) and reduced recruitment (Monteith *et al*., 2015). Across each winter range, we calculated cumulative average precipitation (cm) and average minimum temperatures (°C) between December and March. These metrics were used to indicate winter severity, as harsh winters prior to parturition can reduce maternal condition in ungulates (Parker *et al*., 2009).

Mule deer data

Between 1980 and 2010, posthunting season helicopter surveys were conducted in each mule deer DAU in most years. Surveys occurred between 1 December and 15 January; survey data collected in January were considered data from the previous calendar year (the biological birth year of the fawns). During surveys, nonrandom paths were flown across the winter ranges with the purpose of observing a representative sample of deer to assess herd composition. Deer were classified as adult females, fawns (7–8 month olds), or males based on body size and antler morphology (mean number of deer classified/DAU/year = 1507). Annual ratios of the number of fawns/100 adult females (n = 904 fawn ratios) and the number of males/100 adult females (n = 694 male ratios) for each DAU were calculated from classification data. We also recorded CPW's estimate of the number of female deer harvested during hunting seasons in each year for each DAU.

We used annual fawn ratios as our measure of fawn recruitment. In actuality, fawn ratios (R) are a function of year-specific birth rates (B), juvenile survival rates (S_J), and adult female survival rates (S_A) following the equation:

$$R = 100 \times B \times \frac{S_J}{S_A}$$

Given that juvenile survival in ungulates is extremely variable, while the birth rate and adult female survival tend to be consistently high (Gaillard *et al*., 2000; Forrester & Wittmer, 2013), these ratios are strongly correlated with juvenile survival and thus recruitment (Raithel *et al*., 2007; Harris *et al*., 2008). While fawn ratios were the primary response variable in our analyses, male ratios and the number of females harvested were included as key covariates. Male ratios largely depend on variation in annual male survival, which is primarily driven by DAU-specific harvest rates in Colorado (Bergman *et al.*, 2011). High male ratios have been found to be inversely related to fawn ratios, presumably as a consequence of density-dependent effects (Bergman *et al.*, 2011, 2015). Female harvest was included as a covariate because the fawn ratio is expected to be higher when more adult females are killed.

Examining associations between changes in land-use and weather with deer recruitment

We quantified annual changes in residential development, energy development, and weather conditions between 1980 and 2010, years when mule deer ratios were also collected. We estimated the temporal trends in these conditions for each DAU, winter and summer ranges by fitting linear mixed models (LMMs; Pinheiro & Bates, 2000) with 'year' as the explanatory variable. We included DAU as a random intercept to account for repeated measurements over time. In addition to estimating mean trends in habitat conditions across DAUs, we also estimated trends for individual DAUs by treating DAU as a fixed effect and interacting DAU with 'year'.

Because there was high potential for multicollinearity among variables, we did not initially fit a single global model, but first investigated the univariate relationships between covariates and fawn recruitment and assessed the correlations among covariates. We used LMMs with a random intercept for DAU; land-use and weather variables that were associated with fawn ratios (80% confidence intervals were nonoverlapping zero) were retained for further modeling (Table S1). We evaluated residential development variables with respect to recruitment only in the current year t (no lag effects), due to linear interpolation of many values. Because the proportions of urban and suburban development within DAUs were so small (<0.05%), we limited our analyses to proportions of rural, exurban, and total development. Energy development variables were evaluated with respect to fawn recruitment in year t and year $t-1$, as we assumed that there may be lag effects for energy impacts, which has been found for other species (Harju *et al.*, 2010). We assessed all summer and winter weather metrics with respect to fawn recruitment in year t, and we also assessed the lag effects (year $t-1$) for summer and winter precipitation and temperature. We expected that cold, wet weather in June could be especially detrimental for fawn survival, so we tested for an interaction between June temperatures and precipitation. We found evidence for this interaction ($\beta = 0.2032$, SE = 0.0961; 95% confidence interval did not overlap zero) and thus included June temperature and precipitation as a 'June weather' interaction term (with main effects) for all further modeling. We also tested for an interaction between winter temperature and precipitation, as we expected that cold winters with high precipitation would be particularly detrimental to subsequent recruitment. There was no evidence for a significant interaction ($\beta = 0.0538$, SE = 0.0374; 95% confidence interval was overlapping zero), and so we excluded this effect from further modeling.

From those variables associated with fawn recruitment, we first examined pairwise correlations among variables within each land-use or weather factor. When variables were highly correlated (Pearson's correlation coefficient $r > |0.6|$), we retained the variable that exhibited a stronger relationship with recruitment based on univariate t-values. Among the residential development variables, % total development across the DAU had the strongest univariate relationship with fawn ratios (Table S1). This variable was highly correlated with all other development variables ($r \geq 0.70$) except for exurban development on winter range ($r = 0.56$) so we retained only these two variables for further analyses. For energy development, the variables associated with fawn ratios were % summer range$_{(t-1)}$ and winter range$_{(t \text{ and } t-1)}$ within 2700 m of a well (Table S1). Due to a high correlation between those variables ($r \geq 0.93$), we only retained % winter range within 2700 m of well$_{(t-1)}$. Except for summer maximum temperatures, all weather variables were associated with fawn recruitment. June minimum temperatures were correlated with winter minimum temperatures$_{(t \text{ and } t-1)}$ ($r \geq 0.60$), and winter temperatures were also correlated across years$_{(t \text{ and } t-1)}$ ($r = 0.68$); we removed winter temperatures from further analyses.

Our final variable set included % total development across the DAU$_{(t)}$, % exurban development on winter range$_{(t)}$, % winter range within 2700 m of a well$_{(t-1)}$, summer precipitation$_{(t)}$, winter precipitation$_{(t \text{ and } t-1)}$, and June weather$_{(t)}$. We checked for correlations among these variables, but none were highly correlated ($r < 0.4$). We then tested for interactions between some variables across factors with respect to fawn recruitment. We tested for an interaction between energy development and total residential development because we expected that there may be a synergistic effect between these development types on mule deer. We also tested for interactions between energy development on winter range and winter precipitation and between exurban development on winter range and winter precipitation; we assumed that the impacts of development on winter range may be particularly pronounced during harsh winters. There was only evidence for an interaction between energy development and precipitation on winter ranges ($\beta = 0.0112$, SE = 0.0044; 95% confidence interval did not overlap zero) so we retained this interaction (and its main effects) for further modeling.

From those variables that were retained, we then conducted model selection on all subsets of variables (Table S2). We used LMMs with a random intercept for DAU and assessed model assumptions by checking residual and fitted values and using quantile–quantile plots of the residuals of fixed and random effects. Where energy development and precipitation on winter range occurred in the same model, we also tested a model with an interaction between those variables (31 additional models). Given a strong association between male deer ratios in year $t-1$ with fawn ratios in year t (Table S1; Bergman *et al.*, 2011), and an association between female harvest and fawn ratios in year t (Table S1), we also included these variables as nuisance parameters in all models. We did not have male ratio data in year $t-1$ for all observations of fawn ratios, but male ratios were highly temporally correlated ($r = 0.75$) so we used linear interpolation to generate missing values between years with observed ratios. When the first male ratio in a time series for a DAU was missing, we assumed that the ratio in year t was the same as in year $t + 1$. Univariate coefficients for the association between fawn recruitment (year t) and male ratios (year $t{-}1$) for the actual data ($\beta = -0.1104$, SE = 0.0412) and the interpolated data ($\beta = -0.1284$, SE = 0.0400) were similar.

We calculated AIC_c, ΔAIC_c, and the weight of each model (Burnham & Anderson, 2002). Because several models had similar AIC_c scores, we averaged all models (based on model weights) with weights > 0 to obtain final parameter estimates. The coefficient for a variable was averaged from all models where that variable was present, using unconditional standard errors (Burnham & Anderson, 2004). Additionally, we calculated standardized coefficients (averaged across the same top set of models) to assess the relative effects of different covariates on fawn recruitment (Schielzeth, 2010). To estimate standardized coefficients, we ran models using predicator variables that were centered and scaled. All models were fit with maximum-likelihood estimation using the package 'lme4' (Bates *et al.*, 2013) in program R version 3.0.2 (R Core Team 2013). Model averaging was conducted with the R package 'MuMIn' (Barton, 2013).

Results

Changes in land-use and weather

Between 1980 and 2010, an additional 1 004 331 ha of DAUs were impacted by changes in residential development (96% was rural or exurban), representing a 37% increase in residential land-use in deer DAUs within that time. Increases in residential development were significant for all density classes, particularly on mule deer winter ranges (Table 1). On average, 23.8% of deer winter ranges overlapped with residential development in 1980, while 31.2% overlapped with development in 2010. On average, 14.0% of deer summer ranges overlapped with development in 1980 and 19.5% in 2010. Increases in residential development varied widely among deer DAUs (Fig. 1). By 2010, between 0.7% and 66.0% of DAU winter ranges overlapped with residential development, while between 0.8% and 46.0% of summer ranges overlapped with residential development.

Table 1 Model parameters from testing for temporal changes to mule deer winter and summer ranges from residential development, energy development, and weather conditions from 1980 to 2010. We report the mean changes in habitat conditions across all deer data analysis units (DAUs) and for individual DAUs (estimated using random coefficients). We also report temporal trends in fawn ratios (fawns/100 adult female deer), male ratios (males/100 adult female deer), and female deer harvest, which are relevant to the entire DAU

Habitat variable	Deer range	All DAUs			Range of β among DAUs
		Estimate	SE	t	
Residential development (%)					
Rural	Winter	0.1016	0.0073	13.96	−0.600, 0.716
Exurban	Winter	0.1357	0.0046	29.24	0.010, 0.835
Total development	Winter	0.2460	0.0057	43.27	0.000, 0.850
Rural	Summer	0.1127	0.0051	22.19	−0.270, 0.651
Exurban	Summer	0.0658	0.0022	30.17	0.000, 0.332
Total development	Summer	0.1845	0.0045	40.78	0.017, 0.650
Energy development (%)					
200 (m)	Winter	0.0299	0.0022	13.76	0.000, 0.318
700 (m)	Winter	0.1259	0.0083	15.21	0.000, 1.229
2700 (m)	Winter	0.2376	0.0117	20.39	0.000, 1.441
200 (m)	Summer	0.0128	0.0013	9.94	0.000, 0.262
700 (m)	Summer	0.0658	0.0053	12.51	0.000, 1.018
2700 (m)	Summer	0.1754	0.0105	16.64	0.000, 1.908
Weather variables					
Winter Precip (cm)	Winter	−0.0067	0.0106	−0.63	0.012, 0.075
Winter Min Temp (°C)	Winter	0.0294	0.0041	7.23	−0.055, 0.053
June Min Temp (°C)	Summer	0.0440	0.0033	13.33	−0.276, −0.052
June Precip (cm)	Summer	−0.0141	0.0058	−2.42	−0.090, 0.150
Summer Precip (cm)	Summer	−0.1622	0.0161	−10.10	0.005, 0.046
Summer Max Temp (°C)	Summer	0.0200	0.0032	6.34	0.002, 0.052
Fawn ratio	DAU	−0.4986	0.0598	−8.34	-8.501, 0.172
Male/female ratio	DAU	0.6825	0.0317	21.51	−3.076, 1.276
Female harvest	DAU	−7.8143	1.4400	−5.43	−26.590, −0.077

Over the course of the study, the area within 200 m, 700 m, and 2700 m of wells on mule deer ranges increased by 118 295, 539 830, and 1 250 654 ha, respectively. Given these three buffer distances, this equated to an increase in the area impacted on deer ranges of 246%, 146%, and 56%, respectively. The proportions of both winter and summer ranges affected by energy development increased significantly over time at all spatial scales, although winter ranges experienced the greatest impacts (Table 1). In 1980, across all DAUs, the average proportion of winter range within 200 m of a well was 0.2%, within 700 m was 2.5%, and within 2700 m was 16.7%; in 2010, it was 1.1%, 6.3%, and 23.8%, respectively. Similarly, in 1980, the average proportion of summer range within 200 m of a well was 0.1%, within 700 m was 1.2%, and within 2700 m was 10.3%; in 2010, it was 0.5%, 3.2%, and 15.6%, respectively. Increases in energy development varied widely among DAUs (Table 1). By 2010, up to 9% of a winter range was within 200 m of well, up to 39% was within 700 m of well, and up to 80% was within 2700 m of a well. By 2010, up to 8% of a summer range was within 200 m of a well, up to 29% was within 700 m of a well, and up to 68% was within 2700 m of a well.

Seasonal temperature metrics increased significantly over time, while seasonal precipitation metrics significantly decreased. The only exception to this pattern was winter precipitation which displayed no temporal trend (Table 1). Between 1980 and 2010, models estimated that on average, June mean minimum temperatures increased from 3.91 °C to 5.23 °C, summer mean maximum temperatures increased from 21.98 °C to 22.58 °C, winter mean minimum temperatures increased from −10.72 °C to −9.84 °C, June precipitation decreased from 3.42 cm to 3.00 cm, and summer precipitation decreased from 26.29 cm to 21.42 cm.

Changes in mule deer ratios

The mean fawn ratio across all DAUs over the course of the study was 56.0 fawns/100 adult females (SE = 13.6), with mean ratios in different DAUs ranging between 42.9 and 76.6. Across all DAUs, in 1980 the modeled mean ratio was 65.4 (SE = 1.4), and in 2010, it was 50.4 (SE = 1.3, Table 1). Over the course of the study, recruitment decreased by an average of 0.5 fawns/100 adult females/year (Table 1). Rates of change were highly variable among DAUs. Forty DAUs exhibited declining trends over time, while 4 DAUs exhibited slightly increasing trends (Fig. 2), with the rates of change varying between −8.50 to 0.15 fawns/100 adult females/year. Between 1980 and 2010, the ratio of adult male to adult female mule deer significantly increased (Table 1). In 1980, the mean was 13.5 adult males/100 adult females (SE = 1.1), and by 2010, the mean was 34.0 adult males/100 adult females (SE = 1.0). Female deer harvest significantly decreased over time (Table 1), as in 1980 the mean number of females harvested in a DAU was 384.1 (SE = 52.5) and by 2010 it was 149.7 (SE = 49.3).

Associations between changes in land-use and weather with deer recruitment

We ran a total of 160 models to investigate the effects of land-use change and weather on fawn recruitment. These models included all subsets of our final seven variables (refer to Methods for details) with additional models to test for an interaction between precipitation and energy development on winter range (Table S2). A total of 28 models had a weight > 0 and were included in model averaging. Considering those models, the top model accounted for 21% of the model weight and included all variables (and interactions) except for exurban development on winter range. The second best model, accounting for 16% of the model weight, included the same variables, but omitted summer precipitation.

Fawn ratios decreased in association with increasing residential development, energy development, June minimum temperatures, and winter precipitation prior to parturition (Table 2, Figs 3 and 4a). Fawn ratios increased in association with winter precipitation in the previous year (lag effect; Table 2, Fig. 3). There was a significant interaction between energy development and precipitation on winter range, suggesting that

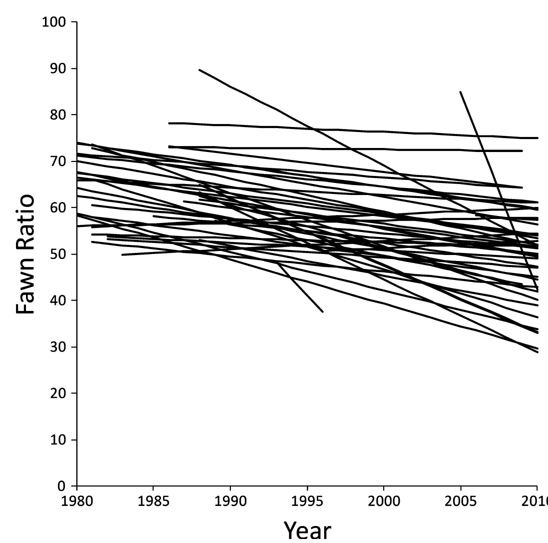

Fig. 2 Temporal trends in mule deer fawn ratios (the proportion of 7–8 month olds/100 adult females) for deer data analysis units in Colorado, 1980–2010.

Table 2 Unstandardized and standardized model-averaged coefficients (and 95% confidence intervals) for associations between mule deer fawn ratios and habitat variables for deer data analysis units (DAUs) in western Colorado. Model parameters are listed in order of the magnitude of their standardized coefficients, and identify whether they are correlated with fawn ratios in the current year (t) or the following year (lag effect; $t-1$). 'Range' signifies whether the variable was summarized across the winter range, summer range, or over the entire DAU

		Unstandardized coefficients				Standardized coefficients			
Model parameter	Range	β	SE	L95%	U95%	β	SE	L95%	U95%
Intercept	–	68.351	5.294	57.975	78.727	56.923	1.387	54.204	59.642
Total residential develop$_{(t)}$	DAU	−0.310	0.128	−0.561	−0.059	−2.892	1.178	−5.201	−0.583
Energy Develop$_{(t-1)}$	Winter	−0.191	0.083	−0.354	−0.028	−1.462	1.149	−3.714	0.790
Winter Precip$_{(t-1)}$	Winter	0.308	0.115	0.083	0.533	1.317	0.492	0.353	2.281
Winter Precip$_{(t)}$	Winter	−0.508	0.190	−0.880	−0.136	−1.215	0.504	−2.203	−0.227
June Min Temp$_{(t)}$	Summer	−1.133	0.440	−1.995	−0.271	−1.214	0.879	−2.937	0.509
Energy Develop$_{(t-1)}$ * Winter Precip$_{(t)}$	Winter	0.012	0.004	0.004	0.020	1.083	0.414	0.272	1.894
June Min Temp$_{(t)}$ * June Precip$_{(t)}$	Summer	0.198	0.095	0.012	0.384	0.949	0.454	0.059	1.839
Summer Precip$_{(t)}$	Summer	0.142	0.082	−0.019	0.303	0.886	0.508	−0.110	1.882
% Exurban development$_{(t)}$	Winter	−0.124	0.207	−0.530	0.282	−0.734	1.206	−3.098	1.630
Male/female ratio $_{(t-1)}$	DAU	−0.054	0.044	−0.140	0.032	−0.600	0.492	−1.564	0.364
Female deer harvest$_{(t)}$	DAU	0.001	0.001	−0.001	0.003	0.469	0.526	−0.562	1.500
June Precip$_{(t)}$	Summer	−0.739	0.190	−1.111	−0.367	0.366	0.500	−0.614	1.346

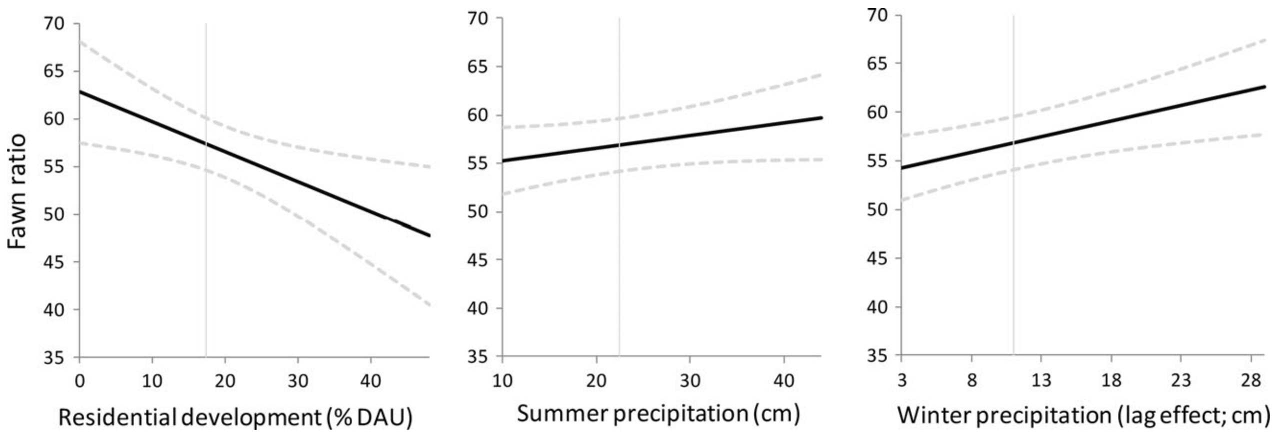

Fig. 3 Modeled predicted effects of the proportion of residential development (across deer data analysis units), summer precipitation, and winter precipitation on mule deer fawn ratios in western Colorado. The effects of residential development and summer precipitation are depicted for the current year (t), and winter precipitation is depicted in the previous year (two winters prior to parturition; year $t-1$). Predictions are based on the top linear mixed-effect model and are shown across the observed range of variation for covariate values. Median covariate values are depicted by the gray lines.

winter severity had the greatest effect on fawn recruitment when energy development was minimal and dampened as the proportion of energy development increased (Fig. 4b). Fawn recruitment was predicted to be highest when both winter precipitation and energy development were low. There was also a significant interaction between June temperature and precipitation, which indicated that cold weather was most beneficial for fawn recruitment when precipitation was low, while warm weather was most beneficial when precipitation was high (Fig. 5). There were other variables that were included in the top model set, but had coefficients with confidence intervals overlapping zero. These were summer precipitation and female deer harvest, which both had a positive association with recruitment, and exurban development and the male ratio (in the previous year), which both had a negative association with recruitment (Table 2).

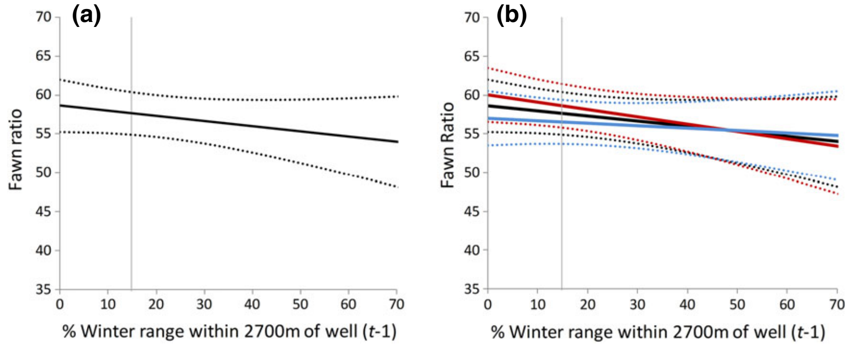

Fig. 4 Modeled predicted effects of the interaction between energy development (the proportion of winter range within 2700 m of a well) and winter precipitation on mule deer fawn ratios in western Colorado. Energy development is modeled with a lag effect (year $t-1$), and winter precipitation is modeled just prior to parturition (year t). Predicted fawn ratios for a) the observed range of energy development values given the median amount of winter precipitation (11.0 cm) and b) for the 25% (red lines), 50% (black lines), and 75% (blue lines) quartiles of winter precipitation values. The median value of energy development is depicted with a gray line.

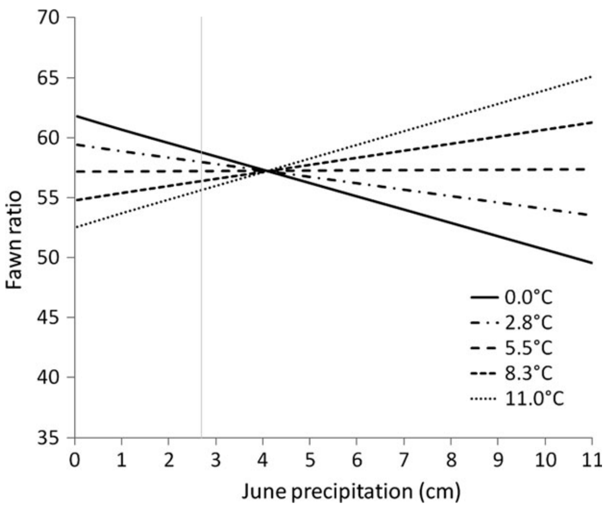

Fig. 5 Modeled predicted effects of the interaction between June minimum temperature and precipitation on mule deer fawn ratios in Colorado (modeled for the current year t). Predictions were based on the top linear mixed-effect model and are shown across the range of observed temperature and precipitation values. The median value for June precipitation is depicted by the gray line.

Standardized coefficients of the main effects suggested that residential development had the largest effect on fawn recruitment, having approximately 2 times the magnitude of any other effect. Fawn ratios were predicted to vary by approximately 15 fawns/100 adult females across the observed range of residential development values. Energy development had the second largest effect on recruitment, followed closely by the weather variables (Table 2).

Discussion

Land-use change due to residential and energy development is projected to increase rapidly in the western United States (Theobald, 2005; Copeland *et al.*, 2009) and around the world (Seto *et al.*, 2012; International Energy Agency 2015). Land-use change is often associated with shifts in animal behavior (Tuomainen & Candolin, 2011) and habitat use (Nellemann *et al.*, 2007), with most studies focusing on short-term effects (<10 years) at relatively local scales (within a municipality or county; Pejchar *et al.*, 2015). Researchers have hypothesized that land-use change may have long-term or lagged effects on animal population dynamics (Hansen *et al.*, 2005; Harju *et al.*, 2010), but this has rarely been evaluated empirically. We combined broad-scale, long-term data on land-use change and mule deer demography to conduct the first analysis to quantify the impacts from residential and energy development to deer habitat and to correlate those changes with deer demographic performance. Our results indicate that declining recruitment rates are correlated with expanding residential and energy development, particularly within deer winter ranges. Comparing the relative associations between recruitment and land-use and weather factors, we found that residential housing had two times the magnitude of effect of any other factor correlated with recruitment and that energy development had an effect size similar to key weather variables known to be important to juvenile deer survival (Hurley *et al.*, 2011, 2014; Monteith *et al.*, 2015).

While residential development and energy development were associated with declining fawn recruitment, the specific mechanisms responsible for these correlations are unknown. Land-use change causes direct habitat loss and fragmentation through the construction of infrastructure, and indirect habitat loss through deer avoidance of infrastructure and related activities (Vogel, 1989; Sawyer *et al.*, 2009; Northrup *et al.*, 2015); these consequences likely reduce the carrying capacity of the landscape. It has also been documented that deer migrating through areas with high densities of energy development detour from established routes, increase rates of movement, and reduce stopover use (Sawyer *et al.*, 2013), impacts that may increase energetic costs while decreasing access to high-quality forage. Additionally, mule deer may suffer higher mortality rates in developed landscapes compared to natural areas (but see Hebblewhite & Merrill, 2011). Deer in close proximity to residential housing can experience increased vehicle collisions, harvest, poaching, accidents (i.e., entrapment in fences), and predation from domestic pets (Porter *et al.*, 2004; Krausman *et al.*, 2011). Deer in the vicinity of energy development may also experience higher rates of vehicle collisions, harvest, and poaching, particularly as a function of the associated road network (Dzialak *et al.*, 2011). We suspect that several of these factors contribute to the negative association between land-use change and deer recruitment, but experimental research is needed to identify the specific mechanisms responsible.

Both types of land-use change were correlated with declining recruitment rates, but the relationship with residential housing was much stronger than that of energy production. We suspect that risks for mule deer are more pervasive around residential housing where human activities are continuous or may increase over time (i.e., as the human population and housing densities increase), compared to areas impacted by energy development where disturbance typically declines over time (i.e., as new drilling and construction of infrastructure wane, see Northrup *et al.*, 2015). Rural and exurban housing are also likely to be constructed in areas of particularly high-quality mule deer habitat, especially on winter ranges where the same biophysical features selected by deer are also often selected by people (i.e., low-elevation valley bottoms with minimal snow and high solar radiation; Hansen *et al.*, 2005; Leu *et al.*, 2008). Differences in the magnitude of the correlation between residential and energy development may also stem from disparities in land ownership, and the associated development patterns and management practices, that are associated with these two development types. In the intermountain west, energy development occurs primarily on federally owned public property where land management agencies are required to consider impacts to natural resources, including wildlife. Meanwhile residential development occurs primarily on private property with few constraints and often in areas where planning jurisdictions have limited capacity to incorporate conservation considerations into development decisions (Miller *et al.*, 2008). We suspect that these differences contribute to a stronger negative association between recruitment and residential housing, yet to date, there has been much more research on the effects of energy development on ungulates (Polfus & Krausman, 2012). Our findings underscore the need to understand the effects of low-density housing on mule deer and other wildlife, despite the conservation challenges associated with private property.

Weather conditions have long been recognized to influence ungulate fecundity and juvenile survival through both direct effects on fawns and indirect effects on maternal condition; our results largely echo findings from other studies. Winter precipitation just prior to parturition was negatively correlated with recruitment, presumably by taxing the energetic demands of pregnant females (Parker *et al.*, 2009). Conversely, winter precipitation in the previous year ($t-1$; two winters before parturition) was positively associated with recruitment in year t. This pattern likely resulted from changes in adult female body condition. Harsh winters reduce subsequent fecundity and increase the number of nonlactating adult females during the summer. These females should be in excellent condition the following year, which likely gives a boost to fecundity rates in year t (Parker *et al.*, 2009; Monteith *et al.*, 2013). As other investigators have found (Gilbert & Raedeke, 2004), cold, wet June weather was negatively associated with fawn recruitment, presumably due to the detrimental effects of harsh weather on neonates. That said, June precipitation in western Colorado is usually very low (median value was 2.7 cm), and under typical dry conditions, warm weather was more negatively associated with recruitment than cool weather (Fig. 5). Warmer temperatures have been related to shorter durations of spring and summer green-up, reducing the availability of high-quality forage to ungulates (Middleton *et al.*, 2013; Monteith *et al.*, 2015), a mechanism that may be responsible for lower fawn ratios in our study. Relative to other weather metrics, the positive correlation between overall summer precipitation and recruitment was nonsignificant (Table 2). Late summer rainfall is generally scarce across the intermountain west, causing higher precipitation to be associated with increased recruitment (Hurley *et al.*, 2011), presumably due to improved forage quality. Colorado, however, regularly benefits from late summer monsoon rains, which likely reduces the importance of this variable in our study system.

Of the three buffers around oil and gas wells that we evaluated, only the 2700-m buffer was correlated with recruitment, and the effect was consistently associated with an interaction with winter precipitation (Table S1, Table 2). While Sawyer *et al.* (2006) found that mule deer resource selection declined within 2700 m of a well pad in the Green River Basin of Wyoming, Northrup *et al.* (2015) found that deer reduced their selection of habitat around well pads at smaller buffer distances in the Piceance Basin of Colorado (generally <800 m). We suspect that recruitment in our study was correlated with the larger buffer distance due to the broad spatial extent of the analysis, as associations were summarized across multiple habitat and terrain types. With respect to the interaction, both energy development and winter precipitation were negatively correlated with fawn ratios (Table 2, Fig. 4a), but the influence of winter severity dampened as a greater proportion of the winter range was impacted by energy development (Fig. 4b). We hypothesize that this relationship is a function of the effects of both these factors on maternal condition, with subsequent implications for recruitment. Both energy development and winter precipitation values were estimated before fawns were born, and would have influenced adult female deer on winter range just prior to parturition. We speculate that female deer on ranges with widespread energy development may have diminished body condition as a consequence of direct and indirect losses of habitat (Sawyer *et al.*, 2006, 2009; Northrup *et al.*, 2015). If body condition is already reduced in these deer, with ensuing effects on recruitment, the additional influence of harsh winter weather may be minimal.

We were interested in assessing the relative strength of correlations between land-use change and weather variables with mule deer recruitment, but we expect that the cumulative effects of these factors, and other factors outside the scope of our study, are driving observed variation in deer productivity. Variation in forage quality, harvest, predation, disease and interspecific competition (with domestic livestock and wild ungulates) can all influence ungulate demographic rates (Gross & Miller, 2001; Cook *et al.*, 2004; Bergman *et al.*, 2011; Brodie *et al.*, 2013; Hurley *et al.*, 2014). While we did not have data with comparable spatial or temporal extents to investigate these other factors, we suspect that some are highly important in the dynamics of deer across our study area (e.g., forage quality; Bishop *et al.*, 2009; Bergman *et al.*, 2014). For those land-use and weather factors that we did investigate, their long-term temporal trends are highly disconcerting for mule deer. The intermountain west continues to experience some of the highest rates of human population growth in the United States, with extensive changes in land-use projected along the urban–wildland interface (Theobald & Romme, 2007). At the same time, climate change models forecast increases in temperature and reductions in summer precipitation (Ray *et al.*, 2008), patterns that were negatively correlated with deer recruitment. Finally, model-averaged coefficients demonstrated that increasing male ratios were weakly associated with declining recruitment (although confidence intervals overlapped zero). Male ratios closely correspond to harvest management, and increases in ratios that are intended to boost male numbers and hunter satisfaction, may inadvertently decrease productivity through density-dependent effects (Bergman *et al.*, 2011, 2014). Combined with those factors that we could not address in our analysis, we suspect that further losses of habitat, unfavorable climate conditions, and high male ratios may pose considerable challenges for maintaining deer recruitment rates in the future.

We detected significant relationships between deer recruitment and habitat conditions, but it is important to acknowledge the drawbacks of our analysis that limit our scope of inference. The correlations we detected between recruitment and habitat conditions do not demonstrate causation, as our analyses relied on long-term observational data. Additionally, the data sources used in this analysis were coarse. Fawn ratios are strongly correlated with juvenile survival (Raithel *et al.*, 2007; Harris *et al.*, 2008), but are not a precise measure of the number of recruits that are added annually to a population. This is particularly true for our early-winter fawn ratios (collected Dec–Jan) which did not incorporate the survival of juveniles through the end of winter. In addition, we were not able to identify the effects of different types of residential and energy development disturbances on recruitment, although studies have found that behavioral responses of mule deer vary in association with distinct activities at energy wells (Sawyer *et al.*, 2009; Northrup *et al.*, 2015). The extensive spatiotemporal scale of our study also limited the data sources available for tracking changes in habitat conditions. We used the best information available, but these included model-based estimates (SERGoM residential development data, PRISM climate data), relatively large grain sizes for some variables (800 m pixel size of PRISM data), and coarse temporal resolution for others (SERGoM data). We believe that population and habitat data depicted important trends in these variables over time, but also expect that considerable noise was inherent in these datasets. Despite these drawbacks, we were able to use extensive spatiotemporal variation to identify a critical link between deer demography and landscape conditions, relationships that should be investigated further with finer-scale data.

Our findings have important implications for the conservation of mule deer in Colorado. Adequate, high-quality winter range has been hypothesized to be the primary factor limiting mule deer in the state

(Bergman *et al.*, 2015), and our findings support this speculation as land-use changes on winter ranges were more strongly correlated with declining recruitment than changes on summer ranges. Indeed, over the course of the study, an additional 1 335 992 ha of winter range was impacted by land-use change, such that by 2010, an average of 31% of winter ranges were affected by residential development and 24% were affected by energy development (at the 2700 m buffer distance). If healthy mule deer populations are going to be maintained, conservation practitioners, policy-makers, and land-use planners will need to collectively work to ensure that seasonal habitats, particularly winter ranges, are well preserved. DAUs with larger proportions of privately owned land will be particularly susceptible to increases in residential development and should be prioritized for conservation. Wildlife professionals will need to work closely with state and municipal governments to adopt land-use regulations and incentives to minimize subdivisions, and encourage land trusts and open space agencies to implement conservation easements for habitat protection (Pruetz & Standridge, 2008; Reed *et al.*, 2014). DAUs with larger proportions of public land may be more productive over time, particularly those with minimal energy development. For those DAUs experiencing high levels of energy development, wildlife professionals will need to encourage federal land management agencies to minimize the spatial extent and density of wells (Sawyer *et al.*, 2006) and avoid sensitive periods when scheduling drilling activities (e.g., winter months; Northrup *et al.*, 2015). While research is needed on the mechanisms responsible for the correlation between land-use change and declining mule deer recruitment, our results suggest that additional development will likely exacerbate reductions in recruitment, a pattern that should be carefully considered when wildlife agencies specify long-term population objectives.

Short-term and local-scale research on the effects of residential development on ungulates largely indicate limited impacts on habitat use (e.g., Goad *et al.*, 2014), but our analysis suggests that such development may have substantial long-term effects on population processes. Indeed, we observed stronger correlations between deer recruitment and residential housing than for weather factors that are well known to drive annual variation in ungulate productivity. Unfortunately, quantifying the impacts of residential development on animals is challenging (Polfus & Krausman, 2012); opportunities for experimental research are limited, the new construction of housing units occurs gradually, there is high potential for a diversity of direct and indirect effects, animals are likely to alter their behavior to mitigate demographic impacts, and population-level consequences may take several years to manifest. Given these constraints, reliable long-term datasets that track animal population dynamics with respect to changes in landscape conditions will be critical for elucidating the role of potentially important, but subtle factors, before they degrade populations beyond recovery.

Acknowledgements

We thank all CPW staff that collected mule deer classification data across Colorado. We are grateful to D. Ahlstrand and C. Woodward for their assistance processing data from Colorado's Oil and Gas Conservation Commission, and J. Northrup and C. Anderson for advice on quantifying energy infrastructure on the landscape. We thank J. Runge for statistical advice. Funding to quantify changes to mule deer habitat from spatial covariates was provided by CPW's Auction and Raffle Grant Program.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Results from univariate linear mixed models correlating different habitat variables with mule deer fawn ratios.
Table S2. Model selection results from testing all subsets of habitat variables with mule deer fawn ratios.

COLORADO
Parks and Wildlife
Department of Natural Resources
Glenwood Springs Area Office
0088 Wildlife Way
Glenwood Springs, CO 81601

Attachment G

November 7, 2016

White River National Forest
Scott Fitzwilliams, Forest Supervisor
c/o Matt Klein, Realty Specialist
PO Box 190
Minturn, CO 81645

RE: Berlaimont Estates Access Route EIS Scoping Comments

Dear Mr. Fitzwilliams,

Thank you for the opportunity to review the proposed access route for the Berlaimont Estates private inholding. Colorado Parks and Wildlife (CPW) appreciates the opportunity to be actively engaged throughout the NEPA process. CPW has a statutory responsibility to manage all wildlife species in Colorado; this responsibility is embraced and fulfilled through CPW's mission to protect, preserve, enhance, and manage the wildlife of Colorado for the use, benefit, and enjoyment of the people of the State and its visitors. Colorado Parks and Wildlife staff has reviewed this project and we offer the following comments and recommendations for your consideration.

General Comments:

While the Alaska National Interest Lands Conservation Act (ANILCA) statute, Section 1323 (a) (incorporated into 36 CFR Subpart D), compels the USFS to authorize access to non-federal land within the boundaries of NFS lands, ANILCA also states, "...to the extent that such access is adequate for providing reasonable use and enjoyment of that inholding consistent with other, similarly situated non-federal lands. In addition to providing reasonable use and enjoyment, 36 CFR Subpart D requires that any authorized access route be located and constructed so as to minimize damage or disturbance to NFS lands and resources."

There are numerous similarly situated non-federal lands within the White River National Forest that do not require a paved all-season road for reasonable use and enjoyment. Some examples would be Fulford, Homestake Creek, Tigiwon Road, Piney Lake, and Carbonate.

The request for a 20' wide paved road with 3' gravel shoulders on each side is a requirement from Eagle County and not required under ANILCA. There are numerous roads throughout Eagle County that provide access to private lands with the same or higher density of homes that don't have paved 26' wide road platforms.

Amending the Forest Plan to the detriment of Management Area 5.41 (Deer and Elk Winter Range) and several species on the Region 2 sensitive species list does not appear to be meeting 36 CFR Subpart D that requires any authorized access route be located and constructed so as to minimize damage or disturbance to NFS lands and resources. Loss of wildlife connectivity due to the road construction across the mule deer migration corridor would have noteworthy impacts to the mule deer herd within Eagle County.

Since the land cannot be developed without the road improvement. The proposal would appear to be a connected action with the development of the land. As such, the EIS should include the impacts from the development as well as the road construction.

Wildlife Comments:

CPW has reviewed this proposal based on the Area of Influence (AOI) which spans from Berry Creek west to Red Canyon, all within game management unit (GMU) 36. Due to the wide ranging nature of the big game species and their associated habitats impacted by this project, this AOI is as small a unit as could be looked at with any level of confidence.

Mule Deer: The proposal is located within Data Analysis Unit (DAU) D8, which contains GMUs 35, 36, 45 and 361. The AOI contains the following significant mule deer habitats; winter range, severe winter range, winter concentration areas and deer migration corridor. Any additional loss of these habitats could result in a further reduction in population levels. CPW updated the Data Analysis Unit Plan for the Upper Eagle River Valley deer herd (DAU D8) in 2009. The population objective for D8 has been reduced several times since 1980; in 1988 it was reduced from 26,000 to 21,000 and it was reduced from 21,000 to a range of 13,500 to 16,500 in 2009. The need to reduce the population objective was due to several factors with the main three factors being; loss of winter habitats (largely due to development), habitat fragmentation and recreational impacts.

The AOI contains 17% of the winter range, 21% of the severe winter range and 25% of the winter concentration areas for the entire GMU 36. The three-year average for winter classification counts shows that 27.9% of the total deer classified in GMU 36 are within the AOI. These figures show that mule deer use the AOI at a slightly higher ratio than the habitats occur on the overall landscape within the GMU, signifying the importance of this area.

The most critical habitat within the AOI is the mule deer migration corridor. This corridor was well documented during studies for the construction of I-70 through Eagle County. The road will bisect what is generally considered the second largest migratory mule deer herd in Colorado. The work done for the I-70 construction showed the corridor to extend from south of Vail Pass to as far west as Gypsum and Dotsero. The deer migration corridor is generally cut off at an elevation of 9,000' by snowfall. Studies have shown that when a migration corridor is blocked or seriously restricted, wildlife is negatively impacted. The impacts are varied and range from increased chances of disease from increased animal densities, poor body condition resulting in reduced birth rates, winter mortality from starvation, reduced population levels, over grazing of the winter range, reduced plant vigor, and more soil erosion.

Elk: The proposal is located within Data Analysis Unit (DAU) E12, which contains GMUs 35, 36, and 361. The AOI contains the following significant elk habitats mapped by CPW; winter range, severe winter range, and winter concentration areas. CPW updated the Data Analysis Unit Plan for the Upper Eagle River Valley elk herd in 2013. During the period from 1988 to 2005, E12 had an estimated elk population of over 5,000. The population reached a high of just under 7,000 elk in 2001. In 2013 the population objective for E12 was set at a range of 3,000 to 4,600. The need to reduce the population was due to several factors with the main three factors being; loss of winter habitats (primarily due to development), habitat fragmentation, and recreational pressures. Any additional loss of these habitats could result in a further reduction in population levels.

The AOI contains 16% of the winter range, 23% of the severe winter range and 22% of the winter concentration areas for the entire GMU 36. The three-year average for winter classification counts for the AOI shows that 23.8% of the total elk classified in GMU 36 are within the AOI. These figures show that elk use the AOI at a slightly higher ratio than the habitats occur on the landscape within the GMU.

Greater sage-grouse: The AOI for greater sage-grouse (GrSG) is from June Creek west to Red Canyon. This AOI is based on satellite collar data from GrSG during the winter of 2009-2010.

The proposed project bisects GrSG occupied range for the North Eagle and South Routt (NESR) population. The area is classified as a General Habitat Management Area (GHMA) in amended federal plans for GrSG. This project is located in the southeast extent for the NESR population and also the very southeasterly portion for the entire range of GrSG in the western U.S. Although this population is small, only 115 known males, and isolated, it is important to protect so not to reduce the overall extent of the range. GrSG are considered landscape scale species that need large, intact, undisturbed sagebrush habitats to maintain populations. Additionally, GrSG are considered a Forest Service Region 2 sensitive species that occur on the WRNF.

It is difficult to quantify GrSG numbers and habitat use in this area due to the ruggedness of the terrain and the small population size. However, in 2009 CPW recorded several GPS locations of a collared GrSG in the location of the proposed project (12/29/2009 to 2/11/2010). In addition, a USFS Wildlife Biologist reported a GrSG hen with 3 chicks on Forest Service property near Berry Creek on July 3, 2012. These observations identify the area as being important for GrSG winter range and brood rearing habitats.

The proposed access road disturbs 2.4 miles of GrSG habitat; 0.5 miles of this is new road construction (Figure 1). The species is sensitive and easily disturbed by land use activities that subdivide the landscape, disrupt the birds' site fidelity to traditional lekking and nesting areas, and ultimately isolate remnants of the population. It has been well documented that roads and other anthropogenic features fragment GrSG habitat and lead to increased predation. Ground nesting birds like grouse are known to experience high levels of nest predation; they will attempt to minimize the risk of predation by directly avoiding predators and indirectly avoiding risky habitats. Roads have been shown to have a negative relationship with grouse survival rates and GrSG often display avoidance behavior towards roads. In recent decades, exurban growth, expressed as rural small-parcel development, has increased the fragmentation of sagebrush habitat in former rangelands. The subsequent expansion of road networks, even low-volume secondary roads, negatively affects GrSG. Recent studies have indicated that minimal road traffic (1-12 vehicles per day) reduces female grouse nest initiation (Lyon and Anderson 2003) and the number of breeding males displaying at leks (Holloran 2005).

Fences are another anthropogenic feature that increase risks for GrSG. Sage-grouse collisions with fences have been studied and documented across the western states. It is not uncommon to find GrSG fence strikes, especially with newly built fences or fences near breeding grounds. Fence posts located in sagebrush habitats also provide raptor perches in areas that lack natural perches.

WRNF has approximately 7,750 acres classified as GrSG occupied range for 3 populations (NESR, Middle Park and Meeker/White River). These are the 3 smallest Colorado GrSG populations and most threatened by anthropogenic activities. The WRNF Land and Resource Management Plan guidelines are inadequate to protect GrSG and its habitat. The guidelines do not address disturbances such as road construction or recreational activities. In 2020, the U.S. Fish and Wildlife Service will review the status of GrSG and assess whether the collective actions of public land agencies and their partners were effective. One of the USFWS concerns specifically addressed the management and implementation of public land agencies' conservation actions to protect GrSG and its habitat.

CPW recommends that WRNF follow the guidelines provided in the BLM Northwest Colorado Greater Sage-Grouse Approved Resource Management Plan Amendment (ARMPA). The plan seeks to minimize impacts in occupied habitat on BLM and USFS lands that require special management to sustain GrSG populations. All threats require and ensure mitigation that provides a net conservation gain to GrSG for actions that result in habitat loss and degradation. Infrastructure and fragmentation are two of the major threats listed in the ARMPA that cause population declines. Infrastructure and urbanization were specifically identified as a threat for the NESR population. The ARMPA recommends avoiding any major or minor new infrastructure disturbance in GHMA.

The ARMPA objective for travel and transportation management is to 1) reduce mortality from vehicle collisions, 2) limit change in GrSG behavior, 3) avoid, minimize and compensate for habitat fragmentation, 4) limit the spread of noxious weeds, and 5) limit disruptive activity associated with human access. The ARMPA suggests avoiding recreational activities that disrupt GrSG, fragment GrSG habitats or spread noxious weeds.

CPW recommends that the AOI surrounding the proposed project be surveyed during the spring (minimum of two years) for sign of GrSG prior to any disturbance. Depending on the survey results, any proposed construction within occupied breeding areas should be prohibited during the lekking, nesting, and brood rearing periods (March 1 to June 30). Any new fences should be marked to help decrease collisions. There are several recommended methods in the literature; any marking methods should be reviewed with CPW to select the ones most appropriate (reflectors, wood stays, etc.).

Miscellaneous Wildlife Species:

Bears & Mountain Lions: Residential developments provide attractants for black bears and mountain lions in a number of ways. Bears are well known to feed on garbage, bird feeders, barbeque grills, pet food, etc., while mountain lions often prey on domestic dogs and cats. Once these animals become habituated to these food sources they often become threats to public safety and must be euthanized by CPW officers. Furthermore, the increase in road-killed animals along the new paved access road will attract bears, coyotes, foxes, etc. as they scavenge on carcasses.

Columbian sharp-tailed grouse: CPW has started a restoration program for Columbian sharp-tailed grouse (CSTG) in Eagle County. CSTG were historically found in Eagle County from Red and White Mountain to Gypsum. CPW has completed two transplants in the area south of State Bridge, there are additional transplants planned. To date, these birds have done well and have spread into adjacent areas with sufficient habitat, including the Muddy Pass area on USFS lands. Historical records show CSTG using the suitable habitat on Red and White Mountain in the 1970's. There is sufficient habitat within June and Berry Creek for CSTG to repopulate these areas. CSTG are listed as a Forest Service Region 2 sensitive species occurring on the WRNF.

Brewer's Sparrow: The Brewer's sparrow is considered a Management Indicator Species (MIS) under the WRNF's 2006 Forest Plan Amendment. In a recent article published by the National Wildlife Federation (Home on the Sage, 2016), the National Audubon Society stated that "Brewer's sparrows won't breed within 40 yards of a road". Applying a 40 yard buffer to each side of the proposed access route would preclude approximately 170 acres of breeding habitat for this species. According to the North American Breeding Bird Survey, populations of Brewer's sparrows have declined by about 49% from 1966 to 2014 with habitat fragmentation listed as a leading cause.

Recreational Impacts:

The increasing level of year-round recreation is having a significant impact on wildlife (Naylor and Wisdom 2009. Behavioral Responses of North American Elk to Recreational

Activity). Any analysis for new road development needs to fully include the impacts from increased access for all forms of recreation. Further, in order to eliminate or reduce these impacts sufficient mitigation measures must be put in place to prevent or offset new impacts to wildlife. There are numerous research studies available documenting the impacts of recreation on wildlife.

The construction of an approximately 5 mile paved road (1.04 miles on NFSR 774, 3.09 miles on NFSR 780 and 1.16 miles of new road across NFS lands) further into Management Area 5.41 has the potential to greatly alter recreational use levels. The development of the paved road could shift the current recreation usage from occurring in areas adjacent to significant human density to areas that have previously provided quality habitat and solitude areas for wildlife. Further, the ability of the public to be able to drive halfway up the mountain before they begin their non-motorized recreation has the potential to impact wildlife habitat use and to negatively impact the percent of time spent feeding and resting. Such impacts can alter the survival of developing fetuses, recruitment, and overall survival of adult animals (Colin, 2007. The Behavioral Ecology of Disturbance Responses). Non-motorized recreation impacts have been documented to impact wildlife use from 100 meters on either side of a trail for deer and up to 1,500 meters for elk (Naylor and Wisdom 2009. Behavioral Responses of North American Elk to Recreational Activity). Research conducted by CPW on mule deer in the Piceance Basin has shown significantly reduced levels of use within 200 meters of oil and gas roads. Figure 2 shows the potentially affected habitat from the proposed access road at both the 200 and 1,500 meter scales. Figure 3 contains the acres of elk and mule deer habitats that would be indirectly impacted at these levels.

The development of the paved road has the ability to cause a change in recreational use patterns. Recreationists may no longer choose to recreate in the area just north of Moonridge Road and may instead choose to recreate in new areas that had previously provided wildlife solitude during the winter and spring periods. These areas could be outside the Berry Creek drainage and the EIS needs to consider these impacts to develop a complete analysis of the cumulative impacts.

CPW feels that there are many unknowns associated with the proposal, and would like to see the following questions addressed in the draft EIS:

1. Will the road be open to public use year-round?
2. What will be the level of vehicle use on the road for people driving the road to access public lands for recreation?
3. Will winter non-motorized recreation be allowed on trails along or adjacent to the road?
4. How will this increase in winter recreation impact wildlife?
5. What type of mitigation can be developed to minimize the cumulative impacts from the new road, increased traffic, and increased recreational use of the Berry Creek drainage?

Road Impacts:

The proposal calls for a 20' wide paved road with 3' shoulders on each side (26' wide overall). However, this does not include the requirement from Eagle County for areas with guardrails needing a 5' shoulder and drainage areas requiring an 8' drainage swale. The proposal also does not include the number and size of pullouts and parking areas required for both emergency vehicles and public access. Without all of the necessary information it is impossible to accurately assess the overall impact from the road construction. Based on GIS analysis, CPW estimates approximately 16.72 acres of big game habitat will be lost on NFS lands based on a minimal road construction width of 30'.

The road plan submitted and approved by Eagle County does not include a geologic hazard study or a debris flow/flood study. Nor has the existing fill material in the present NFS road platform been evaluated to determine if it requires removal prior to the construction of the final road. These items have the potential to impact the location of the road, the duration of construction, and the level of construction traffic. Having these details are essential in determining the overall impacts from the road and if the road is even feasible in its current location.

The road approved by Eagle County shows a total of 22,800' of guardrails. Of this, 9,100' of guardrail is from Moonridge Road to the southeast corner of the Berlaimont property. There is an additional 13,700' of guardrail required for the construction across the private land and for the new road (1.16 miles) across NFS lands to reach the northern portion of Berlaimont Estates. The impact from guardrails in combination with steep slopes has a significant effect on wildlife's ability to safely cross the road. The 2006 publication of AASHTO's Roadside Design Guide recommended that newly installed D4 (1S) W-beam guardrails have a nominal minimum height of at least 27" to the top of the rail, allowing for construction variation of plus or minus one inch. The recommended height for wildlife friendly fencing is 42". As shown in Figure 4 (attached), slope makes a significant difference in the ability for wildlife to cross such barriers. The following table shows the estimated effective fence height based on the slopes referenced within the engineering report and a 27" guardrail.

Slope	Effective Height
Flat Ground (no slope)	27 inches
3 : 1 Slope	47 inches
2 : 1 Slope	60 inches
1.5 : 1 Slope	70 inches

- *Even at a 3:1 slope (33% gradient), the effective height of a 27 inch guardrail surpasses CPW's recommended fence height of 42 inches.*

The plan approved by Eagle County shows the slopes for cut or fill areas (depending on the height of the section) to be as follows:

Cut/Fill Wall Height	Slope to be Used
0 to 4 ft tall	3 : 1
4 to 8 ft tall	2 : 1
8 ft and greater	1.5 : 1

Having obstructions greater than 42" within a deer migration corridor could significantly impact mule deer's ability to cross the road for migration or during daily winter movements. When you consider the addition of snow piled against and over the guardrail from snow plowing, the combination has the potential to make the road a considerable barrier.

The road approved by Eagle County shows a total of 6,435 linear feet of cut wall, 5,335' of this is just from Moonridge Road to the southeast corner of the Berlaimont property. There is an additional 1,100' of cut wall required for the construction of new road (1.16 miles) across NFS lands to reach the northern portion of Berlaimont. These vertical walls range from 2' to 28' high and some are up to 800' long. These figures do not include the required fill walls, some of which are 27' tall and up to 900' long, on USFS lands or the cut and fill walls required on the private lands. Such barriers have considerable impacts to wildlife connectivity and many of these structures are complete barriers to terrestrial wildlife. Such barriers and obstructions can increase road kills and reduce road safety. Also, accelerated snowmelt along the road during spring and any salt used during the winter will both create attractants for wildlife alongside the road.

Aquatic impacts:

The proposed access road will parallel the lower section of Berry Creek and bisect the Beard Creek and Thames Creek drainages. CPW is concerned that impacts from the proposed project could have consequences to locally important fisheries.

Berry Creek maintains a population of Colorado River cutthroat trout that have been genetically identified as green-lineage cutthroat trout. Green-lineage cutthroat trout are indigenous to the Eagle River watershed and are currently federally listed, along with Greenback cutthroat trout, as a Threatened Species by the U.S. Fish and Wildlife Service. Aside from the existing population of cutthroat trout in Berry Creek, this stream is also being considered for relocation of a Core Conservation Population of green-lineage cutthroat trout from a neighboring stream where they are currently isolated.

Cutthroat trout feed primarily on aquatic and terrestrial insects and require cold, clear, well-oxygenated streams with gravel bottoms to reproduce. In Colorado, cutthroat trout typically spawn in the spring with eggs hatching and fry emerging throughout the summer months. CPW recommends that activities with the potential to impact aquatic ecosystems be conducted between August 15th and September 30th to reduce impacts to fish spawning behaviors. Portions of the proposed Berlaimont access road appear to be within 50 feet or less of Berry Creek. CPW typically recommends “no surface occupancy” within 300 feet of occupied cutthroat trout habitats.

The confluence of Berry Creek with the Eagle River is within close proximity (less than 1 mile) of the proposed road enlargement. The Eagle River is a river renowned for its rainbow and brown trout fishing which brings in millions of dollars to local communities. The fish also rely on cold water and clean gravels to support their populations. Colorado Department of Public Health and the Environment (CDPHE) has provisionally listed the Eagle River from the confluence with Berry Creek downstream (Segment 9A) as impaired for Aquatic Life, and is currently listed as impaired due to Sediment and Temperature (CDPHE’s 303(D) List, 5CCR 1002-93, Regulation #93). Impacts within the Berry Creek watershed that increase sediment and temperature of Berry Creek will likely exacerbate water quality issues documented downstream in the Eagle River.

Anthropogenic impacts resulting from the proposed Berlaimont access road and subsequent residential development will occur in several ways. The primary impact from the access road will be increased sediment contributions to the stream channel. Initial construction activities may contribute sediment by disturbing soils and removing vegetation from the hillside directly above the stream. After construction, sediment loads may increase due to elevated runoff from the road surface, sanding of the road during the winter, and additional recreational use and soft-surface trail construction. Increased sediment contributions may overload the system’s ability to flush it downstream and will eventually smother fish spawning areas and habitat for aquatic invertebrates.

Stream-side vegetation and riparian habitats help reduce siltation, maintain cooler water temperatures by providing shade, and offer habitat for terrestrial insect species. Snow plowing, applications of magnesium chloride and/or sand, non-point source pollution (vehicle emissions, etc.) and litter will all impact the waterway and riparian vegetation. The Eagle River Watershed Plan has identified these issues currently impacting stretches of the Eagle River and Black Gore Creek.

Culverts and crossings proposed on Beard Creek and Thames Creek are significant and will impede movements of fish and other aquatic species. Additionally, roads are well known vectors for noxious weed species. Riparian habitats are especially susceptible to weed infestations which reduce the diversity of native plant species.

To reduce aquatic impacts to the greatest extent possible, CPW recommends the following measures for implementation:

- Conduct aquatic baseline (pre-construction) surveys of Berry Creek. Surveys should assess aquatic invertebrates, water temperature, streambed substrate composition, sediment transport, and overall water quality. Post-construction conditions should match that of pre-construction and if not, adjustments should be made to mitigate any impacts.

- Utilize an effective stormwater management and erosion control plan during construction to minimize sedimentation.
- Fully analyze the environmental impacts of using magnesium chloride instead of sand as a deicer during the winter. Magnesium chloride may help reduce sedimentation issues associated with road sands.
- Include sand/sediment traps within the road's drainage system to prevent sediment from reaching Berry, Beard, and Thames Creek.
- Ensure the maximum buffer possible between the road and Berry Creek.
- Consider spanning bridges at creek crossings instead of culverts. Bridges will maintain permeability for aquatic and terrestrial species which utilize drainages for movements.

Mitigation Recommendations:

The general mitigation hierarchy is to avoid, minimize, and compensate for impacts. Compensating for unavoidable wildlife impacts should be considered after all appropriate measures have been taken to minimize the project's effects on wildlife. Any compensatory mitigation designed to improve habitat for wildlife should be for the life of the project. CPW welcomes the opportunity to work with the applicant and WRNF staff to develop effective compensatory mitigation ideas to offset the remaining impacts to wildlife. The following measures have been developed by CPW for consideration during the environmental analysis to avoid, minimize, and compensate for impacts to wildlife and wildlife habitats:

** Greater sage-grouse and aquatic mitigations are included within their respective sections.*

- Road design should maximize the use of spanning bridges or underpasses and wildlife overpasses to prevent and reduce wildlife/vehicle collisions and maintain habitat connectivity for wildlife. Spanning bridges and underpasses should be a minimum of 10' high by 25' wide with native vegetation along the bottom to encourage wildlife use. Where spanning bridges or underpasses may not be feasible for wildlife connectivity the road should be elevated to allow for wildlife movement. Wildlife crossing structures should be no further apart than every ¼ mile.
- Road speeds should not exceed 20 mph. Fines and points for speeding should be doubled due to the heavy level of wildlife use on the proposed road. The development should fund the cost of providing law enforcement personnel for speed control.
- The project should fund a person to remove any road kills to prevent additional road kills of raptors or other predators while feeding on carcasses.
- Compensatory mitigation for acres of deer and elk severe winter range impacted at a rate of 10 acres to 1 acre. Winter concentration areas for both deer and elk at a rate of 5 acres to 1 acre. Winter range for both deer and elk at a rate of 1.5 acres to 1 acre.
- No road construction from January 1 to May 1 to protect wintering wildlife.

- No blasting during nesting periods (generally May 1 to June 15).
- All compensatory mitigation should be for the life of the project and should treat sufficient acres every three years to offset the impacts to wildlife.
- Mitigation to prevent additional impacts from recreation should include funding for sufficient law enforcement coverage to enforce any recreational closures or use restrictions.
- Finding locations to complete compensatory mitigation can be difficult. As such, the development should fund all the necessary environmental studies and reviews required by the USFS to complete the necessary mitigation adjacent to the project area.
- Compensatory mitigation should be done within a 4 mile radius of the development, but not directly adjacent to the road to prevent mitigation projects from attracting wildlife to the roads.
- Areas with cut and/or fill slopes that are over 6' tall should be fenced with 8' tall fencing to prevent wildlife or livestock from running off the edge when startled.

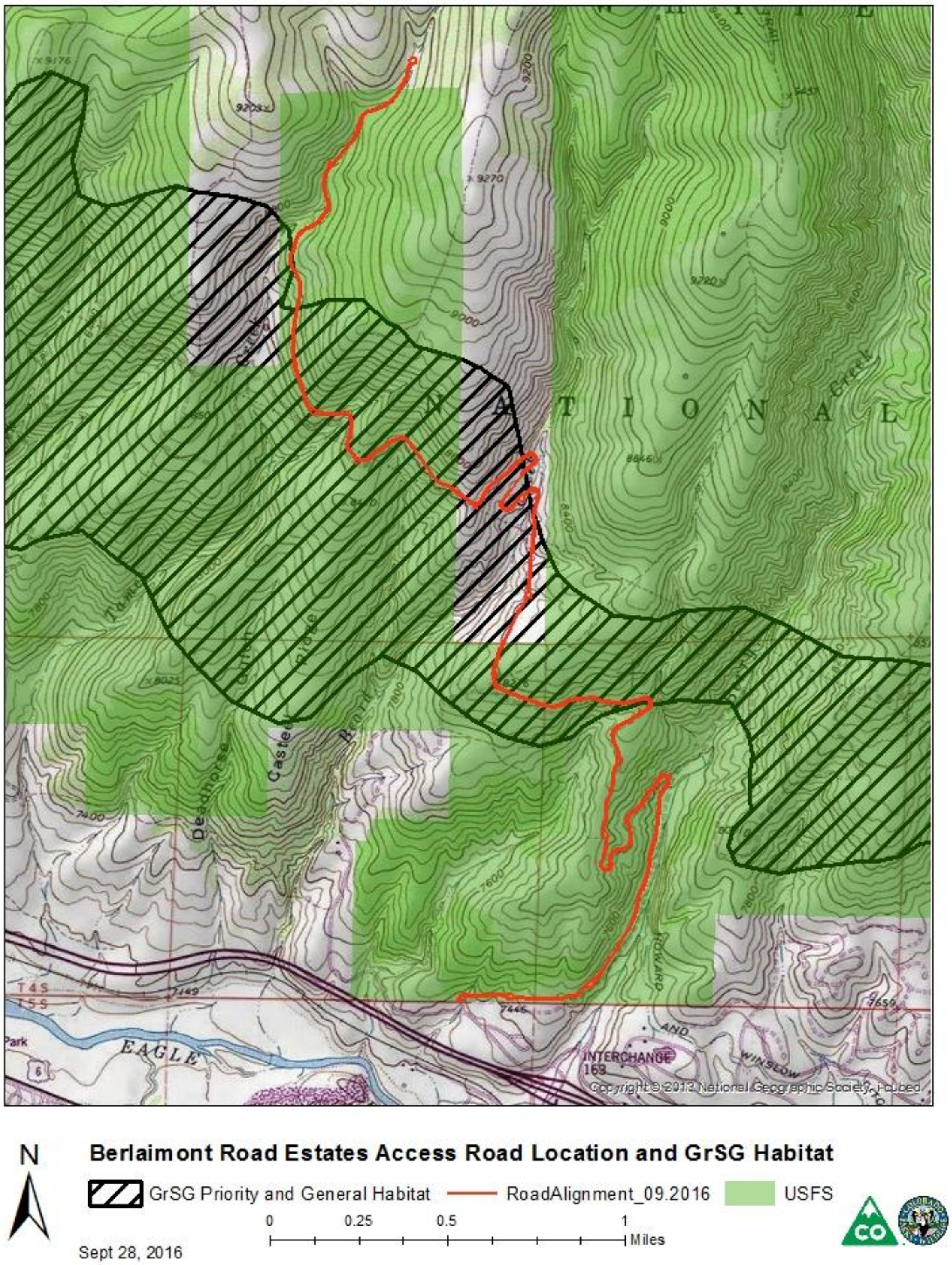
Thank you for the opportunity to review this project and provide scoping comments. CPW looks forward to providing additional feedback if this project proceeds. If you have questions please contact DWM, Bill Andree, at (970) 328-6563.

Sincerely,

Perry Will,
Area 8 Wildlife Manager

Cc: Ron Velarde, Northwest Regional Manager
Dean Riggs, Deputy Regional Manager
Bill Andree, District Wildlife Manager
Taylor Elm, Land Use Specialist
File

Figure 1:



Park
EAGLE
INTERCHANGE
163
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N
Berlaimont Road Estates Access Road Location and GrSG Habitat
GrSG Priority and General Habitat
RoadAlignment_09.2016
USFS
0
0.25
0.5
1
Miles
Sept 28, 2016

Figure 2:

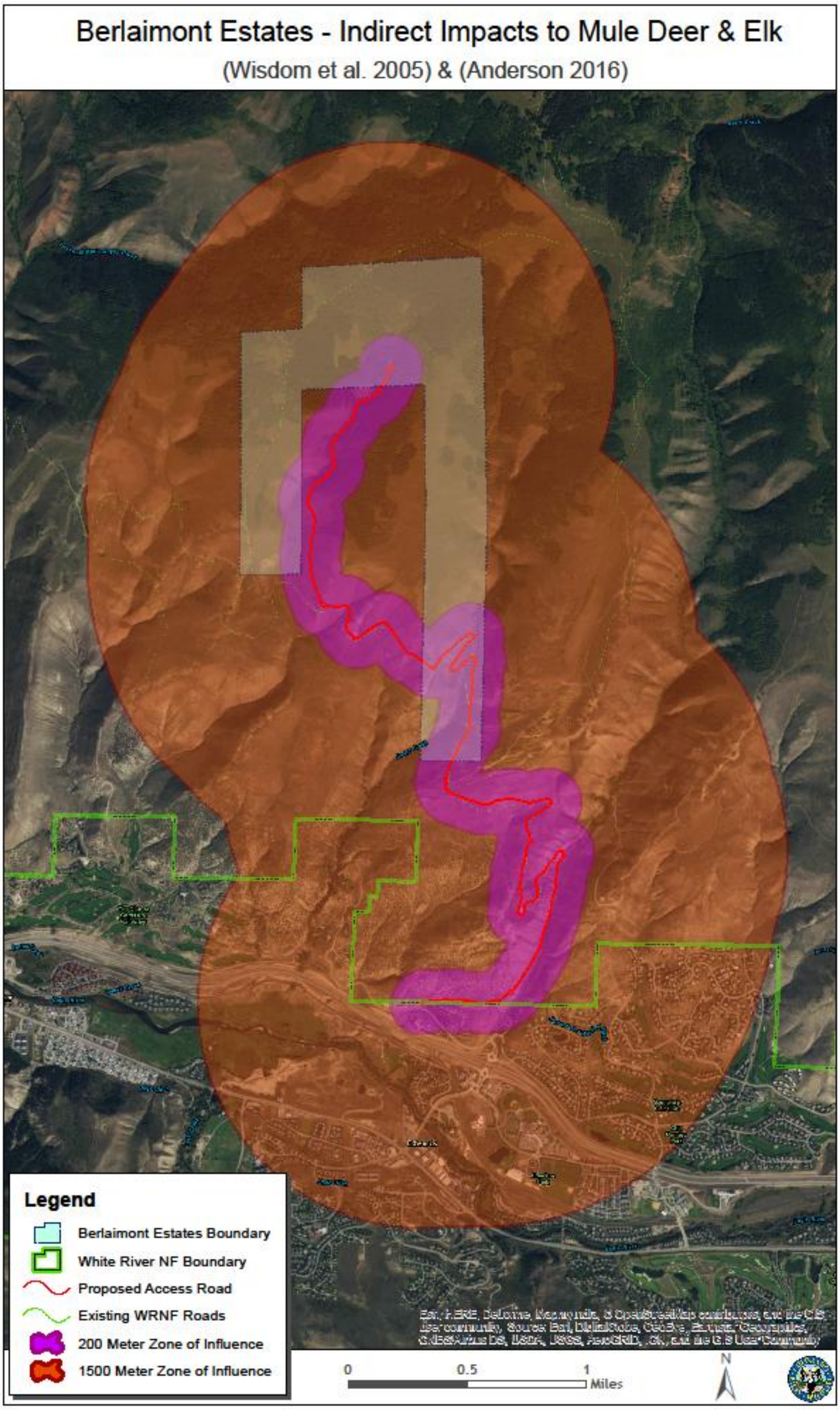

Berlaimont Estates - Indirect Impacts to Mule Deer & Elk
(Wisdom et al. 2005) & (Anderson 2016)
Legend
Berlaimont Estates Boundary
White River NF Boundary
Proposed Access Road
Existing WRNF Roads
200 Meter Zone of Influence
1500 Meter Zone of Influence
0
0.5
1
Miles
N

Figure 3:

	Potential Impacts to Mule Deer Habitats			
	Mule Deer Migration Corridor	Mule Deer Winter Range	Mule Deer Severe Winter Range	Mule Deer Winter Concentration
Direct Impacts	19.99	21.42	4.77	9.5
200 m Buffer	666.65	766.58	143.02	307.23

	Potential Impacts to Elk Habitats		
	Elk Winter Range	Elk Severe Winter Range	Elk Winter Concentration
Direct Impacts	21.42	11.95	6.15
1500 m Buffer	5634.45	2044.08	908.62

** Estimates include USFS and private lands.*

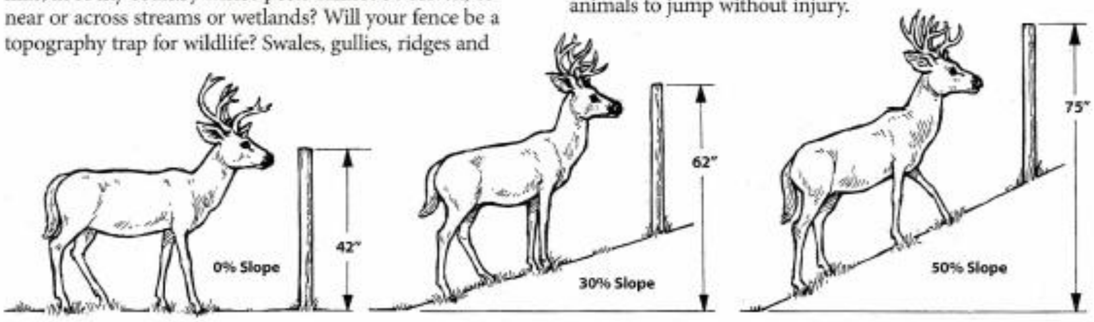
Figure 4:

to riparian habitats, water holes and other high quality habitats. Place crossings, jumps, open gates and other wildlife openings in appropriate locations. Deer, elk, and pronghorn are more likely to use openings at fence corners than in the middle of a fence run, unless there is cover, habitat or natural corridors or trails to attract them through. Intermittent openings should be placed where animals naturally travel: in riparian corridors, along gullies and ridges, and on existing game trails.

Topography

Work with your land's topography. Are you fencing on hills, in rocky country where posts cannot be driven, or near or across streams or wetlands? Will your fence be a topography trap for wildlife? Swales, gullies, ridges and stream corridors can funnel wildlife through an area—keep these open to allow wildlife passage and avoid topography traps.

A fence of any height is more difficult to cross when placed across a steep slope. As ground slope increases, the distance an animal must jump to clear the fence increases considerably (see illustration below). For instance, a 42" fence may be passable on level ground, but a slope of only 10% increases the effective fence height to 48.6"; a slope of 30% increases effective height to 62", and on a 50% slope animals encounter an obstacle 75" high. Fences on steep slopes become nearly impossible for animals to jump without injury.



Wildlife-Friendly Fencing

The ideal wildlife-friendly fence:

- *Is highly visible to ungulates and birds*
- *Allows wildlife to jump over or crawl under*
- *Provides wildlife access to important habitats and travel corridors*

The "friendliest" fences for wildlife are very visible and allow wild animals to easily jump over or slip under the wires or rails. The Colorado Division of Wildlife recommends:

- Fencing wire placed on the side of the fence posts where the domestic animals are located;
- Smooth wire or rounded rail for the top, smooth wire on the bottom;
- Height of top rail or wire should be 42" or less;
- At least 12" between the top two wires;
- At least 16" between the bottom wire or rail and the ground;
- Posts at minimum 16' intervals;
- Gates, drop-downs, removable fence sections or other passages where animals concentrate and cross;
- Using a rail, high-visibility wire, flagging or other visual markers for the top.

Visibility

High visibility helps wildlife negotiate fences. Visibility is especially important in grasslands and near creeks and wetlands to protect low-flying birds, such as grouse, owls and waterfowl. For big game, increased visibility helps animals judge their jumps better so that they can clear the fence or use another location to cross. Using a vinyl coated high-tensile wire for the top wire, or covering the existing top wire with PVC pipe, flagging, or tape helps wildlife see fences and dramatically reduces wildlife damage to fences of all heights. Another solution is using a rounded top rail, which will shed snow easily.

For wire fences, the least expensive solution is to simply hang flagging, or other materials along the top, although many materials can fade or be lost and need regular replacement. Another alternative is to slip sections of small diameter PVC pipe over the top strand. High-

United States Department of Agriculture

NRCS Natural Resources Conservation Service

Technical Note No. 75

Attachment H

Agricultural Wildlife Conservation Center

May 2007

Effects of Exurban Development on Wildlife and Plant Communities

Issued May 2007

Information in this publication was compiled by **Jeremy D. Maestas**, wildlife biologist, Natural Resources Conservation Service. Special thanks to **R. Knight**, **E. Odell**, **B. Lenth**, and **W. Gilgert** for providing helpful comments and peer review for this publication.

Suggested citation:

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Effects of Exurban Development on Wildlife and Plant Communities

Introduction

Exurban developments are low-density residential developments that occur beyond incorporated city limits. Houses in these developments are typically situated on lots from 10 to 40 acres in size, but some exurban developments have higher housing densities. Since 1950, the amount of land in this type of development has increased fivefold in the United States (Brown et al. 2005). In fact, exurban development now occupies about 25 percent of private land in the lower 48 states and is currently the fastest growing form of land use (Brown et al. 2005; Heimlich and Anderson 2001). Consequently, many lands that once were agricultural or natural areas are being converted to residential settlements (fig. 1).

The location of exurban developments on the landscape also is not random. They occur on private lands, which are often the most productive, well-watered, and hospitable places on the landscape (Scott et al. 2001). Furthermore, scenic private lands adjacent to national parks, national forests, wetlands, and streams often are preferred for development for their amenity values.

Landscapes that undergo this land-use conversion experience a dramatic increase in infrastructure (houses, roads, fences, power lines) and human influence as residents bring with them their cats, dogs, hobby livestock, night-lights, garbage, and ornamental landscaping (Mitchell, Knight, and Camp 2002) (fig. 2). Scientists are just beginning to understand the ecological effects of exurban development, but recent study results suggest that the consequences for natural resource conservation may be troublesome.

Figure 1 Sign advertises rural subdivision

Figure 2 Horses on exurban property

Ecological effects

Birds

Studies of birds on exurban developments indicate that species abundances differ from those seen on undeveloped lands. Human-adapted native species, such as the black-billed magpie and American robin, and exotic species, such as the European starling, reach significantly higher densities on exurban developments than on undeveloped areas (Hansen et al. 2005; Maestas, Knight, and Gilgert 2003; Odell and Knight 2001; Lenth, Knight, and Gilgert 2006). Conversely, native species of conservation concern, such as the orange-crowned warbler, dusky flycatcher, Brewer's sparrow, and vesper sparrow, have reduced densities on exurban developments when compared to undeveloped lands (Hansen et al. 2005; Maestas, Knight, and Gilgert 2003; Odell and Knight 2001; Lenth, Knight, and Gilgert 2006). In general, exurban developments favor common bird species that are able to cope with human disturbances while species of higher conservation concern tend to avoid these areas.

Bird reproduction and population growth also can be influenced by exurban developments. One study in Montana found that yellow warblers had lower nest success—a measure of chicks successfully raised—on exurban developments than on ranchlands (Hansen and Rotella 2002). Furthermore, warbler mortality rates exceeded birth rates, which meant that reproduction was insufficient to sustain a viable warbler population in the study area. The results of this study suggest that exurban developments actually functioned as a population sink by taking individuals away from the overall population while contributing very few.

Mammals

Some literature indicates that native mammalian carnivores may be affected by exurban developments, as well. Foxes and coyotes have been shown to occur more frequently away from houses in developments (Odell and Knight 2001). Additionally, these species occur more frequently on undeveloped areas than on both high- and low-density exurban developments (Maestas, Knight, and Gilgert 2003; Odell and Knight 2001). A survey of exurban homeowners in central New Mexico indicated that bobcats were seen more frequently in undeveloped areas than near houses (Harrison 1998). A more detailed study of gray foxes in the same area showed that foxes avoided high-density exurban developments but used lower-density developments to some extent (Harrison 1997). This study also revealed that gray foxes were using exurban developments mostly at nighttime and undeveloped areas during the daytime. Results of these studies suggest both spatial and temporal avoidance of exurban developments by some mammals.

Domestic predators, such as dogs and cats, increase considerably across the landscape as it is subdivided. One study documented that dogs and cats were found frequently near houses in exurban developments, but these predators were almost nonexistent at points 330 meters from houses and in undeveloped areas (Odell and Knight 2001). In a study of different rural land uses (ranches, protected areas, and exurban developments), dogs and cats were pervasive on lands used for exurban development and largely absent or undetectable on protected areas or intact ranches (Maestas, Knight, and Gilgert 2003). Sampling points were located throughout the developments in this study, not just near the houses, which indicates that many pets were free roaming. Dogs and cats are known to harass and kill wildlife, and their presence on the landscape extends the realm of human influence and can expedite the local extinction of some species (Miller, Knight, and Miller 2001; Crooks and Soulé 1999). In the United States alone, it is estimated that domestic cats kill hundreds of millions of birds, small mammals, reptiles, and amphibians each year (American Bird Conservancy 2006).

Plants

Plants are less well studied on exurban developments than wildlife. One study in northern Colorado compared plant communities between exurban developments, ranchlands, and protected areas (Maestas, Knight, and Gilgert 2002, 2003). In this study, native plant species richness—an indicator of site health that measures the number of species present—was higher on ranchlands than on exurban developments. Conversely, nonnative plants were more common on exurban developments than undeveloped lands. Alarmingly, there were over twice as many introduced plant species documented on exurban developments as on ranchlands, with eight of the nonnative species on exurban areas found there and nowhere else. Two of these eight species, spotted knapweed and leafy spurge, are considered to be noxious weeds in the study area. Although these invasive plants are known to occur on ranchlands elsewhere, they were not encountered on ranches in this study, which suggests that these species were either absent on these ranches or at least less pervasive on ranches than on exurban developments. Exurban developments also had a higher percentage of bare ground at sampling points than did protected areas.

Researchers in another study compared plant communities between exurban developments and undeveloped natural areas and found a similar pattern (Lenth, Knight, and Gilgert 2006). Nonnative plant species were more common, and natives less common, on exurban developments with dispersed or clustered housing than on undeveloped areas (Lenth, Knight, and Gilgert 2006).

Although limited data exists, these two studies indicate that exurban developments may serve as sources of new invasive or nonnative plant species and contribute to increased soil erosion (fig. 3).

Conclusions

The few ecological studies that have been conducted on exurban development suggest that its impacts on biodiversity may be significant, both in the immediate vicinity of homes and on nearby public and private lands (Hansen et al. 2005). The long-term result of continued land conversion to exurban development could be an increasing number of conservation problems, as desirable species begin to show population declines and less desirable, opportunistic species increase in abundance and colonize new areas.

Private lands are often critically important for wildlife during at least some portion of their life cycle. Many rare or declining species depend upon private lands to persist. In the western United States, private lands are often located on productive soils at middle to lower elevations with abundant springs and riparian areas, which make them disproportionately important to wildlife.

Figure 3 On this ranchette, a horse corral located on a steep slope adjacent to a stream accelerates soil erosion and nonpoint source water pollution.

As exurban developments become a larger component of the landscape, conservationists will find it increasingly difficult not only to maintain native species populations, but also to manage adjacent lands. For example, fire is a natural ecological process that is critical to the health of most ecosystems, but traditional land management tools, such as prescribed burning, may no longer be available because of liability concerns. Wildfires will also be aggressively put out, which may further degrade the ecological health of the land. Additionally, noxious weeds will become more problematic as new invasive plants grow more abundant and move across property boundaries and throughout the watershed.

Conservation planners can help minimize the effects of exurban development by working with landowners and local land use decisionmakers. Protecting farms, ranches, and open spaces with conservation easements is one effective method for maintaining intact landscapes. Government and nongovernment organizations offer a number of programs to compensate landowners for the development value of their land while allowing the landowner to retain ownership. Planners aware of these programs can assist producers in realizing some of financial value of their land without having to subdivide. Local government land-use planning processes may provide another opportunity for conservationists to guide exurban development. Zoning or other land use planning tools can be used to steer development away from lands that may be ecologically sensitive or critically important for natural resource conservation.

If exurban development is unavoidable, clustered housing developments may be a desirable alternative to minimize negative ecological effects (Odell, Theobald, and Knight 2003). In contrast to traditional exurban developments where houses are dispersed throughout a large parcel of land, clustered developments concentrate roughly the same number of houses on a small portion of the land, leaving the remaining area undeveloped and protected by a conservation easement or similar restriction. Clustering houses reduces the landscape fragmentation caused by houses, roads, and other features and potentially reduces the zone of human influence (Odell, Theobald, and Knight 2003). However, these changes alone may not be sufficient to protect species of conservation concern (Lenth, Knight, and Gilgert 2006). It may be necessary to further improve the conservation value of clustered developments by grouping houses closer together, requiring larger protected outlots, restricting recreational use to certain portions of the property, keeping open space contiguous, providing better stewardship of protected outlots, and incorporating other ecological considerations into clustered development designs (Lenth, Knight, and Gilgert 2006).

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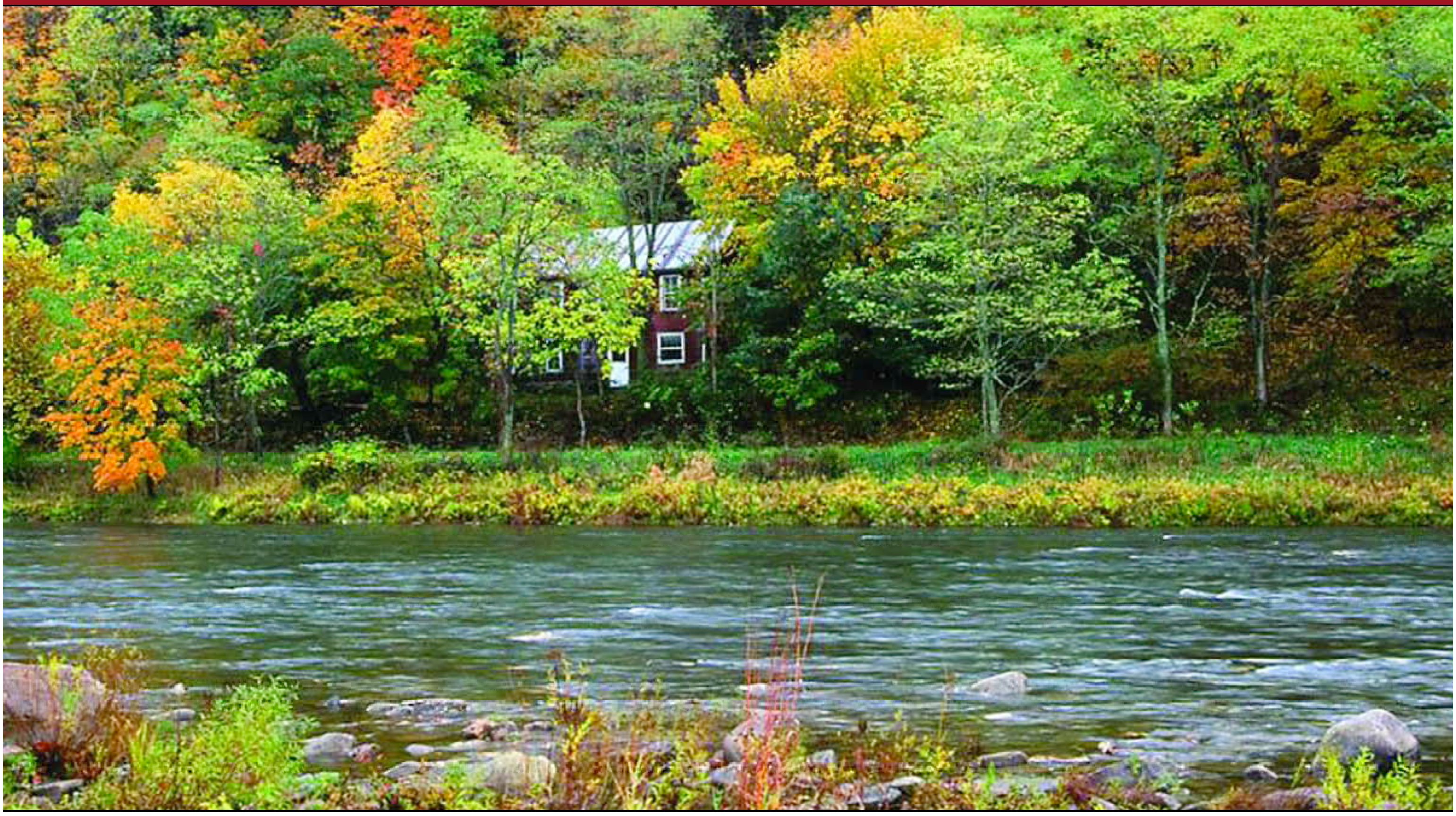
NATIONAL FORESTS ON THE EDGE

DEVELOPMENT PRESSURES ON AMERICA'S NATIONAL FORESTS AND GRASSLANDS

Attachment I



U.S. Department of Agriculture

Forest Service

Pacific Northwest Research Station

General Technical Report
PNW-GTR-728
August 2007

Susan M. Stein, Ralph J. Alig, Eric M. White, Sara J. Comas, Mary Carr, Mike Eley, Kelly Elverum, Mike O'Donnell, David M. Theobald, Ken Cordell, Jonathan Haber, and Theodore W. Beauvais

ABSTRACT

Stein, Susan M.; Alig, Ralph J.; White, Eric M.; Comas, Sara J.; Carr, Mary; Eley, Mike; Elverum, Kelly; O'Donnell, Mike; Theobald, David M.; Cordell, Ken; Haber, Jonathan; Beauvais, Theodore W. 2007. National forests on the edge: development pressures on America's national forests and grasslands. Gen. Tech. Rep. PNW-GTR-728. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 26 p.

Many of America's national forests and grasslands—collectively called the National Forest System—face increased risks and alterations from escalating housing development on private rural lands along their boundaries. National forests and grasslands provide critical social, ecological, and economic benefits to the American public. This study projects future housing density increases on private rural lands at three distances—½, 3, and 10 miles—from the external boundaries of all national forests and grasslands across the conterminous United States. Some 21.7 million acres of rural private lands (about 8 percent of all private lands) located within 10 miles of the National Forest System boundaries are projected to undergo increases in housing density by 2030. Nine national forests are projected to experience increased housing density on at least 25 percent of adjacent private lands at one or more of the distances considered. Thirteen national forests and grasslands are each projected to have more than a half-million acres of adjacent private rural lands experience increased housing density. Such development and accompanying landscape fragmentation pose substantial challenges for the management and conservation of the ecosystem services and amenity resources of National Forest System lands, including access by the public. Research such as this can help planners, managers, and communities consider the impacts of local land use decisions.

Keywords: Land use change, national forest, housing density, road density, ecosystem services, amenity resources, amenity migration, housing development, planning.

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INTRODUCTION

America's National Forest System is composed of 155 national forests and 20 national grasslands managed by the U.S. Department of Agriculture, Forest Service. Many of these forests and grasslands are facing increased risks and impacts from escalating housing development on private rural lands along their boundaries. Encompassing about 192 million acres across 44 states, Puerto Rico, and the Virgin Islands, national forests and grasslands account for 8.5 percent of the total U.S. land area and 20 percent of its forest land (USDA Forest Service 2004a) (fig. 1). Nearly a quarter of the U.S. population lives in a county that contains National Forest System land (Johnson and Stewart 2007).

National Forest System lands provide critical social, economic, and ecological benefits to the Nation, including aesthetic and spiritual values, recreation opportunities, fresh drinking water, clean air, timber and other forest products, minerals, oil and gas, livestock grazing, and abundant habitats for fish and wildlife species (see page 4 for examples). These ecosystem services and amenity resources can be altered when new houses are built on private lands within or near forest and grassland boundaries.

The population of the United States is projected to increase by at least 135 million people to approximately 420 million people by 2050 (U.S. Census Bureau 2004), resulting in substantial projected expansion in U.S. developed area (Alig and Plantinga 2004, Alig et al. 2004, Cordell and Overdevest 2001, Macie and Hermansen 2003, Nowak and Walton 2005). Counties with national forests and grasslands already are experiencing some of the highest population growth rates in the Nation as people move near public lands (Garber-Yonts 2004, Johnson and Stewart 2007, USDA Forest Service 2006a). Even **within**

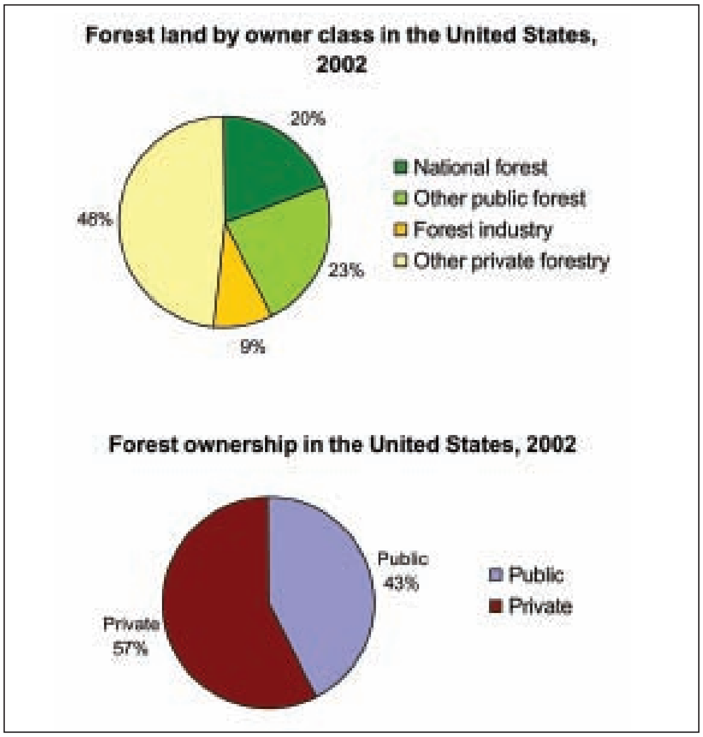
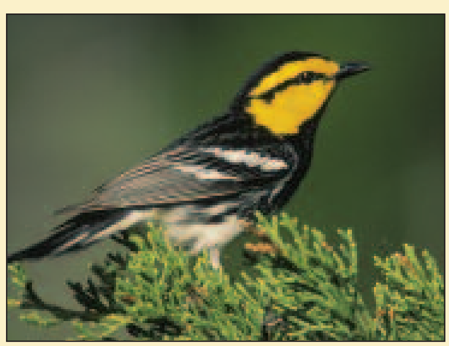


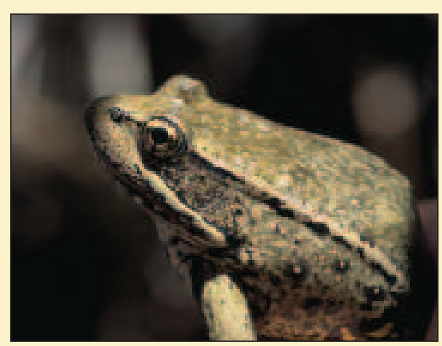
Figure 1—**Who manages America's forests?** National Forest System lands are managed by the U.S. Forest Service and account for about 20 percent of America's forested land. Some 148 million acres of National Forest System lands are forest; about 44 million acres are nonforest. Other forested lands in the country are managed by private landowners (57 percent) or by other public agencies or local governments (23 percent). Source: Smith and Darr (2004).

Although most National Forest System lands are in the West, national forests along the Appalachian Mountain chain and scattered across other Eastern and Midwestern States are within a day's drive for millions of Americans (USDA Forest Service 2005b). Private lands in the vicinity of national forests and grasslands are becoming developed at an increasing rate across the country.

national forest boundaries, the number of housing units on privately held lands increased from 500,000 to 1.5 million between 1950 and 2000 (Radeloff et al. 2005a).[1]

[1] Nationwide, some 17 percent of all lands located within the boundaries of national forests or grasslands are "inholdings" held by private or other non-Forest-Service landowners (USDA Forest Service 2005b). Inholdings may be managed by other federal agencies; state, county, local, or tribal governments; private individuals; or corporate entities. Inholdings are particularly prevalent in the East, where national forests were established much later than those in the West, often to protect damaged watersheds and restore abandoned farmlands (Shands and Healy 1977); nearly half (46 percent) of the lands located within Eastern national forest boundaries are inholdings (USDA Forest Service 2006a). Western national forests generally have a more consolidated ownership pattern providing larger blocks of public land with fewer inholdings.





A third of all federally listed threatened or endangered species currently occur on National Forest System lands or are potentially affected by national forest and grassland management (Bosch 2006). Photos courtesy of U.S. Fish and Wildlife Service.

Examples of benefits and resources associated with management objectives on National Forest System lands

National forest/grassland objective[a]	Benefits and resources
Maintain national forests for future generations (93.5)[b]	All those listed below
Protect streams and other sources of clean water (94.9)	The largest single source of fresh water in the U.S., providing 14 percent of the country's water runoff and high-quality water valued at $3.7 billion per year[c]
Provide habitat for wildlife and fish (89.2) Protect rare plant or animal species (86)	Wildlife and fish habitats for numerous species, including a third of all federally listed threatened or endangered species[d]
Manage national forest areas to leave them natural looking (86.8) Provide quiet, natural places for personal renewal (75.8)	Special areas, such as wilderness, research natural areas, national scenic areas, and national monuments
Emphasize planning and management for timber (79.1)	2 billion board feet of timber in a single year, valued at $224 million[e]
Provide recreation access, facilities, and services (74.5)	205 million recreation visits annually; 4,300 campgrounds with 122,000 camp sites; 135 alpine ski areas; 4,418 miles of wild and scenic rivers; 133,087 miles of hiking trails[f]
Provide roads, services, accommodations to support local tourism businesses (57.0)	$7.5 billion annually in direct spending in local economies resulting from recreation visits to national forests[f]

[a] Identified in Tarrant et al. (2003) as "assets."
[b] Numbers in parentheses represent the percentage of the public responding to a survey (Tarrant et al. 2003) who said they considered this management objective ("asset") important.
[c] Dissmeyer 2000, USDA Forest Service 2000b.
[d] Bosch 2006.
[e] USDA Forest Service 2005a.
[f] USDA Forest Service 2004b.

National Forests on the Edge is the second analysis conducted by the Forests on the Edge project sponsored by the Forest Service, State and Private Forestry, Cooperative Forestry staff. This report identifies national forests and grasslands across the conterminous United States most likely to be affected by increased housing density on rural private lands outside the external boundaries[2] of National Forest System lands. It also discusses how this type of development may affect national forests and grasslands; similar effects might logically be expected to confront other local, state, and federal public lands. These findings and discussions should prove useful as tools to facilitate decisionmaking about future land use options.

About Forests on the Edge

Sponsored by the U.S. Forest Service, State and Private Forestry, Cooperative Forestry staff, the Forests on the Edge project identifies areas across the country where public and private forests might change because of housing development and other factors. The project focuses on lands that currently are rural and becoming more developed. Development on rural lands is often overlooked because it may not be as visible as higher density development found closer to urban centers. The project's first report (Stein et al. 2005a) identified watersheds across the conterminous United States containing substantial amounts of private forest projected to experience increased housing densities by 2030. In total, more than 44 million acres of private forests were projected to experience increased housing density by 2030.

IDENTIFYING NATIONAL FORESTS AND GRASSLANDS ON THE EDGE

This study focuses on national forests and grasslands in the conterminous United States that might experience change owing to increased housing development on private rural lands along their boundaries. Data necessary to prepare nationally consistent housing density forecasts for lands bordering national forests in Alaska and Puerto Rico are not adequate at this time, and there are no national forests in Hawaii.

[2] "External boundary" refers to the perimeter boundaries of a national forest or grassland. In some cases, this boundary is also referred to as a "proclamation" boundary, or the outer boundary within which Congress authorized a particular national forest to be established. "Internal boundaries" are those boundaries located within the external boundaries that distinguish National Forest System lands from other lands (often referred to as inholdings). The National Forests on the Edge analysis focuses on development on private rural lands outside the national forest or grassland external boundaries.

The analysis ranks individual national forests and grasslands according to the percentage and total area of private lands (including both forest and nonforest vegetation types) adjacent to each that are now rural and are projected to experience increased housing density.

These projections of housing density increases were limited to private lands outside national forest and grassland external boundaries (fig. 2). Although private lands also may be located within the external boundaries, it was not possible to make nationwide estimates for such "internal" private lands because no nationally consistent data were available at the time of this study.

Three distances from external boundaries were chosen—0 to ½ mile, ½ to 3 miles, and 3 to 10 miles. In selecting these distances, it was assumed that changes to national forest and grassland benefits will differ depending on how close development activity is to the boundary. A literature review was conducted to identify several distances as broad indicators within which housing density increases can affect national forest functions and values. Relevant distances were found to differ widely, depending on the type of impact being studied. The distances selected for this study correspond to those routinely used by recreation managers to identify areas where visitor experiences can be affected by the sounds and sights of development.

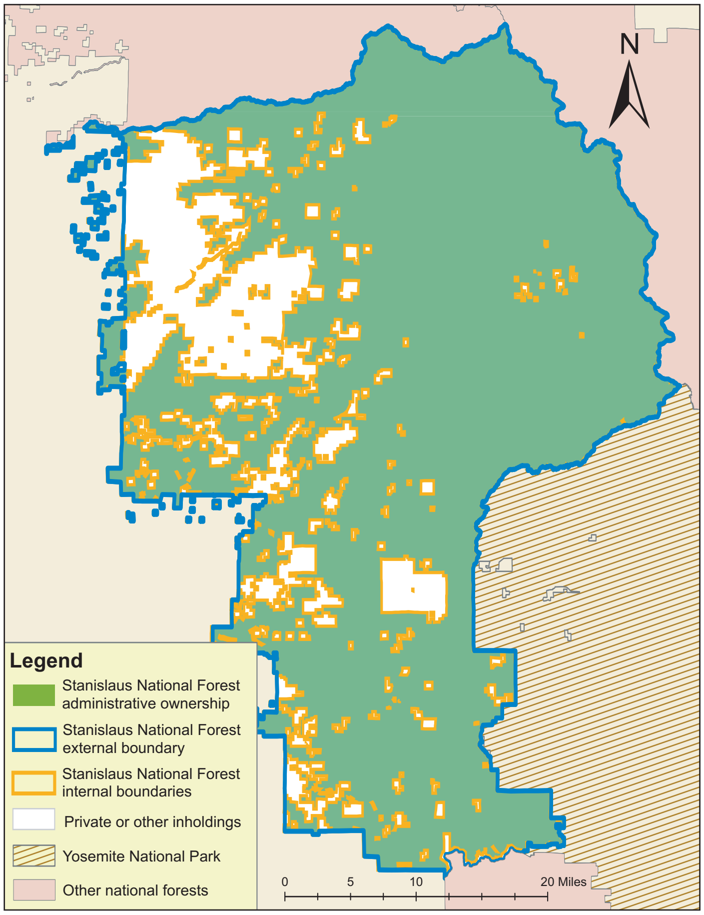


Figure 2—Internal and external boundaries for the Stanislaus National Forest, California.

Distances for Recreation Planning

Research-based distances form the core of the Recreation Opportunity Spectrum (ROS), which is widely used by federal agencies and a number of state agencies in recreation planning. For example, ROS remoteness criteria were used for the Forest Service's Forest and Rangeland Assessment to inventory land available for outdoor recreation at three distances from roads—0 to ½ mile, ½ to 3 miles, and beyond 3 miles (Cordell et al. 1990). Similar applications have been used by federal and state agencies to classify primitive recreation settings that lie beyond 3 miles of roads, semiprimitive settings from ½ to 3 miles from roads, and more accessible settings closer to development and within ½ mile of roads.

Terry Tollefsbol

Grizzly bears have been reported to be sensitive to road densities as low as 1 to 2 miles of road per square mile of land (Mace et al. 1996).

How Housing Density Projections Were Made

Housing density projections in this study focus on increased housing densities on lands that are currently rural. The projections are based on past and current statistics on housing density and population, road density data, past growth patterns, proximity to urban areas, and other factors (see "Appendix" for details; see also Stein et al. 2005b, Theobald 2005). Housing density projections are based on human population estimates of 276 million for the year 2000 (U.S. Census Bureau 2001a) and 385 million for the year 2030 (NPA Data Services, Inc. 2003).

To facilitate description of estimated changes, three housing density categories were defined:[3]

- **Rural I**—Lands with 16 or fewer housing units per square mile.
- **Rural II**—Lands with 17 to 64 housing units per square mile.
- **Exurban/urban**—Lands with 65 or more housing units per square mile.

[3] These housing density categories are identical to those used in the first *Forests on the Edge* report (Stein et al. 2005a, 2005b), but the names of the categories have been changed.

Increased housing density was defined to mean increased number of housing units per unit area on lands defined here as rural I or rural II, such that the housing density would shift to a higher level category.

Because this study focuses on areas where the 2000 housing density was 64 or fewer units per square mile, housing density increases for private lands already above this housing density level are not reflected in this analysis. Similarly, many national forests surrounded by housing densities greater than 64 units per square mile also may not be highlighted in this study because they have too little surrounding rural land that would change to a higher category.

Private land refers to all lands not identified as "public" (under federal, state, or local government management).

How This Analysis Was Conducted

The analysis quantifies and displays the extent of projected increases in housing density on rural lands located near National Forest System lands throughout the conterminous United States.

Each national forest or grassland consists of numerous, often disconnected parcels (see "Appendix" for details). Three basic steps were completed to estimate increases in housing densities on private lands surrounding these parcels:

- **Step 1**—For each of the three distances, we determined the area of private land surrounding each national forest or grassland parcel that is currently under each of the three housing density categories (rural I, rural II, or exurban/urban).
- **Step 2**—For each of the three distances, we determined the area of private land now classified as rural I or rural II that is estimated to experience housing density increases between 2000 and 2030, such that the housing density would change to a higher density category.
- **Step 3**—We determined the total area and percentage of private land around each national forest and grassland estimated to experience increased housing density within each of the distances studied.

Urban National Forests

A number of national forests and grasslands located in the conterminous United States and Puerto Rico have been designated as "urban national forests" based on their proximity to large urban centers. An urban national forest is defined as one within an hour's driving distance of a million or more people (USDA Forest Service 2003b). Owing to the presence of large urban areas, the densities of residential development around many of these urban national forests may already be higher than the rural densities that are the focus of this report, so further changes in housing densities near these urban national forests may not be represented in this study. However, these forests are likely facing many of the same management challenges as those forests where rural residential development is projected to increase.

Metropolitan Design Center Image Bank, © University of Minnesota

It's a familiar and accelerating trend—new houses with large individual lots scattered across a rural landscape. Dispersed low-density housing can create disproportionately high ecological and economic impacts **per housing unit** because each rural residence occupies more land area than an urban residence (Lubowski et al. 2006, Radeloff et al. 2005b, Theobald 2005, USDA Forest Service 2006a) and because desirable home sites often lie in environmentally sensitive places such as shorelines, riparian areas, or wildlife winter ranges (Johnson and Beale 2002, USDA Forest Service 2006a).

Table 1—Percentage and area of private land at four distances from national forest and grassland boundaries nationwide projected to experience housing growth, 2000 to 2030

Distance from boundary	Amount of private rural land projected to experience housing density increase	
Miles	*Percent*[a]	*Million acres*[b]
0 to 0.5	7	1.5
0.5 to 3	7	6.2
3 to 10	8	14.1
0 to 10	8	21.7

[a] Percentage of **all** private lands (rural and nonrural) within the respective distances.

[b] Area of **rural** private lands within the respective distances.

The resulting figures give an estimate of the magnitude of land area within each distance from National Forest System lands in the conterminous United States projected to experience increased housing density. As with any national assessment, our estimates may not completely capture changes in housing density at all local levels.

KEY FINDINGS

This study estimates that between 2000 and 2030, a substantial increase in housing density will occur on more than 21.7 million acres of rural private land (8 percent of all private land) located within 10 miles of national forests and grasslands across the conterminous United States (table 1). The percentages of private land area projected to experience increases in residential development are consistent across the three distances considered—7 percent for the 0-to-½-mile and ½-to-3-mile distances and 8 percent for the 3-to-10-mile distance.

Individual national forests projected to experience the greatest increases in residential development on private lands within 10 miles of forest boundaries are located throughout the conterminous United States (fig. 3). In the East, almost all national forests are projected to experience moderate or high increases in residential development. In the West, moderate and high increases in residential development are projected around national forests located in Colorado, California, Oregon, Idaho, and Montana. We project the nine national forests most affected could see increased housing development on at least 25 percent of the private lands within one or more of the three distances studied (table 2). Three of these national forests are in the West and the other six are located in the East. Overall, the range in

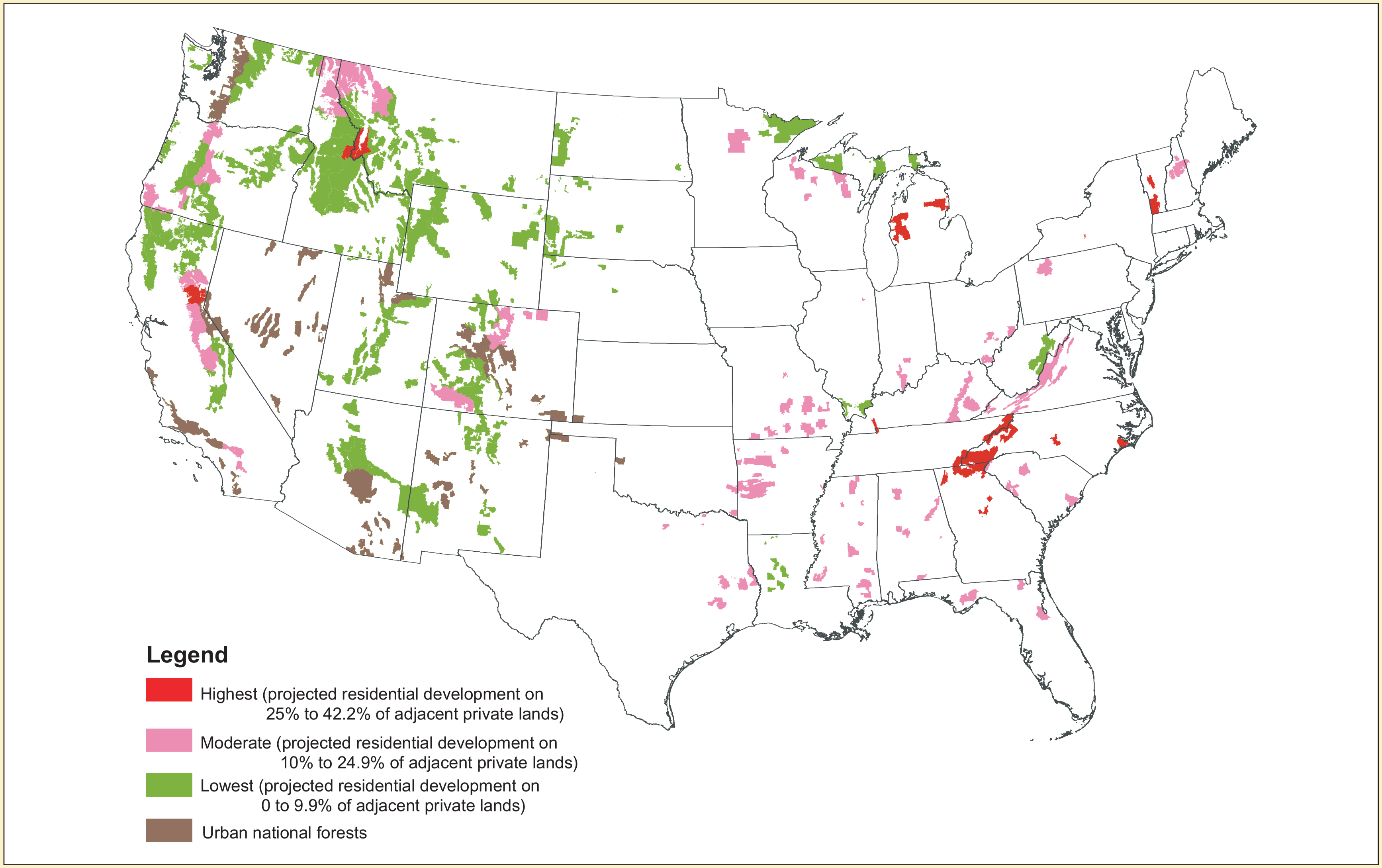


Figure 3—National Forest System lands with private lands within 10 miles projected to experience increased housing density, 2000–2030. Areas shown in brown are designated "urban national forests" (USDA Forest Service 2003b) that were not identified in this study as likely to experience significant increases in rural residential development. Housing densities near the borders of these forests may already be higher than the rural densities that are the focus of this report. Those urban national forests that do register high or moderate change in figure 3 include the Arapaho-Roosevelt, San Bernardino, Eldorado, Mount Hood, Chattahoochee-Oconee, Cherokee, and White Mountain National Forests; the National Forests of Florida; and the Midewin National Tallgrass Prairie. These urban national forests are surrounded by sufficient quantities of rural land projected to change to higher residential densities.

Table 2—National Forest System (NFS) lands with at least 25 percent of adjacent private land (at one or more distances) projected to experience housing growth by 2030

National forests and grasslands	State	Percentage[a] of adjacent private land projected to experience housing density increase[b] — Distance from NFS boundary (miles) (0 to 0.5)	(0.5 to 3)	(3 to 10)	(0 to 10)
Western United States					
Bitterroot National Forest	Idaho, Montana	**33**	**42**	**50**	**42**
Tahoe National Forest	California	18	24	**29**	**26**
Plumas National Forest	California	**25**	24	24	24
Eastern United States					
Chattahoochee-Oconee National Forest	Georgia	**31**	**35**	**35**	**35**
Cherokee National Forest	Tennessee	**30**	**36**	**31**	**32**
National Forests in North Carolina[c]	North Carolina	**26**	**29**	**30**	**30**
Huron-Manistee National Forest	Michigan	**31**	**32**	**26**	**28**
Land Between the Lakes National Recreation Area	Kentucky, Tennessee	5	23	**31**	**28**
Green Mountain and Finger Lakes National Forests	Vermont, New York	**28**	**31**	**25**	**27**

[a] Percentage of all private lands (rural and nonrural) within the respective distances.

[b] Percentages of 25 percent or higher are highlighted red.

[c] Croatan, Uwharrie, Pisgah, and Nantahala National Forests.

percentages of housing density increases for these nine national forests is from 5 percent to 50 percent across all the distances. The Bitterroot National Forest in Idaho and Montana ranks highest in the Nation, with projected housing density increases occurring on 42 percent of the private lands within 10 miles of the forest boundary. The greatest percentage increases on the Bitterroot National Forest are projected to occur in the 3-to-10-mile category.

The percentage of adjacent private lands projected to experience housing density increases does not necessarily become higher with distance from the national forests. For example, the Cherokee National Forest and the Huron-Manistee National Forest have their highest percentages (36 and 32 percent, respectively) at the distance of ½ to 3 miles from their external boundaries, whereas the Plumas National Forest is projected to experience the highest increases in residential housing density at the 0-to-½-mile distance.

The study also ranked National Forest System lands according to the total **area** of adjacent private lands projected to experience increased housing density. Thirteen national forests or grasslands are each adjacent to more than 500 thousand rural acres projected to experience housing increases. As displayed in table 3, ten of these forests or grasslands are found in the South. This finding is not surprising given that (a) many of our southern national forests are surrounded by private lands (in part because the National Forest System lands in the South tend to be smaller, separated parcels); and (b) the South is experiencing the highest rate of urban development in the country (Alig et al. 2004, Macie and Hermansen 2003) (fig. 4). The George Washington-Jefferson National Forest in Virginia and West Virginia is projected to have the most area of increases in housing density of all national forests or grasslands, with projected changes on more than 1.4 million adjacent private rural acres. The Mark Twain National Forest in Missouri stands out among the midwestern forests with more than 1.3 million acres of adjacent rural lands projected to experience an increase in housing density.

Table 3—National Forest System lands with over 500,000 acres of adjacent rural private land (within 10 miles) projected to experience increased housing by 2030

National forest or grassland[a]	Main state	Adjacent rural private land projected to experience housing density increases
		Thousand acres
George Washington-Jefferson	Virginia	1,424
Mark Twain	Missouri	1,326
Chattahoochee-Oconee	Georgia	1,176
National Forests in North Carolina[b]	North Carolina	1,073
National Forests in Mississippi[c]	Mississippi	1,071
National Forests in Alabama[d]	Alabama	963
Huron-Manistee	Michigan	834
Francis Marion-Sumter	South Carolina	720
Ozark-St. Francis	Arkansas	702
Daniel Boone	Kentucky	650
National Forests in Texas[e]	Texas	596
Green Mountain and Finger Lakes	Vermont, New York	590
Cherokee	Tennessee	544

[a] Figures reported for individual national forests in this table should not be combined because of the potential for double counting of residential development around national forests that are close to each other.

[b] Croatan, Uwharrie, Pisgah, and Nantahala National Forests.

[c] Bienville, Chickasawhay, Delta, Desoto, Holly Springs, Homochitto, and Tombigbee National Forests.

[d] Bankhead, Conecuh, Talladega, and Tuskegee National Forests.

[e] Angelina, Davy Crockett, Sabine, and Sam Houston National Forests.

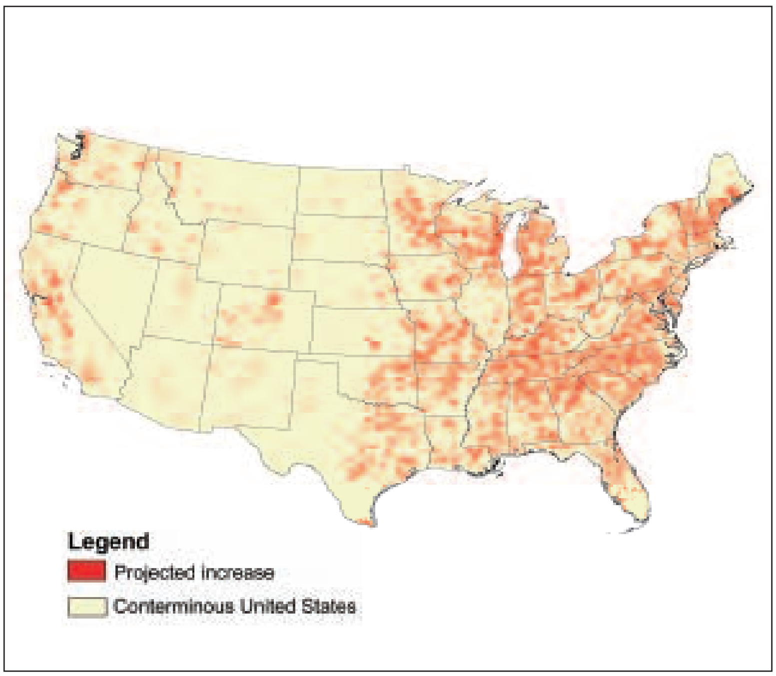
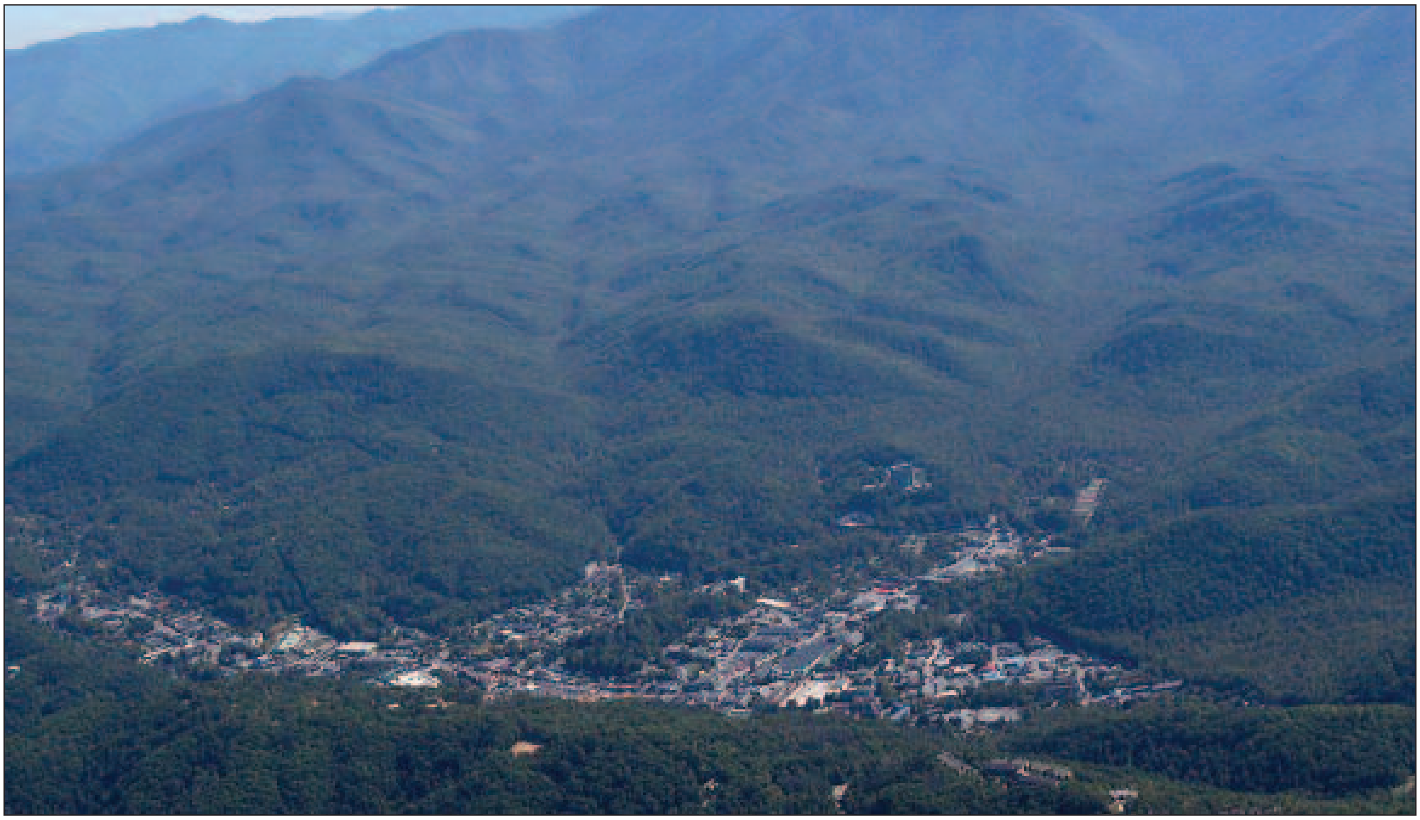


Figure 4—A broader perspective. Across the conterminous United States, approximately 1.4 billion acres of all lands are privately owned. Of these, some 153 million acres (about 10 percent) are projected to experience increased housing density in rural I and rural II areas in coming decades (regardless of their proximity to national forests or grasslands), mostly in the eastern half of the country (Theobald 2004a, 2004b). These national-level figures for all private lands may under- or overstate the situation for specific rural areas where housing development could be more or less intense.



Larry Korhnak

About the movement of people to rural areas.

National Forests on the Edge findings are consistent with recent studies on rural population change in America. Since the 1990s, there has been a substantial trend toward increased population growth in many rural counties, especially those with federal lands and abundant natural amenities (Garber-Yonts 2004; Hammer et al. 2004; Johnson 1999, 2006; Johnson and Beale 1999, 2002; Johnson and Stewart 2005, 2007; Johnson et al. 2005).

Population growth in rural ("nonmetropolitan") counties containing national forests has been consistently higher than in other rural counties over each of the past three decades (Johnson and Stewart 2007). Between 1990 and 2000, nonmetropolitan counties with more than 10 percent of the land in national forest grew by 18 percent —considerably higher than the growth rate in other nonmetropolitan counties (10.8 percent). Cordell and Overdevest (2001) further showed that population growth was particularly acute in counties near national forests in the southern Appalachians, northern New Mexico, southern California, and southeastern Idaho.

Many of the national forests and grasslands projected in this study to experience the highest levels of increased housing density near their boundaries fall within areas identified by Johnson and Beale (1999) as having had the highest recent rural population growth.

This type of lakeshore in northern Minnesota attracts second-home development, potentially affecting water quality and resulting in loss of wetland habitat.

A CLOSER LOOK: FUTURE HOUSING DEVELOPMENT AROUND FOUR NATIONAL FORESTS

Four examples from different regions illustrate how the projected 2030 housing densities (Theobald 2004b) compare to 2000 housing densities (Theobald 2004a) at the local level. Note that internal boundaries were used for these local analyses because adequate geographic information system information was available for these forests. Thus, the maps presented here (figs. 5–8), unlike our national-level maps, do include private inholdings.

On a subzero January morning, a group of elk makes its way over the snowy grassland/sagebrush winter range overlooking the Bitterroot Valley, Montana. Photo by John Vore, courtesy of Montana Department of Fish, Wildlife and Parks.

Bitterroot National Forest, Montana and Idaho

The percentage of private land projected to experience increases in housing density within 10 miles of the Bitterroot National Forest is greater than for any other national forest or grassland (table 2, fig. 5). The northernmost portion of this forest lies along either side of the Bitterroot Valley, in rapidly growing Ravalli County, Montana. One concern related to residential development within the Bitterroot Valley is its potential impact on elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) populations that seasonally inhabit the Bitterroot National Forest. Many areas of elk and mule deer winter range coincide with areas projected to experience substantial increases in the level of housing development. Increased housing density could potentially reduce the availability of winter habitat and browse, serve as impediments to habitat connectivity, and lead to increases in human/wildlife conflicts.

Stanislaus National Forest, California

The Stanislaus National Forest is located in east-central California, extending from the foothills to the crest of the Sierra Nevada. The national forest is bordered to the south by Yosemite National Park and to the east and north by the Humboldt-Toiyabe National Forest and the Eldorado National Forest, respectively. Given this pattern of federal ownership, private residential development is constrained to areas along the western boundary of the Stanislaus National Forest and along

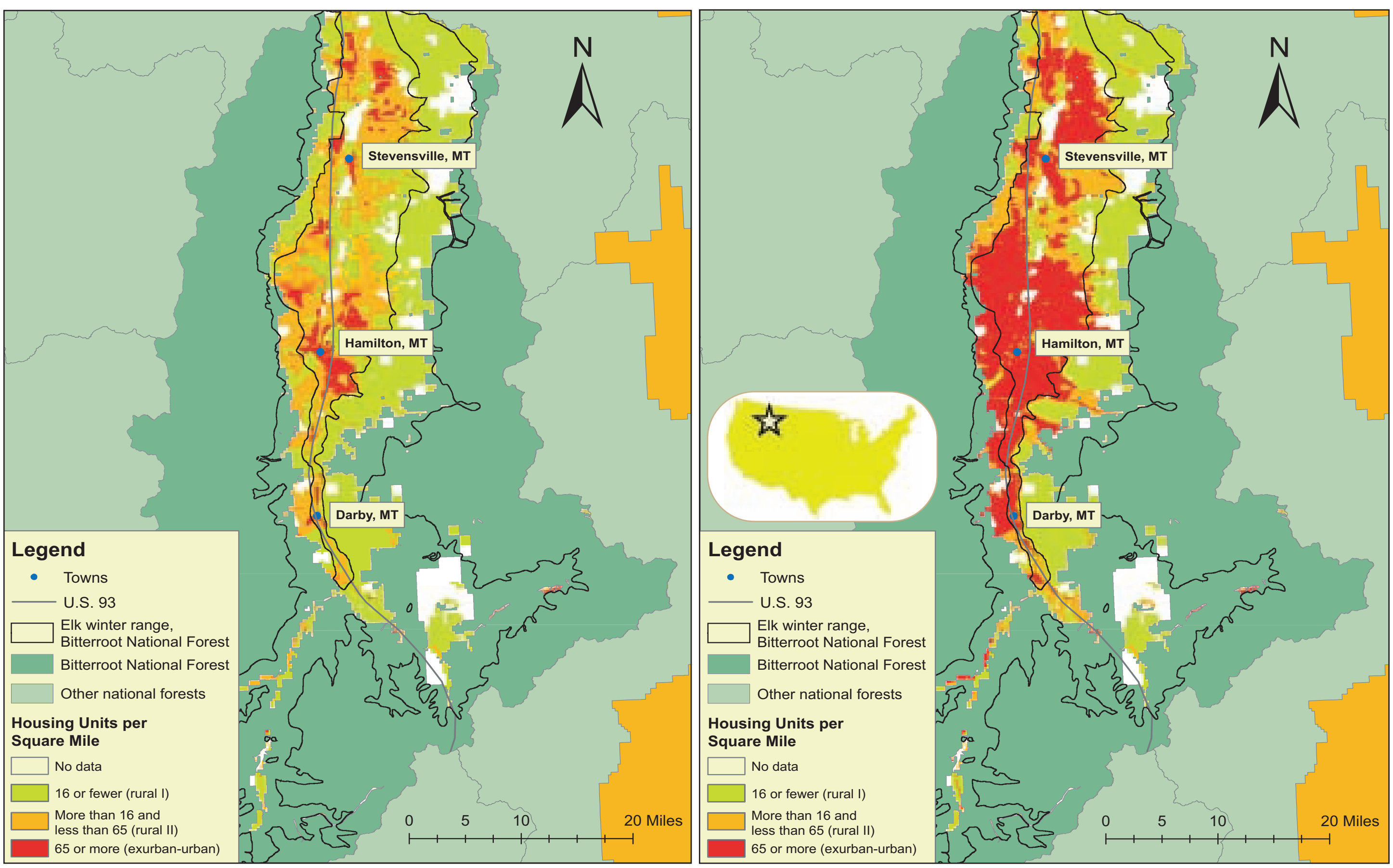


Figure 5—Housing density in the Bitterroot Valley, Montana/Idaho, 2000 and 2030. Source: Theobald 2004a, 2004b.

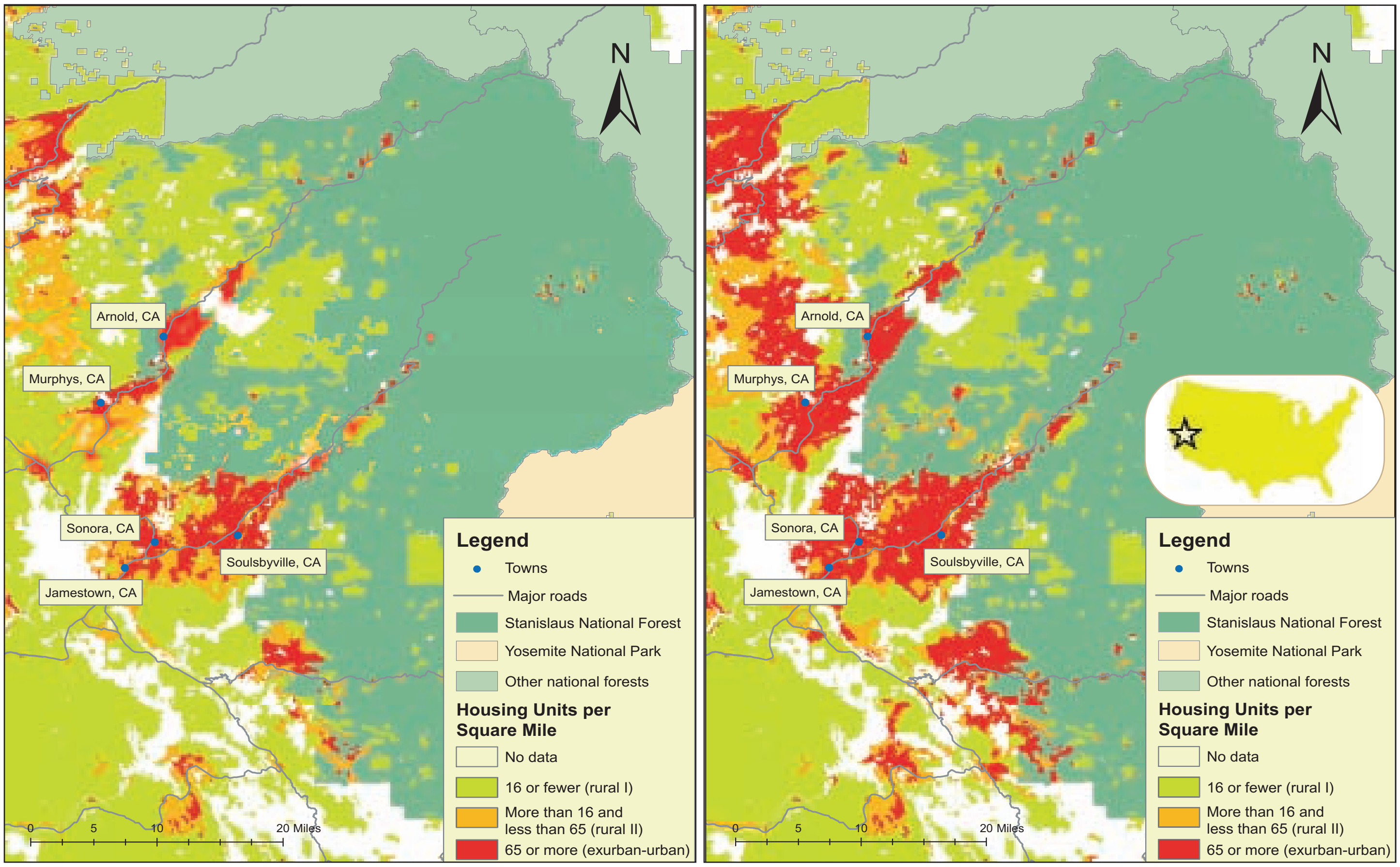


Figure 6—Housing density near the Stanislaus National Forest, 2000 and 2030. Source: Theobald 2004a, 2004b.

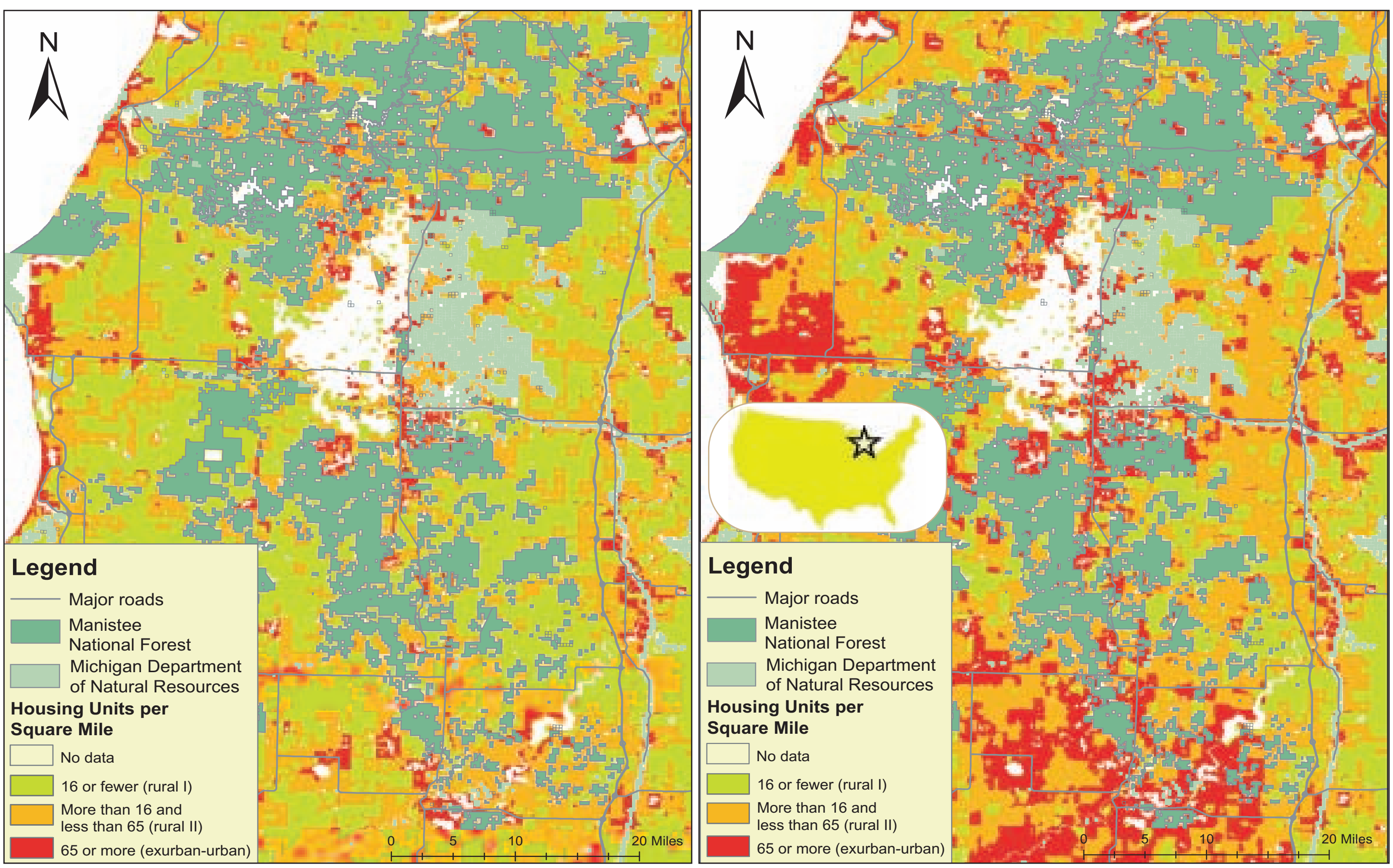


Figure 7—Housing density near the Manistee portion of the Huron-Manistee National Forest, 2000 and 2030. Source: Theobald 2004a, 2004b.

Continue

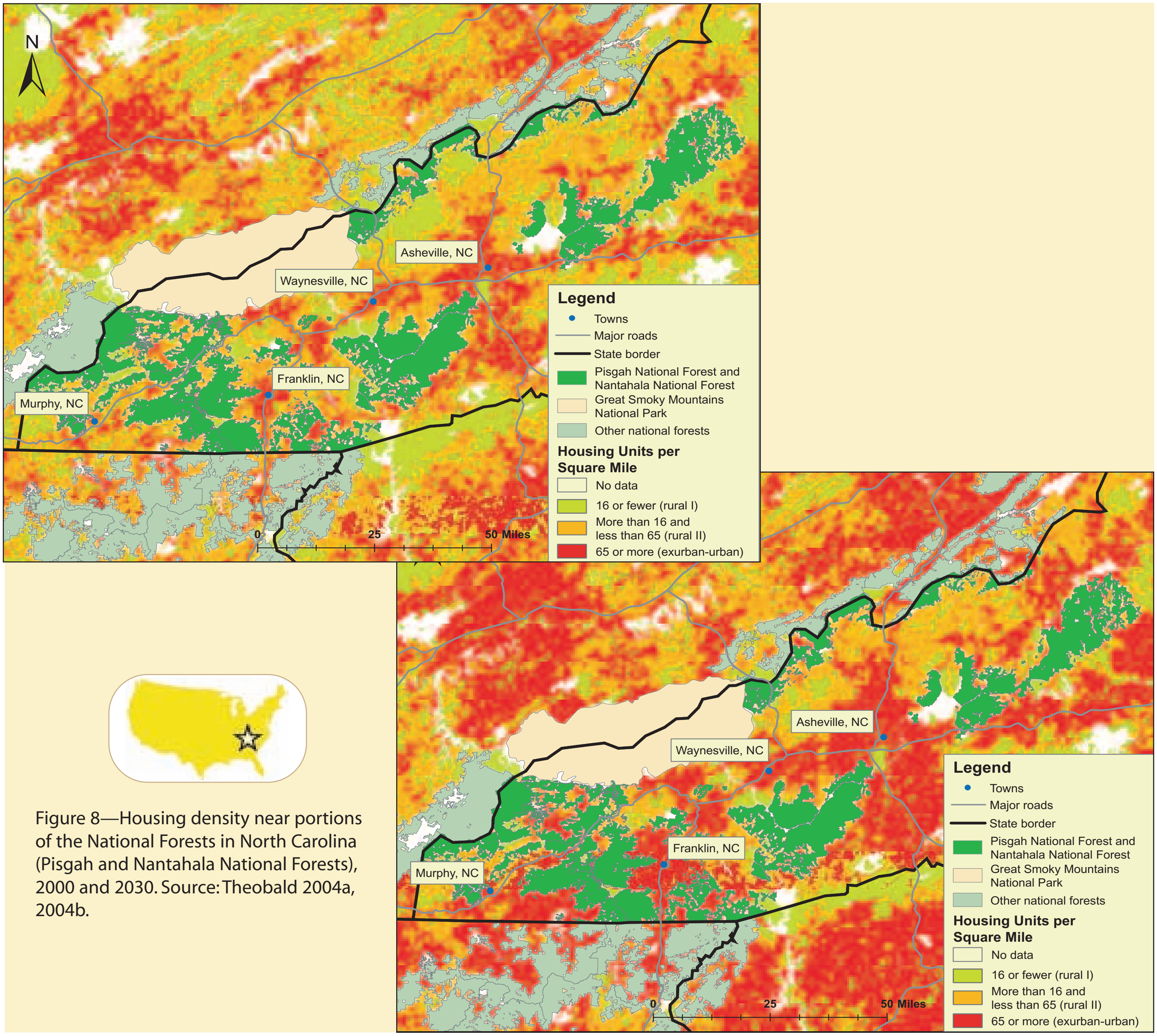


Figure 8—Housing density near portions of the National Forests in North Carolina (Pisgah and Nantahala National Forests), 2000 and 2030. Source: Theobald 2004a, 2004b.

interior travel corridors. Currently, many of the private lands immediately adjacent to the Stanislaus boundary already have housing densities greater than 64 units per square mile, in the exurban/urban category (fig. 6). Consequently, most of the projected increases in rural housing unit density would occur several miles from the national forest boundary. One exception to this general pattern is projected increases in housing density development to the exurban/urban category on currently rural lands that are adjacent to the southwestern boundary of the Stanislaus. Recreation management issues identified for this forest are likely to increase with continued development. These issues include the establishment of user-created trail systems and a decline in availability and quality of recreational opportunities (USDA Forest Service 2003a).

Huron-Manistee National Forest, Michigan

The Manistee portion of the Huron-Manistee National Forest lies in the northwestern portion of the lower peninsula of Michigan. Compared to the Bitterroot and the Stanislaus National Forests, the ownership of the Huron-Manistee National Forest (particularly within the Manistee portion) is unconsolidated, consisting of a few large blocks and many smaller blocks of noncontiguous federal lands. The result is significant intermixing of privately owned lands and federally managed lands. Currently, many areas immediately adjacent to National Forest System lands have rural I and rural II housing densities (fig. 7). However, projections of housing density for 2030 indicate substantial expansion in the extent of rural II and exurban/urban housing density in nearly all privately owned areas immediately adjacent to national forest parcels. Development-related issues

on the Huron-Manistee include user conflicts and the loss of public access (USDA Forest Service 2006c); these issues are likely to increase with additional development near the boundaries.

National Forests in North Carolina

The Nantahala and the Pisgah National Forests are both located in western North Carolina, near the Great Smoky Mountains National Park and the Blue Ridge Parkway. Both forests fall within the broader administrative unit known as the National Forests in North Carolina. The federal lands managed by these two forests are located in a number of separate blocks of noncontiguous ownership. Currently, most areas immediately beyond the boundaries of these national forests have housing densities categorized as rural II, although some areas of exurban/urban housing density do currently occur adjacent to National Forest System lands around Asheville and Franklin. Projections of 2030 housing density indicate significant increases adjacent to the national forest boundaries (table 2, fig. 8), particularly in the southern and central portions of the area. Lesser increases are projected near National Forest System land in the northeastern portion of the area considered here.

IMPLICATIONS

Increased development and accompanying landscape alteration on private rural lands adjacent to national forests and grasslands will have significant implications for the management and conservation of public land resources, ecological services and products, and social and cultural amenities (Johnson and Stewart 2007, Radeloff et al. 2005a, REO 2002). The following examples are among the specific consequences that may be associated with increased housing density on the peripheries of National Forest System lands.

Impacts on Native Fish and Wildlife Habitats and Populations

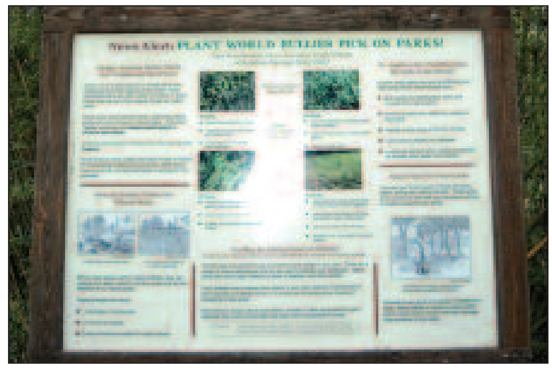
Wildlife populations on public lands—especially threatened and endangered species—can be at heightened risk from several factors associated with increased housing development on nearby private rural lands (Bass and Beamish 2006, Danielson et al. 1997, Deem et al. 2001, Ewing et al. 2005, Lepczyk et al. 2003, Manolis et al. 2002, Radeloff et al. 2005a, Riitters et al. 2002, Riley et al. 2003, Servheen 2006, Singleton et al. 2002). For example, wildlife may be excluded from usable habitats outside the national forest or grassland boundary or be otherwise affected by the fragmentation (Butler et al. 2004, Plantinga et al. 2007), degradation, or loss of those habitats. Wildlife also may suffer higher levels of mortality or displacement from increased traffic on both national forest and public roads (Jacobson 2006). They may experience disturbance or changes in behavior caused by the presence of people, roads, noise, or light; and they may be preyed upon by pets or other predators attracted to newly opened forest edges. Housing developments and associated roads may prevent wildlife from migrating or moving through areas outside forest boundaries and thus affect species that rely on a variety of ecosystems or large areas to survive. Migratory fish that spawn in National Forest System streams also can be affected by changes in water quality associated with development.

Research indicates that roads with moderate traffic volume have the highest rates of wildlife mortality, whereas roads with higher traffic volumes present the greatest barriers to wildlife movement. Traffic volumes are increasing to these critical levels on highways both on and off public lands, with large increases in areas with rapid development near national forests and other public lands (Jacobson 2006).

Impacts From Invasive Plant Species

Remnant sagebrush stand on the west side of the Bitterroot Valley, Montana, where abundant native sagebrush communities once played host to a variety of birds, butterflies, and other wildlife both on and off the nearby Bitterroot National Forest. Today most Bitterroot sagebrush communities are gone; remaining sagebrush stands are threatened by development activity and competition from plants used for livestock forage (Daniel 2006).

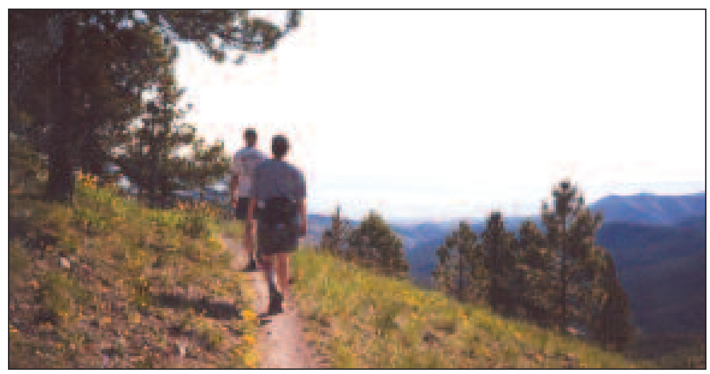
The health of national forest and grassland ecosystems can be affected by invasive plant species, which can find new points of entry into National Forest System lands through adjacent fragmented lands, new roads, and recreation trails (Dickens et al. 2005, Holway 2005, Sieg et al. 2005, Yates et al. 2004). Invasives can compete with and replace native plants, reduce plant diversity, and cause other disruptions to ecosystem function. Diseases and insects can be introduced into wildland protected areas by nursery plants used in nearby landscaping; for example, widely used rhododendron (*Rhododendron* spp.) and camellia (*Camellia* spp.) plants can be hosts to the pathogen that causes sudden oak death in native oak (*Quercus* spp.) trees (Koch and Coulston, in press).



Larry Korhnak

Impacts on Recreation Access and Management

Access for the general public to national forests and grasslands is a growing concern. In 1999 it was reported that about 14 percent of National Forest System land had limited public access and that managers were seeing significant reductions in access on many national forests (Peterson and Williams 1999). Housing development may lead to additional decreases in access to public lands, especially national forests, for recreation and other uses if roads on or across adjacent private lands are closed to the general public when new residents move in. Such restrictions may shift recreational use to other locations on National Forest System lands that do not have adequate infrastructure for increased recreation. Alternatively, increased housing development near National Forest System lands could lead to proliferating entry points, easier access, and increased usage of recreation services on National Forest System lands (Johnson and Stewart 2007), with accompanying challenges for effective recreation management. Unmanaged recreation has been cited by the Chief of the Forest Service as one of the top four threats to the Nation's forests (USDA Forest Service 2006b).



Anita Morzillo

Nationally, more than 50 percent of recreation use comes from those living within 30 straight-line miles of a national forest boundary (Stynes and White 2005). Public lands may become used even more heavily as nearby private lands become developed (USDA Forest Service 2006a).

Increased housing development near forest boundaries can lead to additional damage from unmanaged recreation, such as this bank erosion caused by off-highway vehicles on the Arapaho-Roosevelt National Forest.

Larry Korhnak

National forests and grasslands provide vital recreational opportunities for the American public.

Impacts on Fire Management

Potential for wildland fires is higher along the boundaries of forests where the human population has grown significantly (GAO 1999). Increased numbers of houses and people can be associated with more frequent ignitions (Cardille et al. 2001; Prestemon and Butry, in press; Radeloff et al. 2005b), especially in the Eastern United States, where nearly three-quarters of the area burned in wildland fires in federal forests from 1986 to 1996 were caused by human-related ignition sources (Prestemon and Butry, in press). Increased housing density can also be accompanied by an increase in air pollution, which has been shown to increase susceptibility of a forest to wildfire (Grulke et al., in press). A proliferation of houses increases the number of structures needing protection, complicates public land fire management and suppression, and drives up management costs (DellaSala et al. 2004, Grace and Wade 2000, Heuberger and Putz 2003, Podur et al. 2002, Radeloff et al. 2005b, Russel and McBride 2003).

Kari Greer, National Interagency Fire Center

Some 60 percent of all housing units built in the 1990s in the United States were constructed within the wildland-urban interface (Alig et al., in press, Radeloff et al. 2005b). Such houses can require intensive resources to protect them from wildland fire.

Paul Ryan, J.N. "Ding" Darling National Wildlife Refuge

A recent study of patterns of wildfire occurrence in Alabama found that most wildfires occurred in counties with population sizes between 10,000 and 63,000 or total road length (interstate highway, U.S. highway, and county road) from about 156 to 200 miles (Chen 2007).

Impacts on Water Quality and Hydrology

Water bodies and shorelines are among the sensitive areas likely to experience more environmental stress with increased human activity (Johnson and Beale 2002). Development along rivers and streams can cause excessive and unnecessary damage to banks, beds, and riparian vegetation and waterways; degrade water quality; interrupt hydrologic cycles; and affect watershed function upstream or downstream from the development activity (Schweitzer 2006). Increased housing density also creates more impervious surfaces, which lead to more runoff and increased risk of water pollution on both private and public lands (Zipperer 2002).

Developments along water courses can impact water quality and hydrology.

In the West, most fishing and hunting occurs on public lands, bringing important economic benefits to local communities (U.S. Fish and Wildlife Service and U.S. Census Bureau 2001, as cited in Sonoran Institute 2006).

Social and Economic Considerations

The presence of increased housing development near National Forest System lands can reduce open space and alter aesthetic qualities that contribute to recreation experiences (Clark and Stankey 1979). Increased human populations have been associated with an increase in crime on public lands, such as vandalism, drug activity, assaults, and illegal garbage dumping (Tynon and Chavez 2006, Whittaker 2006). Increased public access and activities on public lands could also create heightened concerns and higher costs for management of cultural resources.

Impacts on Boundary Management

Increased housing density in areas adjoining National Forest System lands can enhance the potential for encroachment, trespass, and unauthorized use and occupation of the public's land and resources. Encroachments onto national forests and grasslands can transform publicly owned environments into privately claimed backyards, lawns, flower and vegetable gardens, playgrounds, garbage dumps, and personal storage sites—potentially destroying or significantly damaging a natural environment. Among the most significant impacts on National Forest System lands from development and urbanization on adjoining private lands include illegal private road building, timber harvest, and user-created off-highway-vehicle trails on national forests and grasslands.

The Forest Service faces management challenges associated with control of property lines along the rapidly spreading wildland-urban interface. Limited funding, resources, and workforce have not kept pace with increased development on adjoining non-National Forest System lands. The Forest Service estimates that control of property lines for approximately 1 million acres of public land has been heavily compromised because of encroachment and trespass by adjoining landowners (Cunningham 2006).

Impacts on Other Federal Land Use Planning and Administration

Increased development activities on private lands in the vicinity of National Forest System boundaries can complicate resource planning on National Forest System lands and make land use planning and administration more expensive. Additional private landowners adjacent to national forests and grasslands means more neighbors with whom the Forest Service needs to coordinate in arranging access for fire management and recreation, managing ecosystems jointly across the landscape, and other management issues. Laws (such as the National Environmental Policy Act and the Endangered Species Act) and regulations (such as 36 CFR 212.55(b)) require the Forest Service and other land management

Trash dumping on national forests and grasslands associated with increased human populations can have detrimental impacts on streams and other resources.

agencies to include the environmental effects of neighboring land uses when analyzing cumulative effects of federal actions. Travel management plans for public lands are also required to be compatible with existing conditions in nearby populated areas.

SUMMARY AND CONCLUSIONS

Increased housing development in rural areas bordering America's National Forest System lands could alter the ecological, social, and economic resources and services provided by those public lands and increase their management costs. The many natural amenities of lands located close to protected areas such as our national forests and grasslands are attracting more and more homeowners. This study estimates future housing density on rural lands at three distances from National Forest System boundaries.

Nine national forests and grasslands are projected to experience increased housing density on at least 25 percent of private lands at one or more of these distances by 2030, posing potential challenges to forest and grassland management and conservation. Thirteen national forests and grasslands are projected to experience housing density increases on over a half-million acres of rural lands within 10 miles of their boundaries. Nationwide, some 21.7 million acres of private rural lands adjacent to national forests and grasslands are projected to experience change owing to increased housing development. Much of this land is next to national forests in the Eastern United States.

The findings of *National Forests on the Edge* can help direct our attention to places where changes to National Forest System lands could be substantial. This report also helps to describe potential effects of development near National Forest System lands. Such an understanding can help scientists, resource managers, and communities anticipate potential impacts, plan for prudent growth, and implement policies that take into consideration the implications for national forests and grasslands on the edge of development while the windows of opportunity for effective conservation action remain open.

Future research to address data limitations of this effort could include:

- Compilation of nationally consistent data on private inholdings for all National Forest System lands, to enable more accurate estimates of housing density increases.
- Estimates of housing density increases on private lands that are currently at or above 65 units per square mile, because this type of increase can also affect National Forest System lands.

- Estimates of housing density increases on lands adjacent to national forests in Alaska and Puerto Rico.

Strategic, collaborative approaches are needed at local, state, regional, and national levels to help guide development in ways that reflect people's needs and values and are complementary to or consistent with the protection of resources and services on national forests and grasslands (USDA Forest Service 2006a). Current examples include:

- Keeping land in forests through such programs as the Forest Service's Forest Legacy Program.
- Concentrating growth in existing towns and clustering development away from environmentally valuable land.
- Protecting private forests with conservation easements or tax incentives.
- Coordinating among landowners to control the spread of noxious weeds or address other resource issues.

The Forest Service is committed to working in partnership with landowners, local communities, and their governments to help maintain working landscapes, conserve critical open space, and keep National Forest System lands healthy and able to sustain ecological, social, and economic benefits far into the future.

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METRIC EQUIVALENTS

When you know:	Multiply by:	To find:
Feet	0.3048	Meters
Acres	.405	Hectares
Miles	1.609	Kilometers
Square feet	.0929	Square meters
Square miles	2.59	Square kilometers

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APPENDIX

INTRODUCTION

National Forests on the Edge projected development of rural private lands within three distances of national forests and grasslands in the conterminous United States. The projections were made for private lands surrounding external forest and grassland boundaries, defined here as the outer boundary within which a national forest or grassland was established (referred to as "proclamation" boundaries for some forests). **Internal boundaries** distinguish lands actually managed by the federal government as national forests and grasslands from private lands or "inholdings" found within external boundaries. External boundaries were used for this study because there is no national-level geospatial database of private land located within national forest and grassland external boundaries.

The housing density categories used for this study are identical to those in the first *Forests on the Edge* report (Stein et al. 2005a, 2005b). However, the terms used have been changed slightly:

- **Rural I** (lands with 16 or fewer housing units per square mile).
- **Rural II** (17 to 64 housing units per square mile).
- **Exurban/urban** (65 or more housing units per square mile).
- **Private land** is defined to include all lands not classified as public by the Protected Areas Database (described further below).
- **Increase in housing density** was defined to mean shifts from rural I to rural II or from either rural category to the exurban/urban category, based on the projected increase in the number of housing units per unit area between 2000 and 2030.

Housing Density Projections

Housing density projections were based on past, current, and projected statistics on housing density and population, road density data, past growth patterns, locations of urban areas, and other factors that were used in analyses for the first *Forests on the Edge* report (Stein et al. 2005a, 2005b; Theobald 2005).

Housing density was estimated by first drawing from historical and current housing densities at a fine grain to examine spatial patterns of development. Using the historical and current housing density patterns as data inputs, a projection (simulation) model of future housing density patterns to 2030 was developed based on county-level population projections generated by NPA Data Services, Inc. (2003).

Nationwide estimates of population and housing density were computed from the U.S. Department of Commerce Census Bureau's block-group and block data for 2000 (U.S. Census Bureau 2001a). To estimate current housing density patterns, housing densities were computed by using dasymetric (density measurement) mapping techniques described in detail in previous work (Theobald 2001). Essentially, blocks were refined by using public land information and water polygons (from Census Bureau). Public land information was derived from the Protected Areas Database (PAD) (DellaSala et al. 2001), v.2—an ArcInfo polygon coverage compiled by the Conservation Biology Institute (CBI). The PAD contains boundaries of most federal and state owned/managed protected areas in the conterminous United States and Alaska, and includes county, city, and private reserves where data are available. Portions of census blocks found on public land were removed, as were portions of blocks identified as streams, rivers, ponds, lakes, and reservoirs.

Based on these refined census block geographies, the number of housing units per block, obtained from the 100 percent data from the 2000 Census Summary Tape File 1 (U.S. Census Bureau 2001b), were allocated throughout the refined blocks. The allocation of housing density is weighted to reflect the probable heterogeneity of the placement of houses that are more likely to be located near roads and less likely in portions of blocks distant (greater than about 1 km [0.62 mi]) from roads; the weighting is based on road density (computed using an 800-m [2,624-ft] radius moving neighborhood).

Road density was classified into four arbitrary categories that distinguished different levels of development: very low (0.0 to 0.25 km/km^2 [0.0 to 0.15 mi/mi^2]), low (0.25 to 1.0 km/km^2 [0.15 to 0.62 mi/mi^2]), medium (1.0 to 5.0 km/km^2 [0.62 to 3.1 mi/mi^2]), and high (greater than 5.0 km/km^2 [3.1 mi/mi^2]). Weights of 1, 2, 3, and 4 were assigned to very low to high (respectively) levels of development and were used to allocate housing density values to cells within a block. Housing density estimates for 1990 were generated from the "Year Housing Built" question from the sample data Summary File 3 data set (U.S. Census Bureau 2001c). These data are provided at the block-group level and were adjusted to ensure that the sum of units by block groups in a county equaled the counts from decadal census by using established methods (Hammer et al. 2004, Radeloff et al. 2001, Theobald 2001).

The Spatially Explicit Regional Growth Model (SERGoM) v1 (Theobald 2005) was used to model the full urban-to-rural spectrum of housing densities. It uses a supply-demand-allocation approach and assumes that future growth patterns will be similar to those found in the past decade. Four basic steps were used in SERGoM v1 to project future patterns on a decadal basis.

First, the number of new housing units in the next decade was forced to meet the demanded quantity associated with the projected county-level population. Population growth was converted to new housing units by the county-specific housing unit per population ratio for 2000. Population estimates were obtained from a demographic-econometric model (NPA Data Services 2003).

Second, a location-specific average growth rate from the previous to current time step (e.g., 1990 to 2000) was computed for each of four density classes: urban, suburban, exurban, and rural. These growth rates were computed for each 100-m [328-ft] cell, using a moving neighborhood (radius = 1.6 km [.9936 mi]) that allows within-county heterogeneity and cross-county and state boundary growth patterns to be captured. Also, new housing units were spatially allocated based on these locally determined growth rates, which assumes that areas of future growth are likely to be near current high growth areas or "hot spots."

Third, the distribution of new housing units was adjusted according to accessibility to the nearest urban core area. That is, urbanization and conversion to urban and exurban land use typically occurs at locations that are nearer to urban core areas but that are on the fringe where land is undeveloped. Accessibility is computed in terms of minutes of travel time from urban core areas as one would travel along the main transportation network (major roads and highways). An urban core area is defined here as a contiguous cluster larger than 100 hectares (247 acres) at urban housing density. The distribution of housing density was then adjusted by creating a weight surface based on travel time from urban areas and was used to modify the location of new housing units computed in the first step.

Fourth, the new housing density was added to the current housing density, which makes the assumption that housing density does not decline over time, which is reasonable to represent patterns of expansion in suburban and exurban areas but may underrepresent areas that are in fact declining in housing density through urban decay or expansion of commercial land use into residential areas.

Analysis Procedures

A raster layer of projected changes in housing density (100 m by 100 m [328 ft by 328 ft]) was created from spatial layers of year 2000 and projected year 2030 housing densities (Theobald 2004a, 2004b, 2005). A cross-walk table was developed to translate the change categories in the raster layer to the housing density category changes considered in this report (i.e., rural I to rural II, either rural to exurban/urban).

Based on a spatial database of National Forest System lands (USDA Forest Service 2000a), buffer polygons were created for three distances from the external boundaries of individual administrative national forests: 0 to ½ mile, ½ mile to 3 miles, and 3 to 10 miles. Owing to the existence of disconnected forest parcels that are administered by the same national forest, some buffers overlapped within individual national forests. These overlapping buffers were dissolved. As a result of the shape and arrangement of the forest parcels, each national forest typically had several hundred forest buffer polygons. The buffers of adjacent national forests that overlapped one another were identified but not dissolved.

Using the projected change raster layer, the numbers of private land acres were tabulated for all forest buffer polygons for the following sets of changes: changes from rural I to rural II, from either rural to exurban/urban, and those acres not changing housing density classes. Forest-level estimates of the number of acres changing and not changing housing density classes within the three distances considered were constructed by summing the tabulated acres of each forest buffer polygon for each administrative national forest. National-level results were computed by summing across all forest buffer polygons within the distance categories, after accounting for acres in forest buffer polygons that overlapped between forests. Accounting for overlapping forest buffers between forests avoids double counting of acres in the national-level results.

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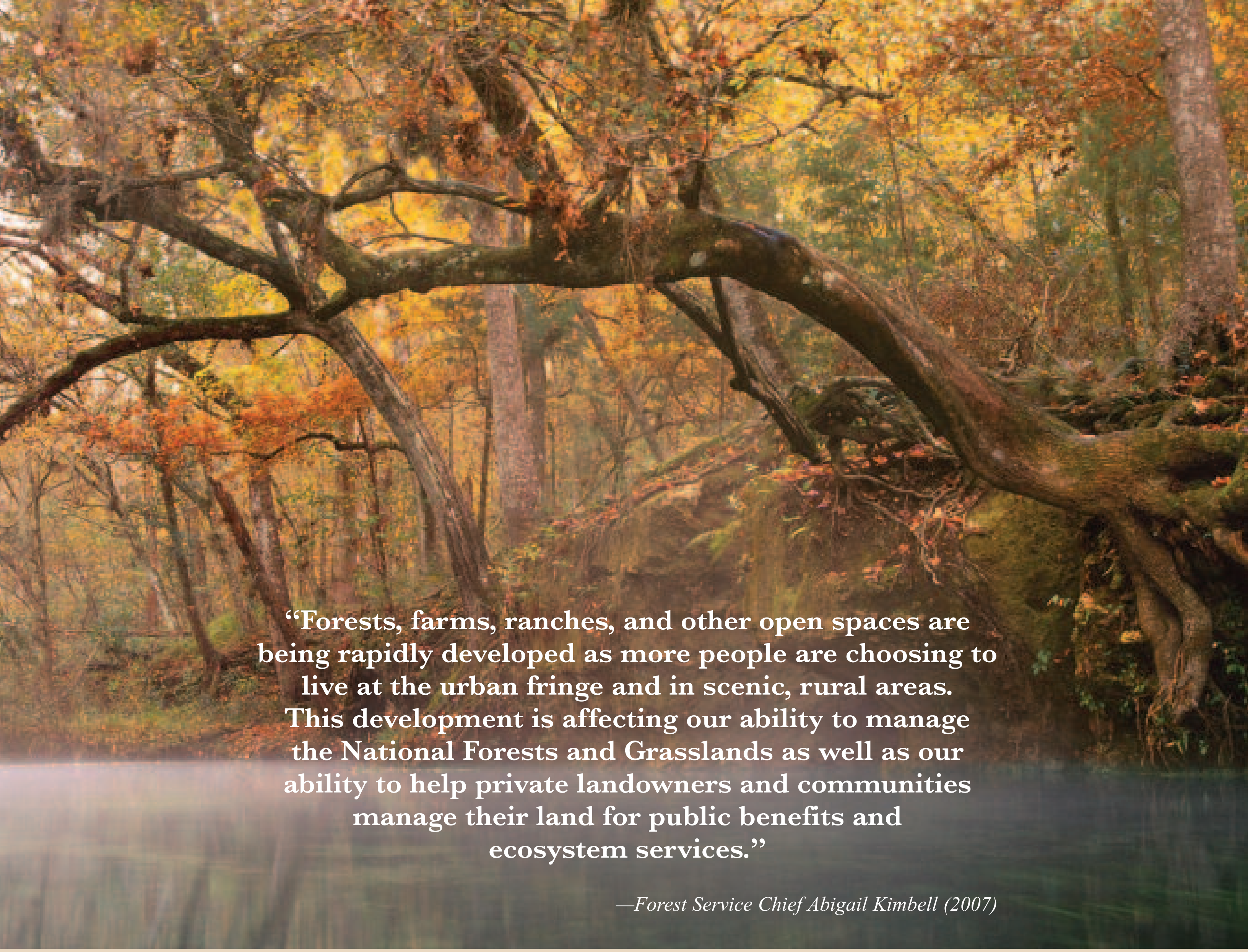

FORESTS ON THE EDGE

Forests on the Edge, a project of the U.S. Department of Agriculture, Forest Service, aims to increase public understanding of the contributions of and pressures on America's forests, and to create new tools for strategic planning. Our first report, *Forests on the Edge: Housing Development on America's Private Forests* (Stein et al. 2005a), identified private forested watersheds most likely to experience housing development. This second report identifies national forests and grasslands most likely to experience increased housing density on rural private lands along their borders.

Future studies will examine:

- Threats to private forest contributions—presenting data related to private forest benefits such as water quality, timberland, and wildlife values, as well as threats such as development, fire, insects pest and diseases; and air pollution.
- Detailed descriptions of top watersheds of concern.
- Development projections for private forest lands in Alaska, Puerto Rico, the Virgin Islands, Hawaii, and the Pacific Islands.

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http://www.fs.fed.us/openspace/fote/

Attachment E

esa

ECOSPHERE

Evaluating the influence of energy and residential development on the migratory behavior of mule deer

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Abstract. Migratory ungulates are often exposed to anthropogenic infrastructure along their migration routes. Understanding the influence of such development on migratory behavior is critical to successful planning and conservation. Impermeable barriers have obvious and detrimental effects to migratory ungulate populations, but the influence of semi-permeable barriers, where the connectivity of migration habitat is maintained but the migration routes are compromised by anthropogenic development, remains unclear. We evaluated the influence of development on the migratory behavior of individual mule deer (*Odocoileus hemionus*) in western Wyoming, USA. We used fine-scale movement data to evaluate the influence of anthropogenic infrastructure on deer movement rates, stopover use, and fidelity to migration routes for individual animals across multiple seasons and years. Deer avoided human infrastructure when selecting stopover sites. Fidelity to migration routes and stopover areas, as measured by the degree of spatial overlap between years, was not influenced by development, except in one heavily developed area. Our results suggested that deer increased rate of movement, reduced time in stopovers, and shifted stopovers in areas of intense development. In most cases, deer maintained fidelity to migration routes, regardless of development, suggesting that deer mediated exposure to development by altering movement—rates and timing—rather than the routes they traversed. This work adds to a growing number of studies indicating that development can disrupt migratory behavior. Understanding how different types and intensities of development influence migration can help inform land-use planning and conservation of migratory ungulates.

Key words: energy development; habitat fragmentation; habitat loss; migratory behavior; movement rate; mule deer; route fidelity; rural residential development; stopover.

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Introduction

Migratory populations of diverse taxa are declining globally (Robbins et al. 1989, Sanderson et al. 2006, Flockhart et al. 2014, Monnahan et al. 2014), with habitat loss and fragmentation being a leading cause of decline (Fischer and Lindenmayer 2007). In particular, terrestrial migrations that expose ungulates to extensive and diverse anthropogenic disturbances have led to population declines (Berger 2004, Bolger et al. 2008, Harris et al. 2009). The long-distance migrations of ungulates are an adaptation to exploit seasonal changes in resources (Festa-Bianchet 1988, Fryxell et al. 1988, Albon and Langvatn 1992, Mysterud 1999). It is well known that populations will decline if access to critical forage and other resources is obstructed by development (Williamson and Williamson 1984, Whyte and Joubert 1988, Spinage 1992, Ben-Shahar 1993, Leu et al. 2008). Development types that cause habitat fragmentation, such as infrastructure that results in impermeable barriers to migration—where habitat connectivity is completely lost, such as game-proof fencing—pose significant threats to the persistence of migratory ungulate populations (Dobson et al. 2010, Holdo et al. 2011). Less clear, however, is how semi-permeable barriers—anthropogenic infrastructure that still allows movement—affect the persistence of ungulate migration corridors (Sawyer et al. 2013).

Semi-permeable barriers allow movement between seasonal ranges, but the functional attributes of a route such as stopovers, parturition sites, or predator avoidance habitat can be negatively impacted. Such effects on functional attributes are likely related to the intensity of development or degree of permeability (Sawyer et al. 2013). Recent work indicates that anthropogenic disturbance alters the behavior of migratory ungulates. For example, ungulates avoid linear structures such as roads, seismic lines, and pipelines, but their movement is not entirely blocked as they are still able to move between seasonal ranges (Dyer et al. 2002, Beyer et al. 2014, Seidler et al. 2014). Studies have also found that migratory ungulates move more quickly through developed areas, potentially reducing their access to resources in those areas (Dyer et al. 2001, Sawyer et al. 2013, Lendrum et al. 2013). In addition, avoidance of development has been found in species from mule deer (*Odocoileus hemionus*; Sawyer et al. 2009*a*) to caribou and reindeer (*Rangifer tarandus*; Bradshaw et al. 1997, Dyer et al. 2001, Reimers and Coleman 2006).

As anthropogenic infrastructure increases, migratory ungulates may suffer from incremental loss of access to resources, which could result in population declines. During migration, mule deer spend 95% of their migration time in stopover areas (Sawyer and Kauffman 2011), which they rely on for energy intake to facilitate recovery of fat stores in the spring after leaving winter range (Torbit et al. 1985, Monteith et al. 2011). Foraging during migration allows access to plants low in fiber and high in digestible energy, which supports reproduction and survival (Albon and Langvatn 1992). Similar to summer, winter, and parturition areas, we now understand migration routes as critical seasonal habitats that are especially important for forage (Sawyer et al. 2009*b*, Sawyer and Kauffman 2011, Aikens et al. 2017).

Migration routes provide animals with gradients in forage quality that can be exploited as conditions change (McNaughton 1985, Mysterud 1999, Wilmshurst et al. 1999), and in some areas, they offer habitats with reduced predation risk (Fryxell et al. 1988, Hebblewhite and Merrill 2007). Yet, the impact of semi-permeable barriers on the fitness consequences of migration, due to shifts in ungulate behavior, remains unclear. We expect that reduced functionality of migration routes, in the form of stopover loss, would translate to a reduction in forage availability along impacted routes. For example, environmental variability as common as drought can alter the length of spring forage availability for elk (*Cervus elaphus*), with associated fitness costs (Middleton et al. 2013).

Previous work has shown that ungulate movement patterns shift following the development of anthropogenic infrastructure (Boulanger et al. 2012, Johnson and Russell 2014). Analyses, however, have typically been conducted on specific development types (i.e., petroleum extraction or mining activities) rather than over a broad range of types that vary in intensity and rapidity with which they appear on the landscape (Johnson and Russell 2014). Some studies have focused on the effects of habitat fragmentation caused by road networks that impede migration (Alexander and Walters 2000, Frair et al. 2008). In other areas, however, a mixture of anthropogenic features, including roads, residential, oil and natural gas extraction, and highways, prompting ungulates to potentially respond in different ways, can influence migration routes. Unlike oil and natural gas, which generally results in rapid development in previously intact habitat, residential development may occur more slowly in and around existing populated areas, possibly resulting in some level of habituation by migratory individuals over time (Haskell and Ballard 2008, Polfus et al. 2011). Understanding the extent to which ungulates adjust to different types and rates of development during migration may provide insight into the potential loss of the functional attributes of routes.

Many ungulates generally maintain fidelity to their migration corridors (Garrott et al. 1987, Andersen 1991, Sawyer et al. 2009*b*, Sawyer and Kauffman 2011, Eggeman et al. 2016). Migration in ungulates is a learned behavior and is culturally transmitted from mother to young (McCullough 1985, Sweanor and Sandegren 1988, Nelson 1998, Nelson and Mech 1999, Harrison et al. 2010). Migration routes are resources that, historically, have been reliably available to migrants. Within the narrow template upon which ungulates migrate, discovering new resources and embarking on new routes to avoid anthropogenic infrastructure areas may be constrained by high fidelity. Site fidelity has been shown to be a stronger driver of movement behavior than forage quality alone in a free-ranging American bison (*Bison bison*) population (Merkle et al. 2015). Boreal woodland caribou maintained site fidelity despite the encroachment of petroleum-sector development, resulting in the potential for fitness consequences due to increased predation (Tracz et al. 2010). Elk displayed more behavioral plasticity by switching between resident and migratory strategies, suggesting that some migratory ungulates respond to a variety of factors, including density dependence (Eggeman et al. 2016). Sawyer et al. (2013) found that a few deer detoured around a newly expanded energy area during their migration, but returned to the same summer range despite the detour. Route fidelity has the potential to alter the influence of anthropogenic infrastructure on migratory movement patterns, but fidelity has yet to be incorporated into how we understand the influence of development on migratory behavior.

Although previous work (Sawyer et al. 2013) has shown an influence of development on mule deer migrations, we do not yet know how different types of development influence stopover use or route fidelity. We evaluated the influence of development on migratory behavior for three migratory mule deer herds that moved through residential (i.e., houses, residential roads, fences) and petroleum extraction (i.e., well pads, compressor stations, drilling rigs, well-pad roads) areas that varied in development type and intensity along their migration routes. We used fine-scale temporal movement data derived from GPS-collared deer from three herds in western Wyoming, USA (Sawyer et al. 2009*b*, 2013), and evaluated the influence of development on three behaviors: (1) rate of movement, (2) stopover use, and (3) fidelity to migration routes. We expected animals exposed to development would increase movement rates, reduce stopover use, and lessen fidelity to migration routes.

Materials and Methods

Study area

Our study focused on three mule deer populations generally located near the towns of Pinedale, Rawlins, and Saratoga, Wyoming, USA (Fig. 1a). Deer migration routes throughout the three study areas crossed a mix of public (70%) and private (30%) lands. All three study areas were characterized by high-elevation basins ranging from 1700 to 1800 m in elevation, dominated by sagebrush (*Artemisia* spp.) steppe shrublands, and interspersed with occasional greasewood (*Sarcobatus vermiculatus*) flats, Gardner's saltbush (*Atriplex gardneri*), and a variety of forbs and grasses. The basins are surrounded by mountain ranges ranging from 3400 to 4000 m in elevation, dominated by lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmannii*), and subalpine fir (*Abies lasiocarpa*), and interspersed with aspen (*Populus tremuloides*) and cottonwood (*Populus* spp.) woodlands. Precipitation ranges from 15–38 cm in the basins to 53–150 cm in the surrounding mountains (Wyoming State Water Plan 2010) where winter snow is the dominant precipitation regime (Western Regional Climate Center 2003). Deer ranged in elevation from 1762 m in winter to 3413 m in summer. Western Wyoming includes a variety of oil, gas, and other mineral production sites from several petroleum-producing geologic formations (Smith et al. 2010), as well as rural and residential areas. Deer in the Pinedale area migrated 16–183 km between seasonal ranges. The primary development type overlapping routes in this area was rural residential housing, so we referred to this as the "residential study area" (Fig. 1b). Deer in the Rawlins area migrated 11–87 km between seasonal ranges. The migration routes here were exposed to considerable levels of energy development (i.e., coalbed natural gas), so we referred to this as the "energy study area" (Fig. 1c). Deer in the third population near

Saratoga migrated 10–182 km between seasonal ranges and routes were minimally influenced by anthropogenic infrastructure, so we referred to this site as the "dispersed rural area" (Fig. 1d).

Movement data

We used helicopter net-gunning to capture adult female mule deer across winter ranges. We collected movement data from individual female mule deer (n = 186) between 2003 and 2012 (Sawyer et al. 2006, 2009*a*, *b*, 2013; Appendix S1: Table S1). Data were collected using store-on-board GPS collars (TGW 3500; Telonics, Mesa, Arizona, USA) programmed to record a location every 2 or 2.5 h and to drop off 1–2 yr after deployment. Analyses were conducted in program R version 3.1.3 (R Development Core Team 2017) unless otherwise indicated. Deer departed winter ranges between March and June and arrived on summer ranges between April and June. Deer departed summer ranges between October and January and arrived on winter ranges between October and February, with most deer completing autumn migrations in October and November.

Development

We defined development as anthropogenic infrastructure on the landscape, including roads, well pads, and residential development (Figs. 2, 3). We first quantified the extent and intensity of anthropogenic features across each study area. We developed a measure that could be applied to an entire migration route or to smaller segments within a route. Anthropogenic infrastructure types included line feature classes representing residential roads, well pads (polygons were converted to lines; refer to Appendix S1 for development data details) associated with oil and natural gas infrastructure (Garman and McBeth 2015), well-pad access roads, county roads, and major roads.

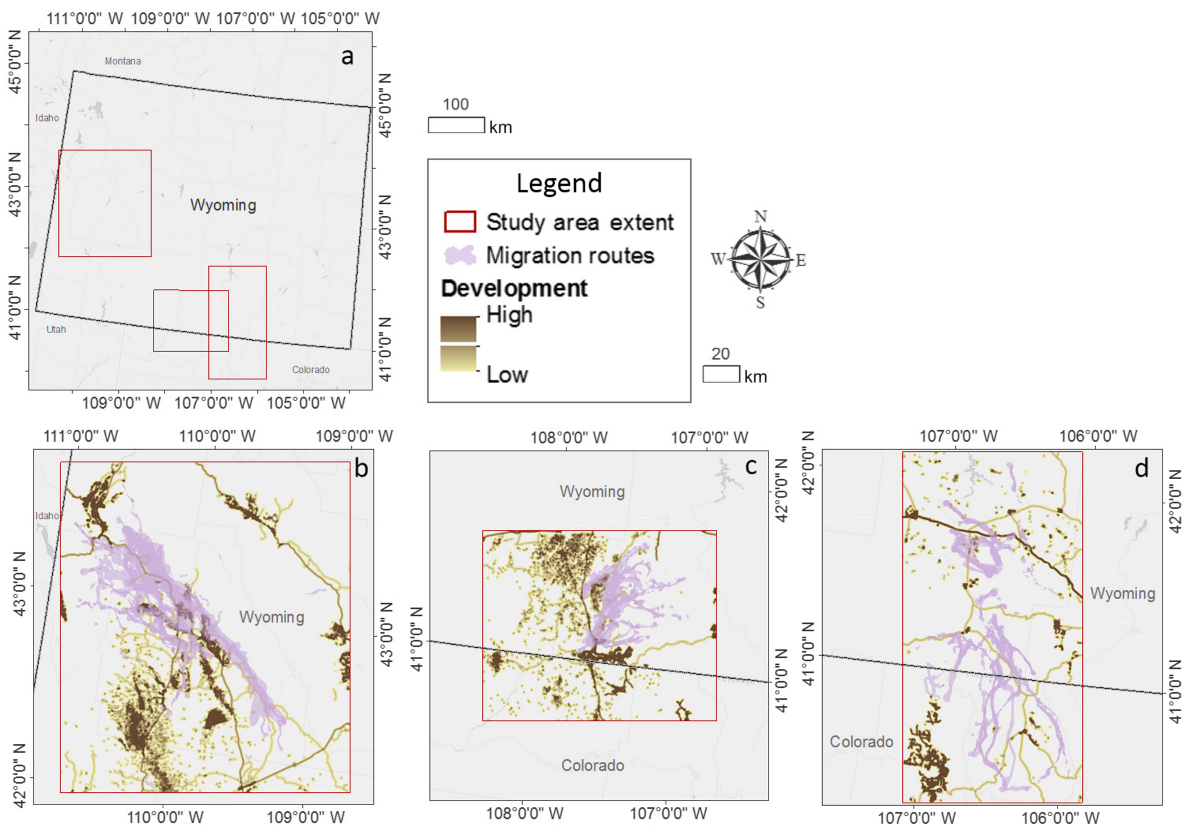

Fig. 1. The three study areas in western Wyoming, USA (a), wherein migratory mule deer were collared with GPS units. Maps include migration routes and modeled development (see text) in (b) the residential (2003–2011), (c) energy (2005–2010), and (d) dispersed rural (2011–2012) study areas.

Fig. 2. Examples of energy development (a, b) and residential development (c, d) along mule deer migration routes in western Wyoming, USA.

We applied a kernel density estimate with a 1 km distance decay function to create continuous raster datasets of each feature type (well-pad access roads, county roads, etc.). Each development type was assigned a weight (Copeland et al. 2007) based on our estimation of the expected influence on migratory mule deer across our study areas: residential 1.0, major roads 0.9, well pads 0.8, well-pad roads 0.3, and county roads 0.3. While collection of human presence and noise data was beyond the scope of this study, our weighted design was based on our best understanding of associated levels of human activity. Residential development was the highest category due to the potential for highest activity and noise potential. The feature weight served as our proxy for human presence and noise. Assigned weights were used to generate a single raster dataset representative of all anthropogenic features for each study area, and for each year for which we had GPS-collar data for deer. We used ArcGIS 10.2 software (ESRI 2014) and raster calculator to combine the kernel density raster datasets. The development raster datasets were constructed using the same methods for all study areas, as each included all development types (Appendix S1), which were additionally used for density estimation. We conducted the analysis of migratory behavior across the three study areas that represented a wide variety of landscapes, though our intention was not to compare between different types, but rather to characterize them at a broad scale. Based on what Sawyer et al. (2013) found in the energy development area, we evaluated a wider range of development types at a broad scale. The resulting footprint generally aligns with our categories (types) of development. Migration routes traversed intense natural gas development in the energy area (well-pad density increased from 1.49 to 2.82 wells/km^2 during the study period), intense rural development (i.e., ranch homes on 2- to 8-ha spacing outside of municipal boundaries) in the residential area, and through no intense areas of development in the rural area (i.e., most homes outside of municipal boundaries are on 28-ha lots or larger). Although we had multiple years of data, the years were not consistent, making our data unsuitable for a time-series or before-after type of analysis; the energy study area, however, had temporal data sufficient to evaluate the change in migratory behavior of deer over time. In the residential study area, population in the town of Pinedale, Wyoming, changed relatively rapidly, increasing from 1412 in 2000 to 2030 in 2010. In the rural study area, population in the town of Saratoga, Wyoming, decreased from 1681 in 2011 to

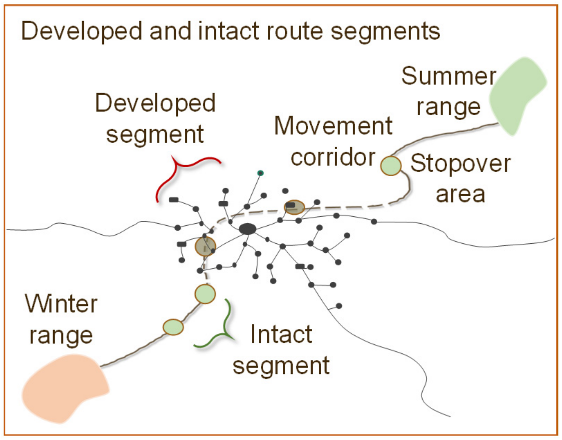

Fig. 3. Migration route (green line) and route segments (intact, solid line; disturbed, dashed line) for migratory mule deer in three study areas in western Wyoming, USA, that migrate through different types of development, where black dots represent development of well pads or residential development with the associated network of roads indicated by the black lines. We paired intact and disturbed route segments for comparison of movement rate and stopover area use. Deer migrate from winter range to summer range and return in autumn, spending the majority of their migration time stopped over foraging in stopover areas (green circles). The use of movement corridors and stopover habitat in development (dashed line and brown circles in developed area) indicates the areas in question for this study: differences in behavior and use between intact and disturbed portions of migration routes.

1664 in 2012 (U.S. Census Bureau 2016). Because we lacked replication across development types, our analysis is best viewed as a general comparison across the three development settings; we were not able to make statistical comparisons across development types.

Movement rate

We evaluated movement rates of mule deer using routes with development compared to those with no development. We selected two segments for each individual, season, and year for developed (>0.5 development level; development footprints ranged in level from 0 to 15) and intact (<0.05) habitats. In order to maintain discrete segments for comparison, development and intact segments were separated by a minimum distance of 2 km, which roughly aligns with the distance that deer respond to human disturbance associated with well pads (Sawyer et al. 2009*a*). We used a paired t test with an α level of 0.05 to evaluate the movement rate (km/h) differences between intact and developed segments of each migration route for each individual, by season and year. These analyses were restricted to our two study areas with large amounts of development; the dispersed rural area was not evaluated due to the paucity of disturbed areas.

Stopover use

We used a Brownian bridge movement model (Horne et al. 2007) in the BBMM package (Nielson et al. 2013) to develop utilization distributions (UD) for each migration route. BBMMs use time-specific location data to estimate the probability of a deer location between temporally adjacent GPS locations. We selected the top 25% UD as areas of high use, or stopover areas. We used an area-based selection ratio approach (Manly et al. 2007, Sawyer and Kauffman 2011) to evaluate stopover locations relative to anthropogenic features using an individual's spring or autumn migration as the unit of replication. Because a deer can stop over anywhere along its route, we defined stopover habitat availability as the 99% UD, with the mean level of development along the entire route. We then calculated a selection ratio for each route as the average level of development within stopovers (25% UD) along a route divided by the mean level along the entire route. Using the route as the level of availability, we evaluated whether more stopovers occurred in more intact portions of habitat in relation to the mean development value along the route. A selection ratio different than 1.0 indicates either selection for (ratio > 1.0) or avoidance of (ratio < 1.0) development.

Route fidelity

We used BBMM analyses to evaluate the overlap between migratory habitats for deer with two or more complete spring or autumn migrations for a paired-spring or paired-autumn comparison (Appendix S1: Table S2). We estimated the area of overlap between stopovers, and the full route in consecutive years as a measure of migration route fidelity. We estimated the mean level of development for each stopover or full route comparison. To evaluate differences in fidelity between stopovers and routes, we used a paired *t* test—pairing stopovers and routes—for the same individual, in each year and season. We used linear regression to evaluate the influence of development on fidelity to stopovers by regressing the overlap of stopover areas between years for individuals for the same season against the level of development for each pair of stopovers as measured between consecutive years by season. Similarly, we used linear regression to assess the influence of the mean development score for each route on fidelity measured by overlap between consecutive routes.

Results

Rate of movement

In the energy study area—Rawlins—deer moved more rapidly through development in autumn (paired *t* test, $n = 47$, $t = 1.8$, df = 46, $P = 0.07$, 1.02 ± 0.47 km/h) and spring ($n = 104$, $t = 1.7$, df = 103, $P = 0.09$, 0.82 ± 0.44 km/h) than through intact habitat (though not statistically significant with an $\alpha = 0.05$, autumn 0.90 ± 0.38 and spring 0.74 ± 0.34 km/h). In the residential study area—Pinedale—deer moved more rapidly through development in autumn ($n = 61$, $t = 2.9$, df = 60, $P = 0.005$, 0.80 ± 0.35 km/h) but not in spring ($n = 50$, $t = -0.8$, df = 49, $P = 0.4$, 0.4 ± 0.22 km/h) than through intact habitat (autumn 0.67 ± 0.27 and spring 0.43 ± 0.21 km/h; Appendix S1: Fig. S1). Movement rate differences between intact and developed segments of routes may indicate a difference in habitat use, including reduced stopover use for foraging.

Stopover use

Deer stopped over more frequently in intact habitat in two of the three study areas. Mean stopover (95% CI $\pm$ SE) selection ratios were 0.84 ± 0.31 in the energy ($n = 163$ migrations), 0.98 ± 0.28 in the residential ($n = 121$), and 0.22 ± 0.14 in the dispersed rural study area ($n = 108$), where ratios below 1.0 indicate selection for areas with less development. When data for both seasons were combined and pooled by year, means did overlap 1.0 in some years (see Appendix S1: Table S3 for mean and CIs by year and Fig. 4; see Appendix S1: Table S3 for statistical variables by year). In the energy study area, selection ratios decreased through time, suggesting increased avoidance as development increased. In the residential study area, selection ratios were variable through time, indicative of other factors influencing habitat selection. In the dispersed rural study area, intact habitat was available to mule deer, and they strongly avoided development. Overall, mule deer spent less time in stopover areas influenced

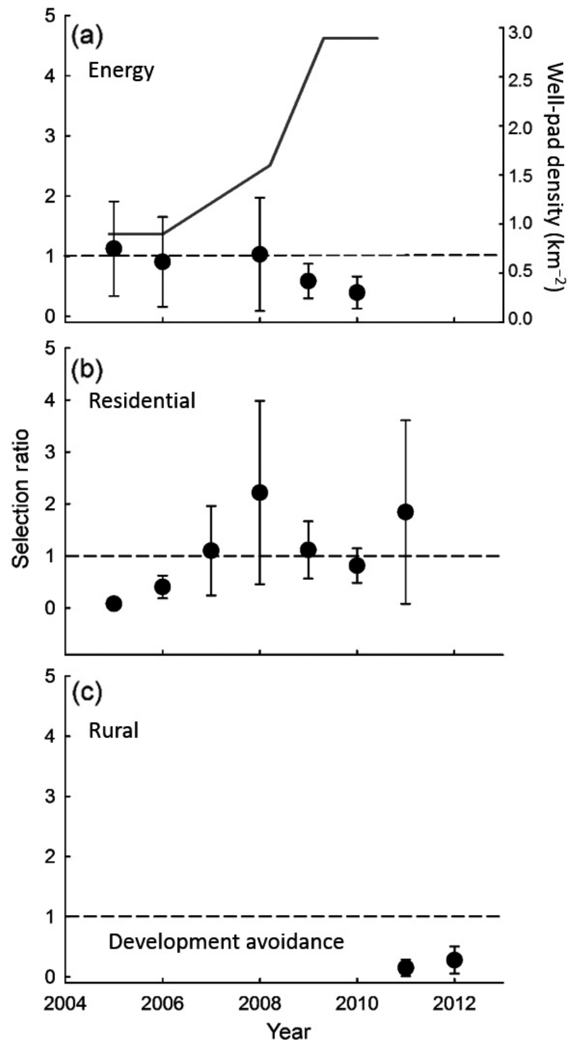

Fig. 4. Avoidance of development as evidenced by the location of stopover areas used by migratory mule deer in three study areas in western Wyoming, USA (2005–2012). Selection ratios (dashed line) below 1.0 indicate avoidance of developed habitat, for (a) energy, (b) residential, and (c) dispersed rural study areas. Black circles indicate selection ratios pooled by year with 95% CI bars. In the energy study area (a), development as represented by well-pad density (solid gray line) increases rapidly over the course of the study.

by development than in intact habitat. In the energy development area, deer shifted stopovers away from development as development intensity increased through time (2005–2010; Appendix S1: Fig. S2) as indicated by selection ratios that became increasingly <1.0 over time.

Route fidelity

In general, deer displayed high spatial overlap (i.e., fidelity) between years for migration routes (Appendix S1: Fig. S3). Fidelity to full migration, season-specific routes was greater than to stopover areas (paired t test, $t = -13.96$, df = 95, $P < 0.001$; Fig. 5). Based on linear regression of paired data for each season and year, fidelity to stopover areas ($n = 195$, $F = 0.7$, df = 122, $r^2 = 0.2$, $P = 0.9$; Appendix S1: Table S4) and to the full route ($n = 187$, $F = 1.1$, df = 48, $r^2 = 0.7$, $P = 0.2$) was not influenced by development (Appendix S1: Fig. S4 and Table S4). There was an indication of a negative influence of the mean development level of the route on fidelity to stopover areas in the energy study area, resulting in lower fidelity. We also aggregated data by year and regressed stopover and route overlap against mean development of route for the energy study area where temporal data existed, which indicated that deer shifted stopover areas away from development but maintained routes overall (Appendix S1: Fig. S5).

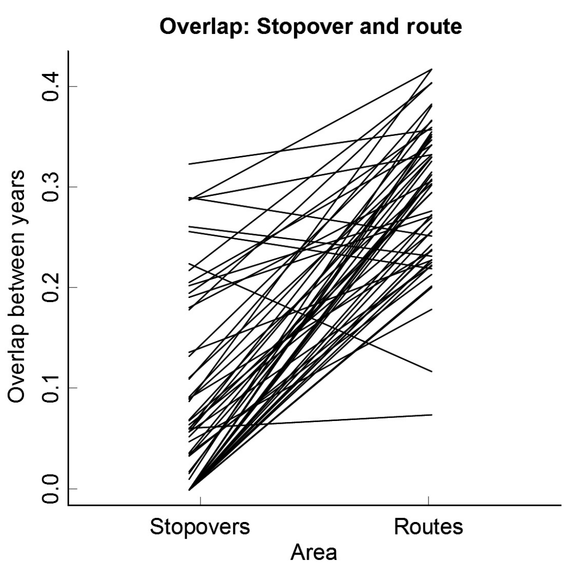

Fig. 5. Spatial overlap of routes and stopover areas for migratory mule deer in western Wyoming, USA. Each line represents paired data for an individual deer, season, and paired between years (2003–2012) represented as paired data. The overlap between years was calculated as the top 25% and 95% overlap in a Brownian bridge movement model used to identify stopover areas and migration routes for comparison between years. Deer displayed higher fidelity to routes than to stopover areas, as reflected by higher overlap values for routes than for the corresponding pair of overlap of the stopover area.

Discussion

As expected, we found migratory mule deer increased movement rate and reduced stopover use in response to development along migration routes. Behavioral responses of migrating mule deer differed across the three study areas that varied in the pace, type, and intensity of development. Contrary to our expectations, deer maintained fidelity to migration routes in most cases, and did not exhibit less fidelity to routes influenced by development, although the lack of fidelity to the rapidly developing energy study area was a notable exception (Appendix S1: Fig. S6). Taken together, these results indicate that development along migration routes may alter the migratory movement patterns of mule deer, with the potential to diminish the foraging benefits of migration. Diminished forage benefits (Sawyer et al. 2013), if maintained over a sufficiently long time, could lead to the loss of traditional migration corridors. Previous research had documented the loss of migration across numerous ungulate herds, sometimes due to complete severance of the corridors (Ben-Shahar 1993, Mwangi 1998) and other times due to habitat fragmentation or overhunting (Newmark 1996, Milner-Gulland et al. 2001, Bolger et al. 2008, Harris et al. 2009, Sawyer et al. 2013).

Behavioral responses of migrating deer across different developed landscapes were generally negative. Within the constraints of our analyses, the most pronounced responses occurred in the energy area, where development expanded rapidly, most notably between seasons and over a period of five years during the study period, providing a unique temporal assessment of migration and development. In the initial low-development phase in 2005 and 2006, the road and well-pad densities in our focal area were 0.56 km/km^2 and 0.77 wells/km^2, respectively. During the development phase in 2008, road and well-pad densities increased to 1.07 km/km^2 and 1.49 wells/km^2, respectively. In 2009 and 2010, road and well-pad densities increased again, before plateauing around 1.92 km/km^2 and 2.82 wells/km^2, respectively (Sawyer et al. 2013). These landscape changes caused increased movement rates, altered stopover use, and, in a few cases, resulted in a loss of fidelity. Results were consistent with evaluations of the migrations in the energy study area by Sawyer et al. (2013), which our work builds upon. Results also were consistent with work in Piceance Basin, Colorado, USA, where Lendrum et al. (2012, 2013, 2014) found deer moved more rapidly through habitats with higher levels of development. Deer in our residential study area displayed fewer migratory movement changes relative to undeveloped portions of their routes. Residential development in this area generally occurred relatively slowly and in close proximity to existing residential areas. We suspect that the rapidity of energy development (<10 yr)—and its occurrence coupled with high human presence during the drilling phase in otherwise intact habitats in Wyoming—elicited stronger behavioral responses than the other study areas which were settled and developed over a century or longer. However, recent work in Colorado suggests the impacts of residential development on mule deer can be similar to those of energy development given the rapidity of change in an area (Johnson et al. 2016). Some habituation to development in an ungulates' home range may be possible (Tracz et al. 2010), though the influence on migrants, or to mule deer specifically, remains to be seen. As migratory landscapes continue to be fragmented, the pace of development—in addition to density and configuration—should be taken into account when designing conservation strategies to sustain migration routes.

Although the effect was not particularly strong and only marginally significant, deer generally increased movement rate through disturbed compared to intact portions of their route in both autumn and spring. Energy expenditure for mule deer increases linearly with velocity of motion; thus, we assume that increased movement rate results in an increased energetic cost (Parker et al. 1984). In the energy area, deer moved quickly through development in both autumn and spring. Although these results are similar to those of Sawyer et al. (2013), there was a lot of noise in the data across the different development areas and the signal of the effect of development was relatively weak. In the residential area, deer showed more variability with faster movement in autumn than in spring. In some instances, spring movement may be more strongly driven by green-up and foraging opportunity (Sawyer and Kauffman 2011) than by human disturbance. For mule deer, among other large ungulates, the speed of migration may be tied to the pursuit of forage resources by following green-up across the landscape in spring (Sawyer and Kauffman 2011, Bischof et al. 2012, Merkle et al. 2016, Aikens et al. 2017). The need to hold pace with spring phenology may explain deer movements as slower in spring than in autumn, though we were not able to evaluate this possibility (see Rivrud et al. (2016) for discussion of movement rate differences in hunted populations).

Stopover habitat is consistently higher in forage quality than the route as a whole (Sawyer and Kauffman 2011) and is emerging as a critical component for long-distance migrations, including mule deer in western Wyoming (Sawyer et al. 2016). Across our three study areas, deer used stopovers during both spring and autumn migrations but avoided stopping over in developed portions of their routes, which likely indicates a reduction in forage access along impacted route segments. In the energy area, an increasing level of avoidance was detected (Fig. 4; Appendix S1: Fig. S2) over time, as deer shifted their stopovers away from development along the corridor. Here, deer also selected stopovers farther from anthropogenic infrastructure as development increased. In the dispersed rural area, deer located stopovers to avoid anthropogenic features. In the residential area, stopover habitat selection was variable and unrelated to development (stopover selection ratios overlapped 1). Deer in the residential area were generally constrained by topography and were forced to move through areas disturbed by humans to reach their respective summer ranges—these deer simply may not have had a sufficient area of undisturbed habitat to shift to in response to development. This study provides additional evidence that certain types of development can reduce the amount and use of stopover habitat for migrating mule deer.

In contrast to our expectations, deer maintained high fidelity to migration routes even when moving through development, but showed lower fidelity to stopovers. Although stopovers and routes are different spatial entities, which may preclude a strict comparison given our measure of fidelity, the lower overlap of stopovers is strikingly different from that of the corridors. The energy area—where development occurred rapidly and several deer detoured around former migration routes (Sawyer et al. 2013)—was an important exception, indicating that rapidly altered habitat can cause a loss of route fidelity through developed areas. While there are a variety of environmental factors that influence migration speed, such as green-up (Aikens et al. 2017) or snow depth (Jones et al. 2014), mule deer have high fidelity to migration routes (Garrott et al. 1987, Sawyer et al. 2009*b*, Sawyer and Kauffman 2011), as do other terrestrial migrants (Bolger et al. 2008; Morrison et al. *unpublished data*). High fidelity presumably increases knowledge of and access to known foraging habitats (Eliassen et al. 2009, Olsson and Brown 2010, Berger-Tal and Avgar 2012). When landscapes are rapidly altered by anthropogenic influence, such high-fidelity behavior has the potential to be maladaptive and could cause ungulates to continue to use routes, despite deteriorating functionally. Given this high fidelity, the increased movement rates and selection of undisturbed habitat that we and others (Sawyer and Kauffman 2011, Sawyer et al. 2013) observed likely comes at a cost of lost foraging opportunities. Migratory ungulates vary in their strength of fidelity (Eggeman et al. 2016), and the extent to which fidelity influences the impact of development on migrating ungulates remains an open question.

Increasing demand for energy, housing, and roads associated with an expanding human population will continue to influence the behavior of migratory ungulates (Johnson et al. 2016). Our work has shown that anthropogenic infrastructure of all types can cause shifts in stopover location and use and that intensive, rapid development causes migrating deer to increase movement rate and alter stopover use in anthropogenic infrastructure areas. Expansion of energy extraction infrastructure into previously intact habitats that support remaining migratory populations is likely to have the most profound effects. Changes in migratory movements will likely decrease access to forage and other functional attributes of migration routes (Sawyer et al. 2013). Thus, a clear mechanism exists whereby development has the potential to reduce the fitness benefits of migration even when connectivity between seasonal ranges is maintained. Because migration routes of mammals including deer are learned (Fieberg et al. 2008, Harrison et al. 2010), the long-term loss of individuals due to the likely reduction in the forging benefits of impacted routes may ultimately result in the loss of the routes themselves. Similar losses of migratory herds have occurred throughout the globe (Bolger et al. 2008, Harris et al. 2009), although the mechanisms of reduced foraging and demography have almost never been quantified. Understanding how different kinds of anthropogenic infrastructure—from oil and natural gas extraction to residential development—influence migratory behavior can help managers design new development in a way that minimizes consequences and maintains migratory populations.

Acknowledgments

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Data Availability

GPS-collar data used in these analyses can be accessed through the Wyoming Migration Initiative (https://migrationinitiative.org/). Datasets used in analyses are as follows: Atlantic Rim (energy), Pinedale Anticline (residential), and Platte Valley (rural) mule deer. Well-pad data are available through the U.S. Geological Survey Data Series 800 (https://pubs.usgs.gov/ds/800/). Road data are available through the U.S. Geological Survey Data Series 821 (https://pubs.usgs.gov/ds/821/).

Supporting Information

Additional Supporting Information may be found online at: http://onlinelibrary.wiley.com/doi/10.1002/ecs2.2113/full